3.0 ATI Investment and Financing

The world's ATI and its complex modernization programs have reached an inflection point. As air traffic volumes recover from the latest global recession, congestion, and gridlock are returning. Aviation infrastructure continues to erode. Cash-strapped governments must turn to new fees and taxes, and private sources of funding, for infrastructure renewal.

This section describes the critical evolving trends underway in ATI investment, finance, and modernization cash flows. While the need for capital funding of ATI goes without saying, new sources for such capital are described herein.

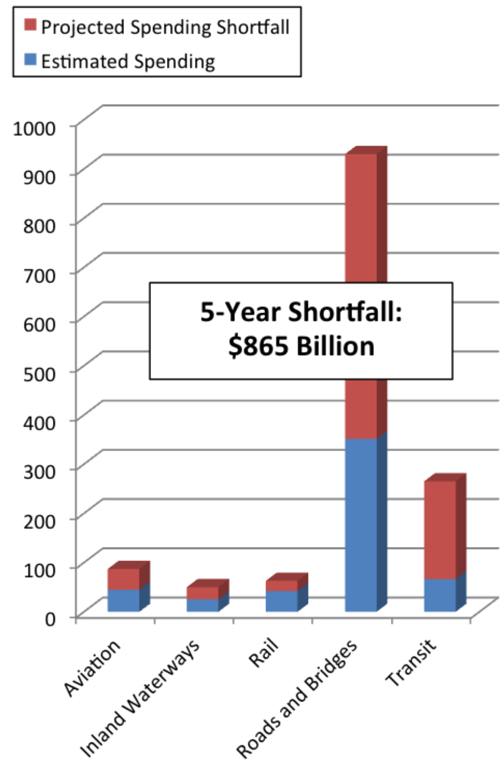
3.1 Background

The financial crisis that began in 2008 continues to have a global impact on air traffic infrastructure development. The 2008 recession weakened government finance globally, and also led to a significant restructuring of financial markets. The 2008 global crisis resulted in bailouts of banks, manufacturers, and even nations. Tax revenues dropped with the shrinking economic base, and social spending was increased to stimulate economic recovery. Governments, the traditional source of infrastructure funding, are strapped for cash and face enormous deficits. The political environment has changed, resulting in intensified calls for austerity and deep cuts to government budgets to reduce deficits. With doubtful prospects for rapid global economic recovery, many air traffic infrastructure projects will be hard pressed to secure funding unless new approaches to project finance are explored.

As shown in Figure 3-1, there is a significant and growing gap in transportation infrastructure needs. (graph is for US only – no statistics are available or have been compiled for the world.) The aviation figure includes airports, runways and the air traffic system. While governments themselves cannot afford to pay to close these gaps, hundreds of billions of dollars of private sector capital are available to step in under reasonable terms and conditions.

Figure 3-1

US 5-Year Infrastructure Shortfall



Source: American Society of Civil Engineers

Although efficient air transportation is critical to economic growth and development, the gap between infrastructure funding supply and demand is widening at an economically devastating pace. On November 2011, the European Commission (in Single European Sky ATM Research Programme (SESAR) Progress Report Memo/11/831) warned that member nations' failure to commit funding and other resources is jeopardizing critical near-term milestones for the SESAR initiatives, including implementation of streamlined Functional Airspace Blocks by the end of 2012.

Given this growing gap and the persistence of the factors that created it, air traffic growth and worsening congestion can be expected to lead to further gridlock. Public outcry will compel governments to look for alternative methods of financing infrastructure, especially from private-sector sources. Private-sector participation (PSP) models – whose varieties include public-private partnerships (PPPs) and private-finance initiatives (PFIs) – have demonstrated their ability to narrow the funding gap and drive improvements in services provided by publicly owned and run agencies.

As shown in Figure 3-2, there are many ways, in fact a spectrum of possibilities, for public and private entities to form partnerships to provision future infrastructure. Most of the models in this table when applied to ATI are in use today.

The private-sector elements of funding may vary. Broad new international bank-liquidity rules soon to take effect, such as the Basel III standards, are increasing financier interest in deals with greater amounts of subordinated debt in infrastructure financing, for instance. The mix of public and private-sector involvement in infrastructure improvement also will vary based on the specifics of each project, the characteristics of public and private parties involved, types of securitizable revenue streams, the legal, political and social frameworks, and the PSP experience levels of the countries and regions in which they operate.

A common element within ATI, however, will be the expectation of investors and airlines (ANSP customers) that a project's progress toward its goals will be monitored closely and will be met. This will require more transparent and responsible governance and efficiency than air navigation service providers have achieved typically. To meet those expectations and to protect their ability to secure future private-sector financing, ANSPs will turn more than they have in the past to the commercial sector for expertise in defining, developing, deploying, and even operating infrastructure using advanced CNS/ATM systems and capabilities.

Future revenues from user charges are at the heart of ATI financing, whether for public-agency or private-entity projects. Both ANSPs and airlines recognize that the approach recommended by ICAO for determining charges, which is to set them at a level sufficient to recover the cost of providing air navigation services, is inadequate for several reasons. There is growing recognition that an ANSP's performance should be benchmarked and tracked, creating the prospect of applying competitive metrics to what are largely monopoly markets.

Figure 3-2

Public and Private Provision of Infrastructure

Public Project	←→					**Private Project**
				Public-Private Partnership		
			←→			
Contract Type	**Public-sector procurement**	**Franchise (*Affermage*)**	**Design-Build Finance-Operate (DBFO)**	**Build-Transfer Operate (BTO)**	**Build-Operate Transfer (BOT)**	**Build-Own Operate (BOO)**
Construction	Public Sector	Public Sector	Private Sector	Private Sector	Private Sector	Private Sector
Operation	Public Sector	Private Sector	Private Sector	Private Sector	Private Sector	Private Sector
Ownership	Public Sector	Public Sector	Public Sector	Private Sector during construction, the public sector	Private Sector during Contract, then Public Sectors	Private Sector
Who Pays?	Public Sector	Users	Public Sector or Users	Public Sector or Users	Public Sectors or Users	Private-sector offtaker public sector or users
Who is Paid?	N/A	Private Sector	Private Sector	Private Sector	Private Sector	Private Sector

Source: E.R. Yescombe, Public-Private Partnerships: Principles of Policy and Finance

Some ANSPs may face competition from alternate transportation modes, such as high-speed rail. Additionally, policymakers are debating whether the aviation industry should shift from the longstanding “service-driven” philosophy of providing a basic set of air navigation services to all aviators, to a “performance-driven” philosophy of offering different service levels based on the user’s need and willingness to pay.

Driven by the fiscal challenges of their governments, ANSPs are becoming more independent and, therefore, increasingly responsible for recovering the cost of their operations through mechanisms such as user-fees, airport taxes, fuel taxes, and ticket taxes. At the same time, many have been entering private capital markets for long-term infrastructure development funds for the first time. The next decade should attract as much as $86 billion flowing into long-term ATI projects by ANSPs, helped by mechanisms such as the collateralization and securitization of revenue streams paid by air transport operators. Add to this a mix of sovereign loan guarantees and other finance leverage mechanisms, and the ATI sector may enjoy a renaissance in capital construction programs. Billions of dollars are available from private and public investors targeting infrastructure projects due to the relatively secure revenue stream.

Key points:

- Both government-owned and privately run ANSPs are turning to the private sector for funding and expertise to develop, finance, and execute critically needed ATI.
- Private-sector participation in ATI modernization will by necessity and design include stable revenue sources such as user fees paid by airlines. Private sector investors will hold ANSPs accountable to meet schedule and budget goals and will require broader governance and transparency.
- As ANSPs gain experience securitizing revenue streams to tap capital markets, airlines will become increasingly vigilant to validate that fee increases coincide with real operational benefits that new infrastructure should provide.

3.2 Overview of Historical ATI Capital Financing by Government

The visible growth of civil aviation leading up to World War II led to international recognition of the need for a convention of rules and regulations to set a framework for expansion beyond national borders. The Chicago Convention of 1944 established 96 basic protocols considered critical to the growth of international civil aviation. However, there was no protocol that required air traffic control services be run by government, but rather “the States concerned shall designate the authority responsible for providing such services.”

By the 1970s, governments generally owned and operated ATI through dedicated agencies or, in some cases, ANSPs, but accepted significant responsibility for funding ATI construction, operation, and sustainment. They did so through a variety of public-financing sources including general taxes, funds from the general treasury of their sovereign banks, pay-as-you-go user-fees, and joint financing from development banks and other sources.

At first not at all obvious, it became increasingly clear that a country’s ATI projects would regularly compete with a variety of other improvement needs including port, road, and rail projects. While ATI’s economic benefits are acknowledged explicitly throughout the world, often they are under-prioritized in practice by politicians and government officials. ATI projects have lower funding priority when compared to roads and electric-power grids because these substitutes have more immediate and visible local and political benefits. This finding has become well documented for both developed and emerging nations, and is particularly evident when governments are coping with recessions that have sapped tax revenues and left more citizens in need of social aid programs to find jobs, pay for food, provide basic utilities and obtain health care.

But it is difficult and risky to ignore ATI modernization for too long. There are intimate links between the modernization of a nation's air transport facilities infrastructure and its prospects for development and economic growth. As national economies increasingly become joined into regional blocs which, in turn operate within the global economy, the supporting ATI must sustain the efficient flow of both passengers and goods worldwide. In aviation, the need for standardization and interoperability among systems in air traffic control is particularly acute.

Conflicts between funding resources and demand for improved, expanded and more efficient ATI can be an impetus for change. That was the case in the 1980s, when the UK faced a combination of economic, budgetary and ideological pressures that led to a campaign of privatizing government enterprises. Just a few examples include British Aerospace, British Shipbuilding, British Telecom, British Airways, and eventually National Air Traffic Services.

The resulting trend spread across a variety of government activities in much of the world, including air navigation services, and it continues today. Among the current privatization plans is that of the UK to sell the remainder of its stake in its ANSP, now called NATS, and Spain's proposal to sell a 49 percent stake in AENA, its airport operator and ANSP. (Editor's note: A chronology of 60 countries and their evolution toward more business-like models is found in the Appendix).

Other nations have explored more options for reducing the cost and increasing the efficiency of their air navigation services, including reforms intended to allow their ANSPs to operate as a corporation or commercial entity. For example, privatization or contractual commercialization of specific ATI functions can allow a country to reduce air navigation-related costs while avoiding the

Figure 3-3

World Bank Active Projects

Active Projects (Millions US$)	**IBRD (International Bank of Reconstruction and Development)**			**IDA (International Development Association)**			**IFC (International Finance Corporation)**			**Total**		
	FY11	**FY10**	**change**	**FY11**	**FY10**	**change**	**FY11**	**FY10**	**change**	**FY11**	**FY10**	**change**
World Bank Group Total Active Portfolio	102,305	100,427	1.90%	69,450	62,111	11.80%	42,777	38,730	10.40%	214,532	201,268	6.60%
World Bank Group Active Portfolio - Transport	26,005	23,667	9.90%	13,156	10,486	25.50%	2,814	2,103	33.80%	41,975	36,256	15.80%
% of Total Active Portfolio	25.40%	23.60%	1.90%	18.90%	16.90%	2.10%	6.60%	5.40%	1.10%	19.60%	18.00%	1.60%
Air Transport Active Projects	285	281.8	1.10%	334.2	287	16.50%	685.5	649.7	5.50%	1304.8	1247.2	4.60%
% of Total Active Portfolio	0.30%	0.30%		0.50%	0.50%		1.60%	1.70%		0.60%	0.60%	
% of Total Transport Portfolio	1.10%	1.20%		2.50%	2.70%		24.40%	30.90%		3.10%	3.40%	

Source: World Bank

high hurdle of addressing national security concerns that a wholesale ANSP privatization may provoke. Some nations have turned to the private sector to run all or parts of their ANSP functions, including airspace design, procedures design, and training and certification of ATCOs, tower operations, etc., on a contract basis (Figure 3-3).

Key points:

- With limited and generally dwindling central government funding available, it is expected that a greater percentage will be allocated to projects other than ATI, such as roads, electricity, schools, and hospitals.
- Governments around the world are increasingly turning to private-sector participation for financing to satisfy critical long -term ATI requirements.

3.2.1 Government Fiscal Landscape: 2012 through 2021

The prospects for government spending are expected to vary around the world through the forecast period of this report.

Mature ANSPs in Europe, UK, Australia, the US, and Japan will remain under pressure to constrain spending. There is a new economic grouping, Heavily Indebted Industrial Countries (HIIC), which includes the US, UK, Europe, and Japan. HIICs are displaying the kinds of investment risks traditionally associated with developing markets. The ongoing concern about deficit levels and the increased requirements for social spending as populations grow older will limit available funds for ATI.

Nations in Asia and th Middle East generally were less affected by the global 2008 recession than those in other regions and are poised for continued growth that will support sustained government spending. Indonesia, for instance, is intent on making its economy one of the world's largest by 2025 and should experience domestic growth sufficient to support spending toward that goal. However, India has increasing social costs and is aggressively moving toward PPPs for its ATI needs.

Developed countries whose ATI has deteriorated to the point of impeding their economies must find ways to reduce that adverse impact through upgrades and expansion that address future demands. Failure to do so places an increasing burden on government, business, and society through reduced productivity, trade, and commerce, and other inefficiency costs due to competitive disadvantage.

As an example, the US has long neglected its ATI. In recent years, its standing has declined in the World Economic Forum's Global Competitiveness Report from the first to the fifth most competitive nation in the world. The Global Competitiveness report analyzed a host of economic, legal, government, and societal factors. These are sorted into 12 "pillars of competitiveness," one of which is infrastructure. Transport makes up 50% of the infrastructure ranking, which is based on five factors: roads, rail, ports, ATI, and available seat kilometers. In 2008, the US ranked 12th among 134 nations in the quality of ATI. In 2011, it dropped 19 positions, to 31^{st} of 142 nations. A related survey of business executives in 2008 ranked US ATI 6.3 on a scale on which seven represents the world standard. The ranking fell to 5.7 in 2011 (Figure 3-4).

Figure 3-4

Comparison of Global Executives' Ranking of the Quality of Their Country's Air Transport Infrastructure (Listed by 2011 Ranking)

Country	2008/2009	2008/2009 World Ranking (of 134 countries)	2011/2012	2011/2012 World Ranking (of 142 countries)
Singapore	6.9	1	6.9	1
Switzerland	6.5	6	6.5	3
United Arab Emirates	6.6	4	6.5	4
Netherlands	6.3	9	6.5	5
Germany	6.7	3	6.5	6
France	6.5	5	6.3	7
Norway	6.3	10	6.3	9
New Zealand	6	23	6.2	12
Panama	5.7	30	6.2	15
South Africa	5.9	25	6.1	17
Bahrain	6	21	6.1	18
Malaysia	6	20	6	20
Spain	5.6	34	6	21
Canada	6.1	17	6	22
United Kingdom	5.8	27	5.9	24
South Korea	5.9	26	5.9	28
Australia	6	19	5.9	29
United States	6.3	12	5.7	31
Thailand	5.8	28	5.7	32
Saudi Arabia	5.3	47	5.6	33
Jordan	5.7	31	5.6	34
Chile	5.9	24	5.6	35
Ireland	5.3	46	5.5	36
Oman	5	57	5.5	38
Turkey	5	55	5.5	40
Jamaica	5.4	41	5.5	41
Lebanon	NA	NA	5.5	43
Egypt	5.1	52	5.3	48
Ethiopia	4.8	60	5.3	49
Japan	5.1	49	5.2	50
Uruguay	3.4	116	5.2	52
Trinidad and Tobago	4.7	67	5	58
Kenya	4.7	68	4.9	61
Mexico	5	56	4.8	65
India	4.7	66	4.7	67
Peru	3.9	94	4.6	70
Italy	4.3	78	4.6	71
China	4.4	74	4.6	72
Indonesia	4.4	75	4.4	80
Pakistan	4.2	83	4.3	85
Ghana	4.1	91	4.2	87
Bulgaria	3.6	104	4.2	89
Colombia	4.8	64	4.1	94
Vietnam	3.9	92	4.1	95
Ukraine	3.6	105	3.9	101
Kazakhstan	3.7	102	3.9	103
Nigeria	4.2	84	3.9	104
Russian Federation	4.2	88	3.8	105
Bolivia	3.1	122	3.8	108
Romania	3.9	96	3.6	113
Philippines	4.1	89	3.6	115
Venezuela	3.5	108	3.6	116
Bangladesh	3.4	118	3.5	117
Tanzania	3.5	111	3.5	118
Argentina	3.1	123	3.5	119
Brazil	3.7	101	3.4	122
Iran	NA	NA	2.9	137
Afghanistan	NA	NA	NA	NA
Libya	NA	NA	NA	NA
Myanmar	NA	NA	NA	NA

Source: World Economic Forum Global Competitiveness Reports for 2008 and 2011

A separate 2011 transportation infrastructure report entitled *Building America's Future: Falling Apart and Falling Behind,* by the bi-partisan coalition Building America's Future Educational Fund, judged U.S. air traffic congestion as the world's worst and said 37 percent of flight delays can be attributed to an outdated ATC system. ATC congestion has contributed to the loss of roughly US$30 billion in annual revenue and taxes, according to the US Travel Association (Figure 3-5).

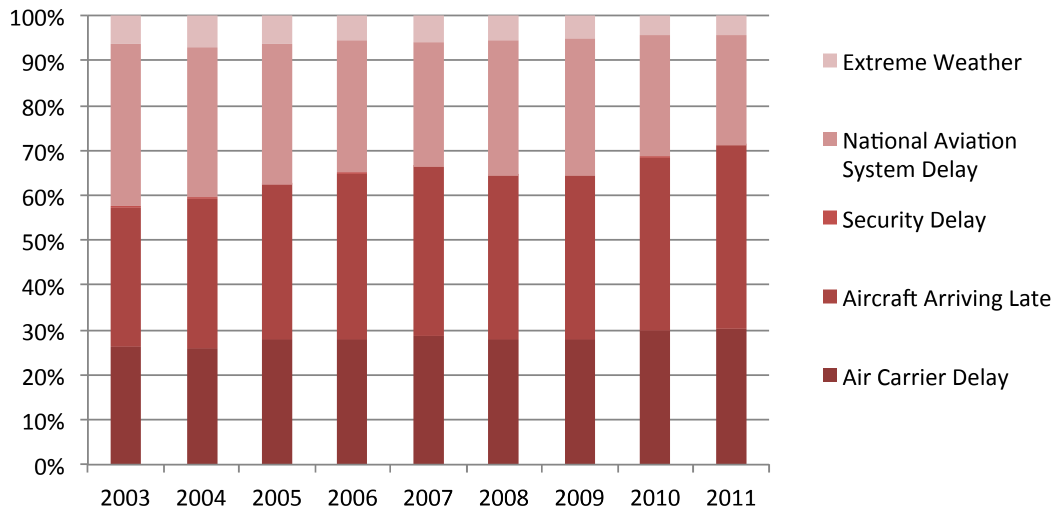
For emerging economies, a lack of ATI capable of supporting current and future demand also impedes existing business and industry and discourages the development of new economic activity. If air traffic expands beyond a country's existing capacity by outpacing ATI development, economic activity may stall, leading to unstable conditions, including economic decline. For instance, India's air traffic grew at more than 15 percent in 2011 and is expected to lead the world, with China, in growth through the coming decade. But executives continue to cite inadequate infrastructure as the biggest hurdle to doing business in India. India's ATI was ranked 67th of 142 nations in the 2011 World Economic Forum report. China's was ranked 72. For reference, Vietnam's ATI was ranked at 95 and Brazil's at 122.

The gap between ATI infrastructure needs and available government funding extends beyond finding new finance sources. It includes the need for an ANSP to improve its ability to complete ATI upgrades on time and budget and deliver the promised capabilities for which airlines and their passengers are increasingly paying.

Government-run agencies have a long history of failing to complete infrastructure upgrades and expansions on schedule, and ANSPs are no exception. They often are constrained by ponderous decision-making, funding and review processes, inflexible personnel practices, and lack of transparency and accountability. In addition, employees of a government agency may focus primarily on satisfying the demands and interests of the bureaucrats and politicians that oversee the agency instead of the users of its services.

Figure 3-5

Percent of Total Delays by Cause in US



Source: Bureau of Transportation Statistics

Going forward, ANSPs that pursue ATI upgrades consistent with international concepts intend to shift much of the burden of financing to air transport operators. Those operators must also pay for outfitting their aircraft with the avionics critical to advanced CNS/ATM capabilities. Depending on an operator's fleet size, those costs could range from US$100,000 to more than $1 million for a single aircraft, considering transmission-only ADS-B (or ADS-B out), RNAV/RNP, and the like. NEXA estimates that a $19 billion investment in aircraft equipage will be required for both forward fit and retrofit needs over the next decade.

Operators, including airlines, are gaining new influence over ATI modernization. The world's airlines will become the gate keepers that determine whether specific modernization initiatives proceed. Operators are not likely to support initiatives and mandates and pay the related costs if there are doubts about the promised benefits or the ability of the ANSP to deliver those benefits on budget and on time.

Even if ANSPs do not seek outside investors for their modernization efforts, they will be spurred by the presence of these new gate keepers to develop technical, airline operations, and project management expertise to ensure they can meet budget, schedule, and service expectations. Developing that expertise among ANSP staff personnel can be time consuming, difficult, and costly. Retaining employees, who then have highly mobile and marketable skills, will also be costly and difficult. Staff development and retention will be less of a problem for ANSPs whose governments are flush with funds from robust economies. But ANSPs whose governments seek to control budgets and deficits likely will be expected to reduce personnel expenses, including skills development programs. These ANSPs may find it more feasible to secure that expertise through a commercial vendor or private-sector partner.

The risks facing the world today -- global financial collapse, economic woes, and widespread social unrest aggravated by government budget cuts -- have the potential to provoke swift and significant changes in political power and policy that could affect ATI markets in both emerging and developed economies. These risk factors will be key considerations for the government fiscal landscape through 2021.

Key points:

- Evidence is mounting that neglect and deterioration of ATI impedes a nation's economic standing and competitive position in the world.

- ANSPs intend to shift much of the burden of ATI modernization financing to air transport operators in the form of user charges and aircraft equipage requirement.

- Operators are not likely to support ATI improvement initiatives and pay the related costs if there are doubts about the promised benefits or the ability of the ANSP to deliver those benefits on budget and on time.

- The private sector can help governments avoid adverse effects with improved benefit management, and a mix of financing and technical expertise.

3.2.2 ANSP Funding

Due to the lack of guidance on this topic following the Chicago Convention, there is little uniformity in the protocols that nations around the world adopted for funding air traffic control systems. Today, some are funded through an assortment of taxes unrelated to ANSP cost or revenue drivers. Others are funded through general treasury funds, with no charges imposed on airspace users. Charges may be unrelated to the quality of service provided by the ANSP. There may be no incentive in a charging scheme to improve quality and performance. Some ANSPs may be allowed to include the cost of regulatory compliance, capital, depreciation and reserve-fund contributions and even may be permitted a reasonable return on assets.

Other ANSPs self-regulate how revenues are generated through imposing charges or have charges imposed by their national governments, with or without consultation with airspace users. Some are subject to external review of proposed charges or to user appeals of those charges to an outside body. Still others are restricted to increasing charges in relation to an economic metric such as the rate of inflation. Some have no regulation of such charges.

Many follow ICAO's *Policies on Charges for Airports and Air Navigation Services* (Doc 9082) recommendations that nations should only permit ANSP charges for services and functions "provided for, directly related to, or ultimately beneficial for civil aviation operations." This document also recommends that nations should establish charges, or user-fees, on the principle of recovering the costs of providing air navigation services and allocating those costs to user groups based on the resources required by that group's operations. The cost to be shared, ICAO recommends, "is the full cost of providing the air navigation services, including appropriate amounts for cost of capital and depreciation of assets, as well as the costs of maintenance, operation, management, and administration." Administration costs may include those incurred to comply with national regulations.

ICAO suggests that costs of air navigation services should be allocated "in a manner equitable to all" users and in proportion to the use of those services by different groups: international civil aviation, domestic civil aviation, government or other exempted aircraft (such as those on search-and-rescue missions) and non-aeronautical users. No users should be "burdened with costs not properly allocable to them according to sound accounting principles."

ICAO also calls on nations to collect basic data on the utilization of their air navigation services, including: the number of flights by user category (i.e. airline, general aviation and others in both domestic and international operations); the distance flown, and aircraft type or weight, where such information is relevant to allocation and cost recovery.

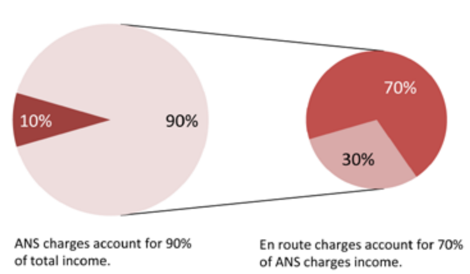
The main goal of user-fees, according to ICAO principles, is to ensure that the proper amount of charges are applied to different types of operations in a fair manner based upon the necessary resources required for that particular type of operation. Because air traffic is not homogeneous, the individual characteristics of different types of traffic are a basis for determining costs, and this can easily vary from country to country.

For ANSPs that are financially autonomous from government, revenues derived from air navigation service users are a necessary element for covering operations and maintenance costs. They also may be a means of contribution to funding modernization programs.

The business of providing air navigation services is at times a fixed-cost, cash-flow enterprise with a very long term horizon for capital expenditures. The service life of CNS/ATM equipment and systems is often measured in decades. CANSO estimates 85 percent of an ANSP's cost structure is made up of fixed costs. It further estimates that 90 percent of an ANSP's revenues are from ANS user charges. Roughly 70 percent of those revenues are from en route charges, with the remaining balance from terminal-area charges (Figure 3-6).

ANSP revenues can drop quickly when external events, such as the 2001 terrorist attacks or the recent global economic downturn, result in reduced air traffic activity. It is difficult to adjust costs or charges at the same pace as quickly falling demand, which can lead to periods after a downturn when an ANSP's revenues are not covering its costs. This poses challenges, since revenues play a vital role in the future of ATI modernization and financing. Some ANSPs that have well-defined procedures for governance oversight and customer appeal of user charges, such as Switzerland's Skyguide, are required to reimburse users when revenue growth outpaces cost increases. A few, such as NAV CANADA, are permitted to build up financial reserves to help stabilize charges when revenues and costs fluctuate.

Figure 3-6
ANSP Revenues



Source: CANSO

ANSPs, airlines, and other airspace users now battle continually over the justification and application of air navigation service revenues. Airlines challenge the very foundation of cost-recovery method as the basis for user-charges and taxes. Suggestions for improving the cost-recovery method or replacing it are always under debate, with some ANSPs (such as EUROCONTROL) exploring new measures, as discussed in the next section.

Key point:

- Political pressure and limited financial resources will combine with customer expectations to increase pressure on ANSPs to better manage costs and carefully allocate revenues generated through user-charges.

3.2.2.1 Evolution in ATI Revenues

ANSP revenues are quickly becoming the principal source for ATI cash flow securitization. Over the past three decades, ANSPs from all world regions have reduced their reliance on general taxes and opted for user-charge (or user-fee) approaches. ICAO's *Policies on Charges for Airports and Air Navigation Services* (Doc 9082) distinguish between a charge ("designed and applied specifically to recover the costs of providing facilities and services for civil aviation") and a tax ("designed to raise national or local government revenues" that generally are "not applied to civil aviation").

The change from taxes to user-charges reflects moves to increase the financial autonomy and the efficiency of ANSPs. ANSPs dependent on funds provided through their government agencies have often found themselves constrained by funding levels and tax/charge schedules determined more by political motives than operational requirements and international best practices. Today, 80 percent of the ANSPs that are members of CANSO are separate from government; only about a dozen are still inside government. Most ANSPs, whether they are government-owned or privatized, base their user-charges on ICAO's cost-recovery principles.

Some nations publish differences with specific ICAO recommendations. These differences are summarized in a supplement, currently No. 6, to Doc 9082.

As mentioned earlier, the cost-recovery method is being challenged by the world's commercial airlines and some in the ANSP community. Airline leaders and IATA argue that:

- ANSPs have no incentive to improve efficiency as long as they can recover whatever costs they incur.
- Under cost-recovery principles, the ANSP's customers bear all the risk for cost increases.

Some ANSP officials argue that the cost-recovery approach is flawed because it sustains stringent cost regulation in an industry that has undergone extensive liberalization among airlines and, to a lesser extent, airport operators; it creates little incentive for innovation; it amplifies downturns by increasing costs for customers already confronted with reduced revenues and constrained in their ability to pass those higher costs onto passengers and shippers; and it reduces an ANSP's leverage in negotiating productivity gains with its ATCOs and other employees.

A key point that cost-recovery advocates cite in defending the method is that it enhances safety by eliminating a profit incentive from an ANSP's operations. Since safety is the stated primary goal of each ANSP, and they collectively have achieved an unrivaled safety record over the last two decades, this is has been a powerful argument. However, ANSPs would clearly be able to operate with safety as the highest priority in a more business-like structure that requires careful attention to market driven service, as indeed, the airlines have done.

CANSO compiles annual performance reports using data volunteered by its members. Its *Global Air Navigation Services Performance Report 2011* includes cost, revenue, and productivity data from about two dozen members and shows that collectively their traffic (measured in IFR flight hours), ATCO staffing, and productivity (measured as IFR flight hours handled per controller in operations) were essentially unchanged from 2009 to 2010. Over that same period, their collective air navigation service costs increased 1.4% and ANS revenues rose 3.3 percent, while total costs per IFR flight hour were up 1.2 percent and total revenues per hour were up 1.7 percent.

The 2011 CANSO report did not judge or compare capabilities of ANSPs but indicated the variation in performance levels. Looking just at continental ANS (excluding oceanic airspace):

- In 2010, the average number of annual IFR flight hours per ATCO was 1,149. Controllers with Sakaeronavigatsia in the former Soviet republic of Georgia worked the fewest IFR hours (384). Those with the United Arab Emirates' General Civil Aviation Authority worked the most (4,033). US FAA controllers worked 1,803 IFR hours per year.
- The average cost per IFR flight hour was US$562 in 2010. The Netherlands' LVNL charged the most ($1,425), while Airports Authority India charged the least ($68).
- Average revenue per IFR flight hour in 2010 was US$624. LVNL earned the most ($1,378). Seneam in Mexico earned the least ($126). The U.S. FAA does not charge for air navigation services except for overflights, and does not report revenue.

Figure 3-7 presents a sample of data from CANSO's 2011 report.

Despite inertia favoring current cost-recovery approaches, pressure from airlines is expected to build over the forecast period to develop better charge-setting methods. The recent global economic crisis and its related decline in flight activity highlighted a key flaw in cost recovery. According to former CANSO Secretary General Alexander ter Kuile, "It is a method designed for growth, not downturns."

Proposals for improving the basis for revenue generation include:

- Altering risk distribution between an ANSP and its customers by having the ANSP accept some cost risk in exchange for customers committing to pay for a specific volume of air navigation services.
- Permitting ANSPs to build into their charges an amount contributed to a reserve fund, which could be used to offset sudden changes in costs or flight activity.
- Making mid-year adjustments to charge schedules to account for rapidly changing business conditions.
- Adopting schedules that include a range of permissible charges between a cap and floor on those rates.

EUROCONTROL recently revised the charging regulation for its 39 member nations to include some risk-sharing. EU nations and their ANSPs are to now cap costs and set traffic forecasts for a specific performance period. If an ANSP keeps costs below that cap, it will retain the difference. If it exceeds the cap, the ANSP incurs the difference. If traffic exceeds forecasts, the additional revenue would be "shared in a fair manner" between the ANSP and airspace users. If traffic fails to meet forecasts, the ANSP and users also would share in making up the shortfall.

Integral to EUROCONTROL's revised charging rules is regular benchmarking and monitoring of member ANSPs' performance. International efforts to establish benchmarks for ANSP performance provides some impetus for revising charge-setting regimes by making more visible the best practices in air navigation service costs, revenues, and productivity.

Figure 3-7

Selected ANSP Performance - Average Annual Changes
2006 through 2010 (Non-Oceanic Services)

ANSP	Cost/IFR Flight Hour (Percent)	Revenue/IFR Flight Hour (Percent)	IFR Flight Hour/ ATCO in Ops (Percent)
AENA (Spain)	(1.0)	3.3	1.4
Airways New Zealand	3.7	1.6	(0.8)
ANS Czech Republic	2.0	2.2	(0.3)
GCAA (UAE)	NA	NA	8.5
Irish Aviation Authority	3.9	2.5	1.6
LFV (Sweden)	14.8	7.4	(0.1)
LVNL (Netherlands)	2.8	1.4	(0.4)
NATS (U.K.)	4.5	4.6	(2.4)
NAV CANADA	0.1	(1.7)	1.0
NAV Portugal	(2.4)	(0.6)	(0.3)
NAVIAIR (Denmark)	9.6	1.9	3.1
ROMATSA (Romania)	1.4	10.0	8.1
SENEAM (Mexico)	5.0	4.4	(1.9)

Source: CANSO Global Air Navigation Services Performance Report 2011

Key points:

- The growing trend toward benchmarking ANSP performance will increase scrutiny on air navigation costs and charges at a time when ANSPs will require airspace user concurrence for ATI modernization efforts.
- “Best practice” methods of charging for air navigation services continue to evolve toward more “performance-based’ processes that will create more incentive for improving productivity and efficiency to better manage costs.
- Airlines with a concern for escalating rates and charges have yet to insert their full political pressure to demand reforms on the ATI landscape.

3.2.2.2 Air Navigation Charges

ATI user-fees are separated into two main categories: airport services and air navigation services. In addition to Doc 9082, ICAO recommendations related to these charges are included in its *Manual on Air Navigation Service Economics* (Doc 9161) and *Airport Economics Manual* (Doc 9562), as well as *Highlights in the Economic Development of Airports and Air Navigation Services.*

Nations that adhere to ICAO standards typically establish airport and air navigation service fees in a manner compliant with the recommendations in those documents. The individual nation is responsible for establishing service fees. A nation may decide to not fully recover the cost of air navigation services (because of local, regional, or national benefits from air traffic) or to not to charge at all for air navigation services.

Some nations have established multi-country agreements and organizations for handling such fees. Guidance on the establishment of a multi-country agreement can be found in ICAO’s regional air navigation plans, which are in Doc 9082. Examples are:

- EUROCONTROL, the 50-year-old civil-military European Organization for the Safety of Air Navigation whose role as coordinator and performance monitor of ANSPs in the European Union and elsewhere on the continent continues to evolve.
- ASECNA (L’Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar/Agency for Aerial Navigation Safety in Africa and Madagascar), which serves six FIRs (Antananarivo, Brazzaville, Dakar, Dakar Oceanic, Niamey and Ndjamena) and all or much of the airspace for 17 African nations (Benin, Burkino Faso, Cameroon, Central African Republic, Chad, Comoros, Congo, Equatorial Guinea, Gabon, Guinea Bissau, Ivory Coast, Madagascar, Mali, Mauritania, Niger, Senegal and Togo).
- COCESNA (Corporación Centroamericana de Servicios de Navegación Aérea), which serves the Central American Flight Information Region (FIR) for Belize, Costa Rica, El Salvador, Guatemala, Honduras and Nicaragua.
- North European ANS Providers (NEAP), also known by the initial title Borealis, is a collaboration among the ANSPs of nine countries: Denmark, Estonia, Finland, Iceland, Ireland, Norway, Sweden, Latvia, and the UK. Its goals include contributing to the restructuring of Northern European airspace, gradually harmonizing services and infrastructure and integrated environmental concerns.
- Roberts Flight Information Region, the airspace off Western Africa jointly run by Guinea, Liberia, and Sierra Leone.

ICAO protocols recognize that developing nations may have difficulty financing ATI installation and maintenance and “are particularly justified in asking the international air carriers to contribute through user charges towards bearing a fair share of the cost of the services.” They also note that air navigation revenue may exceed all direct and indirect operating costs “and so provide for a reasonable return on assets (before tax and cost of capital) to contribute (in advance) towards necessary capital improvements.”

Examples of Air Navigation Service Charges

NAV Canada's Customer Guide to Charges (effective September 2008) outlines the following formulas that apply to propeller aircraft over 6,614 pounds (three metric tons) and jet aircraft. There are various provisions for adjusting charges depending on where a flight is operated in Canada, the nature of its operator, its purpose.

Enroute Charge

This charge, applied on a per flight basis, is equal to the product of the unit rate (R), the weight factor (W), and the distance (D), as described below:

$$\text{Charge} = R \times W \times D$$

The unit rate (R) is composed of a base rate of $0.03445 effective September 2008.

The weight factor (W) is obtained by taking the square root of the permissible maximum takeoff weight (MTOW) of the aircraft. At the aircraft operator’s choice, this factor can be determined in one of two ways: by the average permissible MTOW of all aircraft of the same type in the operator’s fleet that are expected to be operated in Canadian airspace, or by the specific MTOW of an aircraft.

The distance (D) in km is generally equal to the great circle distance in Canadian-controlled airspace for overflights, international flights landing or taking off in Canada. This excludes the Gander Flight Information Region/Control Area and any Canadian airspace delegated to another ANSP. It includes airspace delegated to Canada and, for flights between points in Canada, the great circle distance whether or not the flight transits U.S. airspace.

Distance may be adjusted. For instance, the calculated distance is reduced by 65 km for each destination airport of flights within Canada where dedicated approach/departure control services are provided. If such dedicated services are not provided at one airport, the distance is reduced by 35 km. International flights receive the same reduction for the single Canadian airport used

Terminal Services Charge

This charge covers services provided or made available at or in the vicinity of an aerodrome, including approach/departure control services, airport advisory services from a flight service station, and air traffic control from a tower. It is applied to departing flights from aerodromes with air navigation facilities staffed by either NAV Canada personnel or a person acting under the authority of the Minister of National Defence.

The charge is applied on departures only on a per flight basis and is equal to the product of the unit rate (R) and the weight factor (W), as described below:

$$\text{Charge} = R \times W$$

The unit rate (R) is composed of a base rate of $23.90 effective September 2008.

The weight factor (W) is obtained by taking the 0.8 power of the maximum permissible takeoff weight of the aircraft, with operators given the same option as for enroute charges in determining that weight.

Oceanic Charges

There are two oceanic charges: the North Atlantic Enroute Facilities and Services Charge and the International Communication Services Charge. Both are based on a flat fee per flight.

The North Atlantic charge (Canadian $93.24 or US$92.86) covers the provision or availability of air navigation services to an aircraft during the course of a flight in the Gander Oceanic Flight Information Region/Control Area.

The International Communication Charge is for air-to-ground radio frequencies and certain other communication links provided or made available to an aircraft during the course of an international flight, other than a flight between Canada and the continental US, to obtain communication services. The charge is C$58.56 (US$58.32)for position reporting using voice and C$22.04 (US$ 21.95) for position reporting using datalink.

INTERNATIONAL FLIGHT WITH TAKE-OFF AND LANDING AT A CANADIAN AIRPORT

Example: B777-300 – Montreal to Paris (return)

MTOW = 344.5 metric tonnes
Distance (**D**) = 1,550 km

A) OCEANIC CHARGES

NAT		= $ 93.24	
	return (x2)		= $ 186.48
Int’l Comm - Data Link[1]		= $ 22.04	
	return (x2)		= $ 44.08

[1] If voice, charge is $58.56 or $117.12 return.

B) ENROUTE CHARGE

Weight Factor (**W**) = $MTOW^{0.5}$ = $344.5^{0.5}$ = 18.56071
Rate (**R**) = $0.03445

Formula = **R** x **W** x **D**
0.03445 x 18.56071 x (1,550-65) = $ 949.53
return (x2) = $ 1,899.06

C) TERMINAL SERVICES CHARGE - MONTREAL (ON DEPARTURE ONLY)

Weight Factor (**W**) = $MTOW^{0.8}$ = $344.5^{0.8}$ = 107.09061
Rate (**R**) = $19.62

Formula = **R** x **W**
23.90 x 107.09061 = $ 2,559.47

TOTAL ANS CHARGES (CYUL - LFPG - CYUL) = $ 4,689.09

ANS charges are typically divided into three main categories based on the flight phase (shown in Figure 3-8). This simple model generally permits the identification of resources required for each category and the allocation of costs for those resources to user groups.

The responsibility for aerodrome control can be assigned to a national ANSP or to the airport, depending on the structure of agreements between the two. In Doc 9082, ICAO says, "The number of autonomous entities operating airports or air navigation services is expected to increase," which will result in more situations during which an airport's airspace is controlled by someone other than a national ANSP. ICAO recommends consolidating charges regardless of which entity provides aerodrome control services. Combined revenues should be distributed among those entities "in a suitable way."

Figure 3-9 outlines the specific services that support aircraft in each of the three flight phases, including six unique services that are considered elements of air traffic management. ICAO recommends that an ANSP consider the cost for each specific service in determining the total cost for each of the three flight phases. The total costs of providing services are combined with traffic forecasts to determine the cost per unit of service based on each of the three phases, or the unit rate. ICAO recommendations envision the unit rate being combined with the distance flown and aircraft weight to determine the ANS charge for a particular flight. (IATA challenges the inclusion of weight as a factor in determining ANS charges, arguing that the services required by any given flight are largely independent of aircraft weight.)

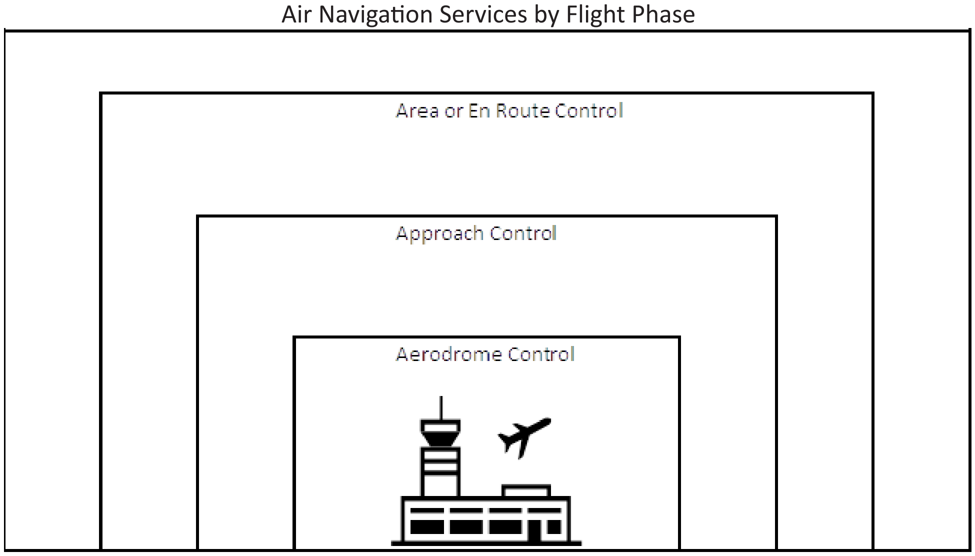
Key points:

- International standards for setting air navigation service charges, the primary source of ANSP revenue, are well defined in theory but not uniformly applied in practice.
- Funding ATI investments will vary by ANSP where securitized revenue streams will apply to project loans.
- Nations with underdeveloped infrastructures might not have the capability to properly levy fees on those who use their airspace.

3.2.3 Restructuring of ANSP Charging Systems

As ANSPs have evolved into commercialized entities, the shift has been to user-fees based on cost-based recovery for the ANSPs. Currently, the majority of ANSP user-fees are designed to capture all costs of providing

Figure 3-8
Air Navigation Services by Flight Phase



Source: NEXA Advisors

services (including, in some nations, funding for modernization programs) and to allocate them to users. There are exceptions. While the FAA adopted a corporatized model for its Air Traffic Organization (the US ANSP), it has not changed its system for funding air navigation services and continues to rely on taxes and government-appropriated funds.

Several factors are likely to combine to drive additional restructuring of ANSP charging systems. These include dissatisfaction with the cost-recovery approach, growing government-spending constraints, intensifying efforts by airlines to better manage all costs (including relatively minor ANS charges), greater accountability for the environmental impact of flights, and the increased role that airlines and other airspace users will demand in defining and financing air navigation services and their ATI.

In addition, expanded use of validated ANSP benchmarking and advanced ATM techniques (flexible airspace boundaries and dynamic flight re-routing, for example) will raise the performance bar for ANSPs. Airspace users will become less willing to pay the same price for air navigation services that lengthen flight times, increase fuel burn, harm the environment, and offer no flexibility in mitigating such adverse effects when other ANSPs offer more efficient and customer friendly services.

Figure 3-9

Cost Basis for Navigation and Airport Services

Air Navigation Services	Airport Services
• Air Traffic Management ○ Air Traffic Control Service ○ Air Traffic Advisory Service ○ Flight Information Service ○ Alerting Service ○ Air Traffic Flow Management ○ Airspace Management Service • Aeronautical Information Services • Search and Rescue Services • Meteorological Service • CNS Services	• Approach, Landing and Take-off, Lighting • Terminals, Parking Spaces, Hangars • Security Measures • Aircraft Rescue and Firefighting • Noise Alleviation and Prevention • Emissions Mitigation and Prevention • Other

Another factor that may motivate revisions to ANSP charging practices is heightened international attention to compliance with ICAO standards for the provision of air navigation services that will result from the latest round of compliance audits.

One possible change is a shift toward a more performance-based approach to air navigation services. The approach common throughout the world today is supply-driven and focused on the provider of air navigation services rather than the consumers of those services. This supports a focus on the costs of providing those services and discourages transparency in how those costs are determined rather than a focus on the quality and efficiency of the services provided (which would drive greater interaction with airspace users). EUROCONTROL's recent revisions to its charging regulation would appear to be a harbinger of such a shift (Figure 3-10).

There are no internationally applicable guidelines for allocating the cost of funding of capital improvements. While service costs are categorized based on levels of resources necessary to provide the services, capital improvement revenues are not categorized by the type of users that likely will be using future infrastructure. In this situation, it is possible for certain types of users to be burdened with fees based on capital improvements that may never benefit them. Indeed, some airlines oppose the concept of "pre-funding" improvements through an ANS surcharge. Their argument is that fees paid on flying or shipping today for an improvement made in the future will not benefit the person footing the bill.

If ANSPs are to be responsible for the direction of modernization initiatives, user-fees that include the cost of capital improvement programs must be designed in a way to incorporate a level of fairness as to which users are paying for specific projects. This point supports the fundamental theory of this study that airlines are emerging as the new gate keepers of ATI modernization.

Figure 3-10

Barriers to Adoption of a Performance-Based System

Airspace Structure & State Defense	Airspace is separated into FIRs, which are controlled by the underlying country. Differences in policies and procedures among FIRs impede the process of creating seamless airspace. This leads to increased costs of administering and providing navigation services on a global scale. FIRs are loosely based on state/country borders, which is important because sovereign airspace is highly critical for national defense purposes. National defense issues will remain a significant factor for developing global air navigation plans. The necessity of having national airspace for defense purposes burdens the push towards a global air navigation plan that seeks to remove the inefficiencies of air transport caused by airspace boundaries. General structure of billing separated by FIRs is a barrier to future user-fee modernization. Removing the barriers in the sky allows for restructuring of user-fees.
Global Vision	The major ATI modernization programs do not clearly define what the end vision is in terms of quantifiable benefits. Global vision must be defined and incorporated into regional visions for ATI modernization to ensure interoperability of modernization programs.
Modernization Costs	Large upfront costs for modernization are required to create an environment that enables the realization of any benefits.
Global Uncertainties	Global Economy Political differences War

Source: NEXA Advisors Research

Key points:

- Ongoing dissatisfaction with air navigation service charging schemes will combine with greater scrutiny by formal and informal overseers (including airlines) to compel moves toward more customer-focused services, charges and transparency.
- Disagreements over the permissibility of "pre-funding" of ATI infrastructure improvements through ANS charges will drive greater collaboration among ANSPs and airlines on the most equitable and efficient methods of financing those projects.
- Funding support will work best when tied firmly to demonstrable airline benefits such as fuel savings or reduced system delays.

3.3 Capital and Investment Programs

Capital and investment programs for government-owned ANSPs are developed within the budgeting and appropriations procedures and practices of the agencies that control the ANSPs. These procedures and practices are often protracted and involve bureaucratic and political tradeoffs that can cause investment objectives to diverge from operational requirements, keeping key initiatives underfunded and imposing conditions that airspace users do not want. In addition, these procedures and practices make it difficult to conduct long-term planning and execute those plans efficiently.

Privatization or corporatization of an ANSP or of some of its key functions can help to overcome many of these shortcomings. Airservices Australia, for instance, develops five-year capital expenditure programs to support development of charging schedules covering that same time period. Australian law enables the ANSP to pre-fund capital expenditures through these long-term plans.

Airservices Australia's five-year plans are subject to review and comment from airspace users and review by a government oversight agency. In late 2011, that agency, the Australian Competition and Consumer Commission, objected to Airservices Australia's proposed price increases for terminal navigation, aviation rescue, and firefighting services on the grounds that the ANSP's proposed rate of return on capital was too high.

NAV CANADA uses three-year capital plans intended to address several factors, including operational and regulatory requirements, contractual commitments, and obsolescence. The capital plan is built on NAV CANADA's ANS plan, which is developed in consultation with internal stakeholders and customer groups. NAV CANADA relies on debt markets for capital investment, and currently has roughly C$2 billion (US$1.99 billion) in bonds of various denominations and maturities, ranging from two to three years to 30 years.

A bundled and flexible approach to investing in infrastructure, with enhanced interest from the private sector, supports extracting the value created through modernized transportation systems. Improving the use of debt financing through private sector equity can create a proper balance of debt to equity and reduce the burden on taxpayer-supported financing. Professional investor involvement is key when developing an approach to infrastructure financing involving private sector capital participation.

Key points:

- With the exception of privatized/ corporatized ANSPs, the development of capital expenditure and investment programs remains mired in red tape and political interference, which foil efforts to satisfy efficiency requirements.
- Greater private-sector participation in ATI infrastructure improvements can mitigate those adverse effects by clearly defining goals, timelines, deliverables, and penalties for unsatisfactory performance. This will be voiced more loudly as airlines begin to understand the costs that ATI modernization will entail.

3.3.1 Credit and ANSPs

Providers of financing, such as investors and lenders, require assessments of the risk that their money will not accrue returns or may not be repaid. Credit ratings are one tool in performing such assessments. More than 70 companies around the world regularly analyze the credit risks of borrowers, including governments and government agencies, and assign or update risk ratings to them. Most of these companies describe their ratings as subjective assessments of a borrower's history in generating returns or repaying debts and its ability (as well as its commitment) to do so through the term of current financing proposals.

These rating agencies look at many factors in making those assessments, including a borrower's ownership, financial and operational history, business forecasts, financial strength, competitive position, customer-base diversity, management/ownership structure, geographical location, demographics and environmental issues.

Each rating agency has developed its own assessment labels, but they have a common purpose. That is to distinguish among borrowers that have the lowest risk of default (investment grade risks), those that pose a danger of default (speculative risks) and those with a significant risk of default (questionable risks, or '"junk").

Because governments at all levels regularly borrow money to sustain day-to-day liquidity and operational requirements, they have acquired credit ratings. National governments have been assigned sovereign credit ratings through an assessment that also includes current and prospective domestic and international political environments and projections of economic growth, government spending, and deficits. These sovereign credit ratings can be used as a basis for assigning ratings to government-owned ANSPs seeking to borrow funds from public markets.

In addition, government-owned ANSPs permitted by policy and legal standing to issue general-obligation bonds or ones linked to revenue streams (such as those derived from specific special charges) likely have been issued credit ratings for those financial instruments.

ANSPs that have been privatized or corporatized generally acquire their own credit ratings based on their financial and operational performance and fulfillment of commitments in debt offerings and other financial instruments.

As with any business, credit ratings affect an ANSP's cost of obtaining financing and its ability to attract investors for infrastructure projects or other activities. Considering the monopolistic nature of air navigation services and the global demand for ATI, ANSPs should maintain relatively stable credit ratings. Factors that can influence those ratings include ownership structures, regulatory oversight, capital needs, management, leverage, and financial performance. Regionally, ANSPs could experience lower volumes of demand due to economic recessions, but in the long run there will continue to be a growing base level of demand for air navigation services and accompanying infrastructure.

Interest rates for NAV CANADA illustrate the low capital costs obtainable for good credit. In February 2011, NAV CANADA issued C$250 million (US$248.5), 4.397 percent medium-term notes, due in February 2021. Also, after considering issue costs and the proceeds from a bond forward transaction into which NAV CANADA had entered to hedge interest costs related to this issue, the effective interest rate will be approximately 3.9 percent. Figure 3-11 shows some examples of ANSP credit ratings.

Figure 3-11

Examples of ANSP Credit Ratings

ANSP	Rating		
AEROTHAI	S&P	Moody's	Other
Airservices Australia			TRIS: AA (Stable)
DFS Deutsche Flugsicherung GmbH	AAA		
NATS (En Route)	AAA	Aaa	
NAV CANADA (General Obligation)	AA-	A2	
Skyguide	AA	Aa3	DBRS Ltd.: AA (Low)
Skyguide			Credit Suisse: AAA (Stable)

Source: NEXA Advisors Research

Key points:

- Many ANSPs borrow from public markets for operational and capital needs and can benefit from favorable credit ratings that result from stable operational and revenue environments.
- The combination of a monopolistic business and projected steady growth in air traffic producing steady revenue streams should keep credit ratings applied to ANSPs stable.

3.3.2 Current Momentum with Private-Sector Participation

By removing barriers between public and private-sector funding sources, private sector participation (PSP) initiatives have the ability to successfully narrow the infrastructure gap in nations that do not have sufficient public-sector funding available. PSP can address other problems as well. For instance, public-sector management has historically been plagued by the inability to complete projects through to delivery. Projects run by public-sector entities are consistently over budget and behind schedule. In the US, the FAA has a history of program delays and cancellations costing taxpayers and airlines hundreds of millions of dollars, including the Advanced Automation System, Microwave Landing System, and Controller-Pilot Data Link Communications. By combining the skills and efficiencies of the private sector with the backing of government assets, delays and project failures can be mitigated.

PSP efforts also add a layer of scrutiny to planning for a project. Banks and others providing financing perform upfront due diligence on behalf of the lenders to help ensure that projects are successful and funds are repaid. This motivates both public- and private-sector partners to address potential problems in advance and to not walk away from their obligations during the life of the contract.

PSPs include structures such as a public-private partnership (PPP) or a private-finance initiative (PFI), a contractual agreement between a public agency (national, state/provincial or local) and a private-sector entity in which the private-sector entity takes on some or all of the risk of financing, building, operating and maintaining a public service in exchange for some or all of the revenues from that service and possibly government guarantees for loans and protections against certain liabilities.

Such initiatives can take a wide variety of forms but generally have three common elements: sources of funding, shared skills and assets, and shared risk and reward. Advantages of such initiatives are outlined in Figure 3-12.

Figure 3-12

Advantages of Public-Private Partnerships

- Maximizes the use of each sector's strength
- Reduces development risk
- Reduces public capital investment
- Mobilizes excess or underutilized assets
- Improves efficiencies
- Enables quicker project completion
- Enhances environmental compliance
- Improves service to the community
- Improves cost-effectiveness
- Shares resources
- Shares/allocates risks
- Produces mutual rewards

Source: National Council for Public-Private Partnerships n.d.

The trend that began in the UK three decades ago continues to spread throughout the world. This is illustrated by numerous examples.

- In Asia, public-private partnerships (PPPs) are a focus of infrastructure development efforts in India, Japan, the Philippines, Thailand, and Vietnam (which in 2011 implemented new regulations to promote a three to five-year PPP program in which transport projects are predominant).

- In Africa, private-sector participation in aviation infrastructure development is a central element of plans in Ghana and the Common Market for Eastern and Southern Africa (which is laying the groundwork for PPPs to finance, build, and operate regional CNS/ATM infrastructure). The Program for Infrastructure Development in Africa calls for creating an environment conducive to private-sector investment in air transport.

- In South America, Peru seeks private-sector help improving air service to the country's interior; current ATI doesn't support such expansion.

- Brazil considers PPPs a main instrument for attracting investments in infrastructure.
- Saudi Arabia is modernizing Medina's international airport through a PPP and considering a similar approach for the construction of airport cities in Jeddah and Riyadh. The Public Private Infrastructure Advisory Facility, an international group that works with donors, regional development banks and other institutions to deliver technical assistance to developing countries, says requests from the region have more than doubled in recent years.
- PPPs are overcoming public skepticism in Canada's eastern provinces and British Columbia.
- Mexico's legislature in late 2011 passed a new law supporting wider use of PPPs.
- In Europe, private-sector participation in infrastructure is being used more broadly throughout the continent, particularly in France, Germany, and Spain. Many countries in the region are seeing the volume of PSP deals quadrupling year-over-year.
- The US has been slower to adopt PPP practices on a national level, but more than half the states have passed legislation enabling the use of PPPs.

The 2008 financial crisis impeded the development of private-sector participation initiatives like PPPs by decreasing lenders' appetite for long-term financing and increasing uncertainty about demand.

Key points:

- The ongoing spread of private-sector participation projects around the world provides numerous examples of successful financing options that can be applied to a greater extent to ATI.
- Key regions of the world are turning to private-sector participation to help close infrastructure financing gaps, with air transportation being of focus of those efforts.

3.3.3 Emerging Commercial Build-Operate Models

PSP as outlined in this study is simple in definition and robust in application. There are many different types, each with its own strengths and weaknesses. Each type must address the five main components of infrastructure projects, which are listed in Figure 3-13. A PPP outlines the allocation of the five elements and the associated risks, to either the public or private sector or a combination thereof. The levels of responsibility assigned to each sector with respect to each component will determine the type of PPP.

In combination with limited public finance options, the public sector's inability to effectively deliver projects and provide support for the operation and maintenance components for facilities has created an environment for private sector involvement in Design, Build, Finance, and Operate (DBFO) projects. This type of PSP has emerged as one of the most widely used methods for closing the infrastructure gap. DBFO projects have been successful in improving productivity and service performance outcomes for infrastructure. In Nigeria, the Lagos state government contemplates a DBFO project to develop the new Lekki-Epe International Airport, including a terminal building, air traffic control facilities, airfield ground lighting, and air navigation and ground services.

Figure 3-13

Five Components of an Infrastructure Project

Design	Under virtually any partnership structure the responsibility for design will be shared. Even in partnership structures with high degrees of private responsibility, the public sector's articulation of performance specifications will limit the range of design options. In many projects, the need to ensure compliance with broader planning and environmental guidelines results in a significant degree of public sector design.
Build	This component includes the construction of the physical assets over a prescribed period of time, generally at a prescribed cost. Deciding which party assumes the impact of construction cost overruns and time delays must be considered.
Operate	Operating the asset may include various activities from general management of service provision and revenue collection to performing soft (or non-core) services associated with an asset, such as laundry services within a hospital. Operation typically begins at the end of construction, upon agreement that the construction has been satisfactory. The private partner's compensation is dependent on the achievement of performance standards.
Maintain	Generally, there are two principal types of maintenance to be considered in any infrastructure project: ongoing regular maintenance (or operating maintenance), and major refurbishment, often called life-cycle or capital maintenance.
Finance	This component generally includes financing for the capital costs of construction, as well as working capital requirements.

Source: Deloitte

Figure 3-14 outlines some of the different types of PPPs. The wide range of applicable PPPs being used between governments and the private sector reiterates the robustness of a simple contractual agreement between the parties. Different types of PPPs are used with similar end goals, which is to unlock value from undervalued and underutilized assets or improve the quality of facilities and services. As an additional benefit, PPP transactions free up funds for other infrastructure projects that are not as well suited for PPPs.

Figure 3-14

Types of Private-Sector Participation

- Build-Own-Operate (BOO)
- Build-Operate-Transfer (BOT) or Build-Transfer-Operate (BTO)
- Buy-Build Operate (BBO)
- Design-Build-Operate (DBO)
- Lease-Develop-Operate (LDO) or Build-Develop-Operate (BDO)
- Lease/Purchase
- Sale/Leaseback
- Tax-Exempt Lease
- Turnkey

Source: US GAO

Key Points:

- Private sector participation offers a set of robust and flexible models for defining roles and risks and enabling successful execution of ATI infrastructure improvements.
- These models, such as Design-Build-Finance-Operate, are finding greater use in both developed and emerging nations, in large part because they provide private partners with steady revenue and free up funds for government partners to apply elsewhere.

3.4 Characteristics of Private Sector ATI Financing

ATI financing is complicated by several factors, including the monopolistic nature of the ANSP business, the subtle ways in which competitive forces can influence that business, and the overarching need to address aviation-safety regulations and national-security expectations. In most cases, the nature of safety and security aspects of the business have kept ANSPs in government hands despite widespread adoption of economic deregulation of other aviation sectors, such as airlines and airports. The underlying business activity of an ANSP is long-term, capital-intensive and growing steadily, characteristics inherently appealing to certain classes of investors. The challenge of matching the interest of those investors to ATI financing needs lies in making clear to those who control ANSPs that relinquishing some control will be offset by greater benefits to their nations and economies.

Key point:

- ATI financings can be increased significantly through private investment, provided the public good is obvious and benefits of such partnerships can be made clear to parties controlling ANSPs and their functions.

3.4.1 Policy and Regulatory Needs

Financing ATI is complex. The complexity stems from the potential for an ANSP to alter market prices for its services as a result of economies of scale. Indeed, all infrastructure activities were once thought to be "natural" monopolies, so that a particular market could be served at least cost by a single supplier.

Some ANSPs may be affected indirectly by market forces. For example, in mid-2008 after the Netherlands introduced a departure tax of $17.50 to $70 a person on passengers flying from Amsterdam's Schiphol Airport, about 1.5 million people opted to travel by ground to airports in Belgium and Germany in 2008's second half. Airports Council International-Europe estimates the Dutch economy lost nearly $2 million. The tax was rescinded in mid-2009. As this study goes to press, there are indications that the European Union's imposition of an environmental-credit trading scheme on international airlines is leading some carriers to alter flight plans to minimize their time in EU airspace or to avoid it.

Still, it rarely makes sense to have ANSPs in close proximity competing for the same traffic, just as it makes little sense to have two electricity grids in the same area.

However, the potential abuse of market power in services that affect many consumers creates pressure for governments to intervene, either through intensive regulation or through provision of that service by the public sector. Whether provision is public or private, governments tend to exert some level of price control over infrastructure providers and are often reluctant to allow service charges to fluctuate with costs.

This can create problems because infrastructure services are long-lived, immobile investments. Once built, air traffic systems are difficult if not impossible to dismantle or move. As long as prices cover operating costs, investors cannot credibly threaten to withdraw their services. Investors in infrastructure are often vulnerable, therefore, to changes in government regulations, including those limiting prices. This is apparent today in the UK, where critics challenge the taxpayer benefits of PSP and politicians under pressure to cut spending seek to renegotiate or end certain PSP initiatives.

Another challenge is air traffic's vulnerability to economic and geopolitical disruptions. These can reduce flight activity and hence demand for and revenue from air navigation services and also can prompt customer calls for charge reductions. A case in point is the UK's NATS, which was privatized in July 2001. When terrorist attacks in September and the response to them stymied transatlantic air travel and demand for its services, NATS had to be reorganized, with an injection of an additional $190 million investment from the UK government and BAA plc.

Although private provision has often lowered costs and improved services, political economy problems remain. The problems arising specifically from market power and immobile investments in infrastructure highlight the central role of secure property rights. Private infrastructure firms in particular are concerned not only about outright expropri-

The Santiago Principles

The International Monetary Fund's "Santiago Principles" are a set of 24 voluntary "best practice" guidelines for the world's diverse array of sovereign state investors. They are designed to focus on monitoring three important areas: legal, institutional, and governance frameworks; investment policies; and risk management. They call for improvements in the disclosure of asset allocations, portfolio strategies, and investment priorities. These guidelines offer one way for an increasingly influential set of actors in the global economy to alleviate some degree of the misunderstanding that surrounds their investment activities. So far 25 nations have signed on to the principles.

ation, but also about whether governments will progressively undermine their profitability by imposing ever more severe regulation. Governments must therefore take care to craft rules that constrain market power without unduly weakening property rights.

To foster a climate that encourages investment and partnership between global public investors and governments, transparency and disclosure are principles that must be embraced by all relevant stakeholders. One of the most common concerns NEXA Advisors has observed was a lack of clarity among investors about the long-term regulatory and political environment of a PSP initiative.

Investors reveal a discernible and deep anxiety about the volatility of the political systems and significant concerns about the lack of predictability in the regulatory and legislative domains. Uncertainty persists about future tax regime applied to foreign capital, including some foreign investors anticipating potential "clawbacks" – government reclamation of distributed payments – resulting from altered tax provisions.

Key points:

- The chief obstacle to greater involvement of private finance in ATI infrastructure is inadequate trust by government officials of investors, and by investors of the government's long-term policies and practices.
- This obstacle can be alleviated through the use of transparency procedures for the definition and oversight of public-private infrastructure partnerships.

3.4.2 Securitization of Revenues, Project Finance, and Risk

The first step in addressing the problem of revenue securitization will be to ensure that adequate revenue collection mechanisms are in place. Whether these revenues come from ANS charges, government-paid fees, or other mechanisms is less important than the reliability of their receipt. ATI users can show that they value air navigation services by agreeing to pay for their upkeep, or they can own responsibility for economic decline and its consequences that follow erosion of ATI.

In the event an infrastructure project is anticipated to produce reliable future cash flows stemming from its operation or use, sponsors may employ what is known as *project finance* to fund the construction phase of its lifecycle. In these scenarios, rather than utilizing balance sheets to provide credit support for the project, a project finance approach looks to the projected operating revenues as a direct source of debt service. This distinction is important in that the financing risk shifts to a dependence on anticipated cash flows rather than a firm's existing assets as the underlying security of the project.

At one end of the spectrum, in the case of an electric utility, there is legal protection from competition (though it is subject to regulation on matters such as fees and expansion). Monopolistic projects offer a higher degree of certainty due to their lack of competition from associated business risk. ANSPs may or may not be legal monopolies, but they often operate as such due to high barriers to entry. In some cases competition could potentially arise due to privatization or commercialization of ANS functions, such as the provision of aerodrome control services, as in the UK, the US, Spain, and France. Also, other transport options such as high-speed rail lines may threaten demand for an ANSP's services, and international benchmarking efforts could lead to revisions of an ANSP's charge schedule and revenues.

Generally, the overall level of risk of ATI modernization is a function of individual project-related risks. These are outlined in Figure 3-15.

Key points:

- Major infrastructure projects may make use of project finance to allocate future revenue streams as underlying security for lenders.
- An ANSP's typical long-term prospects for steady revenue and barriers to the entry of competing services can ease concerns of long-term investors like pension funds that funds committed to an ATI project will be at risk.

Other risks, such as the advent of alternate transport modes, external adverse events, and political and regulatory changes, must be addressed to attract sufficient private-sector participation.

3.5 Identification of Future Funding Options for ATI

As an asset class, ATI projects have attributes historically attractive to investors. These include the long duration of such investments, revenue assurance, inherent protections against volatility and inflation, diversification by geography and business line, relative transparency, and predictability of returns on invested capital due to generally stable cash flows.

Funding options can include direct appropriation by governments with sufficient funds and commitment to support the development of improved ATI. Other options include the issuance of general-purpose bonds by an ANSP or its government or bonds whose funds are dedicated to a specific ATI project. ANSPs that are privatized or corporatized have other options: borrowing from public markets (i.e. Airservices Australia and NAV

Figure 3-15

Infrastructure Finance Risks

Unknown commodity Risk	The project field is new and lacks performance history. A lack of market demand data makes it an uncertain proposition, with the increased possibility of failure. This can be an issue in the development, financing and deployment of advanced CNS/ATM technologies such as ADS-B.
Political / regulatory / contract Risk	Political forces and/or government intervention adversely affects the project or causes cancellation of contractual agreements that are critical for infrastructure investments. Other political issues might including labor concerns or fears of foreign ownership
Leverage risk	Infrastructure projects typically involve substantial debt financing.
Interest-rate Risk	This can be hedged by use of swaps and other financial derivatives. However, the persistence of high inflation-adjusted rates over long periods of time can adversely affect investment returns. The problem can be most acute in the case of assets not traditionally considered as infrastructure, such as car parks and service stations, which may be less suited to supporting high debt multiples.
Liquidity Risk	Infrastructure investments usually entail long-term commitments, so there may be no ready market for selling them in the interim. Investors eagerly seek a proposed exit strategy given infrastructure extended lease and concession terms. Potential purchasers of an early investor's interests include strategic acquirers, sophisticated investors looking to gain long-term positions through direct investment or co-investment, and possibly secondary purchasers of partnership positions.
Event Risk	This refers to the devaluation or even destruction of infrastructure assets by terrorist attacks and natural disasters. If portfolios contain a small number of relative large holdings, as is often the case, a significant loss for one may have a large impact on the whole portfolio. Such adverse consequences can be mitigated by insurance policies, assuming they are available, although they may not always cover all possible losses. As is more often the case, this entails the possible obsolescence of the asset.

Source: Capital Matters - Pension Fund Investment in Infrastructure

Project Finance

A common model for financing individual projects – "project finance" – involves an economically distinct or separable financing vehicle created for each project.

Providers of equity and loan capital primarily look to the revenues produced by the project to service the debt and generate returns on the equity investments. In the event of the project's failure, any exposure would be limited to that equity investment.

Some consideration may be needed, depending on whether any guarantees or collateral might have been offered as needed loan commitments or perhaps to gain equity investment for the project.

Many global conglomerates with experience in large-ticket infrastructure projects often utilize project finance in lieu of borrowing against their own balance sheets. Here are examples of companies with transportation project finance experience:

- Battelle
- Halliburton
- HNTB
- Hochtief
- Parsons Brinkerhof
- Schlumberger
- The Shaw Group
- VINCI

CANADA), using bank loans (as do the previous two ANSPs and NATS), or issuing new stock to their government owners (as does Switzerland's Skyguide.)

The prominence of Asian and Middle Eastern Islamic nations in air travel growth forecasts has significance for financing considerations, since Islamic law generally restricts the use of interest in transactions. Those restrictions are contributing to expanded use of the *sukuk* – an Islamic financial certificate similar to a bond that replaces interest with a rental-fee arrangement.

Saudi Arabia's General Authority of Civil Aviation (GACA) in January 2012 offered a ten-year, US$4 billion government-guaranteed *sukuk* to raise funds for construction of the new King Abdul Aziz International Airport in Jeddah. Yemen is considering *sukuks* to finance government projects. Standard & Poor's Ratings Services says *sukuk* issuance is gaining acceptance in markets outside Malaysia, Indonesia, and major Middle Eastern nations in part because European banks are reducing overseas exposure as a result of more stringent capital requirements and weakened domestic economies.

By their very nature, infrastructure projects are lower yielding but predictable, with high switching costs for users and meaningful barriers to entry for competitors.

Key point:

- ANSPs have a variety of funding options available, although not many are not aware of all options and the flexibility they offer.

3.6 Active Sources for ATI Capital Investment

There are an increasingly wide variety of vehicles through which investments in infrastructure can be made.

3.6.1 Government Agency Support and Sovereign Wealth Funds

Foreign government entities are becoming increasingly influential players in the world economy, and the investment strategies of these foreign entities will impact capital flows and affect markets around the world. In addition to equity and debt capital, many governments support infrastructure projects via development dollars or state-owned agencies, including Export Credit Agencies.

ECA's are private or quasi-governmental institutions that act as intermediaries between national governments and exporters to issue export financing. The financing can take the form of credits (financial support) or credit insurance and guarantees, or both, depending on individual mandates. Some agencies are government-sponsored, others private, and others a bit of both.

ECAs currently finance or underwrite about $430 billion of business activity abroad - about $55 billion of which goes towards project finance in developing countries - and provide $14 billion of insurance for new foreign direct investment, dwarfing all other official sources combined (such as the World Bank and Regional Development Banks, bilateral and multilateral aid, etc.).

Export credit agencies use three methods to provide funds to an importing entity:

- **Direct lending:** This is the simplest structure whereby the loan is conditioned upon the purchase of goods or services from businesses in the organizing country.
- **Financial intermediary loans:** Here, the export–import bank lends funds to a financial intermediary, such as a commercial bank, that in turn loans the funds to the importing entity.
- **Interest rate equalization:** Under an interest rate equalization, a commercial lender provides a loan to the importing entity at below market interest rates, and in turn receives compensation from the export–import bank for the difference between the below-market rate and the commercial rate.

State-controlled and state-owned enterprises (SOEs) are commercial businesses owned by foreign governments, but operated somewhat or fully independent of, their owners and their influence. SOEs are heavily represented in the industries focused on resource extraction, and have in recent years emerged as major players in the global competition for energy and mineral resources. Russia's Gazprom, Brazil's Petrobras, Norway's Statoil, and Italy's ENI represent large enterprises in the energy sector largely owned by national governments. They also are heavily represented in the provision of air navigation services and, in some regions, in the aircraft manufacturing and even the airline sectors.

Sovereign wealth funds are the most prevalent mechanism for the deployment of a nation's capital. They have existed for decades, but have grown dramatically in recent years. These funds were initially conceived as vehicles to invest the proceeds generated by resource-rich states. They increasingly concentrated in East Asia and the Persian Gulf and Middle East regions.

Sovereign wealth funds are inherently cautious, focused on capital preservation, asset diversification, predictable returns and the mitigation of political risk. Most limit their equity ownership stake in public companies, financial institutions, and private businesses to minority status and eschew direct management responsibility (Figure 3-16).

The Sovereign Wealth Fund Institute estimates that at the close of 2010, all such funds had total assets under management (AUM) valued at US$4.1 trillion. That estimate is inherently uncertain because some of the world's largest funds, such as the Abu Dhabi Investment Authority (ADIA), the China Investment Corporation, and Saudi Arabia's SAMA Foreign Holdings do not publicly disclose all of their holdings.

As the amount and scope of capital controlled by sovereign wealth funds have grown, so too has the concentration of leading players. The top ten funds ranked by AUM today control roughly 85 percent of total sovereign wealth fund assets. Oil-export nations manage roughly two-thirds of the capital deployed by the largest funds.

Other sources of funding include international organizations like the World Bank Group and its related International Finance Corporation, the International Monetary Fund and the Organization of Economic Cooperation and Development.

A host of national and regional development banks and funds offer financing as well as technical expertise to nations seeking to develop their infrastructure. These range from the African, Asian, Caribbean, and Inter-American development banks to the European Bank for Reconstruction and Development, the International Bank for Reconstruction and Development in the US, and the Arab Fund for Economic and Social Development.

In addition, governments around the world have agencies set up to aid infrastructure development abroad. Belgium, Canada, Denmark, France, Germany, Italy, Spain, and the UK all have such agencies, as do Japan, Russia, and the US.

Figure 3-16

Sovereign Wealth Funds

Fund Name	Abu Dhabi Investment Authority
Size	US$627 Billion
Description	Established in 1976, the Abu Dhabi Investment Authority (ADIA) is a globally diversified investment institution that is wholly owned by the Government of Abu Dhabi. ADIA manages a substantial global investment portfolio, which is highly diversified across more than two-dozen asset classes and sub-categories, including quoted equities, fixed income, real estate, private equity, alternatives and infrastructure.
Website	www.adia.ae
Contact Info	Abu Dhabi Investment Authority 211 Corniche, PO Box 3600 Abu Dhabi, United Arab Emirates Phone +971 2 415 0000 Fax +971 2 415 1000
Fund Name	Australian Future Fund
Size	US$73 Billion
Description	The Future Fund was established by the Future Fund Act 2006 to assist future Australian governments meet the cost of public sector superannuation liabilities by delivering investment returns on contributions to the Fund. Investment of the Future Fund is the responsibility of the Future Fund Board of Guardians with the support of the Future Fund Management Agency. The Board and Agency also invest the assets of the Building Australia Fund, the Education Investment Fund, and the Health and Hospitals Fund which were established by the Nation-building Funds Act 2008.
Website	www.futurefund.gov.au/
Contact Info	Future Fund Management Agency Locked Bag 20010 MELBOURNE VIC 3001 AUSTRALIA Phone: (03) 8656 6400 Fax: (03) 8656 6500
Fund Name	Brunei Investment Agency
Size	US$30 Billion
Description	The Brunei Investment Agency (BIA) is the main agency that holds and manages the government of Brunei's General Reserve Fund, and its external assets. Although Brunei Darussalam is served by nine commercial banks, it operates a currency board system and has no central bank. Under the Banking Acts and Finance Companies Act, the government of Brunei Darussalam regulates the banking industry. Through the Financial Institutions Division, the Ministry of Finance regulates all banking activities.
Website	www.mof.gov.bn/
Contact Info	Administration Division Ministry of Finance Level 15, Ministry of Finance Building, Commonwealth Drive, Bandar Seri Begawan BB3910 Brunei Darussalam Phone: (673) 2380999
Fund Name	China Investment Corporation

Size	$439.6 Billion
Description	China Investment Corporation (CIC) is an investment institution established in September 2007 as a wholly state-owned company. While it operates with independence and its investment decisions are based on the pure economics of each deal, CIC remains accountable to the State Council of the People's Republic of China and, ultimately, to the citizens of the People's Republic of China.
Website	www.china-inv.cn/cicen/
Contact Info	New Poly Plaza, No.1 Chaoyangmen Beidajie, Dongcheng District, Beijing, 100010 Phone: +86 (10) 8409 6167 Fax: +86 (10) 6408 6731
Fund Name	Government of Singapore Investment Corporation
Size	$247.5 Billion
Description	GIC was incorporated in 1981 under the Singapore Companies Act and is wholly owned by the Government of Singapore. They invest globally in many asset classes such as: equities, fixed income, real estate, private equity, infrastructure, marketable alternatives and natural resources. In the 1970s, Singapore had a high national savings rate, thus reserves grew rapidly. The government of Singapore decided that its reserves would be better invested in longer term and high-yielding assets. These assets would be managed by a new institution, the GIC. Established in May 22 1981 as a private company, it is now a large sovereign wealth fund. The Government of Singapore Investment Corporation does not own the funds it manages but manages them on behalf of their clients: the government of Singapore, and the Monetary Authority of Singapore.
Website	www.gic.com.sg/
Contact Info	168 Robinson Road #37-01 Capital Tower Singapore 068912 Phone: (65) 6889 8888 Fax: (65) 6889 8722
Fund Name	Heritage and Stabilization Fund (Trinidad and Tobago)
Size	$2.9 Billion
Description	Prior to the Heritage and Stabilization Fund (HSF) which was established in March 2007 with the passing of the HSF Act. No. 6. Historically, the fund was identified as the Interim Revenue Stabilization Fund (IRSF) which has been in around since 2000. The fund has initiated a corporate governance structure. The fund is paid by petroleum revenues and is used to help stabilize budget shortfalls. The HSF is separate from the overall foreign exchange reserves of Trinidad and Tobago. Its purpose is to generate saving and investment income for future generations. The fund is headed by a president and a five member board. The board also includes an officer of the Central Bank and Ministry of Finance. The Central Bank has the responsibility to manage the fund.
Website	www.finance.gov.tt
Contact Info	Communications Unit Ministry of Finance Level 18 Eric Williams Finance Building Independence Square Trinidad and Tobago Phone: (868) 627-9700 ext: 2805-9 Fax: (868) 627-9700 ext: 2810
Fund Name	Hong Kong Monetary Authority Investment Portfolio
Size	$293.3 Billion
Description	Established in April 1993, it is managed by the Hong Kong Monetary Authority (HKMA). The Exchange Fund acts as a stabilizer and invests primarily in its local exchange, the Hang Seng. All Exchange Fund assets can be used to support the Hong Kong dollar exchange rate. The Exchange Fund uses global external managers to administer about one third of its total assets, including all of its equity portfolios and other specialized assets.
Website	www.hkma.gov.hk/

Contact Info	55th Floor Two International Finance Centre 8 Finance Street Central Hong Kong Phone: (852) 2878 8196 Fax: (852) 2878 8197
Fund Name	Korea Investment Corporation
Size	$43 Billion
Description	Korea Investment Corporation (KIC) is a government-owned investment management company, specializing in overseas investments. Enacted by the Korea Investment Corporation Act and created in July 2005. The KIC is structured as a corporation and was initially created by receiving US$17 billion of foreign exchange reserves from the Bank of Korea with an additional US$3 billion from the foreign exchange stabilization fund from the Ministry of Finance and Economy. The asset classes may include securities, foreign currencies, and derivatives, etc. The fund will also utilize external managers.
Website	www.kic.go.kr/
Contact Info	Korea Investment Corporation 16F Seoul Finance Center, 136(Mukyo-dong) Sejong-daero, Jung-gu, Seoul 100-768, Korea Phone: +82-2-2179-1000 FAX: +82-2-2179-1065
Fund Name	Kuwait Investment Authority
Size	$296 Billion
Description	The Kuwait Investment Authority is the parent organization of the Kuwait Investment Office, which was initially established as the Kuwait Investment Board. The KIA, a government-owned institution, invests in the Local, Arab and International Markets with its main office located in Kuwait City and a branch office in London.
Website	www.kia.gov.kw/
Contact Info	P.O. Box: 64, Safat, Z. Code: 13001, Kuwait Telephone : +(965)2485600 Fax : +(965)2454059
Fund Name	Oil Revenues Stabilization Fund of Mexico
Size	$6 Billion
Description	Mexico's government finances are heavily dependent on the petroleum industry. In 2000, the fund was created to lessen the effect on public finances and the national economy when there are declines in oil revenues. The fund receives inflow from a special levy on oil revenues. The oil fund's resources are managed and invested by the Central Bank of Mexico. The fund was created for stabilization purposes, rather than intergenerational savings. The fund invests in short-term money market instruments together with the entire central bank's foreign exchange reserves.
Website	www.swfinstitute.org
Fund Name	SAFE Investment Company (China)
Size	$567.9 Billion
Description	The State Administration of Foreign Exchange (SAFE) is responsible for managing China's foreign exchange reserves. SAFE has a subsidiary in Hong Kong called the SAFE Investment Company which has made purchases in foreign equity investments. The SAFE Investment Company is organized as a privately held firm; however, SAFE officials serve on its board. They have made significant investments in the UK Equity Market. Some top holdings include: Royal Dutch Shell, Rio Tinto, BG Group, Tesco, BHP Billiton, and Barclays.
Website	www.safe.gov.cn
Contact Info	Huarong Plaza No.18 Fucheng Road, Haidian District, Beijing Phone: 68402265
Fund Name	SAMA Foreign Holdings (Saudi Arabia)
Size	532.8 Billion

Description	A Saudia Arabiran sovereign wealth fund. The fund is controlled by the Saudi Arabian Monetary Authority, a part of the central bank. According to the Sovereign Wealth Fund Institute, SAMA Foreign Holdings is the third largest sovereign wealth fund in the world as of 2009. The majority of the wealth held in the SAMA Foreign Holdings fund is derived from the oil wealth of Saudi Arabia, but the fund also manages certain Saudi public pensions. It is estimated to be the second largest of the three major Gulf country funds. The fund is highly secretive regarding its holdings and investment strategies.
Website	www.sama.gov.sa
Contact Info	Saudi Arabian Monetary Agency P.O. Box 2992 Riyadh 11169 Saudi Arabia Phone: +966-1- 463-3000 Fax: +966-1- 466-2936 / 466-2966
Fund Name	Social and Economic Stabilization Fund (Chile)
Size	$21.8 Billion
Description	In 2007, the Chilean Government created the second fund, the Economic and Social Stabilization Fund (ESSF). This fund replaced the original Copper Stabilization Fund. It receives fiscal surpluses which are above one percent of GDP and came into existence with a one-off payment of approximately $5 billion (as a result of the closure of the original Copper Stabilization Fund). Through the ministry of finance of Chile, the financial committee proposed investment policy on the social and economic stabilization fund to the minister of finance during March of 2007. The investment strategy intends to diversify assets in the fund, putting 15 percent of the portfolio into variable income assets, 20 percent in corporate fixed income papers, gradually adjusting assets currently held, especially liquid assets.
Website	www.hacienda.cl/
Contact Info	Ministry of Finance
Fund Name	Strategic Investment Fund (France)
Size	$28 Billion
Description	Known locally as Le Fonds Stratégique d'Investissement (FSI), it was established in November 2008. The Strategic Investment Fund (SIF) was created to enhance equity and to help stabilize French firms. SIF will be managed by Caisse des Dépôts. The SIF will be a French public limited company (société anonyme), a subsidiary of Caisse des Dépôts, and controlled by it, whose accounts will be consolidated with those of Caisse des Dépôts. The FSI is 49 percent owned by Government of France and 51 pecent by Caisse des Depots et Consignations.
Website	www.fonds-fsi.fr/
Contact Info	Phone: 0158479332
Fund Name	Temasek Holdings (Singapore)
Size	$157.2 Billion
Description	Temasek Holdings is an investment company owned by the government of Singapore. Currently, Temasek Holdings' sole shareholder is the Ministry of Finance. As the years progressed, Temasek Holdings began to diversify its holdings from the local Singapore market, to other surrounding countries. Also an ctive shareholder and investor in diverse industry sectors such as banking and financial services, real estate, transportation and logistics, infrastructure, telecommunications and media, bioscience and healthcare, education, consumer and lifestyle, engineering and technology, as well as energy and resources."
Website	www.temasek.com.sg/
Contact Info	Temasek Holdings (Private) Limited 60B Orchard Road #06-18 Tower 2 The Atrium@Orchard Singapore 238891 Phone: +65 6828 6828 Fax: +65 6821 1188

Key points:

- Government and sovereign wealth funds have billions of dollars available for financing of long-term, stable projects including ATI modernization.

- Infrastructure projects hold the added appeal of being unlikely subjects of a scandal that would garner headlines and embarrass investors.

- These funds may make direct or indirect investments in infrastructure projects, but typically have little interest in direct ownership or control of those projects.

3.6.2 Pension Funds and Endowments

Government employee pension and retirement funds are a longstanding and reliable source of infrastructure financing. National, regional, state/provincial, and local governments have pension funds that invest capital in corporations, buy government securities, or take positions in a wide range of investment vehicles. Due to their conservative investment philosophy, sensitivity to "headline risk" that can stimulate government action, and long-term investment horizons, such funds are predisposed to conventional portfolio management strategies. They typically decline to purchase controlling interests in individual companies or financial institutions and do not seek to exercise management control. They are drawn to long-term returns and willing to accept lower yield for lower risk.

The US maintains the largest reserve of public pension funds with assets of $US2.6 trillion at the end of 2010. This represents 54 percent of the $4.8 trillion in public pension reserve funds (PPRF) reported by participating OECD countries in 2010, up from closing 2009 at $4.6 trillion. Argentina, China, and Saudi Arabia, non-OECD countries but members of G20, also reported PPRF assets for 2010. Saudi Arabia's general organization for social security is estimated at over $400 billion, placing them third in the world behind the US and Japan for largest PPRF. Overall returns for pension funds in 2010 averaged net returns on investment of 3.5 percent (5.4% percent nominal).

3.6.3 Private Equity and Debt Capital

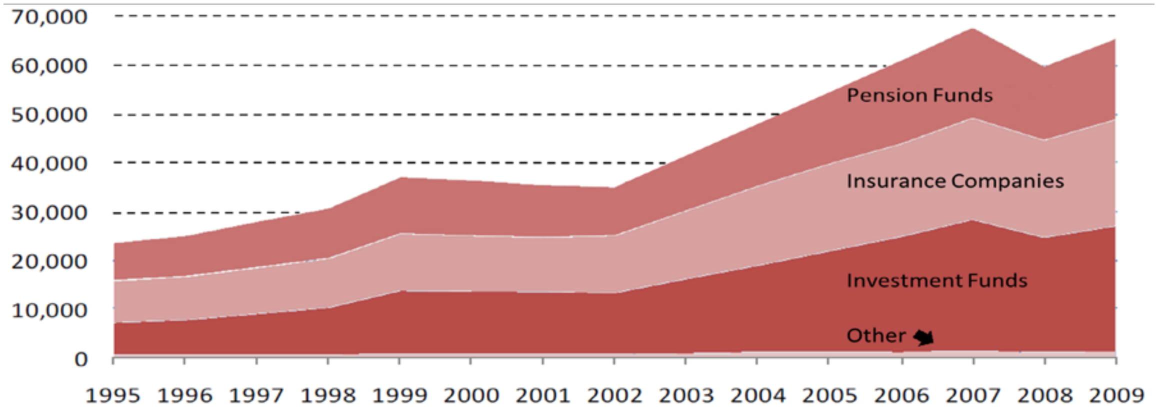
Private infrastructure funds pool capital from multiple investors, both foreign and domestic. Their investors include pension funds, sovereign wealth funds, endowments, and high-net-worth individuals. While fund governance mechanisms are rarely publicly disclosed, they typically limit the role that a single investor can play to an advisory capacity and minority status, with no rights for operational control of infrastructure assets. What these funds have in common is that they allow quick and easy access to investments in the infrastructure marketplace. They are set up to investigate infrastructure opportunities quickly and efficiently and can commit large amounts of capital in a short time-frame. Investments in infrastructure can be made either indirectly, through a separate fund created to finance a particular infrastructure project, or directly through an equity stake in the project.

Most investments are made via indirect investments, which utilize asset managers to deploy pooled capital to the most promising projects or funds. There are generally two types of such funds. The first is listed for public trading on a financial exchange and hence are referred to as listed infrastructure funds. Listing has implications regarding regulation, governance, investment constraints, reporting requirements and access to the funds. The second type may also trade, but that is done privately and not on a public exchange. These are referred to as unlisted infrastructure funds.

A listed fund may permit greater diversification, depending on how global its investment approach is (in terms of type of infrastructure, geographic location, etc.). Insofar as the underlying investments are publicly traded securities, portfolio valuations are presumably independent and transparent. An investment in this type may be made via a stock exchange as individual shares or via an investment fund/index. Listed investments offer an entry point for smaller amount of invested capital and provide higher liquid-

Figure 3-17

Assets Held by Institutional Investors in the OECD area, $ Billions



Source: OECD

ity options, since shares can be easily traded. But listed funds have several potential downsides, including a higher correlation to equity portfolios and less protection against inflation. They also may have a short-term focus and lower risk-adjusted returns, along with higher volatility (Figure 3-19).

Unlisted infrastructure funds involve pooled capital arrangements – often in the form of limited partnerships investing in a diversified pool of assets and companies. These funds are usually large, often over $1 billion in assets, require a substantial investment to join, and frequently involve complex deals with intricate debt and equity arrangements, with higher fees. Examples of unlisted infrastructure funds are listed in Figure 3-18.

Unlisted funds may be closed- or open-ended. Closed-end funds have specified maturity dates and private equity-like structures and fees. The investment by definition is illiquid, with no withdrawals until the fund is liquidated at the end. A typical fund like this has a defined term and, depending on its size, may place limitations on diversification. Some investment management firms utilize hybrid structures across varying asset classes to compensate for the different terms of projects.

Open-end funds extend indefinitely. Because they tend to have longer terms, they are usually more in line with the underlying asset characteristics (for example, an ability to retain the asset as an ongoing investment with an ongoing revenue stream). They also bring more liquidity options and typically offer investors the opportunity to remain fully invested. Because investors aren't locked in, however, open-end funds must maintain a cash balance, which can have negative impacts on returns.

Figure 3-18

Examples of Unlisted Infrastructure Funds

Alinda Global Core Infrastructure Fund
Australian Infrastructure Fund
CVC European Infrastructure Fund
Energy Capital Partners
Global Infrastructure Partners
Goldman Sachs Infrastructure Partners
Hadrian's Wall Capital
Highstar Capital
International Public Partnerships
Macquarie Funds
Morgan Stanley Infrastructure Partners
RREEF Pan-European Infrastructure Fund

Source: NEXA Advisors Research

Figure 3-19

Size of public pension reserve fund markets in selected OECD countries and other major economies, 2010

Country	Name of the fund or institution	Founded in	Assets		
			USD billions	**% of GDP**	**% increase**
Selected OECD countries					
United States	Social Security Trust Fund	1940	2 609.0	17.9	2.7
Japan (1)	Government Pension Investment Fund	2006	1 312.8	25.9	n.d.
Korea	National Pension Fund	1988	280.4	27.6	16.7
Canada	Canadian Pension Plan	1997	136.0	8.6	13.0
Sweden	National Pension Funds (AP1-AP4 and AP6)	2000	124.7	27.2	8.1
Spain	Social Security Reserve Fund	1997	85.3	6.1	7.3
France (1)	AGIRC-ARRCO	n.d.	71.7	2.7	n.d.
Australia	Future Fund	2006	65.8	5.5	8.4
France	Pension Reserve Fund	1999	49.0	1.9	11.1
Ireland	National Pensions Reserve Fund	2000	32.3	15.9	9.3
Belgium	Zilverfonds	2001	23.3	5.0	4.3
Norway	Government Pension Fund - Norway	2006	23.1	5.6	16.9
Portugal	Social Security Financial Stabilisation Fund	1989	12.8	5.6	2.5
New Zealand (2)	New Zealand Superannuation Fund	2001	11.2	7.9	17.1
Chile	Pension Reserve Fund	2006	3.8	1.9	12.2
Mexico	IMSS Reserve	n.d.	3.6	0.3	-6.7
Poland	Demographic Reserve Fund	2002	3.4	0.7	39.1
Total selected OECD countries (3)			4 848.1	19.6	5.0
Other major economies					
Saudi Arabia	General Organisation for Social Insurance (1,4)	1969	400.0	106.4	n.d.
China	National Social Security Fund	2001	126.5	2.2	10.3
Argentina	Sustainability Guarantee Fund	2007	45.7	12.3	26.4
Total other major economies (3)			572.2	75.9	14.6
Memo item: Sovereign Wealth Funds with a pension focus (5)					
Norway	Government Pension Fund - Global	1990	509.1	122.8	16.6
Russian Federation	National Wealth Fund	2008	88.4	5.9	-2.7

Source: OECD Global Pension Statistics

1. Data refer to 2009.
2. Data refer to June 2010.
3. Weighted average for assets as a % of GDP and % increase.
4. OECD estimate.
5. Norway's Government Pension Fund - Global and Russia's National Wealth Funds are sovereign wealth funds, and not public pension reserve funds, because their mandate goes beyond financing pension expenditures.

With the preferred strategy in mind, fund investors select its investment options based on distinguishing features, a few of which are shown below in Figure 3-20.

Figure 3-20
Investment Features

Feature	Options
Fund Size	150m-8bn
Currency	Euro /USD/GBP/Etc.
Term	10 Years/25 Years/Evergreen
Geography	National /US/Europe/ EM/ Global/Etc.
Industries / Sectors	Airports/Transportation/ General/Etc.
Investment Stage	Greenfield/Brownfield
Regulation	Low/Med/High
Type of Investment	Equity/Mezzanine/Debt
Target Return	Yield, IRR
Risk Profile	Low/Med/High

Source: NEXA Advisors Research

Both listed and unlisted funds may have complex structures. Clearly, a careful examination of the fund prospectuses or other documents is essential to ascertaining the nature and extent of either type of fund's investment strategy, attendant financial returns and risks, etc.

As opposed to indirect investments via asset managers, direct investments into infrastructure projects or funds, by definition, offer direct control. They allow investors to match allocations and bypass high fund performance fees and allow funds to hold positions over the economic life of the investment. Direct investment requires expertise that can often preclude smaller investor's capability to provide expertise required to make/manage asset acquisitions and ensure proper diversification. This expertise becomes critical in correctly pricing and assessing potential conflicts of interest in any analysis performed by parties promoting the infrastructure sale. They generally focus investments on mature assets, but will often include some brownfield projects and developing markets.

Although the vehicles described above focus on equity, there are also a range of debt-based investments. Debt is the most extensive form of infrastructure capital, accounting for a majority of (70-90 percent) of a project financing.

Traditional bank loans can be underwritten by individual banks for smaller projects and, more often, divided between a syndicate of banks for larger projects. The terms of bank loans can be set on a project by project basis, with interest and principle varied to reflect risk or characteristics unique to a unique set of cash flows. The duration of the project may or may not qualify for bank appetite, requiring development or creative structures to bridge the gap. Once a bank loan is in place, repayments become senior to all other debt financing.

Bonds are another option for larger transactions and longer-term projects. They have specific repayment stipulations which depend on both the individual project (like bank loans) but also on prevailing conditions in capital markets. While bonds have the advantage of supporting much longer projects, they also come with less flexibility for repayment terms due to a broader distribution to many different holders of the bond.

The effects of the 2008 financial crisis and recent and pending changes to financial regulations have spurred greater interest in infrastructure financing through subordinated debt, for instance. Such debt, subordinate to senior debt in a transaction but superior to equity investments, can help address concerns about risk and liquidity requirements for a lender. Hadrian's Wall Capital, an investment advisory firm, has partnered with the European insurer Aviva to set up an infrastructure fund to pursue infrastructure financing that includes subordinated as well as senior debt and equity (Figure 3-21).

Other debt-based investments may include mezzanine debt linked to private-sector acquisitions, hybrid debt/equity instruments, and bonds whose cash flow is linked to infrastructure and structured products. These are not usually offered as stand-alone invest-

Figure 3-21

Infrastructure Debt Providers

Fund Name	Credit Agricole Corporate Investment Bank France)
Description	Crédit Agricole CIB, the Corporate & Investment Banking arm of the Crédit Agricole group, specialises in the businesses of capital markets and investment and corporate banking. Crédit Agricole CIB's specialised teams meet clients' requirements in terms of structured finance or otherwise, syndicated finance or otherwise, Islamic finance, bond issues, equity related operations, domestic or international flows management, trade finance, capital and risk management in liaison with the bank's business lines.
Website	www.ca-cib.com/
Fund Name	Barclays Bank UK)
Description	One of the fastest-growing banks in the UK in terms of turnover, Barclays has doubled in size since 2004. As well as retail and corporate banking, Barclays also provides wealth management and investment services to customers and clients in the UK. Barclays is consistently rated among the top-three specialists in government bonds and, due to its focus on the major UK corporates, is set to gain from its expansion in European equities, and mergers and acquisitions. Its subsidiary, Barclays Private Equity, is one of the most active private equity firms in the country.
Website	www.group.barclays.com/
Contact Info	Barclays PLC 1 Churchill Place London E14 5HP Phone: +44 (0)20 7116 1000"
Fund Name	Banco Santander (Spain)
Description	The ninth bank in the world and first in the euro zone by stock market value. Santander Group, the holding company for Banco Santander, is the largest financial group in Spain and Latin America, with leading positions in the United Kingdom and Portugal and a broad presence in Europe through its Santander Consumer Finance arm. Total assets: €1.252 trillion (US$1.52 trillion) (as of December 31, 2011). Net profit: €5.351 billion ($US6.5 trillion) (2011).
Website	www.banksdaily.com/
Contact Info	Cantabria s/n 28660 Boadilla del Monte, Madrid, Spain Phone: +34(0) 942206100 Fax: +34(0) 915813388
Fund Name	Royal Bank of Scotland
Description	The RBS group is a large international banking and financial services company. From its headquarters in Edinburgh, the group serves over 30 million customers in the UK, Europe, the Middle East, the Americas and Asia. The group provides a wide range of products and services to personal, commercial and large corporate and institutional customers through its two principal subsidiaries, the Royal Bank of Scotland and NatWest.
Website	www.rbs.com/
Contact Info	Phone: +44 20 7672 1758. Fax: +44 20 7672 1801.
Fund Name	BNP Paribas Corporate and Investment Banking France)
Description	BNP Paribas provides to its clients financing, advisory and capital markets services. It is a globally recognised leader in many areas of expertise including among others structured financing and derivatives across a variety of asset classes. CIB also has a solid corporate advisory franchise in Europe and Asia.
Website	www.bnpparibas.com/
Contact Info	Phone: +33 1 42 98 12 34
Fund Name	HSBC Bank
Description	HSBC Private Bank provides private banking and trustee services worldwide.

Website	www.hsbcprivatebank.com/
Contact Info	78 St James's Street London SW1A 1JB United Kingdom Phone: (+44) 20 7860 5000 Fax: (+44) 20 7860 5001
Fund Name	Societe General Corporate and Investment Banking
Description	Societe Generale Corporate & Investment Banking (SG CIB) has been an active player in Asia Pacific for over 35 years, offering a range of financial solutions to the region.
Website	www.sgcib.asia/
Contact Info	Level 34, 3 Pacific Place, 1 Queen's Road East, Hong Kong Phone: (852) 2166 5388 Fax: (852) 2868 2368
Fund Name	European Investment Banking (Luxembourg)
Description	The European Investment Bank is owned by the 27 EU countries. It borrows money on the capital markets and lends it at a low interest rate to projects that improve infrastructure, energy supply, or environmental standards both inside the EU and in neighbouring or developing countries. It borrows money on the capital markets rather than drawing on the EU budget. The money is lent on favourable terms to projects in line with EU policy objectives. In 2008, the EIB raised nearly €60 billion (US$72.8 billion). The EIB works on a non-profit basis and lends at a rate close to the cost of borrowing.
Website	www.europa.eu/
Contact Info	98-100 boulevard Konrad Adenauer L-2950 Luxembourg Luxembourg Phone: +352 43 79 1 Fax: +352 43 77 04
Fund Name	Sumitomo Mitsui Banking Corporation (Japan)
Description	Sumitomo Mitsui Financial Group, Inc., was established in December 2002 through a stock transfer as a bank holding company, and SMBC became a wholly-owned subsidiary of SMFG. In March 2003, SMBC merged with the Wakashio Bank, Ltd. SMFG has functions such as strategic planning, management, resource allocation, strategic planning of information systems, financial management, investor relations, risk management, human resource management for group executives, and business auditing of the group as a whole.
Website	www.smfg.co.jp/
Contact Info	1-2, Marunouchi 1-chome, Chiyoda-ku, Tokyo 100-0005, Japan Phone: 81-3-3282-8111
Fund Name	WestLB (Germany)
Description	WestLB was created in 1969 by the merger of its old-established predecessor institutions, Landesbank für Westfalen Girozentrale, Münster, founded in 1832, and Rheinische Girozentrale und Provinzialbank, Düsseldorf, founded in 1854. In August 2002, WestLB was transformed into a joint stock company after the public mission activities were integrated into Landesbank NRW (now NRW.BANK), which was established in August 1 2002.
Website	www.westlb.de/
Contact Info	Head Office WestLB AG Herzogstraße 15 40217 Düsseldorf Phone: +49 211 826-01 Fax: +49 211 826-6119

ments, but are lumped in with other kinds of corporate debt.

Special purpose companies also serve a distinct need in the changing landscape of air traffic infrastructure finance. Much like the asset financing techniques in other industries (including aircraft sales), innovative approaches can help defray what have traditionally been large capital costs by extending financing terms such as leases and service fees to governments and end users in exchange for upfront costs borne by private investment. For example, the NextGen Equipage Fund, a newly created investment vehicle utilizing a leveraged lease model, aims to enable accelerated avionics equipage for airlines currently struggling with the high capital costs of upgrades. A strategy of diversifying risk across a pooled collateral asset base allows for better financing terms from lenders. With smaller initial outlays and a lower cost of capital, airlines are better able to close the business case for equipping their fleets with next generation avionics and help improve air traffic system efficiencies related to infrastructure modernization.

Key points:

- Private infrastructure funds investigate infrastructure opportunities quickly and efficiently and can provide large amounts of cash in a short time frame to the most favorable candidates.
- The complex structures of these funds' transactions may include a mix of debt and equity that can further facilitate funding for ATI infrastructure.
- Innovative financing vehicles can utilize private investment to fund air traffic projects by employing new structures such as pooling of assets and tax-efficient governance.

3.7 Top 100 ATI Projects

What are the next decade's top ATI projects globally, and what policy, technology and financial issues will define them? The following are ATI projects from each of the six regions: Africa (AFR), Asia Pacific (APAC), Europe (EUR), Latin America (LAM), Middle East (MES), and North America (NAM). These projects are relevant to the timeframe of 2021.

ICAO Region	Country / Agency	Contractor / Organization	Value $ MM	Program Type	Description
AFR	ASECNA	Thales		CNS/ATM	The Agency for Air Navigation Security in Africa and Madagascar (ASECNA) selected Thales to modernize the air traffic control centers in six countries: Senegal, Congo, Niger, Ivory Coast, Chad, and Madagascar. The modernized ATC systems will include a Multi Sensor Tracking System, integrating all surveillance means, including radars, ADS-B, ADS-C, multilateration and wide area multilateration. Thales will also deliver a training and test platform for air traffic controllers. ASECNA is in charge of five flight information regions (FIRs), controlling the largest area in the region and covering a total of 16 million square k across the African continent.)
AFR	Eastern Africa	Eastern Africa Community Regional Aviation Project	123	Airports	The components of the EAC regional aviation project may include funding for 1) institutional development and capacity building; 2) enhancing airworthiness inspection; 3) upgrading aviation infrastructure (ADS-B system in Tanzania, GNSS-based procedures in the EAC, and support the harmonization of the upper flight information region); 4) supporting the liberalization of air transport, and 5) aviation security enhancements at key airports. The overall objective of the project will be the deepening of regional integration within the EAC, by fostering the development of air services within the community, and strengthening the East African Community Civil Aviation Safety and Security Oversight Agency (CASSOA).

ICAO Region	Country / Agency	Contractor / Organization	Value $ MM	Program Type	Description
AFR	Egypt	Cairo Airport Development Project	280	Airports	Rehabilitation and expansion of Terminal Building 2: The objectives of the Second Terminal Building (TB2) Cairo Airport Development Project (CADP) are to assist the government of Egypt (GOE) to: 1) enhance the quality of airport services through an increase in the capacity of Cairo International Airport (CAI), and 2) strengthen air transport in Egypt. The new TB2 will be operated in combination with the recently completed TB3. CAI is the largest airport in Egypt and the second largest in Africa after Johannesburg in South Africa. Today, CAI is used by 58 passenger airlines, including charter operators, ten cargo operators, and has a total capacity of 21 million passengers per annum) divided among three terminal buildings. The second component of the project is technical assistance and studies. The project is based on the expectation of strong traffic growth in the coming decade. It finances the necessary airport infrastructure improvements to meet and facilitate this growing air transport market. However, given the increased complexity of the air transport sector, the project will include a component to strengthen institutional capacity. This component will support policy initiatives and the enhancement of air transport services in Egypt.
AFR	South Africa		-	Airports	Airside capacity enhancements at Cape Town, King Shaka (Durban), and O.R. Tambo (Johannesburg) international airports. US TDA gives ATNS a $758,000 grant that will develop a roadmap to help US. companies increase sales into South Africa for ATNS upgrades air traffic infrastructure.
AFR	Tonga	Pacific Aviation Investment Program	125	CNS/ATM	US$62 million grant to improve aviation in the Pacific region and make air travel safer and more efficient for people traveling to and from the Pacific Islands. Supported by the government of Australia through the Pacific Region Infrastructure Facility (PRIF), the first phase of the Pacific Aviation Investment Program will focus on Kiribati, Tonga, and Tuvalu, and will boost trade and tourism across the region.
APAC	Afghanistan	Thales	1,000	Restructuring	Re-establishment of civil ATI in the wake of foreign military withdrawal, reduction of foreign grants, and slowing economic growth. Effort will build on a nationwide ADS-B/wide-area multilateration network and standard requirement for RNP in country. The Afghan Ministry of Transport and Civil Aviation (MOTCA) selected Thales to supply a wide area multilateration system (WAM) for surveillance in the vicinity of Kabul, Mazar-e-Sharif, and Heart airports. The ground stations include ADS-B capability.

ICAO Region	Country / Agency	Contractor / Organization	Value $ MM	Program Type	Description
APAC	Australia	AirServices Australia	1,000	CNS/ATM	Estimate is US$1 billion. Capital expenditures in latest long-term pricing agreement (2011-2016) includes funding for numerous projects, including replacement and upgrade of Airservices core air traffic management system, the Australian Advanced Air Traffic System (TAAATS), which will reach its end of life in the second half of the decade.
APAC	Australia	AirServices Australia	-	CNS/ATM	The aircraft avionics equipment mandate is for flight in the upper space at and above flight level 29,000 feet (FL290). The compliance date has been set for December 2013 to allow five years for airlines to comply. At FL290, ADS-B coverage as planned by AirServices Australia will extend over the whole of continental Australia outside radar coverage and over significant areas of oceanic airspace within the FIR. Radar such as ATC surveillance of virtually all passenger transport turbo-jet aircraft operations will result post 2013. NOTE: Australia's nationwide ADS-B network went into operation in late 2009 to provide surveillance above FL300 for the first time in non-radar areas. Users carrying certified equipment can take advantage of five NM separation procedures, with mandated equipage due to see user-preferred routes become available starting in 2014. AirServices has deployed 57 ground stations supplied by Thales at 28 sites since launching the program in 2004. The service is available to over 1,150 aircraft that have approved ADS-B avionics equipment, and the Australian Civil Aviation Safety Authority (CASA) has mandated the installation of this equipment by all aircraft operating in the upper airspace by December 2013. ADS-B equipped aircraft are also given operational priority in the ATC system.
APAC	China		230,000	Airports	China became the second largest aviation market in the world during the period of the 11th five-year plan (2006-2010), with passenger capacity of airliners increasing by 95 percent. The number of airports serviced by scheduled airlines is expected to increase from 186 to 260 by 2015. Senior officials from the Civil Aviation Administration of China (CAAC) said recently that China will build 56 more airports during the next five years to expand airport capacity. Additionally, the Chinese aircraft fleet will increase four times by 2026, reaching nearly 4,460 planes. In the next 20 years, Boeing estimates that China will invest about $390 billion to purchase 3,710 new aircraft. CAAC estimates that the average growth rate for the Chinese aviation industry will be 11 percent for the following decade. CAAC announced that investment in China's aviation industry is likely to reach about $230 billion in the next five years.

ICAO Region	Country / Agency	Contractor / Organization	Value $ MM	Program Type	Description
APAC	China		1,200	CNS/ATM	Install an estimated 40 radar on Beijing-Guangzhou, its busiest route, and there and elsewhere 170 units of VHF VOR/DME systems. Upgrade and automate radar control in Eastern and Central China. Improve ground-air comm facilities and ADS of international and polar routes in Western China. Establish comprehensive civil data comm network and info system to meet increased demand from airlines.
APAC	China		-	Satellite	China to orbit Beidou-2 or Compass GNSS, consisting of 35 satellites (five geostationary and 30 non-geostationary) for regional operational capabilities by 2012 and global coverage by 2020. Also, it is planned to develop a national satellite- based augmentation system (SBAS).
APAC	India		30,000	Airports	Upgrade/modernization of both Metro and Non-metro airports and a new layer of linkages with two-tier/three-tier cities. Development of greenfield airports.
APAC	India		30,000	Airports	Investment opportunities of US$110 billion are envisaged up to 2020 with US$80 billion in new aircraft and US$30 billion in development in airport infrastructure, according to the Investment Commission of India.
APAC	India		1,200	Airports	To ensure that the sector development was not restricted to the metro cities alone, the GOI announced its plans to modernize 35 non-metro airports into world-class entities at an estimated cost of US$1.2 billion. The airports to be modernized include airports Coimbatore, Tiruchi, Thiruvananthapuram, Visakhapatnam, Port Blair, Mangalore, Agatti, and Pune. This is in addition to the large metro airports where modernization is either completed or in progress. The Ministry of Civil Aviation has also approved greenfield airports at Navi Mumbai, Goa, Durgapur, Kannur, and Saras.
APAC	India	Indian Space Research Organization	162	Satellite	IRNSS - Indian Regional Navigational Satellite System (IRNSS)-1, the first of the seven satellites of the IRNSS constellation, is designed for a nominal mission life of seven years and is planned to be launched onboard PSLV during 2012-13, while the full constellation is planned to be realized in the 2014 timeframe. GAGAN - The GPS-Aided Geo- Augmented Navigation (GAGAN) system, aimed at making Indian skies safer, "is currently undergoing the final operation phase since June of last year and is scheduled to be completed by June 2013," an official from the Airports Authority of India (AAI) said.

ICAO Region	Country / Agency	Contractor / Organization	Value $ MM	Program Type	Description
APAC	India	Ministry of Civil Aviation	-	Airports	India already has an open sky policy for air cargo. An air cargo hub is being developed at Nagpur by the Ministry of Civil Aviation. The ministry also has plans to build dedicated cargo airports across the country to cater to increasing demand in air cargo traffic. While the amount of cargo freighted via air is growing steadily, the infrastructure related to air cargo handling and evacuation is not. The government has acknowledged the need for development of cargo-related facilities and is taking the necessary steps to address the situation with consistent and coherent application of policies. For a country like India, with its natural challenges in terrestrial transportation, a well networked air cargo system will go a long way in addressing the problem of networking the remote areas and creating proper international market access to them.
APAC	Japan	Ministry of Land, Infrastructure and Transport	-	Satellite	"Michibiki" Quasi-Zenith Satellite System - GNSS Augmentation. Experimentation to begin in 2012 to identify new GNSS applications for the Asia Pacific region. The current GPS augmentation system used in the regional vicinity of Japan is the multi-functional satellite-based augmentation system (MSAS), which consists of two geostationary Multifunctional Transport Satellites (MTSATs). The design life of the GZSS is ten years. Current QZSS plans call for between four and seven satellites, including Quasi-zenith orbit and geostationary satellites.
APAC	Regional		-	CNS/ATM	CARATS (Collaborative Actions for Renovation of Air Traffic Systems) is a long-term vision for future air traffic systems which will require the collaborative works with various aviation stakeholders to reform Japan's air traffic system.
APAC	Regional		-	ADS-B Mandate	Hong Kong, Singapore, and other countries in the Pacific Rim mandating ADS-B by 2014.

ICAO Region	Country / Agency	Contractor / Organization	Value $ MM	Program Type	Description
APAC	Vietnam	The Southern Airports Corporation (a company under The Ministry of Transportation of Viet Nam)	6,700	Airports	Long Thanh International Airport will replace Tan Son Nhat International as the country's leading international hub. The master plan for this new airport was approved in April 2006. The new airport will be built in Long Thanh county, Dong Nai province, about 50 km northeast of Ho Chi Minh City. The pre-feasibility study for this project is underway. Long Thanh International Airport will be constructed on an area of 50 km². It will have four runways (4,000 km x 60 m) and be capable of receiving jumbo-jets such as the A380. The project started in 2007 and will be divided in two stages. Stage 1, completed in 2010, gave the airport two parallel runways (4,000 km x 60 m) and a terminal with capacity for 20 million passengers per annum. The second stage is planned to be completed in 2015, when the airport will have three passenger terminals and a cargo terminal designed to receive 80 to 100 million passengers and five million metric tons of cargo per year. The total invested capital of this project is estimated at US$8 billion. Upon completion of Long Thanh International Airport, Tan Son Nhat Airport will serve domestic passengers only. Long Thanh International Airport is expected to be the leading airport in the Indochina Peninsula and one of the busiest air transportation hubs in the southeast Asian Region.
APAC	Vietnam		7,000	Airports	CAAV estimates that Vietnam would require about $15 billion in investment to achieve its development plan for the aviation sector by 2020. Of this, $8 billion will be needed mainly for aircraft fleet expansion, $5 billion for constructing and upgrading airports, and the remaining $2 billion for airport operation and air traffic management. According to the International Air Transport Association (IATA), by 2014, Viet Nam will become the world's third fastest-growing market for international passengers and freight, and the second-fastest in the number of domestic passengers. Projects are currently being delayed due to financing difficulties.
EUR	Austria	Saab Sensis	-	ADS-B	Austro Control GmbH has selected Sensis Corporation to deploy a Wide Area Multilateration (WAM) system across the country. The system will provide terminal and en route surveillance of the entire country, including Austria's mountainous regions, encompassing more than 32,000 square miles. The system will provide surveillance of Mode S, Mode S Extended Squitter and Mode A/C equipped aircraft and ADS-B. Austro Control will use the WAM system to complement SSR infrastructure while adding surveillance of areas not previously covered by SSR due to the terrain.

ICAO Region	Country / Agency	Contractor / Organization	Value $ MM	Program Type	Description
EUR	Regional	Single European Sky	42,000	Restructuring	Restructuring of airspace into Functional Airspace Blocks (FABs) relative to operational requirements rather than national boundaries.
EUR	Regional	Galileo	2,640	Satellite	The space segment comprises the European Satellite Navigation System (Galileo) satellites, which function as “celestial” reference points, emitting precisely time-encoded navigation signals from space. The nominal Galileo constellation comprises a total of 27 satellites, which are evenly distributed among three orbital planes inclined at 56º relative to the equator. There are nine operational satellites per orbital plane, occupying evenly distributed orbital slots. Three additional spare satellites (one per orbital plane) complement the nominal constellation configuration. The Galileo satellites are placed in circular earth orbits with a nominal semi-major axis of about 30,000 km and an approximate revolution period of 14 hours.
EUR	Regional	EUROCONTROL	-	Data Communication	The implementation of Controller Pilot Data Link Communications (CPDLC) is identified in the European ATM master plan as a key improvement that will alleviate voice channel congestion. The LINK 2000+ Program was created to coordinate the implementation of CPDLC in Europe. Implementation of CPDLC in Europe in airspace above fL285 became mandatory with the Commission Regulation (EC) No.29/2009 in January 2009. The EU regulation will apply from February 2013 – the deadline by which CPDLC must have been implemented by all ANSPs in Western Europe. The same requirement will apply to all ANSPs in Eastern Europe from February 2015.
EUR	Regional	SESAR	-	CNS/ATM	SESAR enters the deployment phase in 2014 when large-scale installation of systems is scheduled to begin.
EUR	Regional		-	ADS-B Mandate	ADS-B Out mandate for Forward Fit aircraft by January 2015. ADS-B Out mandate for retro-fit aircraft by 2018.
EUR	Regional	SESAR	26,768		Deployment phase (2014–2020) for large-scale production and implementation of the new air traffic management infrastructure, composed of fully harmonized and interoperable components which guarantee high performance air transport activities in Europe.

ICAO Region	Country / Agency	Contractor / Organization	Value $ MM	Program Type	Description
EUR	Regional	SESAR	2,811		Development phase (2008–2013) to produce the required new generation of technological systems and components as defined in the definition phase. This phase is managed by the SESAR Joint Undertaking.
EUR	Russia		-	Satellite	Russia is restoring operational capability for its Glonass GNSS constellation with K-2 Satellites and developing its own augmentation system (SDCM-system of differential correction and monitoring). SDCM will use a global ground network of monitoring stations and transponders on the Luch Multifunctional Space Relay System geostationary communication satellites to transmit correction and integrity data using the GPS L1 frequency. The first of these satellites, Luch-5A, was launched in December 2011. Negotiations for additional SDCM ground stations in Australia, Indonesia, Brazil, and Nicaragua are ongoing to provide adequate coverage in the southern hemisphere. If one or more of the proposed ground stations cannot be realized, then additional stations at Russia's Antarctic research bases could be deployed.
EUR	Russia	Northern Capital Gateway	1,588	Airports	The project is the first competitively and transparently procured airport concession in Russia and is expected to have a positive demonstrative effect for other planned PPP projects there, which is of particular importance given the large infrastructure needs of the country. The project is to expand, develop, operate and maintain Pulkovo airport in St. Petersburg (the "City"). Pulkovo is the only civil airport in the City and the fourth largest airport in the Russian Federation, serving 6.8 million passengers in 2009. In order to modernize the airport and address capacity constraints, the City decided to tender a 30-year concession to operate the existing airport facilities, construct a new terminal, which significantly expands the current terminal facilities, and invest in new airside and landside infrastructure to achieve an airport capacity of 17 million passengers per annum (the "Project"). The Project is Phase I of a master plan for the development of Pulkovo airport, with future phases to be developed and funded at a later stage in accordance with the concession agreement. The concession has been awarded to Northern Capital Gateway (the "project company"), based on a competitive and transparent procurement process, under the terms of a public-private partnership agreement (PPPA) signed in October 2009. The proposed IFC financing will be used for the construction of the new terminal and associated facilities as well as the refurbishment of existing infrastructure and buildings at the airport. It is expected that major construction works will commence in 2010 and be completed by the end of 2013.

ICAO Region	Country / Agency	Contractor / Organization	Value $ MM	Program Type	Description
EUR	Sweden	Saab Sensis	-	CNS/ATM	Sweden's ANSP Luftfartsverket (LFV) contracted Saab Sensis Corporation to provide wide area multilateration (WAM) for surveillance of Swedish airspace. The technology will be deployed across the country, complementing and replacing the existing Monopulse Secondary Surveillance Radar (MSSR) systems with a solution compatible with contemporary avionics. Saab Sensis WAM will support Mode A/C, Mode S, and ADS-B 1090 ES, and systems will be deployed in the Stockholm terminal movement area (TMA), and in a large part of the north of Sweden. LFV's long-term WAM deployment goal is comprehensive coverage within the LFV area of responsibility. WAM will provide surveillance from low level in the Stockholm TMA up to 66,000 feet, depending on coverage requirements.
Global		ICAO	120,000	Re-structuring	Pending approval of the 12th Air Navigation Conference in November 2012, ICAO proposed to enhance global airspace interoperability by initiating "aviation block upgrades" as a programmatic framework that develops a set of air traffic management (ATM) solutions or upgrades, takes advantage of current equipage, establishes a transition plan, and enables global interoperability.
Global		Iridium Aireon	450	Satellite	Anticipated to begin launching in 2015, Iridium NEXT will maintain the existing Iridium constellation architecture of 66 cross-linked, low-earth orbiting (LEO) satellites covering 100 percent of the globe. Iridium NEXT will substantially enhance and extend Iridium mobile communications services, delivering: higher data speeds, powerful new services and devices, advantages of IP technology, and backward compatibility with current handsets, devices, and applications. An ADS-B receiver on every NEXT satellite would provide global, real-time visibility to ADS-B-equipped aircraft everywhere. Extends and augments coverage and significantly enhances currently planned ADS-B terrestrial infrastructure and investments. Extends terrestrial ADS-B infrastructure to monitor aircraft over open oceans, poles, and remote regions where ADS-B ground- based transceivers (GBTs) are not practical. US$450 Million.
LAM	Brazil	Infraero	6,500	Airports	In the run-up to the FIFA World Cup 2014, Infraero is investing US$6.5 billion to modernize and expand its airports in 12 host cities in Brazil. Infraero will contribute about $6.1 billion, of which $408 million will be privately financed. As part of the modernization of the São Paulo-Guarulhos airport, construction of a new passenger terminal (TPS3) was initiated in 2011. It is expected to be completed by 2014. The 230,000m² new terminal is estimated to cost US$700 million.

ICAO Region	Country / Agency	Contractor / Organization	Value $ MM	Program Type	Description
LAM	Brazil	DECEA	1,000	CNS/ATM	Much of Brazil's newly modernized nationwide surveillance (monopulse secondary) radar system will reach the end of its service life between 2015 and 2020. Through 2015, Brazil plans to introduce ADS-B coverage in its entire airspace and begin planning termination of primary and secondary radar coverage to take effect starting in 2016. Brazil also plans to upgrade its ATC centers to receive and process MLAT and ADS-B data and perform data fusion with secondary radar tracks by 2012.
MES	Saudi Arabia	Consortium	-	Airports	The mission of the new King Abdulaziz International Airport (KAIA) project is to become an intermodal hub to promote the economic spirit of the country, to support the national air transportation system and to enhance service as the gateway to the region. The Project will be a landmark economic development for the region and the nation, capitalizing on the Kingdom's ambitious growth plans and the Authority's efforts for Saudi Arabia to enhance the status of Jeddah as an international hub. Includes three new terminal buildings and a high-speed rail link for up to 80 million passengers a year.
MES	United Arab Emirates		136,000	Airports	The UAE is investing in increasing capacity of its airports to 250 million passengers a year by 2020. The amount includes US$8 billion for Dubai International development. The upcoming US$8 billion (Dh29.4bn) upgrade of Al Maktoum International in Jebel Ali will prepare for a five-fold increase in passenger traffic by 2025 as airlines expand their fleets and routes and the budget carrier flydubai begins regular service. It expects a 12 percent per annum growth (that has seen passenger numbers rise from 10 million to 38 million a year since 1999) to be sustained with increased capacity provided by the five-runway Al Maktoum International Airport, which is scheduled to open in phases between mid-2010 and the 2020s.

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MES	United Arab Emirates		-	Airports	SP 2020, Dubai Airports' ten-year master plan, outlines aggressive expansion plans for airspace, airfield, stands, and terminal areas at Dubai International. The plan takes into account the need to minimize constraints on growth by delivering timely capacity, while improving service levels and generating strong cash flow to maximize capital investment. Further, it effectively balances the need for facility development, process improvement, and demand management to ensure optimal utilization of facilities and maximum return on investment. It is also designed to reinforce Dubai's hub status and ensure a smooth transition to Dubai World Central in the long term. During 2018–2023, with construction completed at Dubai International, the additional aeronautical and non-aeronautical revenue generated by higher traffic flows will be used to fund further airport development at Dubai World Central. Construction of Phase 2 of DWC will escalate during this period with the initial iteration allowing for 80 million passengers per year to facilitate the eventual relocation of the Emirates hub. DWC will feature a modular design that can be expanded incrementally to accommodate growth for both Emirates and other airlines. Once fully completed, Dubai World Central will be the world's largest airport with five runways and capacity for 160 million passengers and 12 million tonnes of cargo annually.
NAM	USA	FAA	1,500	CNS/ATM DCIS	The FAA Data Comm project is up for bid. The winner will manage the datacomm network for 17 years. FAA will pay a fee for the service. The Data Comm program is a critically important next step for improving air safety, reducing delays, increasing fuel savings, improving the environment, and leading US aviation into the 21st century. The introduction of data communications between the FAA's air traffic control functions and carrier aircraft represents a key phase of the transition from the current decades old analog voice system to a predominantly digital mode of communication. The Data Comm System supports the NextGen vision by providing air traffic service (ATS) data transmissions directly to pilots via aircraft avionics systems. This ATS data communications capability enables more efficient procedures and flight profiles through services such as revised departure clearances, automation of routine clearances, traffic flow management reroutes, automated transfer of communications, optimized profile descents, and trajectory-based operations. These services contribute to evolving air traffic control from short-term tactical operations to the strategic managements of flights from gate-to-gate.

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NAM	USA	ITT Exelis	-	ADS-B	ADS-B is expected to be available nationwide by 2013. ADS-B services in the USA were pioneered by four programs: Alaska; Houston and the Gulf of Mexico; Louisville, KY; and Philadelphia. Since 2007, ITT has been under contract to the FAA to deploy the ADS-B ground infrastructure under the FAA's Next-Gen modernization program. ITT is installing 794 ADS-B ground stations that will comprise the entire network. By 2020, aircraft flying in controlled air-space in the US must be equipped with ADS-B avi-onics that broadcast their position. The FAA is also using ADS-B technology to provide free weather and traffic information to operators who choose to equip their aircraft with avionics capable of receiving this data. This will allow pilots to view cockpit displays showing where they are in relation to other aircraft, bad weather, and terrain. They will also receive flight information, such as temporary flight restrictions to help them plan safe, more efficient routes.
NAM	USA	FAA	$1,100	TFDM	The Federal Aviation Administration (FAA) has a need for a new terminal flight data management (TFDM) system to be used by controllers at 500+ FAA-owned or operated airport traffic control towers (ATCTs) in the national airspace system (NAS). At this time the nature of the competition has not been determined.
NAM	USA	FAA	1,048	ADS-B	Automatic Dependent Surveillance-Broadcast (ADS-B) is FAA's satellite-based successor to radar. ADS-B makes use of GPS technology to determine and share precise aircraft location information, and streams additional flight information to the cockpits of properly equipped aircraft. Estimated budget through 2016.
NAM	USA	FAA	124	CNS/ATM	Collaborative Air Traffic Management Technologies (CATMT) is a suite of enhancements to the deci-sion-support and data-sharing tools used by air traf-fic management personnel. These enhancements will enable a more collaborative environment among controllers and operators, improving efficiency in the National Airspace System. Estimated budget through 2016.
NAM	USA	FAA	617	Data Commu-nication	Data Communications (Data Comm) will enable con-trollers to send digital instructions and clearances to pilots. Precise visual messages that appear on a cock-pit display can interact with an aircraft's flight com-puter. Offering reduced opportunities for error, Data Comm will supplant voice communications as the pri-mary means of communication between controllers and flight crews. Estimated budget through 2016.

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NAM	USA	FAA	97	Weather	NextGen Network Enabled Weather (NNEW) is part of an interagency effort to provide users of the national airspace system with quick, easy, and cost-effective access to timely, accurate weather information. Through the sharing of common weather data, NNEW will enhance safety and support collaborative decision making. Estimated budget through 2016.
NAM	USA	FAA	120	CNS/ATM NVS	The National Airspace System Voice System (NVS) will supplant FAA's aging analog voice communication system with state-of-the-art digital technology. NVS will standardize the voice communication infrastructure among FAA facilities, and provide greater flexibility to the air traffic control system. Estimated budget through 2016.
NAM	USA	FAA	248	Aero Info (AIS, AIM)	System Wide Information Management (SWIM) is the network structure that will carry NextGen digital information. SWIM will enable cost-effective, real-time data exchange and sharing among users of the national airspace system. Estimated budget through 2016.
NAM	USA	FAA	-	CNS/ATM AIRE	The Atlantic Interoperability Initiative to Reduce Emissions (AIRE) is a cooperative agreement between the US and the European Commission to promote and harmonize environmental initiatives and procedures in European and North American airspace.
NAM	USA	FAA	569	Satellite WAAS	Wide Area Augmentation System (WAAS) for GPS. Estimated Budget through 2016.
NAM	USA	Globalstar	-	Satellite ADS-B	To help meet the NextGen agenda for air traffic management, ADS-B Technologies LLC has teamed with Globalstar, Inc. to develop a worldwide leading edge satellite based air traffic control management system. In July 2011, six new second-generation Globalstar satellites were successfully launched from the Baikonur Cosmodrome in Kazakhstan, using the Soyuz launch vehicle. Globalstar is halfway to its goal of adding 24 new second-generation satellites to its constellation. With these new satellites, ADS-B Technologies is now almost halfway to its goal of creating a system that can someday provide satellite-based ADS-B globally. ADS-B Technologies now has a formal ten-year agreement with Globalstar, Inc. (NASDAQ:GSAT), announced on May 10, 2011 to use its proprietary ADS-B Link Augmentation System ALAS™ technology on Globalstar´s second-generation satellite constellation. The ALAS™ system, which will use Globalstar´s network of satellites and ground stations to provide both ADS-B surveillance and communications services on a global scale, was first announced to the public at the Integrated Communications, Navigation and Surveillance Conference in Herndon, VA in May 2010.

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AFR	Congo	Thales	-	ADS-B	The Congolese Ministry of Transport has selected Thales to supply its Eurocat automation system and install ADS-B ground stations in Kinshasa, Lubumbashi, Buta, Mbandaka, and Ilebo.
AFR	D.R. Congo	Transport connectivity improvement	26		Transport sector connectivity improvement and national economic integration.
AFR	Ethiopia	Selex	-	ADS-B	The Ethiopian CAA awarded SELEX a US$8 million contract to supply the country with radar and ADS-B surveillance. Equipment includes several satellite-linked ASD-B ground stations to enhance nationwide surveillance
AFR	Ghana		-	CNS/ATM	Develop new ATC center at Kotoka International to handle projected growth through 2026. U.S. TDA gave Ghana a $295,000 grant for a feasibility study for the new center.
AFR	Nigeria		47	Airports	Improving safety and security improvements at main airports. World Bank International Development Association funding.
APAC	India	Airports Authority of India	-	ADS-B	Airports Authority of India (AAI) has launched a program to establish a single continuum of upper air space, which will facilitate the uniform application of rules and procedures. AAI plans to amalgamate 11 area control centers initially into four and ultimately into two centers. Each flight information region will have only one upper area control center with multiple sectors to be operated from four major cities. The four main en route centers will be at Delhi, Mumbai, Kolkata, and Chennai. Information is now being integrated from seven existing radars as well as three additional radars and ADS-B sensors into the automation system. A radar picture of all the aircraft in the southern region is available at the Chennai ATC center.

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APAC	Indonesia	ERA and Thales	-	ADS-B	In 2006, Indonesia started trials of a nationwide ADS-B surveillance system. In November 2010, AirServices Australia and the Indonesian Directorate General of Civil Aviation (DGCA) reached a formal agreement to exchange enhanced flight data for aircraft travelling across the two countries' flight information region boundaries. It will allow controllers to precisely track aircraft up to 150 NM inside the other country's airspace using ADS-B technology. Under the arrangement, data from four Australian ADS-B ground stations is transmitted to Makassar Air Traffic Services Centre in Sulawesi, Indonesia. AirServices Brisbane Air Traffic Services Centre receives reciprocal data from four ADS-B ground stations in Indonesia. Indonesia has installed 27 ADS-B ground stations across its archipelago, 18 of which display information to controllers in Makassar. The installation of 30 ADS-B ground stations is underway, and the plan is to have them operational in 2012. The ATM system in Ujung Pandang has been updated to receive ADS-C/CPDLC (FANS-1/A protocols) messages, which became operational in September 2010. Comsoft supplied Quadrant ADS-B units in 2009. In 2009 ERA supplied MSS ADS-B surveillance sensors to DGCA of Indonesia for West Indonesia; three Thales ground stations were deployed in Indonesia in 2007 during a six-month trial in partnership with DGAC, SITA, and AirServices Australia.
APAC	Kazakhstan	Lockheed Martin	-	ADS-B	Kazaeronavigatsia announced a U$S49.9 million contract award to Lockheed Martin at the ATCA 2010 meeting in Washington in October 2010. Lockheed Martin will deploy its Skyline automation system at the new Almaty area control center and thirteen airfield towers. Lockheed Martin will also upgrade existing Skyline installations at Astana and Aktobe centers and provide maintenance and support for the nationwide system through 2025. The contract award includes ADS-B systems.
APAC	Tajikistan	ERA	-	ADS-B	Tajikaeronavigation, the Republic of Tajikistan's ANSP, has selected ERA to provide a nationwide wide area multilateration (WAM) solution in the Republic of Tajikistan. ERA is supplying its MSS multilateration and ADS-B surveillance system in place of costly surveillance radar across the country's mountainous terrain. The nationwide WAM solution will be deployed in three phases. The first phase includes WAM surveillance for the northern portion of the country and will provide air traffic controllers with complete situational awareness of en route traffic in the Khujand portion of the Dushanbe flight information region, as well as the approach surveillance for Khujand International Airport. The second and third phases will include surveillance for the south and central areas of the nation and surveillance for the eastern portion, respectively.

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EUR	Czech Republic	ERA	-	ADS-B	The Czech air navigation service provider ANS CR took delivery of a third wide area multilateration and ADS-B system supplied by ERA in early July 2010. ERA has already supplied WAM systems to Prague and Ostrava, and all three are due to be connected to provide a countrywide WAM network. The Brno system provides coverage out to 80 NM, and is designed to replace the soon-to-be retired secondary radar in Feichtberg, Austria. The network is expected to provide the first nationwide deployment of multilateration and ADS-B in high-density European airspace.
EUR	France	Thales	-	ADS-B	Thales ADS-B trial systems in place.
EUR	Norway	Saab Sensis	-	ADS-B	Avinor has selected Sensis to deploy ADS-B ground stations to strengthen monitoring of airspace extending to the Ekofisk, Sleipner and Heimdal oil fields. A total of three base stations are to be established on the mainland outside Stavanger and Florø – in addition to eight on the oil installations at Ekofisk, Sleipner and Heimdal. Every year there are 160,000 passenger trips between Ekofisk and the mainland alone. The new installations are to be approved in April 2013. The cost of the project is NOK 6.5 million (US$1.09 million).
EUR	Russia	ERA	-	ADS-B	MSS multilateration and ADS-B systems have been certified for operational use by the Interstate Aviation Committee (MAK) for use in Russia following a seven-month process. ERA also reports a second contract in Russia to supply its multilateration and ADS-B surveillance solution, after Domodedovo International.
LAM	COCESNA		-	ADS-B	According to the second meeting of the Surveillance Task Force of the CNS Committee (CNS/COMM) of the GREPECAS ATM/CNS Sub-Group (ATM/CNS/SG) ADS-B trials have been conducted to obtain statistical information on the equipage of aircraft in the region. Preliminary results indicate that several aircraft of the main airline fleets that overfly the central area of Honduras and its proximity use ADS- regularly. In total, 61 aircraft have been registered.
LAM	Mexico		-	ADS-B	SENEAM is in the early stages of assessing the benefits of installing an ADS-B network over the Gulf of Mexico region to enhance surveillance

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MES	United Arab Emirates	Comsoft	-	ADS-B	The General Civil Aviation Authority (GCAA) of the UAE has selected COMSOFT to provide three operational ADS-B ground stations. With Tarif, Sharjah, and the new Sheikh Zayed Centre in Abu Dhabi serving as locations, ADS-B coverage of UAE's air space and adjacent areas is now available. The GCAA later announced it was extending its network of redundant Quadrant ground stations with eight additional ADS-B/WAM sensors plus active interrogation. The upgrade will see a total of 14 sensors and additional processing equipment, covering most of the airspace under control of the GCAA. Four additional locations will be added to the existing sites feeding accurate position reports into the main processing unit at Abu Dhabi's Sheikh Zayed Centre.
NAM	USA	FAA	-	CNS/ATM	RNP capabilities for SIDS/STARS by 2016 and en route by 2018.
NAM	USA	Saab Sensis	-	ADS-B	The FAA has approved initial operating capability (IOC) of the Wide Area Multi-lateration (WAM) system at Juneau International Airport Alaska, supplied by Sensis Corporation. Controllers at the Anchorage area center now see aircraft on approach to Juneau and can provide radar-like separation where previously this was not possible in the mountainous terrain. The WAM system covers the airspace roughly 40 miles west, 10 miles south and 20 miles north of the airport from 200 ft. to 20,000 ft. Due to the remote location of some sensors, communication between the sensors and the target processor is achieved using a variety of communications systems, including leased digital data system circuits, FAA-supplied microwave links, and Juneau police microwave links. Alaska was one of four key sites where the FAA is rolling out ADS-B services. The other sites include Houston and the Gulf of Mexico, Louisville, KY, and Philadelphia. Alaska was the initial test site for ADS-B under a pilot project called Capstone from 1999-2006. Through the Capstone project, the FAA equipped hundreds of general aviation aircraft in Southeast Alaska with ADS-B avionics and installed ground-based infrastructure. Pilots were able to see on their displays where they were in relation to bad weather and terrain, and the fatal accident rate was cut nearly in half for equipped aircraft. The success of the Capstone project led to the FAA's decision in 2005 to deploy ADS-B nationwide. Controllers at both the Anchorage Air Route Traffic Control Center and at the Juneau Air Traffic Control Tower are using ADS-B, which is critical in Juneau because, like in the Gulf of Mexico, there is no radar coverage. Radar transmissions cannot pass through the mountains in Juneau, making it one of the nation's most difficult airport approaches.

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NAM	USA	Saab Sensis	-	ADS-B	Saab Sensis Wide Area Multilateration is the industry's first certified multilateration system for simultaneous approaches to closely spaced parallel runways. The system is providing the highly accurate, constant surveillance needed for PRM procedures.
NAM	USA	FAA	561	CNS/ATM ERAM	En route automation modernization (ERAM). D-position upgrade and system enhancements. Estimated budget through 2016.
NAM	USA	FAA	526	CNS/ATM TAMR	Terminal automation modernization/ replacement program (TAMR Phase 3). Estimated budget through 2016.
NAM	USA	FAA	467	CNS/ATM TFDM	Replace terminal air traffic control facilities. Estimated budget through 2016.
AFR	Egypt		-	CNS/ATM	Conduct studies to support the review of an air transport policy and strategic options and strategy for ATC and ATM. World Bank International Bank for Reconstruction and Development loan, the Cairo Airport Company, and a domestic loan.
AFR	Ethiopia		20	Restructuring	Review and strategic planning of aviation institutional framework. World Bank Economic Sector work funding.
AFR	Guinea, Sierra Leone, Liberia	Intelcan	-	ADS-B	Intelcan has signed a contract with Roberts flight information regions to deliver communications and surveillance systems. The ADS-B portion of the contract consists of two phases to provide five ADS-ground stations, including a new station in Liberia, and will be integrated into Intelcan's existing Skycontrol ATM system. Roberts FIR is a cooperative ANSP of air traffic management for three West African nations – Guinea, Sierra Leone and Liberia.
AFR	Kenya		69	Airports	Airport infrastructure improvements, CAA capacity building, GNSS survey. World Bank International Development Association funding.
AFR	Namibia	ERA	-	ADS-B	In 2009, ERA was selected by Thales to deploy a wide area multilateration system to provide nationwide coverage in Namibia down to FL 145. ERA announced in March 2011 that its multilateration and ADS-B system for the Directorate of Civil Aviation in Namibia (NDCA) successfully passed acceptance testing. ERA's MSS ADS-B and multilateration system provides nationwide coverage for Namibia. The ERA solution provides 36 strategically located MSS ground stations, offering optimum surveillance coverage of the entire country. Covering more than 82,500 square km, the system is one of the world's largest wide area multilateration systems.

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AFR	South Africa	ERA	-	ADS-B	In 2009, South Africa certified its MSS ADS-B and multilateration systems for wide area and surface surveillance at Cape Town International Airport and in Johannesburg International Airport for surface surveillance. ERA's wide area multilateration (WAM) system in Cape Town was the first certified WAM system in Africa for ATC-separation services in terminal area and en route airspace. ERA's WAM provides surveillance out to 60 NM from Cape Town International Airport, covering TMA and upper airspace. Data from system is fused and tracked along with primary radar, traditional MSSR and ADS-B data in the Thales Eurocat X ATM-system.
AFR	Tanzania		55	Airports	Rehabilitation and extension of regional airports. World Bank International Development Association funding.
APAC	Australia	Saab Sensis		ADS-B	Sensis's Wide Area Multilateration (WAM) system over Tasmania, Australia is now operational. The system uses both multilateration and ADS-B to provide AirServices Australia with enhanced en route surveillance of air traffic across the island and down to the surface at Hobart and Launceston Airports. The WAM system provides seamless cooperative surveillance coverage between Launceston and Hobart Airports, with accurate coverage of 150 meters or better from the ground level at the airports to 18,000 ft. Surveillance data is sent to the Melbourne area center where it provides controllers with information to implement five nautical miles of separation in an environment that had largely been controlled with procedural separation measures.
APAC	Australia	Thales		ADS-B	Australia's nationwide ADS-B network went into operation in late 2009, to provide surveillance above FL300 for the first time in non-radar areas. Users carrying certified equipment can take advantage of five NM separation procedures, with mandated equipage due to see user-preferred routes become available from 2014. AirServices has deployed 57 ground stations supplied by Thales at 28 sites since launching the program in 2004. The service is available to over 1,150 aircraft that have approved ADS-B avionics equipment, and the Australian Civil Aviation Safety Authority (CASA) has mandated the installation of this equipment by all aircraft operating in the upper airspace by December 2013. ADS-B equipped aircraft are also given operational priority in the ATC system.

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APAC	Australia	Thales		ADS-B	Airservices Australia has completed a major upgrade of air navigation systems based on Lord Howe Island. The service provider has commissioned a VHF radio and ADS-B services where previously only HF radio was available. The airspace around Lord Howe Island hosted numerous crossing points for Trans-Tasman flight routes between Australia and New Zealand and for international traffic from across the Pacific into Sydney. Controllers can positively identify, track, and directly manage aircraft within a 250 NM radius (460km) of Lord Howe.
APAC	Australia	Sensis		ADS-B	In October 2007, Sensis provided a Wide Area Multilateration system for terminal airspace surveillance and precision approach monitoring at Sydney Airport within 60 NM range.
APAC	China	Saab Sensis	0.00	ADS-B	In October 2007 the company installed two ground stations at Chengdu Shuangliu International and Jiuzhai Huanglong airports in partnership with Aviation Data Communication Corporation (ADCC) to support ADS-B trials.
APAC	China	Telephonics	0.00	ADS-B	CAAC ATMB selected Telephonics AeroTrac ADS-B/radar data fusion system for Zhanjiang, Zhengzhou, and Shantou, bringing to 14 the number of Aerotrac systems in China. Other sites are: Guangzhou, Wuhan, Changsha, Zhuhai, Sanya, Shenzhen, Jinan, Xian, Haikou, Nanning, and Guilin.
APAC	Fiji	ERA, Adacel	0.00	ADS-B	In 2009, ERA was selected by Airports Fiji Ltd to provide a nationwide air traffic management replacement system for the Fiji flight information region (FIR). ERA will deploy its MSS surveillance system to provide ADS-B and multilateration surveillance, and Adacel is supplying its Aurora air traffic management system. Equipment has been installed in the area control center and control towers at Nadi and Nausori International airports. The delivery includes a FlightYield aviation charging system, technical and operational training. Aurora is currently installed in adjacent US and New Zealand airspace. The system is expected to make Fiji the first country in the world with a fully comprehensive, operational ADS-B solution with no reliance on radar.
APAC	India		0.00	Restructuring	Spin-off of ANSP from AAI. KPMG India to complete feasibility study in 2012.
APAC	India		0.00	CNS/ATM	Augmentation of CNS/ATM system including ATFM, implementation of PBN, modernization of MET services and networking of civilian/military radars.
APAC	Japan	Telephonics and NEC	0.00	ADS-B	Telephonics Corporation’s AeroTrac ADS-B/radar fusion system has been deployed in Japan; NEC Corporation’s (ADS) system is in service in Japan.

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APAC	Korea	Telephonics	0.00	ADS-B	In 2004, South Korea selected Telephonic's AeroTrac for joint military civil sites to manage the main traffic corridor between northeastern China, Japan, and Korea.
APAC	Kyrgyzstan	Saab Sensis	0.00	ADS-B	Under contract to Raytheon, Saab Sensis will be deploying a nation-wide WAM system in support of the modernization of the Kyrgyz Republic air traffic management system.
APAC	New Caledonia		0.00	ADS-B	The implementation of ADS-B services, the establishment of GNSS procedures, changing over-water routes, creating itineraries VFR flight preparation are under way.
APAC	New Zealand	ERA	0.00	ADS-B	Wide Area Multilateration system at Queenstown International Airport.
APAC	Pakistan		$20 million	National Trade Corridor Improvement Program	World Bank International Development Association funding.
APAC	Pakistan		2.00	Restructuring	World Bank International Development Association funding.
APAC	Philippines		0.00	ADS-B	The EADS Defense and Security (DS) Monopulse Secondary Surveillance Radar MSSR 2000 I, installed in the Philippines in association with Integrated Energy Systems & Resources Inc. (IESRI), combines active Mode S interrogations with the passive reception of ADS-B signals.
APAC	Singapore	Comsoft	0.00	ADS-B	In early 2009, the Civil Aviation Authority of Singapore (CAAS) selected Comsoft to supply two ADS-B ground stations and a data processing system to begin operations later this year. Comsoft is supplying two sensors and a data fusion system to integrate with the existing ATM system. The ADS-B system features a 300 NM range and low power consumption.
APAC	Taiwan	Comsoft	0.00	ADS-B	The Air Navigation and Weather Services (ANWS) of the Civil Aeronautics Administration of the Republic of China has taken the ADS-B network supplied by Comsoft into operational service. The system includes six redundant Quadrant ADS-B ground stations and eight complimentary QCMS systems for monitoring and control of all sites.

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APAC	Vietnam	The Civil Aviation Administration of Vietnam and Japan International Cooperation Agency (JICA)	6.00	CNS/ATM	CNS/ATM Project for Capacity Development for Transition to the New CNS/ATM Systems in Cambodia, Lao PDR, and Vietnam.
EUR	Armenia	Peleng	0.00	ADS-B	2007 saw completion of the Armenian ATS Provaider (ARMATS) program which began in 2006 and processes data from a wide range of surveillance systems, including ADS-B. Multilateration equipment was supplied by ERA in 2006.
EUR	Bulgaria		0.00	CNS/ATM	Procurement for upgrade/extension of equipment, systems for unified ATM center commissioned in 2008 with intention of handling traffic growth through 2020. Comsoft's ADS-B ground station was implemented at Sofia for trials by BULASTA in March 2008.
EUR	Germany	Raytheon	0.00	ADS-B	Raytheon ADS-B system is supporting Cascade trials.
EUR	Greece	Comsoft	0.00	ADS-B	The Hellenic Civil Aviation Authority (HCAA) has selected Comsoft to upgrade the Radar Message Conversion and Distribution Equipment (RMCDE) in Athens to distribute radar and ADS-B data. The installation includes implementation of HCAA's specific tracker format in order to integrate the existing tracker with other surveillance systems. Comsoft initially delivered RMCDE as part of the CRISTAL trials for ADS-B evaluation in 2006.
EUR	Portugal	ERA	0.00	ADS-B	Nav Portugal has selected ERA WAM and ADS-B to provide surveillance for the Azores in 2009. Surveillance coverage includes the approach, departure, and go-around zones of Portugal's Horta Airport and will extend to over 100 NM in most directions, with accuracy sufficient to enable both en route and approach separation services.
EUR	Slovakia	Comsoft	0.00	ADS-B	Slovakian air navigation service provider LPS has selected the Comsoft ADS-B solution Quadrant. Four sensors and a control and monitoring system are due to be installed across the country after completion of all tests. The new system will also operate with a new ARTAS surveillance data input source that LPS is due to install.

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EUR	Sweden	CNS Systems	0.00	ADS-B	CNS Systems implemented the first ADS-B network with 4DT capability for LFV Group, including 12 VDL Mode 4 systems completed in 2008. The ground stations are installed at the following airports: Malmö, Stockholm Arlanda, Luleå Kallax, Umeå, Norrköping, Stockholm Bromma, and Gothenburg Landvetter, Kiruna, Östersund, Sundsvall, Vizby, and Karlstad. Besides ADS-B information, the systems form part of the airport A-SMGCS and enables time controlled ATM and 4DT applications for more efficient operations.
EUR	UK	Sensis	0.00	ADS-B	NATS and LVNL of the Netherlands have introduced wide area multilateration (WAM) services to monitor helicopter operations in the North Sea. NATS Services is using the Sensis WAM system to support more than 25,000 helicopter operations a year in the 25,000 square miles of the North Sea between Aberdeen Airport and the oil and gas platforms.
EUR	UK	Sensis	0.00	ADS-B	NATS selected Saab Sensis Wide Area Multilateration for flights in the vicinity of Edinburgh Airport. Saab Sensis WAM will provide surveillance of all flights operating within 60 nautical miles of the airport and will replace the existing Monopulse Secondary Surveillance Radar.
EUR	UK	Thales	0.00	ADS-B	NATS has awarded Thales a contract to supply a wide area multilateration (WAM) system for trial purposes as part of the EUROCONTROL CASCADE program. NATS is participating in the CRISTAL UK 3 trials within CASCADE, and aims to validate the safety of ADS-B/WAM in meeting three NM separation standard in busy airspace. Thales is supplying its MAGS system, including six sensors located around London covering the airports of Heathrow, Gatwick, London City, Luton, and Stansted. The data collected will be compared with radar surveillance data to validate WAM performance.
EUR	Ukraine	ERA	0.00	ADS-B	ERA has supplied a wide area multilateration system (WAM) of 18 ADS-B sensors for Kiev airport.
LAM	Bolivia		5.00	Airports	Regional integration strengthening and airport infrastructure development. World Bank International Development Association funding.
LAM	Jamaica	ERA	0.00	ADS-B	In early 2009 ERA was selected to provide an ADS-B system to the Jamaica Civil Aviation Authority (JCAA). The system will be used by the JCAA for extensive operational testing, prior to an eventual nationwide wide area multilateration and ADS-B deployment.

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LAM	Peru		0.00	CNS/ATM	Improving capabilities to support domestic air service to eastern portions of country.
LAM	Peru	Comsoft	0.00	ADS-B	Comsoft Quadrant ADS-B systems were installed in Peru in 2009.
MES	Kuwait	Selex	0.00	ADS-B	The Kuwait General Directorate of Civil Aviation has awarded SELEX a contract worth US$16 million to supply anATCR-33/S primary radar, a SIR-S secondary radar, and ADS-B ground station ADS-B for en route, terminal area and airport surveillance applications at Kuwait International Airport.
MES	Saudi Arabia	Saab Sensis	0.00	ADS-B	In 2009, the General Authority of Civil Aviation selected Saab Sensis to deploy Wide Area Multilateration coupled with Advanced-Surface Movement Guidance and Control Systems at King Abdul Aziz and King Fahad International Airports. The WAM systems will provide terminal area surveillance up to 50 nautical miles from each airport.
NAM	Canada	Saab Sensis		ADS-B	Saab Sensis has deployed wide area multilateration to Fort St. John to provide low level surveillance of flights operating in the “oil sand” area and in Vancouver Harbor to provide surveillance of sea plane traffic that operates below traditional radar. In addition, Saab Sensis deployed a WAM system to support air travel in the “sea to sky” corridor between Vancouver and Whistler for the 2010 Winter Olympics.
NAM	Canada	Saab Sensis	0.00	ADS-B	In March 2008, Saab Sensis began work ADS-B ground stations on Canada’s East Coast to enhance surveillance of trans-Atlantic traffic. ADS-B operates over Hudson Bay. The first flight flew over Hudson Bay using ADS-B surveillance technology in January 2009. Sensis Corporation installed the ADS-B ground stations, each consisting of an antenna, a receiver, and a target processor, along the Hudson Bay shoreline. NAV CANADA estimates customer savings of about 18 million liters of fuel per year and reduced C02 equivalent emissions of 50,000 tonnes per year, once all aircraft using this airspace are equipped for ADS-B. The service provider plans to extend its ADS-B coverage over the eastern coast of Canada and parts of Greenland.

ICAO Region	Country / Agency	Contractor / Organization	Value $ MM	Program Type	Description
NAM	USA	ITT	0.00	ADS-B	Controllers are now able to safely reduce the separation between ADS-B-equipped aircraft to five NM, improving capacity and efficiency. The new technology allows the FAA to provide more direct routes over the Gulf of Mexico, improving the efficiency of aircraft operations while using less fuel. In particular, the technology increases capacity and efficiency for the 5,000 to 9,000 daily helicopter operations in the Gulf of Mexico. Aircraft equipped with ADS-B in the region also have access to weather information and receive flight information including notice to airmen and temporary flight restrictions. The FAA installed ground stations on oil platforms as part of an agreement with the Helicopter Association International, oil and natural gas companies, and helicopter operators.
NAM	USA	Saab Sensis	0.00	ADS-B	In 2009, Saab Sensis wide area multilateration in the "ski country" of Colorado became the first FAA-certified WAM system for the separation of en route aircraft. The system provides FAA air traffic controllers at the Denver ARTCC with surveillance to provide separation services of flights operating to and from Yampa Valley Regional, Garfield County Regional, Steamboat Springs, and Craig-Moffat County Airports.
NAM	USA	FAA	0.00	ADS-B	ADS-B Out is mandated for aircraft starting in 2020.
NAM	USA	FAA	0.00	CNS/ATM	The Atlantic Interoperability Initiative to Reduce Emissions (AIRE) is a cooperative agreement between the US FAA and the European Commission to promote and harmonize environmental initiatives and procedures in European and North American airspace. In the US, AIRE is coordinated by the FAA Office of Advanced Technology Development and Prototyping as part of the NextGen International Air Traffic Interoperability Program (IATI).
AFR	Tanzania		5.70	Restructuring	Upgrading of the Civil Aviation Training Center (CATC). The TCAA estimates a needed US$5.7 million investment, including a building and other education infrastructure, and human capacity building for the center.
AFR	Tanzania		11.00	ADS-B	For surveillance, ADS-B (estimated cost: US$10 million) to cover the whole of Tanzania. GNSS Approaches to replace conventional ones using NDBs for Arusha, Mwanza, Zanzibar, Pemba, Bukoba, Kigoma, Tabora, and Mafia airports (estimated total cost: US$ 1 million).

ICAO Region	Country / Agency	Contractor / Organization	Value $ MM	Program Type	Description
	Tanzania		2.50	CNS/ATM	A VHF Extended Range System Vsat Link: In order to provide communications coverage, six relay stations need to be added, namely Lilungu, Lolkisale, Gairo, Nyanshana, Kaluwe, and Kazeh Hill. In addition, the existing installations are aged and require an expensive and underlying telecommunications link which needs to be replaced with VSAT technology.
	Tanzania		2.40	Aero Info (AIS, AIM)	An integrated automated AIS/ATS Data Processing System. This is a multi-faceted system consisting of a message handling system with an AFTN gateway (US$962,000), an automated AIS system (US$935,000), an FDPS system for giving the air traffic controller trajectory predictions (US$415,000), and an overall billing system (US$91,200). (Total estimated cost: US$2.4 MM)

4.0 CNS/ATM Technologies & Applications

4.1 Introduction and General Overview

The air transport industry plays a major role in world economic activity and remains one of the fastest growing sectors of the world economy. In every region of the world, nations depend on the aviation industry to maintain or stimulate economic growth and to assist in the provision of essential services to local communities. In this light, civil aviation can be seen as a significant contributor to the overall well-being and economic vitality of individual nations as well as the world in general.

Because of the continued growth in civil aviation, in many places demand often exceeds the available capacity of the air navigation system to accommodate air traffic. One of the keys to maintaining the vitality of civil aviation is to ensure that a safe, secure, efficient, and environmentally sustainable air navigation system is available at the global, regional, and national levels. This requires the implementation of an air traffic management system that allows maximum use to be made of enhanced capabilities provided by technical advances.

The current ATI and ATC concepts, most of which were developed and implemented more than 60 years ago, are not capable of supporting increased demands for air travel. When combined with increased awareness of environmental issues, air traffic congestion and subsequent delays result in significant negative consequences not only to the aviation industry, but also to general economic health.

4.1.1 Background

Since the current CNS/ATM system is being tasked to perform well beyond its intended capacity, merely expanding it will not circumvent its inherent shortcomings to satisfy future air traffic demands. The current CNS/ATM system is limited by several factors, including the following:

- Disparate services and procedures resulting from differing systems and limited system and decision-support tools.
- A reliance on increasingly congested voice radio communications for air-to-ground exchanges.
- Rigid airspace divisions and route structures that do not allow the totality of ATM resources to be maximized.
- Limited collaboration among ATM, aerodrome, and aircraft operators.
- Less than optimum use of scarce resources such as airspace and aerodrome airside capacity.
- Limited facilities for real-time information exchange among ATM, aerodrome operators, and aircraft operators, resulting in less than optimal responses to real-time events and changes in users' operational requirements.
- Limited ability to maximize benefits for aircraft with advanced avionics.
- Long lead times involved in developing and deploying improved systems in aircraft fleets or in the ground infrastructure.

ICAO estimates that $120 billion will be spent on the transformation of air transportation systems in the next ten years. While NextGen, SESAR, and CARATS in the US, Europe, and Japan, respectively, account for a large share of this spending, parallel initiatives are underway in many areas including the Asia/Pacific, North and Latin America, Russia, and China. Modernization is an enormously complex task, but the industry needs the benefit of these initiatives as traffic levels continue to rise. It is clear that to safely and efficiently accommodate the increase in air traffic demand, as well as to respond to the diverse needs of operators, the environment, and other issues, it is necessary to renovate ATM systems to provide the greatest operational and performance benefits.

These local and regional CNS/ATM programs are being developed under a broader framework established by ICAO known as the ATM Operational Concept. The ATM concepts are designed as an evolutionary process in order to adapt to industry changes. Implementation of ATM operational concepts falls under a new framework currently being developed by ICAO known as Aviation System Block Upgrades (ASBUs). ICAO's four-block program lays the foundation for implementation of future CNS/ATM systems, providing global standards as a basis for regional programs.

The ASBU framework is structured to allow independence between any regional CNS/ATM improvement programs while ensuring that three main goals are accomplished under all efforts:

- Safety is maintained and enhanced.
- ATM improvements are globally harmonized.
- Barriers to future efficiency and environmental gains are removed at a reasonable cost.

Among the new technologies that facilitate the development and implementation of CNS/ATM capabilities in each of the Block Upgrades are satellite-based communication and navigation and high-speed digital datalink for communication and navigation. These technologies improve upon the capabilities of legacy systems by enabling a new fourth dimension to the ATM concept. The fourth dimension — time — creates the ability to achieve operational improvements by managing traffic flows based on trajectories rather than fixed navigation aids.

Surveillance will ultimately shift from ground-based primary and secondary radars to aircraft-derived position and velocity reports. These reports will be transmitted to the ground, directly or indirectly, in order to reduce aircraft separation and to facilitate an increased collision avoidance capability. Highly accurate position and flight path intent data will be available from suitably equipped aircraft, including oceanic flight where surveillance coverage is currently limited to certain routes. In addition, existing communications, navigation, and surveillance infrastructures will be replaced with systems that are more cost effective with higher capability and reliability.

Following is a brief discussion of the concepts of future CNS/ATM systems and the operational constraints resulting from the inherent restrictions of current technologies and regulations.

4.1.1.1 Shift to Trajectory-Based Operations

The present ATM system has been in use for approximately 60 years. It was conceived while radar was a nascent technology, and the volume of air traffic was significantly less than today's levels. Repeated attempts to increase capacity in order to meet rising demand in the absence of modern automation or new operational concepts proved to be unsuccessful. Consequently, the flexibility to operate efficiently in global airspace has thus far been inadequately addressed.

In the current ATC concept of operation, flight routes and altitude information are provided to airline operators via IFR flight plans and positive (radar) control, which often results in significant operational and economic inefficiencies. Flight plans, when used in conjunction with surveillance radar, provide controllers with predictable flight path data for each aircraft in their sector. With this knowledge, controllers are able to manage traffic and resolve potential flight path conflicts. The problem with this concept is that it is highly inflexible and inefficient, particularly as air traffic growth continues to increase.

Trajectory-based operations (TBO) are those airspace operations in which the future trajectories of all aircraft, i.e., their four-dimensional (4D) paths through space and time, are the basis for separation and efficient flow in the airspace. 4D trajectories are predicted and regularly updated by an automation system and used to solve traffic conflicts, satisfy metering constraints, avoid weather and restricted airspace, and find more efficient flight paths, all in an integrated manner.

TBO focuses primarily on high-altitude cruise operations in enroute airspace. TBO will provide the capabilities, decision-support tools, and automation to manage aircraft movement by trajectory. This shift from clearance-based to trajectory-based air traffic control will enable aircraft to fly negotiated flight paths necessary for full performance-based navigation, taking both operator preferences and optimal airspace system performance into consideration. Applications include:

- Continuous descent arrivals
- Tailored arrivals
- 3D path arrival management
- 4D trajectory-based management
- Required navigation performance (RNP)

The flight management system (FMS) flight plan will be shared with the ANSP and used for flow planning purposes. ADS messages will provide highly accurate aircraft position and velocity vector data. This new information and data exchange between the aircraft and ANSP will facilitate a shift from strategic to tactical separation, resulting in optimized, real-time flight path and trajectory planning.

This requirement leads to a transformation of the national airspace to TBO in which precise management of an aircraft's current and future position enables increases in throughput and improvements in efficiency when necessary by varying the level of performance required to meet the need. All airspace operations are based upon trajectory and are inclusive of all capability levels of aircraft with flexibility inherent in the trajectory clearance that sets the performance required at that time, and allows the aircraft to optimize performance within some bounds or maneuverability to resolve delegated separation from other aircraft.

4.1.1.2 Required Separation Minima

The essential factors affecting conflict rate in enroute and terminal airspace are traffic density, complexity of flow, airspace restrictions, and separation standards. It is proven that reducing the required separation minima by increasing the performance requirements, through the enhanced accuracy of GNSS and ADS reporting, will have a very powerful effect on reducing the conflict rate. However, there are some minimum allowable distances to separate aircraft that, in order to ensure safety, ultimately cannot be eliminated.

The size of the minimal allowed distance between an aircraft and any other hazard, or required separation minima, is a function of several factors that are combined to ensure safety during all stages of flight. With the end goal being achievement of user-preferred routing capabilities, the factor with the greatest level of aircraft position uncertainty is therefore the limiting factor in reducing inefficiencies in the ATM system.

In order to ensure that the required separation minima area is not breached under any circumstances, an additional framework outlining conflict resolution requirements is necessary. An additional separation minima is introduced as a conflict resolution buffer between conflicting flight paths. The size of the separation minima, always larger than the required separation minima, is determined based on the time required to identify, resolve, communicate, and react to a potential conflict with extremely high confidence. The time required to perform conflict resolution is a function of communications, navigation, surveillance capabilities, and pilot controller reaction time with a reasonable period for additional safety.

Aircraft with different CNS performance abilities will have different preferred routing and required separation minima, with the less capable aircraft protected by larger minima. To provide a benefit incentive to offset required flight system investments, resolution maneuvers, when required, could reflect onboard systems capability. For example, aircraft with larger separation (less capable

CNS systems) might be required to execute proportionately larger maneuvers. This way, maximum benefit would accrue to the most capable aircraft, but aircraft with lesser capabilities could still enjoy substantial benefits.

4.1.1.3 Summary of Emerging CNS/ATM Concepts

There are significant benefits to be gained from implementation of modern CNS/ATM systems. Inherent improvements in communication, navigation, and surveillance equipment will be enhanced by ATM automation. In addition, the ability to transmit and receive critical real-time information via datalink will provide the means necessary to transition to the future CNS/ATM environment.

The proceeding sections outline important CNS/ATM concepts regarding trajectory-based capabilities and the limitations of present day systems. The technologies discussed in following sections are efforts to narrow the gap between the current CNS/ATM system and the TBO concept and focus on relevant technical, operational, and institutional issues and future trends. Each technological area should be taken within the context of ICAO's Global ATM Operational Concept, and the transition from the present CNS/ATM environment to that of the future system.

4.1.2 Chapter Overview

This section provides an overview and general discussion of various CNS/ATM technologies and their applications that will be discussed in further detail. Where practical, those technical, operational, and institutional issues that have a direct bearing on the implementation of a specific technology are presented and discussed. Future trend information is also included. The specific content of each section is as follows:

Section 4.2 Global ATM: This section reviews the core benefits to the ATM community provided by the future CNS/ATM system and the limitations of the present system. The general objectives of the new system are discussed in terms of seven operational concepts. The operational concepts were developed by ICAO for planning of ATM to 2025 and beyond.

Section 4.3 CNS/ATM Communications: The communications element of the CNS/ATM systems concept is designed to maximize flexibility. Some of the communication system technologies that provide this capability include VHF datalink, HF voice, Mode Select (Mode S) datalink, and the broader data delivery and communications integration systems.

Section 4.4 Navigation, Approach, and Landing Systems: The initial portion of the section presents a discussion of current satellite-based systems. Included is a description of three main types of satellite-systems: global, regional, and augmentation. The flight phase applications and limitations of the different systems are discussed in detail. A summation of those issues involved with the impending transition from terrestrial-based to satellite-based navigation systems is provided. Also included is a discussion of current terrestrial-based systems used for enroute, terminal area, and precision/non-precision approach and landing operations. Systems discussed include ILS, MLS, DME and others.

Section 4.5 Surveillance Systems: After a discussion of legacy primary radar and secondary surveillance radar, the section proceeds to a discussion of evolving trends, such as automatic dependent surveillance, multilateration (MLAT), and surface surveillance, followed by various issues associated with each. In the final section, the airborne collision avoidance system, referred to as ACAS, is described in terms of technical specifications and future viability.

Section 4.6 Weather Systems: A technical description of automated weather systems is followed by a discussion of wind shear and air turbulence detection systems. Various Doppler radar systems are introduced along with a discussion of current and proposed weather dissemination and display technology systems.

4.2 Global CNS/ATM and Automation Applications

A global ATM system concept can be described as a worldwide system that, on a global basis, achieves interoperability and seamlessness across regions for all users during all phases of flight; meets agreed levels of safety; provides for optimum economic operations; is environmentally sustainable; and meets national security requirements. A key point to note is that the operational concept, to the greatest extent possible, is independent of technology; that is, it recognizes that within a planning horizon of more than twenty years, much of the technology that exists or is in development today may change or cease to exist.

Air traffic management, the operational aspect of the ATM concept, is the dynamic, integrated management of air traffic and airspace — safely, economically and efficiently — through the provision of facilities and seamless services in collaboration with all parties.

The ATM system enables air traffic management capabilities through the collaborative integration of humans, information, technology, facilities, and services, supported by air, ground, and/or space-based communications, navigation, and surveillance. The ATM system is based on the provision of services. This service-based framework considers all resources, such as airspace, aerodromes, aircraft, and humans, to be part of the ATM system.

The primary functions of the ATM system will enable flight from/to an aerodrome into airspace, safely separated from hazards, within capacity limits, making optimum use of all system resources. Regionally, the ATM system will operate at different system performance levels based on the demands of the users and the underlying ATI. The performance of the system will drive the **expected benefits** for the members of the ATM community:

- From an airspace user perspective, greater equity in airspace access, greater access to timely and meaningful information for decision support, and more autonomy in decision-making, including conflict management, will provide the opportunity for better business and individual outcomes within appropriate safety frameworks.
- From a service provider perspective, including that of aerodrome operators, the ability to operate within an information-rich environment, with real-time data, as well as system trend and predictive data, fused with automated decision-support tools, will enable optimization of services to airspace users.
- From a regulator perspective, safety systems will be robust and open, allowing safety not only to be more easily measured and monitored, but also compared and integrated on a global basis as a platform for continuous improvement.

In order attain these benefits, seven operational concept components have been created by ICAO as a framework to organize and describe how services will be delivered. Integration of these seven interdependent operational concepts forms the complete ATM operational concept needed for provision of services.

4.2.1 ATM Operational Concept Components

Disaggregation of the evolving ATM system is necessary in order to understand the complex interrelationships among system components. The seven operational components that constitute a globally interoperable ATM system are:

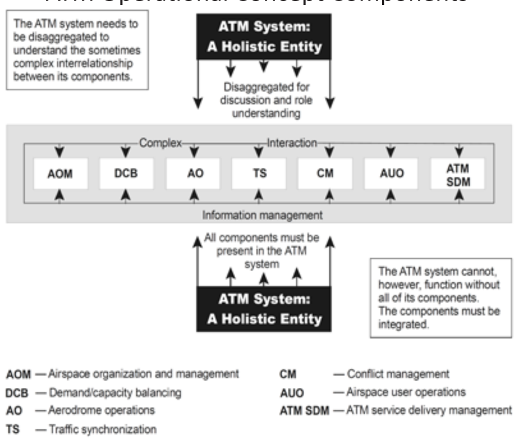
- Airspace organization and management
- Aerodrome operations
- Demand and capacity balancing
- Traffic synchronization
- Conflict management
- Airspace user operations

- ATM service delivery management

Figure 4-1 depicts the relationship of the seven operational components within the ATM system.

Figure 4-1

ATM Operational Concept Components



Source: ICAO

4.2.1.1 Airspace Organization and Management

Airspace organization will establish airspace structures in order to accommodate the different types of air activity, volume of traffic, and differing levels of service. Airspace management is the process by which airspace options are selected and applied to meet the needs of the ATM community. Key concepts include:

- All airspace will be the concern of ATM and will be a usable resource.
- Airspace management will be dynamic and flexible.
- Any restriction on the use of any particular volume of airspace will be considered transitory.
- All airspace will be managed flexibly. Airspace boundaries will be adjusted to particular traffic flows and should not be constrained by national or facility boundaries.

4.2.1.2 Aerodrome Operations

As an integral part of the ATM system, the aerodrome operator must provide the needed ground infrastructure, such as lighting, taxiways, and runways, including exits, and precise surface guidance to improve safety and maximize aerodrome capacity in all weather conditions. The ATM system will enable the efficient use of the capacity of the aerodrome airside infrastructure. Key concepts include:

- Runway occupancy time will be reduced.
- The capability will exist to safely maneuver in all weather conditions while maintaining capacity.
- Precise surface guidance to and from a runway will be required in all conditions.
- The position (to an appropriate level of accuracy) and intent of all vehicles and aircraft operating on the movement area will be known and available to the appropriate ATM community members.

4.2.1.3 Demand and Capacity Balancing

Demand and capacity balancing will strategically evaluate system-wide traffic flows and aerodrome capacities to allow airspace users to determine when, where, and how they operate, while mitigating conflicting needs for airspace and aerodrome capacity. This collaborative process will allow for the efficient management of the air traffic flow through the use of information on system-wide air traffic flows, weather, and assets. Key concepts include:

- Through collaborative decision-making at the strategic stage, assets will be optimized in order to maximize throughput, thus providing a basis for predictable allocation and scheduling.
- Through collaborative decision-making at the pre-tactical stage, when possible, adjustments will be made to assets, resource allocations, projected trajectories, airspace organization, and allocation of entry/exit times for aerodromes

and airspace volumes to mitigate any imbalance.

- At the tactical stage, actions will include dynamic adjustments to the organization of airspace to balance capacity, dynamic changes to the entry/exit times for aerodromes and airspace volumes, and adjustments to the schedule by the users.

4.2.1.4 Traffic Synchronization

Traffic synchronization refers to the tactical establishment and maintenance of a safe, orderly, and efficient flow of air traffic. Key concepts include:

- There will be dynamic four-dimensional (4-D) trajectory control and negotiated conflict-free trajectories.
- Choke points will be eliminated.
- Optimization of traffic sequencing will achieve maximization of runway throughput.

4.2.1.5 Conflict Management

Conflict management will consist of three layers: strategic conflict management through airspace organization and management; demand and capacity balancing; and traffic synchronization, separation provision, and collision avoidance.

Conflict management will limit, to an acceptable level, the risk of collision between aircraft and hazards. Hazards that an aircraft must be separated from are: other aircraft, terrain, weather, wake turbulence, incompatible airspace activity and, when the aircraft is on the ground, surface vehicles and other obstructions on the apron and maneuvering area. Key concepts include:

- Strategic conflict management will reduce the need for separation provision to a designated level.
- The ATM system will minimize restrictions on user operations; therefore, the predetermined separator will be the airspace user, unless safety or ATM system design requires a separation provision service.
- The role of separator may be delegated, but such delegations will be temporary.
- In the development of separation modes, separation provision intervention capability must be considered.
- The conflict horizon will be extended as far as procedures and information will permit.
- Collision avoidance systems will be part of ATM safety management but will not be included in determining the calculated level of safety required for separation provision.

4.2.1.6 Airspace User Operations

Airspace user operations refer to the ATM-related aspect of flight operations. Key concepts include:

- The accommodation of mixed capabilities and worldwide implementation needs will be addressed to enhance safety and efficiency.
- Relevant ATM data will be fused for an airspace user's general, tactical, and strategic situational awareness and conflict management.
- Relevant airspace user operational information will be made available to the ATM system.
- Individual aircraft performance, flight conditions, and available ATM resources will allow dynamically-optimized 4-D trajectory planning.
- Collaborative decision-making will ensure that aircraft and airspace user system design impacts on ATM are taken into account in a timely manner.
- Aircraft should be designed with the ATM system as a key consideration.

4.2.1.7 ATM Service Delivery Management

ATM service delivery management will operate seamlessly from gate to gate for all phases of flight and across all service providers. The ATM service delivery management component will address the balance and consolidation of the decisions of the various other processes/services, as well as the time horizon at which, and the conditions under which, these decisions are made. Flight trajectories, intent, and agreements will be important components to delivering a balance of decisions. Key concepts include:

- Services to be delivered by the ATM service delivery management component will be established on an as-required basis subject to ATM system design. Once established, they will be provided on an on-request basis.
- ATM system design will be determined by collaborative decision-making and system-wide safety and business cases.
- Services delivered by the ATM service delivery management component will, through collaborative decision-making, balance and optimize user-requested trajectories to achieve the ATM community's expectations.
- Management by trajectory will involve the development of an agreement that extends through all the physical phases of the flight.

4.2.1.8 Operational Concept Components Summary

These operational concepts are intended as a guide to the implementation of CNS/ATM technology by providing the foundation for how the future ATM should operate. These concepts are the next step in an evolutionary process that began as the FANS concept. Further information on the ATM operational concepts can be found in ICAO Document 9854.

Key Points:

- Future ATM will require advances in all phases of ICAO's seven operational components: airspace organization, aerodrome operations, demand/capacity balancing, traffic synchronization, conflict management, airspace user operations, and ATM service delivery management
- Each of these components will offer unique investment opportunities as systems integration and data begin to produce the potential for cost savings for aircraft operators.

4.2.2 ATM Automation Applications

All airspace will ideally be organized and managed in such a way as to facilitate the use of full self-separation and autonomous flight, unless safety or efficiency assessment requires the provision of separation services. This must be achieved in conjunction with, or in anticipation of, demand and capacity balancing techniques to ensure that the potential for aircraft-to-hazard conflict is reduced to a level where such self-separation is expected to be conducted to an accepted level of safety. This vision premises an increasing presence of automation in the future ATM system. Applications are being developed for automating all flight phases, including oceanic, enroute, terminal, and surface applications. While originally developed as independent applications, the greatest benefits to the ATM community occur when information can be freely exchanged across all entities and phases of flight among multiple applications.

Automation will benefit the ATM community by enabling improved conflict detection and resolution through intelligent processing, providing for the automatic generation and transmission of conflict-free clearances, as well as offering the means to adapt quickly to changing traffic requirements. As a result, the ATM system will be better able to accommodate an aircraft's preferred flight profile and help aircraft operators to achieve reduced flight operating costs and delays.

Data exchange is the key component of automation applications. The development of and the benefits derived from automation applications is directly reliant on the capacity to share pertinent information in a safe, secure, reliable, and efficient manner with any other component in the ATM system. This capacity is directly related to aircraft equipment, ground equipment, and the datalinks between them.

Beyond having the proper equipment for data exchange, interoperability between regions and applications is a key element of the global ATM system performance. This concept envisages a global information management system that operates more as a data distribution model rather than the data exchange model of the past and present. Information management will ensure that the information needs of ATM stakeholders, both within as well as outside the ATM network, will be satisfied in a much more flexible and cost-effective manner than previously.

The exchange of information will enable the various organizations to update one another continuously on events in real time. Thus, aircraft operators will have up-to-date and accurate information on which to base decisions about flights, while ATM service providers, including aerodrome operators, will have a better knowledge of flight intentions for operational and planning purposes.

4.2.2.1 Oceanic and Enroute Applications

Oceanic and enroute airspace is one of the initial areas where ATM automation applications have been developed. Future oceanic operations will extensively use ADS, satellite-based voice and datalink communications, GNSS, cockpit traffic display, aviation weather system improvements, and automation to integrate ATM systems with flight management computer operations via datalink. These new capabilities will permit flexible routing for system users and dynamic modifications to aircraft routes. This includes reducing oceanic separation standards and responding to changes in weather or traffic conditions. Oceanic automation efforts will also provide fuel and time efficiencies for oceanic airspace users.

4.2.2.2 Terminal Applications

Providing controllers with automated tools to increase capacity in terminal areas is another area where significant automation research and development activities are occurring.

In the departure phase of flight, traffic synchronization will involve the integration of departures into the airborne traffic environment. Improved departure flows will be achieved through automation tools that provide more efficient airport surface operations and improved real-time assessment of traffic activity in departure and enroute airspace.

Arrival operations will also benefit from these automation tools; however, the primary task in this phase will be to plan and achieve optimum spacing and sequencing of the arrival flow. The runway assignment, which provides the basis for this activity, will be made as early as possible. The user's runway assignment preference will be available through the flight object within the ATM environment information system. Departure and arrival decision-support systems and the integrated surface management tools will be used to coordinate an optimal runway assignment.

In the final portion of the arrival phase, decision-support systems will facilitate the use of time-based metering to maximize airspace and airport capacity. Other tools will generate advisories to aid in the maneuvering of flights onto the final approach in accordance with the planned traffic sequence.

4.2.2.3 Surface Applications

Automated systems are also being developed to enhance aerodrome surface safety and capacity. Surface safety automation functions will minimize runway incursions, reduce controllers' workloads, and provide conformance monitoring and voice safety assurance. Aerodrome capacity automation functions are being developed to provide total traffic planning system integration, including enroute, terminal, and surface traffic systems to increase aerodrome capacity and reduce taxi delays. Automated surface traffic functions include the generation of recommended taxi routes for arrival/departure, recommended runway assignments for departing aircraft, recommended taxi clearances and instructions, recommended optimum aerodrome configuration, and forecasts of surface traffic flow.

Automation aids for dynamic planning of surface movements will provide methods and incentives for collaborative problem solving by airspace users and service providers. This will improve the management of excess demand through balanced taxiway usage and improved sequencing of aircraft to the departure threshold. In addition, support tools will permit the optimization of take-off points along the runway by accessing information on aircraft performance capabilities such as required take-off distance and climb-out capabilities. This will also apply in the case of arriving aircraft, allowing exit points from a runway to be accurately predicted or realistically assigned.

The ATM environment will become increasingly integrated as surface-movement decision-support systems provide real-time data to the ATM environment-wide information system. When the aircraft starts moving, the flight's time-based trajectory will be updated in the ATM environment-wide information system, based on the estimated taxi time at the airport under prevailing traffic conditions. When the aircraft becomes airborne, this trajectory will again be updated. This continuous updating of the flight object will improve real-time planning for both the airspace user and the service provider. Real-time information will also improve the effectiveness of ongoing traffic management initiatives and the collaborative decision-making involved with any proposed initiatives.

A critical part of automated terminal systems development is its integration with current and future aerodrome terminal equipment. For example, automated systems must be able to handle inputs from various terminal surveillance sensors, including inputs from vehicles and aircraft. Sensor input will include data from ADS-equipped aircraft/vehicles, DGNSS, Mode S, airport surface radar equipment, and other sensors.

4.2.2.4 Human Factors

Human error attributes to between 70-80 percent of all aircraft accidents. Automation in today's advanced aviation systems has been introduced to increase safety and efficiency. However, as traffic levels continue to increase and more complicated automated systems enter the market, the human factor becomes a real hazard.

For automation to be effective and satisfy minimum safety standards, it must meet the needs of all system users. Flight crews have always benefited from HF attention, while much less consideration has been given to HF aspects in ATC. With increased automation, routine functions change from controlling to monitoring the systems. This alters the demands placed on the controller. Monitoring is not the best function for most humans because it tends to become monotonous, which leads to difficulties maintaining an adequate state of alertness and awareness.

Situational awareness is essential under all conditions. One way to maintain this is to provide the pilot and controller with more information. Although both pilots and controllers might list numerous items of information they think is required, more is not necessarily better. There is a significant difference between what is needed and what is requested. Part of the problem is that each controller knows what is required. However, system designers responsible for providing appropriate information often do not know what controllers do and how the variance among them impacts the need for information and the way it is presented. Until this information is available the human factors cannot be maximized.

ICAO has developed principles of what it calls human-centered automation which is available in ICAO *Human Factors Digest No. 11*. These principles were developed by the ICAO Secretariat with the assistance of the ICAO Flight Safety and Human Factors Study Group, and are based mainly on the work of Dr. Charles E. Billings, formerly of NASA. In essence, the principles of human-centered automation state that for automation to be an effective and valued component of the aviation system, it needs to possess a proper balance of important qualities or characteristics. The principles are based on the concept that the human bears the ultimate responsibility for the safety of the aviation system as follows:

- The human must be in command.
- To command effectively, the human must be involved.
- To be involved, the human must be informed.
- Functions must be automated only if there is a good reason for doing so.
- The human must be able to monitor the automated system.
- Automated systems must, therefore, be predictable.
- Automated systems must be able to monitor the human operator.
- Each element of the system must have knowledge of the others' intent.
- Automation must be designed to be simple to learn and operate.

4.2.3 Technical Issues

This total integration of ground-based ATC systems and airborne elements is a major technical challenge for the evolution of air traffic management, particularly in view of the need to make optimum use of human judgment and the skills of pilots and controllers. The combination and synergy of human skills and automated systems through an effective human-machine interface is perhaps the most difficult technical task in the detailed design of future systems. The primary technical issues facing ATM system developers can be summarized as:

- Developing a system architecture and design that recognizes and accommodates the full ATM system demands as an eventual global, integrated whole.
- Establishing the appropriate balance between the basic ATC separation processes and the overlying ATFM system.
- Establishing the best ways for controllers/system managers to interact with and effectively use automation systems to safely and efficiently handle a large number of variables.
- Achieving the correct balance between strategic planning, tactical execution, and modifying the ATM as near as possible to the scene. This will be accomplished by rapid information exchange from all available sources and by using alternative plans created by rule-based computers.
- Establishing the best tactical responsibility balance between participating flight crews with increasingly capable aircraft systems and the centralized ATM system.
- Achieving basic increases in airport capacity and enroute/transition sector capacity.
- Creating a digital communications system architecture that permits implementing a variety of datalink services (e.g., space, terrestrial, airport surface, and administrative) without requiring multiple datalinks or excessive overhead communication burdens.
- Creating a new level of safety and operational efficiency by developing a full-time airport surface traffic management system.
- Creating an ATM system for oceanic areas and remote land areas that is interoperable within each ICAO region by using new CNS technologies.
- Using environmental data collected from participating aircraft operating in the ATM system.

4.2.4 Operational Issues

The ICAO CNS/ATM systems concept offers a choice of systems for implementation in accordance with the vision of the global ATM operational concept. Optimum benefits, however, can only be derived though a global approach to air traffic management. It is necessary that past mistakes be avoided in the future development of the ATM system. In the past, ATC systems have evolved on the basis of regional and national requirements, resulting in a diversity of systems. This contributes to the current capacity limitations and presents challenges for future integration of emerging regional ATM systems into a unified, global ATM system which is dynamically responsive to the airspace user's needs. In order to realize the benefits expected from implementation of the CNS/ATM systems through an integrated global ATM system, there is a need for guidance in the planning and implementation process on a worldwide basis. This management of the ATM system evolution should include the timely development of the necessary ICAO standards, recommended practices, and procedures.

4.2.5 Institutional Issues

Transition and integration are the most difficult institutional problems facing system designers. Automating the ATM process has already advanced but requires additional improvements and augmentation in the supporting technologies. The need to help controllers/system managers cope successfully and efficiently with increasing numbers of more demanding and capable aircraft requires introducing automation aids for conducting the ATC process itself. While in the past it was possible to spread the work among a variety of separable functions (e.g., oceanic, enroute, terminal, tower/aerodrome, and other functional areas), efficient operations now demand carefully integrating and managing aircraft flows throughout the operating regime without artificial barriers. States must continue to relinquish nationalistic issues of sovereignty to remove these barriers and address automation and integration of ATM in the context of a single system.

4.2.6 Future Trends

Technologies will continue to evolve with changes in air traffic demands. New ground ATC automation systems and controller aids will provide significant benefits to aircraft operators by fully utilizing the navigation and flight planning capabilities that modern aircraft offer. Terminal and enroute automation functions will be integrated using automation to provide a system in which traffic flows smoothly into and out of terminal areas. Military airspace requirements and utilization will be fully coordinated with the civil system to ensure flexible use of airspace while not in use by military aircraft. Aircraft not equipped with avionics capable of enabling participation in the advanced ATM system will continue to rely on legacy systems with greater operational restrictions.

Due to the tremendous scope of automating the modern CNS/ATM environment, automation will continue to be incrementally phased-in. Problems encountered during implementation of prior programs have contributed to the incremental approach. Modern automation systems are very complex and often require millions of lines of code, which take years to develop and test. The funding from public sector stakeholders to develop, test, and field complex automation systems will be limited as state-funded CAA program budgets continue to be reduced. All elements of ATM automation, including enroute and terminal systems, will be developed in parallel with the intent of eventual total system integration. Figure 4-2 shows a summary of ICAO's global initiatives and their relations to the ATM operational concepts.

Key Points:

- The most tangible applications for modernization may emerge in oceanic and terminal operations, where current limitations on surveillance and communications give way to new capabilities.
- Human factors will continue to be pushed to the forefront, especially with situational awareness becoming more

robust, and tactical operations will increase.

- Aircraft will need to maintain capabilities that will require considerable investment to upgrade legacy systems.
- These aircraft investment demands will ultimately dictate applications that provide the most benefits to aircraft operators.

Figure 4-2

ICAO Global Initiates

Global Plan Initiative	EnRoute	Terminal Area	Aero-drome	Supporting Infrastructure	Related Operational Concept Components
Flexible use of airspace	X	X			AOM, AUO
Reduced vertical separation minima	X				AOM, CM
Harmonization of level systems	X				AOM, CM, AUO
Alignment of upper airspace classifications	X				AOM, CM, AUO
RNAV and RNP (performance-based navigation)	X	X	X		AOM, AO, TS, CM, AUO
Air traffic flow management	X	X	X		AOM, AO, DCB, TS, CM, AUO
Dynamic and flexible ATS route management	X	X			AOM, AUO
Collaborative airspace design and management	X	X			AOM, AUO
Situational awareness	X	X	X	X	AO, TS, CM, AUO
Terminal area design and management		X			AOM, AO, TS, CM, AUO
RNP and RNAV SIDs and STARs		X			AOM, AO, TS, CM, AUO
Functional integration of ground systems with airborne systems		X		X	AOM, AO, TS, CM, AUO
Aerodrome design and management			X		AO, CM, AUO
Runway operations			X		AO, TS, CM, AUO
Match IMC and VMC operating capacity		X	X	X	AO, CM, AUO
Decision support systems and alerting systems	X	X	X	X	DCB, TS, CM, AUO
Datalink applications	X	X	X	X	DCB, AO, TS, CM, AUO, ATMSDM
Aeronautical information	X	X	X	X	AOM, DCB, AO, TS, CM, AUO, ATMSDM
Meteorological systems	X	X	X	X	AOM, DCB, AO, AUO
WGS-84	X	X	X	X	AO, CM, AUO
Navigation systems	X	X	X	X	AO, TS, CM, AUO
Communication infrastructure	X	X	X	X	AO, TS, CM, AUO
Aeronautical radio spectrum	X	X	X	X	AO, TS, CM, AUO, ATMSDM

AOM – Airspace organization and management
DCB – Demand/capacity balancing
AO – Aerodrome operations
TS – Traffic synchronization
CM – Conflict management
AUO – Airspace user operations
ATM SDM – ATM service delivery management

Source: ICAO

4.3 Communications

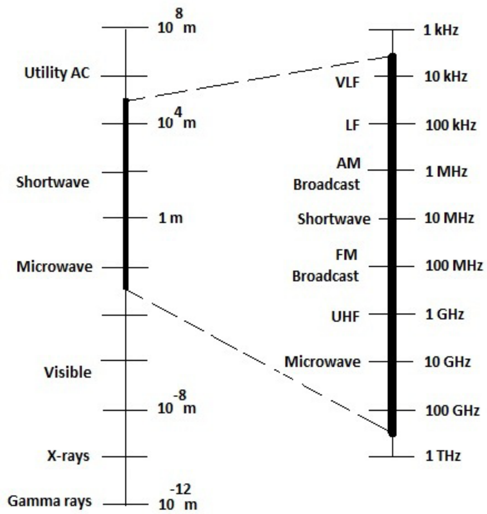
The communications element of the ICAO CNS/ATM systems concept is designed to maximize flexibility because of the various system elements comprising the overall systems architecture. Communications system elements include satellites, terrestrial VHF datalink, HF voice, SSR Mode S datalink, and the Aeronautical Telecommunications Network (ATN). Nations with high density air traffic environment could implement all communications system elements, and states with low density traffic environments (and smaller budgets) could implement only minimum required system elements.

Aeronautical mobile communications will make extensive and increasing use of digital data interchange between the ground and aircraft. Data communications will find applications in air traffic services (ATS), such as flight information and alerting, as well as aeronautical administrative communications. Voice communications, despite the continuing transition to data, will always be required. Voice communications are best suited to applications where a rapid exchange and brief transactions communications style is required, such as high-density terminal airspace and for emergency conditions. Digital communications are best suited for routine communications, such as aircraft identification and current position reporting.

4.3.1 Radio Frequency Spectrum

The electromagnetic frequency spectrum is the range of electromagnetic radiation from high frequencies and short wave lengths to low frequencies and long wavelengths. As shown in Figure 4-3, radio waves are in the radio frequency spectrum.

Figure 4-3
Radio Frequency Spectrum



Above radio frequencies there are light, ultraviolet, X-rays, and gamma rays. The radio frequency spectrum ranges from very low frequency (VLF), to high frequency (HF), ultra-high frequency (UHF), super high frequency (SHF) and extremely high frequency (EHF).

Energy radiates from the antenna and is propagated through space in what is called an electromagnetic wave. Radio waves are propagated outward from the antenna at the speed of light. As the radio wave travels, its strength varies inversely as the square of the distance from the antenna. This is called "space attenuation." Even though its strength diminishes to a very small percentage of the original value, there is still enough energy available at a remote point to produce a usable signal in the receiving antenna, even as far away as a satellite.

A portion of the radiated radio energy is radiated back to earth by what is called line-of-sight propagation. In this mode of propagation, the radio range is a function primarily of antenna heights. Due to some refraction in the earth's atmosphere, radio-line-of-sight is farther than visual line-of-sight. Radio range can also be extended under certain weather conditions such as when there is a temperature inversion.

Propagation software provides the best frequency for HF radio. Inputs to propagation software include date, time-of-day, distance, and direction to be covered.

4.3.2 High Frequency (HF)

High frequency (HF) communications are used by aircraft for long-range navigation and position-reporting procedures over oceanic regions and large land masses where supporting VHF line-of-sight communications are not feasible or economical. Pilots report aircraft identification, current position, altitude, and crossing time to enable controllers to perform flight-following operations. HF communications are difficult due to the large amount of interference caused by several atmospheric factors. Additionally, it is not feasible for aircraft to report their positions very frequently because this would overload the available HF frequencies.

To compensate for HF limitations, procedural rules have been developed for aircraft using HF as their primary means of communications, such as over oceanic or large land masses without VHF capability. Current procedures require pilots to transmit position reports every ten degrees of longitude which is usually about every 45 minutes on North Atlantic and North Pacific routes. International procedures do not allow aircraft in-trail separation by less than 60 NM which is a direct result of the HF communications limiting factor.

HF is also used to provide ground-to-ground communications between ATC facilities located in areas with limited communications infrastructure (e.g., Russian Far East and China). Continued reliance on HF communications for enroute airspace management when line-of-sight communications is not available will diminish as satellite communications systems are included in new aircraft. A portion of older model aircraft flying oceanic and long-distance domestic routes in areas lacking line-of-sight communications systems will eventually be retrofitted with satellite communications when economically feasible. The offering of satellite communications to commercial fleet passengers is proving lucrative to the airlines and will be a driving force in the economic decision to retrofit.

4.3.2.1 Technical Issues

HF communications have reliability limitations imposed partly by the variability of propagation characteristics. Atmospheric dynamics, which vary constantly and are affected by the position of the sun relative to the earth, often impose severe restrictions on the availability of HF signals and the ability to consistently communicate. Digital HF communications devices can improve HF reliability and extend the ability to transmit pilot position reports over the polar regions. These systems are intended to be sold to military clients of emerging nations who find HF more economical than satellite communications.

4.3.2.2 Operational Issues

Aeronautical operations are currently limited because of congestion on the HF band. Implementation of aeronautical mobile satellite (route) service (AMS(R)S) will ultimately eliminate the requirement for HF, although it will continue to be used over polar areas, for economic and/or technical reasons, until productive and economical satellite communications services are available.

4.3.2.3 Institutional Issues

Economic reasons may deter a nation's transition from HF to aeronautical mobile satellite service (AMSS) communications services. The issues of sovereignty and potential military aviation security issues concerning satellite broadcast also may delay transition from HF to satellite communications. Additionally, the inertia of the aviation community will make it resistant to give up any of its protected frequency bands, even though the use of aeronautical HF services will greatly diminish.

4.3.2.4 Future Trend

In the short term, increased traffic on HF will need to be accommodated, and it will be necessary to maintain the integrity of the system during the transition to full AMSS. Continuing congestion on HF might be relieved by the pre-operational use of satellite communications for ATS position reporting as an alternative to HF. States, international aviation organizations, and satellite service providers, such as Iridium and Inmarsat, are implementing satellites communications capabilities to provide coverage in oceanic and polar areas.

4.3.3 Very High Frequency (VHF)

Civil ATC air-to-ground communications are conducted using an analog voice system operating in the very high frequency (VHF) aeronautical band (117.975-137 MHz). The band contains a total of 760 25-kHz channels, of which just over 500 are available for ATC use in the US. The transmitted signal is amplitude modulated (AM) by the baseband voice signal. System users communicate on one or more A/G radio frequency channels assigned for each user.

A shortage of assignable aeronautical VHF communication channels to support growth in ATS and aeronautical operational control (AOC) communication services requirements is an issue in the core area of Europe (Austria, Belgium, Czech Republic, France, Germany, Luxembourg, Netherlands, Northern Italy, Switzerland, and England) and North America. The expected increase in the requirement for frequency assignments, as a consequence of the projected increase in air traffic, will lead to a situation in the core area of Europe whereby the frequency band will be saturated. Current utilization is such that it is difficult to identify an assignable channel for any new enroute service required. Delay in satisfying the demand for communications services, due to the unavailability of VHF channels, has an adverse effect on the growth and efficiency of air traffic movements with consequential financial and operational repercussions. In areas of the world that have lower air traffic densities, HF congestion in not present or expected in the foreseeable future.

As of 2012, most countries divide the upper 19 MHz into 760 channels for amplitude modulation voice transmissions, on frequencies from 118–136.975 MHz, in steps of 25 kHz. In Europe, it is becoming common to further divide those channels into three (8.33 kHz channel spacing), potentially permitting 2,280 channels. Some channels between 123.100 and 135.950 are available in the US to other users such as government agencies, commercial company advisory, search and rescue, military aircraft, glider and ballooning air-to-ground, flight test, and national aviation authority use. A typical transmission range of an aircraft flying at cruise altitude (35,000 ft.) is about 200 miles in good weather conditions.

Key Points:

- HF communications are used by aircraft when VHF is not feasible or economical, although satellite communications may rapidly replace HF's functionality.
- VHF serves as the primary air-to-ground communications, but frequency congestion and utilization currently limit the efficiency of air traffic control.

4.3.4 Future Air-to-Ground Communications

One of the keys to the future ATM system will be the two-way transmission of data between ground-based ATC and aircraft.

4.3.4.1 VHF Digital Link (VDL)

The VHF DataLink or VHF Digital Link (VDL) is a means of sending information between aircraft and ground stations and, in some cases, other aircraft. Aeronautical VHF datalinks use the band 117.975 - 137 MHz assigned by the International Telecommunication Union to AMRS.

Mode 1 - The ICAO AMCP defined Mode 1 for validation purposes. The ICAO AMCP completed validation of VDL Modes 1&2 in 1994, after which the Mode 1 was no longer needed and was deleted from the ICAO standards.

- Mode 2 - The ICAO VDL Mode 2 is the main version of VDL, and is the only VDL mode being implemented operationally to support Controller Pilot DataLink Communications (CPDLC). It has been implemented in a EUROCONTROL Link 2000+ program and is specified as the primary link in the EU Single European Sky rule adopted in January 2009 requiring all new aircraft flying in Europe after January 2014 to be equipped with CPDLC. The ICAO standard for the VDL Mode 2 specifies three layers: the subnetwork, link, and physical layers.
- The subnetwork layer complies with the requirements of the ICAO Aeronautical Telecommunication Network (ATN) standard which specifies an end-to-end data protocol to be used over multiple air-to-ground and ground subnetworks including VDL.
- The VDL Mode 2 link layer is made up of two sublayers, a datalink service and a media access control (MAC) sublayer. The datalink protocol is based on the ISO standards used for dial-up HDLC access to X.25 networks. It provides aircraft with a positive link establishment to a ground station and defines an addressing scheme for ground stations. The MAC protocol is a version of Carrier Sense Multiple Access (CSMA).

The VDL Mode 2 physical layer specifies the use in a 25 kHz wide VHF channel of a modulation scheme called Digital 8-Phase Shift Keying providing a data rate of 31.5 kb/second. This is the highest data rate that can be achieved in a 25 kHz channel with a maximum range of 200 NM and required the implementation of VHF digital radios.

Mode 3 - The ICAO standard for VDL Mode 3 defines a protocol providing aircraft with both data and digitized voice communications via Time Division Multiple Access (TDMA) slots assigned by ground stations. The FAA implemented a prototype system around 2003 but did not manage to convince airlines to install VDL Mode 3 avionics and in 2004 abandoned its implementation.

Mode 4 - The ICAO standard for VDL Mode 4 specifies a protocol-enabling aircraft to exchange data with ground stations and other aircraft. It uses a protocol (Self-organized

Time Division Multiple Access, or STDMA) that allows it to be self-organizing, meaning no master ground station is required. This made it much simpler to implement than VDL Mode 3. Mode 4 can also be used for air-ground exchanges. It is best used for short message transmissions among large numbers of users, (e.g., providing situational awareness, Digital Aeronautical Information Management, D-AIM, etc.).

In November 2001, ICAO adopted this protocol as a global standard. Its primary function was to provide a VHF frequency physical layer for ADS-B (ADS-broadcast) transmissions. However, it was overtaken as the link for ADS-B by the Mode S radar link operating in the 1090 MHz band which was selected as the primary link by the ICAO Air Navigation Conference in 2003.

4.3.4.2 Current VDL Service Providers

Currently there are two major providers of VDL services: ARINC and SITA. ARINC operates the Aircraft Communications and Reporting System (ACARS) air-to-ground datalink network used by more than 4,000 aircraft for ATC, operational, and weather messages throughout North America. ACARS was developed in the 1970s primarily to provide out, off, on, and in messages, commonly called OOOIs for the airlines. SITA provides VDL services similar to ARINC in the remaining regions of the world. As competition for VDL services grows, SITA will most likely try to offer value-added services to their VDL to maintain and attract new customers.

4.3.4.3 Mode S Datalink

Mode S is an enhancement of the ATCRBS SSR system which adds selective interrogation of individual aircraft and a digital datalink between the ground station and the aircraft. A wide variety of ground/air/ground messages can be provided on this link. Mode S datalink capacity depends on many system factors which include the type of ground station antenna (rotating, E-scan, omnidirectional), transponder type, azimuthal distribution in traffic around the station, and whether most traffic is ground-to-air or air-to-ground because the link operates at a different rate in the two directions.

The maximum data rate to a single aircraft is limited by the transponder capacity and by the beam dwell in the case of the ground station with a rotating antenna. A typical transponder limit is in the order of 1200 bps, while a ground station with a rotating antenna can deliver one 16-segment or approximately 122 bit extended-length message each scan, for an average data rate of approximately 300 bps.

Mode S datalink services fall into two general classes of service. The first, Mode S, can serve as a communications channel, one of several which make up the ATN. In this capacity, Mode S can support the transmission of any of the services envisioned for ATN such as ATIS, pre-departure clearance, ATC instructions, weather, and airline operational traffic.

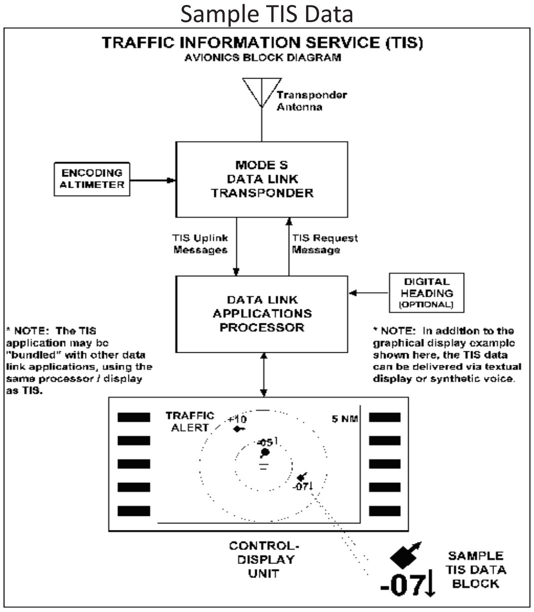
The second class of service is referred to as Mode S specific. These services are offered directly through Mode S and do not use ATN formats or protocols. Currently proposed Mode S specific services include traffic information service (TIS), graphical weather service (GWS), and transmission to aircraft of differential GPS signals (DGPS), and ADS, which are explained as follows:

Traffic Information Service−Broadcast (TIS−B): TIS−B is the broadcast of ATC-derived traffic information to ADS−B equipped (1090ES or UAT) aircraft from ground radio stations. The source of this traffic information is derived from ground−based air traffic surveillance radar sensors. TIS−B is intended to provide ADS−B equipped aircraft with a more complete traffic picture in situations where not all nearby aircraft are equipped with ADS−B Out. This advisory−only application is intended to enhance a pilot's visual acquisition of other traffic.

TIS−B service will be available where there are both adequate surveillance coverage (radar) from ground sensors and adequate broadcast coverage from ADS−B ground radio stations. The quality level of traffic information provided by TIS–B is dependent upon the number and type of ground sensors available as TIS–B sources and the timeliness of the reported data (Figure 4-4).

Figure 4-4

Sample TIS Data



Source: FAA

GWS/Flight Information Service–Broadcast (FIS–B): GWS provides pilots with weather information derived from one or more ground-based weather radars. FIS–B is a ground broadcast service provided through the ADS–B services network over the 978 MHz UAT datalink. The FAA FIS–B system provides pilots and flight crews of properly equipped aircraft with a cockpit display of certain aviation weather and aeronautical information. The weather products provided by FIS–B are for information only. Therefore, these products do not meet the safety and regulatory requirements of official weather products.

DGPS Corrections: Another use of the omni-directional Mode S datalink capability is for the broadcast of DGPS correction signals. Aircraft operating in the vicinity of the airport can use these differential corrections for precision approaches.

Mode S-based ADS: Each Mode S-equipped aircraft emits a spontaneous reply-like signal, called a squitter, every second to permit its acquisition by TCAS-equipped aircraft. The Mode S squitter could be used by aircraft to broadcast its GPS-derived position once every second. This capability can be used for airborne and ground ADS functions.

4.3.4.4 Technical Issues

When designing Mode S, researchers used a similar format for the signal sent by Mode S sensors that requests responses from only Mode S-equipped aircraft. Aircraft with ATCRBS transponders ignore the last pulse, responding with a normal ATCRBS all-call reply. Mode S transponders see the additional pulse, recognize the signal as a Mode S interrogation, and respond with a reply. Without this technique, Mode S-equipped aircraft cannot distinguish between an ATCRBS and Mode S interrogation. They will not know which reply to send, and thus cannot interoperate with the different sensors on the ground.

4.3.4.5 Operational Issues

The Mode S transponder is fully compatible with current SSR and MSSR systems (Mode A/C) and will not cause any operational problems for aircraft with Mode S transponders. Aircraft not equipped with Mode S transponders must rely on other means such as VHF to provide the aeronautical datalink capability.

4.3.4.6 Institutional Issues

Due to the high cost of Mode S systems versus VHF systems, Mode S will most likely first be implemented in only the most heavily congested regions. Mode S equipage becomes mandatory along with ADS-B mandates.

4.3.4.7 Future Trends

Depending on regional airspace operations, Mode S will offer appropriately equipped aircraft with another means of air-to-ground data communications. As Mode S continues to be implemented in the US and throughout other regions of the world where the ATC terminal environment dictates, Mode S datalink will likely be the system of choice since the datalink (part of the surveillance signal) is free. General aviation users and operators not required to have Mode S (including surface vehicles) will most likely rely on some type of local datalink service provider.

4.3.5 Communications Systems Integration

4.3.5.1 Aeronautical Telecommunications Network (ATN)

The ATN provides for the interchange of digital data between end-users (e.g., aircrew, air traffic controllers, aircraft operators) over dissimilar air-to-ground and ground-to-ground communications links. The ATN employs on open systems architecture and provides for the internetworking of aeronautical "subnetworks." User access to the ATN is via one or more subnetworks connected by ATN routers. ATN routers may be either mobile (aircraft) of fixed (ground-based). The ATN router selects a path via aeronautical subnetworks based on user-specified communication requirements and subnetwork availability (e.g., the use of multiple air-to-ground data-links such as Mode S, VHF, and satellite). This action is transparent to the user. Therefore, users do not need to know the area of coverage of specific subnetworks, nor do they need to change communications procedures, depending upon the subnetworks in use. It will allow applications development independent of the air-to-ground links used for communications.

Present day aeronautical communication is supported by a number of organizations using various networking technologies. The most imminent need is the capability to communicate across heterogeneous networks both internal and external to administrative boundaries. ATN and public networks span organizational and international boundaries to support aeronautical applications. Data transfer through an aeronautical internet will be supported by three types of data communication subnetworks.

In summary, the ATN is designed to transfer data between end-users independent of protocols and addressing schemes internal to any one participating subnetwork. To meet this objective, all participating subnetworks must be interconnected via internetwork routers observing common internetworking conventions and standards. This strategy will provide network-independent interface for all ATN users.

ATN Baseline 1: Regarded as an interim solution, it is the standard used in the Link 2000+ datalink program in Europe.

ATN Baseline 2: Supports more complex datalink applications within the FMS, including CM, CPDLC, ADS-C (ADS Contract), and basic FIS.

ATN Baseline 3*:* Intended to be built on top of ATN Baseline 2. That is, ATN Baseline 3 will add datalink services (such as 4D trajectories and expanded FIS) not available in ATN Baseline 2, but will not revise the services in ATN Baseline 2.

4.3.5.2 Future Air Navigation System (FANS)

ATC's ability to monitor aircraft was being rapidly outpaced by the growth of flight as a mode of travel. In an effort to improve aviation communication, navigation, surveillance, and air traffic management, ICAO created standards for a future system, known as the Future Air Navigation System (FANS), which allows controllers to play a more passive monitoring role through the use of increased automation and satellite-based navigation.

FANS-1/A, 1/A+: ATC services are now provided to FANS 1/A equipped aircraft in other oceanic airspaces, such as the North Atlantic. However, although many of FANS-1/A's known deficiencies with respect to its use in high density airspace were addressed in later versions of the product (FANS-1/A+), it has never been fully adopted for use in continental airspace. The ICAO work continued after FANS-1 was announced and continued to develop the CNS/ATM concepts.

FANS-2, FANS-B: Both Boeing and Airbus continue to further develop their FANS implementations, Boeing on FANS-2 and Airbus on FANS-B. These developments aim to apply FANS concepts in high-density airspace (continental). Currently, however, the ICAO standard for CPDLC using the ATN is preferred for continental airspace and is currently being deployed in the core European Airspace by the EUROCONTROL Agency under the LINK2000+ Program.

FANS-C: Looking forward, Boeing and Airbus have committed to cooperatively seek a common standard unifying US standard FANS A+ with European standard FANS B+ in a new FANS C (A+B), with high capacity to support future datalink applications.

Controller Pilot Datalink Communication (CPDLC)

Controller pilot datalink communication (CPDLC) is a means of communication between controller and pilot, using datalink for ATC communication. The CPDLC application provides air-to-ground data communication for the ATC service. This includes a set of clearance/information/request message elements which correspond to voice phraseology employed by ATC procedures. The controller is provided with the capability to issue level assignments, crossing constraints, lateral deviations, route changes and clearances, speed assignments, radio frequency assignments, and various requests for information. The pilot is provided with the capability to respond to messages, to request clearances and information, to report information, and to declare/rescind an emergency. The pilot is, in addition, provided with the capability to request conditional clearances (downstream) and information from a downstream Air Traffic Service Unit (ATSU). A "free text" capability is also provided to exchange information not conforming to defined formats. An auxiliary capability is provided to allow a ground system to use datalink to forward a CPDLC message to another ground system.

- The sequence of messages between the controller at an ATSU and a pilot relating to a particular transaction (for example, request and receipt of a clearance) is termed a "dialogue." There can be several sequences of messages in the dialogue, each of which is closed by means of appropriate messages, usually of acknowledgement or acceptance. Closure of the dialogue does not necessarily terminate the link, since there can be several dialogues between controller and pilot while an aircraft transits the ATSU airspace. All exchanges of CPDLC messages between pilot and controller can be viewed as dialogues. The CPDLC application has three primary functions:

- The exchange of controller/pilot messages with the current data authority.
- The transfer of data authority involving current and next data authority.
- Downstream clearance delivery with a downstream data authority.

Today, there are two main implementations of CPDLC:

- The FANS-1/A System that was originally developed by Boeing, and later adopted by Airbus, is primarily used in oceanic routes by widebody long-haul aircraft. It was originally deployed in the South Pacific in the late 1990s and was later extended to the North Atlantic. FANS-1/A is an ACARS-based service and, given its oceanic use, mainly uses satellite communications provided by the Inmarsat Data-2 service.
- The ICAO Doc 9705 compliant ATN/CPDLC system, which is operational at EUROCONTROL's Maastricht Upper Airspace Control Centre and has now been extended by EUROCONTROL's Link 2000+ Program to many other European flight information regions (FIRs). The VDL Mode 2 networks operated by ARINC and SITA are used to support the European ATN/CPDLC service.

4.3.5.3 Operational Issues

Progress towards full ATN realization has been slower than first hoped because, though there is little opposition to the concept, airlines are obliged to invest only where it clearly benefits the bottom line. Estimates suggest that retrofitting ATN into a Boeing or Airbus all-digital aircraft requires significant investment. This includes the cost of ATN-compliant datalinks, along with multiple interfaces to onboard computers and other equipment. Fleet fittings and factory installations would, naturally, reduce the per-aircraft figure. The cost of achieving worldwide air and ground ATN implementation is estimated at several billion dollars. Moreover, datalink service providers such as SITA and ARINC will have to reflect in their charges the costs of incorporating ATN functionality into their networks.

Clear business cases are needed to persuade airlines to invest. Thus, the promise of CPDLC for improving flight deck ATC communication is attracting takers, particularly in Europe, where efficiency savings can be fed back to operators via reduced service charges.

4.3.5.4 Institutional Issues

Interoperability between FANS/ATN standards continues to be a major issue. While similar, the systems cannot function in a seamless environment. For example, an ATN message element requires a WILCO/UNABLE response and the matching FANS 1/A message element requires a ROGER response.

Both the US and Europe, through RTCA SC-214 and EUROCAE WG-78, are working to establish procedures and policies to address these interoperability issues faced by aircraft operators and air traffic controllers today.

4.3.5.5 Future Trends

Data Communications Program (US)

Digital data communications is a key transformational program within FAA's NextGen effort. To meet future demands and avoid gridlock in the sky and at airports, the agency's NextGen Data Communications Program (DataComm) is designed to advance today's analog voice-only air-to-ground communications system to one in which digital communications become an alternate and eventual predominant mode of communication.

DataComm will automate repetitive tasks, supplement voice communications with less workload-intensive data communications, and enable ground systems to use real-time aircraft data to improve traffic management. It will also allow a two-way exchange of digital information between air navigation service providers and the flight crew.

The goal of DataComm is to improve air traffic control by delivering digital information between controllers and aircrews. By reducing voice communications, congestion, and related errors, the FAA estimates that digital data communications will enable controllers to safely handle approximately 130 percent of current traffic. In the evolution to NextGen, data communications will advance air traffic control from minute-by-minute instructions to collaborative management of flights from takeoff to landing. The FAA considers DataComm as the critical next step in improving air safety, reducing delays, increasing fuel savings, and reducing emissions.

DataComm, for both tower and enroute services, will initially support Future Air Navigation System (FANS) 1/A+ over Very High Frequency (VHF) Datalink Mode 2 (VDL-2) avionics capabilities. The support of the FANS 1/A+ avionics gives airspace users the ability to leverage existing equipage to gain access to DataComm services.

The DataComm ground infrastructure will be subsequently extended to provide support for the Aeronautical Telecommunications Network (ATN) over VDL-2 services. DataComm will support the ATN Baseline 2 (ATN B2) avionics capabilities as these avionics become commercially available. ATN B2 avionics will enable enhanced DataComm enroute services, leading toward full trajectory-based operations. The FAA is considering whether to implement support in DataComm for ATN Baseline 1 avionics capabilities.

As of the publication of this report, the FAA has released a screening information request (SIR) for DataComm, which calls for a solution for the engineering and integration for VDL-2 air-to-ground network services. The selected vendor will establish and operate the DataComm network for up to 17 years, with the FAA paying a fee for the service. Contract award is expected in late 2012.

Link 2000+ Program (EU)

The EUROCONTROL LINK 2000+ program packages a first set of enroute CPDLC services into a beneficial and affordable set for implementation in the European Airspace using the ATN and VDL Mode 2. LINK 2000+ implements three basic services automating the routine tasks which fill up to 50 percent of controller time today, and provide for 11 percent capacity increase (when 75 percent of flights are equipped):

- **ATC communications management (ACM):** to handle repetitive frequency changes.
- **ATC clearances:** to provide standard clearances - ACL (e.g. "Climb to level 350.")
- **ATC microphone check (AMC):** to enable communication in case of blocked frequencies.

These services do not replace voice as a primary means of communication; both media will always be available, thus providing mutual back-up, a definite safety improvement. In case of non-standard communications or emergency, "revert to voice" is the procedure.

The standards comprising the LINK 2000+ baseline combine the entire output of more than three ICAO panels specifying operational, technical, and data link standards over at least seven years (approximately 1990-1997). These were then used to define the interoperability, safety, and performance requirements in EUROCAE and RTCA between 1999 and 2005.

4.3.6 Ground-to-Ground Communications

The combination of ever-increasing demand for services, exponential forecasted telecommunications traffic growth, and advances in the telecommunications industry have created a critical need to upgrade telecommunications infrastructure.

4.3.6.1 Landline Communications

Landline communications provide point-to-point transmission of analog and digital data such as long-range radar data, enroute and terminal inter-facility voice and data communications, ATM systems data, weather data, and maintenance management system data. Landline provides most of the connectivity between ATC facilities in developed nations. Landlines consist of either leased or dedicated circuits. Landlines are comprised of traditional cable wire systems as well as fiber optics and are the most reliable means of communications. Landline communications infrastructure is expensive to install and maintain. Therefore, it is often a limiting factor in the development of the ATC communications infrastructure of developing nations. In developing countries and large desolate portions of major industrialized nations, other methods of communications transmission which are more cost-effective are used such as microwave, satellite, and HF.

4.3.6.2 Federal Telecommunications Infrastructure (FTI) (US)

The Federal Telecommunications Infrastructure (FTI) is the primary means for FAA's telecommunications services and forms the basic infrastructure for NextGen. It replaces FAA's legacy networks to provide consolidated telecom services for the 5,000 facilities and 30,000 circuits in the NAS with reduced costs and improved bandwidth and security. The FTI network supports NAS operations by providing the connectivity required by systems including the Enhanced Traffic Management Systems (ETMS), the Standard Terminal Automated Replacement System (STARS), and the Wide Area Augmentation System (WAAS). In addition, applications like e-mail, internet, payroll, and other administrative services are on the FTI Mission Support Network. FTI provides an enterprise-wide approach to information security assurance. It meets the latest government standards for information security and offers improved security services, like encryption.

4.3.6.3 Pan-European Network Service (PENS)

The Pan-European Network Service (PENS) is an international ground-to-ground communications infrastructure jointly implemented by EUROCONTROL and the European ANSPs in order to meet existing and future air traffic communication requirements. It will provide a common IP-based network service across the European region covering voice and data communication and providing efficient support to existing services and new requirements emerging from future ATM concepts.

PENS will enable its users to exchange critical and common aeronautical information in a seamless and integrated manner, providing a highly cost-effective common infrastructure for the deployment of emerging ATM applications. It will significantly reduce the costly fragmented network services implemented under the umbrella of the outdated X.25 protocol, still in widespread use by some ANSPs. It will meet both current needs for the information exchange between ANSPs and ATM stakeholders, as well as those foreseen by the SESAR program for the System-Wide Information Management (SWIM) initiative.

PENS is expected to enable the 38 current ANSPs of the EUROCONTROL member states to exchange operational ATC data communications in a seamless and integrated manner and provide an alternative to the ad-hoc bi-lateral communications largely in place today between the ANSPs, resulting in improved service levels and reduced overall costs.

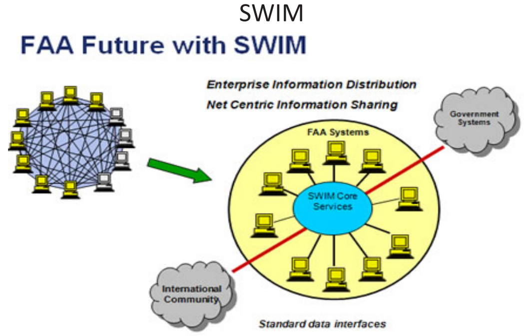
4.3.6.4 System Wide Information Management (SWIM)

System Wide Information Management (SWIM) is a technology enabler that provides the IT infrastructure necessary to share information, increase interoperability, and encourage reusability of information and services. It provides a means for a system to obtain needed information from another system. In the past, all interfaces were developed on a case by case basis as unique point-to-point interfaces. The fact that different computer systems were developed using different technologies at different times rendered information sharing difficult. SWIM does away with building unique interfaces, and instead applies common IT industry standards and commercial software products across interfaces so that once a standard interface is developed and deemed "SWIM-compliant," there will not be a need to redevelop it for every subsequent user who wants that information.

Rather than developing a separate SWIM infrastructure, the program will provide Service Oriented Architecture (SOA)-based standards, guidance, and core capabilities software to NAS programs that will host the software on their existing hardware. SOA technology allows software applications to locate and interact with one another through information services that can be accessed without knowledge of the application's underlying platform implementation.

SWIM will result in a more efficient, cost-effective infrastructure that will improve operations and productivity. This will be achieved through a scalable, evolvable, standards-based network-centric solution that supports information management among ATM systems in a secure information sharing environment (Figure 4-5).

Figure 4-5
SWIM



Source: FAA

4.3.6.5 Microwave Communications

Microwave links provide communications backbones that link ATC facilities and remote radar sites, as well as other facilities requiring high density data and voice communications. Microwave links provide a cost-efficient way to transmit data from remote sites versus establishing hardwire links (Figure 4-6).

Figure 4-6

Microwave Frequency Bands

Letter Designation	**Frequency range**
L band	1 to 2 GHz
S band	2 to 4 GHz
C band	4 to 8 GHz
X band	8 to 12 GHz
Ku band	12 to 18 GHz
K band	18 to 26.5 GHz
Ka band	26.5 to 40 GHz
Q band	33 to 50 GHz
U band	40 to 60 GHz
V band	50 to 75 GHz
E band	60 to 90 GHz
W band	75 to 110 GHz
F band	90 to 140 GHz
D band	110 to 170 GHz

Source: Radio Society of Great Britain

Microwave is essentially a two-way radio operating in the gigahertz bands over 1000 MHz. Microwave systems are almost all Frequency Modulated Single-Sideband Suppressed Carrier (SSBSC). Microwave radio systems require intermediate repeater stations to provide gain and direction for transmission of the signals over extended paths. The normal bandwidth of a high-grade analog voice channel is normally 300 to 3,600 cycles. The multiplex channel bandwidth is, therefore, 4 kHz to provide for spacing. Data added over voice often results in a relatively slow bit rate and the upper band of a voice channel is sometimes reduced to 2,500 cycles, compromising voice quality. Voice channels are arranged in "groups" or "supergroups." Twelve 4 kHz voice channels constitute a "group," and 60 voice channels constitute a "supergroup." In the past, there were unique modules for translation of the channels into groups, and groups into supergroups, with direct-to-line (DTL) allowing any given channel to be applied to any part of the baseband spectrum, with appropriate digital setup switches on each channel.

4.3.6.6 Technical Issues

Landline and microwave communications systems have been in service for a long period of time and are considered a very reliable means of communications. There is continuing effort to expand bandwidth of present systems, and there are no major technical issues concerning the application of these systems in support of ATC/ATM functions.

4.3.6.7 Operational Issues

Operational issues concerning ground-to-ground communications are mainly related to system maintenance. In states where rugged terrain is a major factor, the maintenance and operation of ground-to-ground systems may be difficult and costly due to the logistics of performing maintenance in hard-to-reach locations (e.g., mountains, jungles, and deserts).

4.3.6.8 Institutional Issues

As states continue to upgrade and modernize their ATC/ATM infrastructure, they must carefully weigh the costs associated with implementing appropriate ATC ground-to-ground communications facilities. Since both landline and microwave communications facilities can remain under autonomous ownership and control, states can maintain closer regulation and control of these systems. Standards and specifications for current ground-to-ground communications systems are well established. Therefore, states do not need to spend large efforts coordinating implementation activities with international and regional ATC/ATM authorities.

4.3.6.9 Future Trends

Fiber optics offers greater bandwidth than conventional wire systems, which translates to a greater potential for available bandwidth, if required, by future ATC/ATM systems.

4.3.7 Satellite Communications

Satellite transmission is used extensively in many areas of the world and has become an integral part of the telecommunications infrastructure of most countries. Satellites provide the most economical means of communications in remote regions, especially in lesser developed countries with limited budgets, widely dispersed populations, or rugged terrain. Current and future satellite systems offer unprecedented capabilities for new satellite services, particularly for aviation needs. Satellite communications also provide redundant alternatives and avoid single points of failure through circuit diversity to meet ATC communications service availability requirements.

A satellite is a communication transmission device which receives a signal from a ground station, amplifies it, and broadcasts it to all earth stations capable of seeing the satellite and receiving the transmissions. No end-user transmission either originates or terminates at the satellite, though the satellite does send and receive signals for monitoring and correction of on-board problems or signals indicating its position in orbit. A satellite transmission begins at a single earth station, passes through the satellite, and ends at one or more earth stations. The satellite is an active relay, much like the relays used in terrestrial microwave systems.

A satellite communication involves three basic elements: the space segment, the signal segment, and the ground segment. The space segment comprises the satellite, the mechanics of its orbit, and the means of launching it into orbit. The signal element comprises the satellite's working frequency spectrum, the effects of distance on communications, sources of signal interference, and communications modulation techniques and protocols. The ground segment includes the placement and construction of earth stations, different types of antennas, and multiplexing and multiple access schemes. The advantages of satellites include the following:

- **Stable costs**: The cost of transmission by satellite over a single link is the same regardless of the distance between the sending and receiving station. This means that the cost of a satellite transmission remains the same regardless of the number of stations receiving the transmission.
- **High bandwidth**: Satellite signals are at very high bandwidths, capable of carrying large amounts of data.
- **Low error rates**: Bit errors on a digital satellite signal occur almost completely at random. Therefore, statistical systems for error detection and correction can be applied efficiently and reliably.

There are three types of communications satellite architecture: bent pipe, store-and-forward, and switched.

Bent Pipe

In bent pipe architecture, the communications satellite transmits all data it receives in real time back to earth. This is the simplest communications satellite with all systems intelligence on the ground in ground stations. The two end users do not need to see the same satellite. Note the use of the earth station, a large ground station terminal owned and operated by the satellite company. There may be several earth stations located throughout the service area of the satellite communications system. The source only needs to establish a communications channel from their mobile terminal to an earth station. Then the earth station can either route the call to the intended fixed user using another satellite to the intended user. The two mobile users do not have to wait for a common satellite.

Latency is the time spent waiting for the communications satellite to come into view and the ground-signal processing time. Waiting for a satellite to come into view is an issue in a LEO (low-earth orbit) system. When using a LEO communications satellite, the communications channel through one satellite exists for less than 15 minutes. Average satellite availability latency, which is waiting for a satellite to come into view of both the user and the earth terminal, is normally less than one minute. In a GEO system, the satellite is always in view.

Store-and-Forward

In a store-and-forward architecture, the communications satellite has the ability to either transmit data it receives in real time back to earth or to store the data it receives for later transmissions back to earth. In the former case, it acts like a bent pipe system, and in the latter case it acts as a store-and-forward system. The advantage of store-and forward architecture is that the source only needs to establish a communications channel with a satellite; it does not need to establish a communications channel through the satellite with an earth station. Most of the intelligence of the system is on the ground in earth stations. Again, note the use of an earth station that is owned and operated by the satellite company.

In store-and-forward systems, the latency is the time the received data is stored on the satellite before being transmitted to the earth station. Latency may by several minutes from mid-ocean to a shore-based earth station. Only LEO systems use the store-and-forward architecture, as GEO systems are always in view of both their users and an earth station.

Switched

In switched architecture, the communications satellite has the ability to establish a communications channel direct from the source to the sink or to send the received data to an earth station for delivery to the sink. The advantage of switch architecture is that a real-time two-way communications channel can be established in the satellites, thereby eliminating the requirement that each call be transmitted through an earth station. The disadvantage of a switched architecture is the requirement for complex satellites. They use very intelligent satellites, but still require moderate intelligence on the ground. Note that if the satellite with received data from a source does not see the intended sink or an earth station, it can cross-in the data to another satellite that has the intended sink or earth station in view. Switched architecture is used in both LEO and GEO systems.

Several satellite communications systems exist today. These systems, although designed to provide global hand-held telephone service to remote areas of the world where installing and operating traditional land-based communications is too costly and impractical, can also support various types of ATC data and voice services. Brief descriptions of prominent programs are provided below.

- **Iridium:** The Iridium satellite constellation, owned and operated by Iridium Communications, Inc., is a large group of satellites providing voice and data coverage to satellite phones, pagers and integrated transceivers over earth's entire surface. The constellation operates 66 active satellites in orbit, and additional spare satellites are kept in orbit to serve in case of failure. Satellites are in low-earth orbit (at a height of approximately 485 mi (781 km) and inclination of 86.4°. Orbital velocity of the satellites is approximately 17,000 mph (27,000 km/h). Satellites communicate with neighboring satellites via Ka band inter-satellite links. The satellites orbit from pole to pole with an orbit of roughly 100 minutes.

  Iridium is currently developing, and is expected to launch beginning in 2015, Iridium NEXT, a second-generation worldwide network of telecommunications satellites. Satellites will incorporate additional payload such as ADS-B receivers and sensors in collaboration with some customers and partners. Iridium can also be used to provide a datalink to other satellites in space, enabling command and control of other space assets regardless of the position of ground stations and gateways.

- **Inmarsat**: A British satellite telecommunications company offering global, mobile services. It provides telephony and data services to users worldwide, via portable or mobile terminals which communicate to ground stations through eleven geostationary telecommunications satellites. Inmarsat's network provides communications services to a range of governments, aid agencies, media outlets and businesses with a need to communicate in remote regions or where there is no reliable terrestrial network. In August 2010, Inmarsat awarded Boeing a contract to build a constellation of three Inmarsat-5 satellites, as part of a US$1.2 billion worldwide wireless broadband network called Inmarsat Global Xpress. The three Inmarsat-5 (I-5) satellites will be based on Boeing's 702HP spacecraft platform. The first is scheduled for completion in 2013, with full global coverage expected by the end of 2014. The satellites will operate at Ka-band in the range of 20–30 GHz. There are plans to offer high-speed inflight broadband on airliners.

- **Globalstar:** A low earth orbit satellite constellation for satellite phone and low-speed data communications, somewhat similar to the Iridium satellite constellation and Orbcomm satellite systems. Globalstar satellites are simple "bent pipe" repeaters. Due to the lack of inter-satellite linking, a satellite must have a gateway station in view to provide service to any users it may see. The use of gateway ground stations provides customers with localized regional phone numbers for their satellite handsets. But if there are no gateway stations to cover certain remote areas (such as areas of the South Pacific and the polar regions), service cannot be provided in these remote areas, even if satellites fly over them. The company's products include mobile and fixed satellite telephones, simplex and duplex satellite data modems, and satellite airtime packages. The first six second-generation satellites were launched in October 2010, using a Soyuz launcher from Kazakhstan. These second-generation satellites are expected to provide customers with satellite voice and data services until at least 2025. Six more second-generation satellites were launched in July 2011 followed by another six satellites in December 2011.

- **Orbcomm:** Provides satellite data services. As of August 2009, Orbcomm reported 500,000 billable subscriber communicators on the company's US-based gateway control center. Orbcomm has control centers in the US, Brazil, Japan, and Korea, as well as US ground stations in New York, Georgia, Arizona, and Washington State, and international ground stations in Curaçao, Italy, Australia, Kazakhstan, Brazil, Argentina, Morocco, Japan, Korea, and Malaysia. Plans for additional ground station locations are underway. Orbcomm is best suited for users who send very small amounts of data. To avoid interference, terminals are not permitted to be active more than one percent of the time, and thus they may only execute a 450-ms data burst twice every 15 minutes. A total of 35 satellites were launched by Orbcomm Global in the mid to late 1990s. Of the original 35, a total of 29 remain operational today, according to company filings. In 2009 a deal was announced with Space Exploration Technologies ("Space X") to launch 18 second-generation satellites with SpaceX launch vehicles between 2010 and 2014.

4.3.7.1 Technical Issues

The primary technology issue is the creation of infrastructure to permit PTTs to track and tariff incoming or outgoing satellite communications traffic. Development and implementation of appropriate network architectures and configurations must be accomplished to interface new satellite systems with existing national telecommunications infrastructures. Other restrictions to satellite use include:

- **Signal delay**: The large distance from the ground to a satellite means that any one-way transmission over a satellite link has an inherent propagation delay ("latency.") This delay creates a noticeable effect in voice communications and makes use of satellite links extremely inefficient with data communications protocols that have not been adapted for use over a satellite circuit.

- **Earth station size**: Most satellite earth station antenna diameters, except for some proposed future systems, must be very large to compensate for the extremely weak signal from the low power satellite transmission.

- **Security:** All satellite signals are broadcast and unsecure unless encrypted.

- **Interference:** Satellite signals operating at Ku- or Ka-band frequencies are very susceptible to interference from bad weather, especially rain or fog. Satellite networks operating at C-band are susceptible to interference from terrestrial microwave signals. Bad weather interference can cause sporadic unpredictable performance in the "k" bands for a few minutes up to a few hours. Terrestrial interference in C-band limits the deployment of earth stations in major metropolitan areas where users are concentrated more heavily.

4.3.7.2 Operational Issues

The availability of other communications satellite systems offers the potential for the creation of global and regional Wide Area Augmentation Systems. These systems can be used for GNSS satellite augmentation and integrity/availability monitoring. Potential users of these systems must address system compatibility issues when operating in a multi-system environment.

4.3.7.3 Institutional Issues

There will be strong competition among AMSS providers due to the limited amount of frequency allocations. Companies must compete, through national and international agreements, for a portion of this limited spectrum. Legal issues are also a driving factor. An important legal issue is that international treaties specify satellite bandwidth as an international asset. This requires that multinational agreements be reached, by various states, each with its own agenda. States will vie for position either to gain concessions from other governments or to protect their own satellite communications industries.

4.3.7.4 Future Trends

Future AMSS providers are in the process of developing and deploying their systems. As these systems compete with one another for a share of the aviation communications market, prices will continue to decline. In addition to communications services, these service providers will offer GNSS augmentation services on a global and regional basis, depending on their system coverage.

4.3.8 Network Switching Equipment

Modern network switching equipment is highly flexible, reconfigurable, and expandable software-driven digitized system. The largest network switching systems can accommodate facilities consisting of 50 to 430 positions, over 500 interphone trunks, 350 frequencies, 200 plus backup radio trunks, about 40 PABX tielines, and can handle peak traffic loads of more than 1500 calls per minute. Modern switching equipment consists of four basic subsystems which are the switching subsystem, control subsystem, air traffic communication positions, and the maintenance position.

A powerful microprocessor is the primary component of the network digital switch which provides a non-blocking, independent switch node that has self-contained call processing, test, and fault mitigation functions. The switch nodes are combined to form air-to-ground and ground-to-ground switching functions. The actual air-to-ground and ground-to-ground switches are independent and separate from one another. Both switches provide high quality 64 Kb digitized voice from positions to radio and trunk interfaces.

The air-to-ground switching function contains an independent primary and backup switch to ensure uninterrupted radio communications. Both the primary and backup process voice but only the active switch is allowed to transmit the controller's voice to the pilot. To achieve reliabilities of 0.999999, the switch is designed with redundant control shelves, interface cards, and power supplies. Built-in test functions automatically mitigate faults and then report them to the maintenance position via the redundant bus.

The backup switch automatically takes over in the event of a catastrophic failure of the primary switch and is totally transparent to the air traffic controller.

The intercom call (IC) and interphone call (IP) provide ground-to-ground communications within the facility and between facilities, respectively. The ground-to-ground switch is also designed with redundant control shelves, power supplies, and single circuit interface cards. Fault mitigation and reporting is identical to that of the air-to-ground switch. Modern switches usually have redundant fiber optic trunks, a redundant high speed common channel signaling bus, and switch processor to work efficiently under peak traffic loads.

The switch control subsystem usually contains several microprocessors, depending on the size of the system. The fault tolerant control subsystem supports system reconfiguration, maintenance, communications traffic collection and analysis, and report generation. All communication with other system elements is via the redundant high-speed bus. The control subsystem monitors the status of all system elements every few seconds. The results are reported to the maintenance position for evaluation. The subsystem database stores all air-to-ground and ground-to-ground communication resources (e.g., frequencies, trunks, and intercom connectivity) assigned to the facility and provides configuration maps (software tables) for each position within the facility. Operational flexibility is provided through the reconfiguration of positions by providing the desired air-to-ground and ground-to-ground connectivity at any position, whenever required.

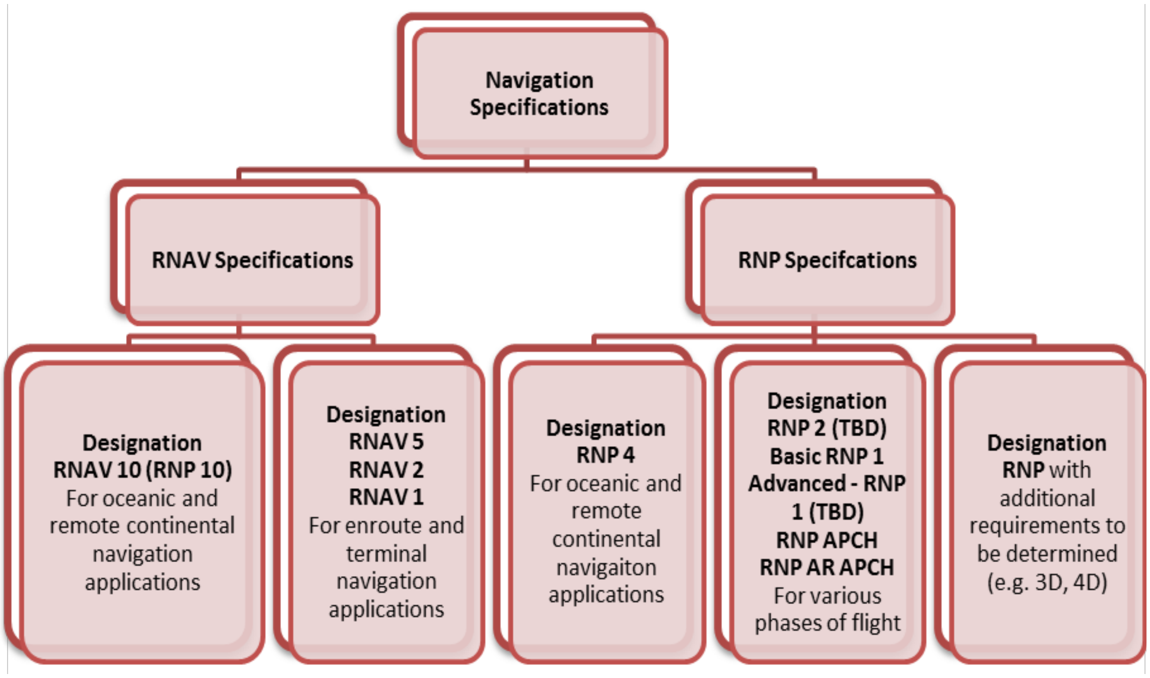
The ATC communications position subsystem consists of console equipment used by air traffic controllers. The air traffic controllers operate the console by using its touch entry display module to perform all air-to-ground and ground-to-ground functions. Each operator position has two touch entry display modules, each capable of displaying either air-to-ground or ground-to-ground button templates in any combination, two dual jacks with individual volume control and preemption capability, one air-to-ground speaker module, one ground-to-ground speaker module with chime capability, one handset, and a foot switch.

An important aspect of modern network switching systems is the man-machine interface (MMI). The MMI ensures that the system meets all of the controller's operational requirements and is user-friendly without compromising flexibility. MMI elements include the use of color coding and icons to allow the controller to easily recognize situations requiring immediate attention, to simplify tasks and reduce workload. MMI factors also consider placement of functions and communication buttons to allow the controller quick access to all communication actions from a central, easy-to-reach location.

Visual display modules display required control frequencies or direct access buttons. An air-to-ground status screen provides overall status of all air-to-ground frequencies at the controllers position without having to page through all screens. A position function verification screen is also provided so that the controller can, if desired, verify position equipment operability.

Modern switching equipment usually comes with a frequency cross-couple capability. This function allows pilots on one frequency to hear pilots transmitting on another frequency (VHF or UHF) in half or full duplex mode. Cross-coupling will prevent two pilots from transmitting simultaneously, thus eliminating garbled receptions. This feature is important during periods of heavy air traffic when large numbers of VHF and UHF aircraft (civil and military) are operating within a sector. Remote mute provides the capability to remotely mute a selected receiver at a remote site, to eliminate the squeal of a stuck transmit button or receiver malfunction. The switch can also provide the supervisor with the capability to patch a public telephone system line to any frequency in the facility for monitoring only. Weather broadcast and monitoring functions are also available to the controller through the panel. Modern switches also provide controllers with the capability to forward incoming calls to another position, call hold, call transfer, and the capability to record the position relief briefing

Figure 4-7
Existing and Future Specification Designations



Source: ICAO

between relieving and relieved controllers. Additionally, conference calling functions provide the capability to conference several participants using direct or indirect access capability. An important feature of the network switching system is a non-latching override button that allows controllers to instantaneously communicate with selected positions in time critical situations without the need to key the handset or foot pedal switch.

4.3.8.1 Important Digital Switching System Features

Modern digital switches offer many features important in the future ATC/ATM environment. One feature is the trend towards decentralized architectures. Decentralized architectures are important because they limit the effects of system faults which also helps to isolate and correct problems more quickly than centralized architectures. Another important feature is the duplication of critical components. System microprocessors constantly monitor system components and automatically switch to redundant subsystems upon detection of system faults, completely transparent (except for appropriate fault notifications) to the controller. Modular construction of modern switches provides flexibility to offer the optimum solution for a variety of ATC applications, from small to large.

Central processing units (CPUs) provide inherent control over the whole switching system, which means that each CPU of the distributed system is provided with complete information about the state of the whole system. Centralized configuration management functions of modern switching systems offer ATM managers the capability to alter the system configuration and centrally send this information to all components that require it. A significant feature of modern switching systems is intelligent control of the remote stations. Over a remote control system, digitized speech is sent to the transmitter or from the receiver to the radio interface. Speech compression permits the leased lines to be used more efficiently. This allows significant savings in line costs and provides very good speech quality. Intelligent line management puts many channels onto one line and is responsible for the lines being constantly checked. Connections are transferred to the remaining lines according to their priorities in the event of a line failure.

4.3.8.2 Technical Issues

Software engineering is one of the main tasks involved in the design and development of a modern network switching system. Switching equipment is extremely complex and may contain upwards of one million lines of software code. Therefore, these systems take years to develop and implement and rank among the costliest category of ATC/ATM equipment to procure. Even upgrading smaller network switching systems requires a large systems and software engineering effort. The main thrust in modern switching design is to ensure that the system is in compliance with international networking and switching standards and designed with inherent flexibility and modularity to provide low cost system upgrades as air traffic densities continue to increase.

4.3.8.3 Operational Issues

There is a wide variety of off-the-shelf equipment that can be procured and modified to support ATC/ATM network switching functions. The key operational issue is to properly identify known system requirements and potential future requirements to support present operations and provide a smooth transition to FANS operations such as ADS. Therefore, implementation and operation of new network switching systems must consider interface with older analog networks, which still carry a majority of air traffic communications in some countries, as well as future digital data networks required to support modern ATC/ATM operations.

4.3.8.4 Institutional Issues

Network switching systems are a vital part of the modern ATC/ATM center. As states continue to consolidate air traffic operations centers, more and more information will continue to flow across national boundaries. One of the implications of consolidation, especially in the European region, is that the newer operation centers will be shared by many states. Therefore, states will lose a certain degree of sovereignty as operations which were once part of their physical domain are consolidated and moved across national boundaries. Issues of information security and integrated military-civil operations and procedures will be paramount. These issues are being addressed within the context of harmonization and integration and are a vital factor in the implementation of the future ATC/ATM system.

4.3.8.5 Future Trends

Network switching equipment accounts for the majority of global ATC/ATM communications equipment sales, and this trend is expected to continue. This is driven by continued increases in air traffic, expansion of ATC/ATM infrastructure, and continued trend towards consolidation of ATC/ATM centers and functions. Modern network switching equipment must be able to handle a wide variety of signals including analog and digital. Data multiplexing is a vital element in providing interfacility communications transmission and enables several independent transmission requirements to be consolidated onto a single circuit. Automated network monitoring and control enables the identification of failed network elements from central lo-

Figure 4-8

Current US Airports with WAAS-capable Procedures

	Part 139 Airports Served	Non-Part 139 Airports Served	Total Airports*
LNAV Procedures	535	1976	2511
LNAV/VNAV Procedures	459	901	1360
LPV Procedures	478	978	1456
LP Procedures	36	198	234
GPS Standalone Approaches	16	158	174

*With WAAS-capable Procedures - GPS, LNAV, LNAV/VNAV, and/or LPV. Number of GPS stand-alone will continue to decrease as they are replaced by RNAV procedures.

Source: FAA

cations and circuit restoral in real-time. The continued consolidation and automation of ATC facilities will spur an increase in requirements for modems, multiplexing modems, statistical multiplexers, and automated network monitor and control systems.

4.4 Navigation, Approach and Landing Systems

In an effort to reduce operating costs, improve efficiency, and maintain, at minimum, current levels of safety, the international aviation community has expressed a desire to have all enroute navigation, approach, landing, and surface functions provided by an integrated system. Today, no single technology has more broad-reaching potential for world-wide civil aviation than the future CNS/ATM applications of satellite-based technology. These applications represent more of an opportunity to enhance aviation system capacity, efficiency of operation, and safety than was provided by the introduction of radio navigation systems more than 70 years ago.

The development of a "seamless" aviation navigation system using a common technology includes a transition from terrestrial to satellite-based CNS/ATM systems. Currently, both terrestrial and satellite-based systems are available for enroute navigation, approach, and landing operations. As satellite-based navigation technology continues to evolve, it will eventually be certified and implemented globally to support additional precision approach and landing operations.

The optimism of the international aviation community concerning the potential of worldwide CNS/ATM services for oceanic, enroute, and terminal area operations is based on the demonstrated performance of the US GPS system. Currently, oceanic, enroute, and non-precision approach operations are being performed using GPS to the benefit of both users and providers. When coupled with newer and more robust communications systems, the aggregate system will facilitate an increased level of CNS/ATM capability and provide additional optimized route structures.

The continuing growth of aviation increases demands on airspace capacity, emphasizing the need for optimum utilization of available airspace. Improved operational efficiency derived from the application of area navigation (RNAV) techniques has resulted in the development of navigation applications in various regions worldwide and for all phases of flight. These applications could potentially be expanded to provide guidance for ground movement operations.

RNAV systems evolved in a manner similar to conventional ground-based routes and pro-

Figure 4-9

Navigation Specification by Flight Phase

Navigation Specification	Flight Phase							
	En route oceanic/remote	En route continental	Arrival	Approach				Departure
				Initial	Intermediate	Final	Missed	
RNAV 10	10							
RNAV 5		5	5					
RNAV 2		2	2					2
RNAV 1		1	1	1	1		1 [2]	1
RNP 4	4							
Basic-RNP 1			1 [1,3]	1 [1]	1 [1]		1 [1,2]	1 [1,3]
RNP APCH				1	1	0.3	1	
1. The navigation application is limited to use on STARs and SIDs only.								
2. The area of application can only be used after the initial climb of a missed approach phase.								
3. Beyond 30 NM from the airport reference point (ARP), the accuracy value for alerting becomes 2 NM.								

Source: ICAO

cedures. A specific RNAV system was identified and its performance evaluated through a combination of analysis and flight testing. For domestic operations, the initial systems used very high frequency omnidirectional radio range (VOR) and distance measuring equipment (DME) for estimating their position; for oceanic operations, inertial navigation systems (INS) were employed. These "new" systems were developed, evaluated, and certified. Airspace and obstacle clearance criteria were developed based on the performance of available equipment, and specifications for requirements were based on available capabilities. In some cases, it was necessary to identify the individual models of equipment that could be operated within the airspace concerned. Such prescriptive requirements resulted in delays to the introduction of new RNAV system capabilities and higher costs for maintaining appropriate certification. To avoid such prescriptive specifications of requirements, ICAO introduced an alternative method for defining equipage requirements by specifying the performance requirements. This formed the basis of performance-based navigation (PBN).

GPS has served as a catalyst for the international aviation community to start converging toward the goal of a single, integrated satellite-based system that will eventually allow aviation users to reduce the number of different types of receivers required for navigation services for all phases of flight (i.e., departure, enroute, approach, landing, and surface).

4.4.1 Performance Based Navigation (PBN)

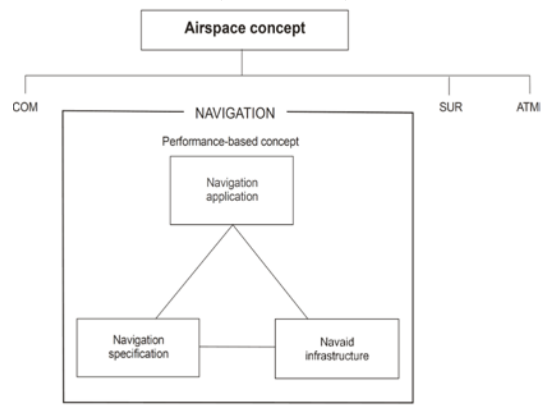
The performance-based navigation (PBN) concept specifies that aircraft RNAV system performance requirements be defined in terms of accuracy, integrity, availability, continuity, and functionality required for the proposed operations in the context of a particular airspace concept, when supported by the appropriate navigation infrastructure. In that context, the PBN concept represents a shift from sensor-based to performance-based navigation. Performance requirements are identified in navigation specifications, which also identify the choice of navigation sensors and equipment that may be used to meet the performance requirements.

These navigation specifications provide specific implementation guidance for states and operators in order to facilitate global harmonization.

The PBN concept is made up of three interrelated elements: the navigation specification, the navigational aid (navaid) infrastructure, and the navigation application. The relation of these elements to the future airspace concept is shown in Figure 4-10.

Figure 4-10

Airspace Concepts



Source: ICAO

The PBN concept encompasses two types of navigation specifications:

- **RNAV specification:** Navigation specification based on area navigation that does not include the requirement for on-board performance monitoring and alerting, designated by the prefix RNAV.

- **RNP specification:** Navigation specification based on area navigation that includes the requirement for on-board performance monitoring and alerting, designated by the prefix RNP.

For oceanic, remote, enroute, and terminal operations, an RNP specification is designated as RNP X, e.g. RNP 4. An RNAV specification is designated as RNAV X, e.g. RNAV 1. If two navigation specifications share the same value for X, they may be distinguished by use of a prefix, e.g. Advanced-RNP 1 and Basic-RNP 1. Current and future designations for RNAV and RNP specifications are shown in Figure 4-7.

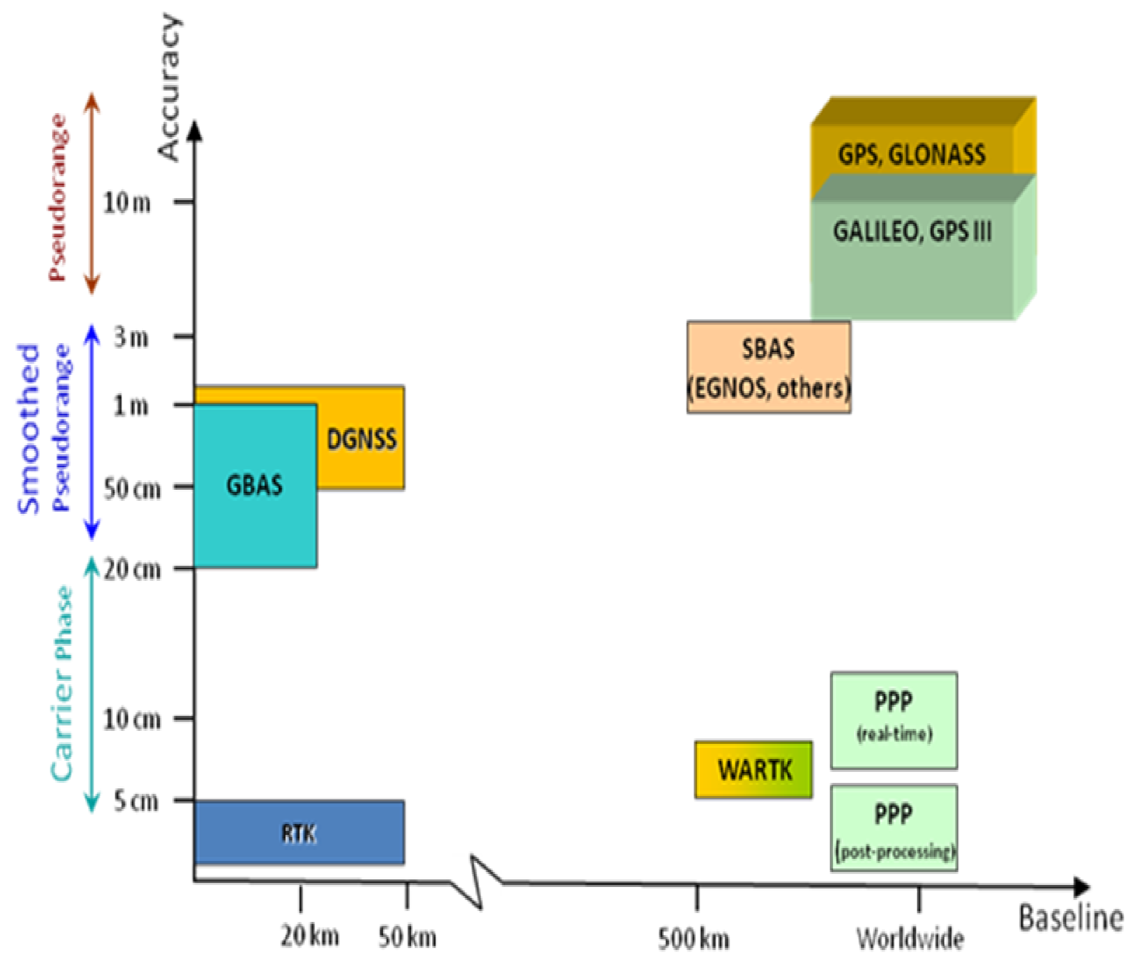
Approach navigation specifications cover all segments of the instrument approach. RNP specifications are designated using RNP as a prefix and an abbreviated textual suffix, e.g. RNP APCH or RNP AR APCH. There are no RNAV approach specifications.

For both RNP and RNAV designations, the expression "X" (where stated) refers to the lateral navigation accuracy in nautical miles, which is expected to be achieved at least 95 per cent of the flight time by the population of aircraft operating within the airspace, route, or procedure.

The 2007 36th ICAO General Assembly resolution A36-23 urges all nations to implement PBN for enroute and terminal areas, and to implement PBN approach procedures with vertical guidance (APV) using Baro-VNAV and/or augmented GNSS for all instrument runway ends (as primary or back-up for precision approach) by 2016, with 30 percent by 2010 and 70 percent by 2014.

Figure 4-8 lists the number of airports in the US that support different WAAS non-precision approaches as of June 2012. The current number of LPV approaches in the US outnumbers ILS Cat I approaches. It is expected that all future navigation applications will identify the navigation requirements through the use of PBN performance spec-

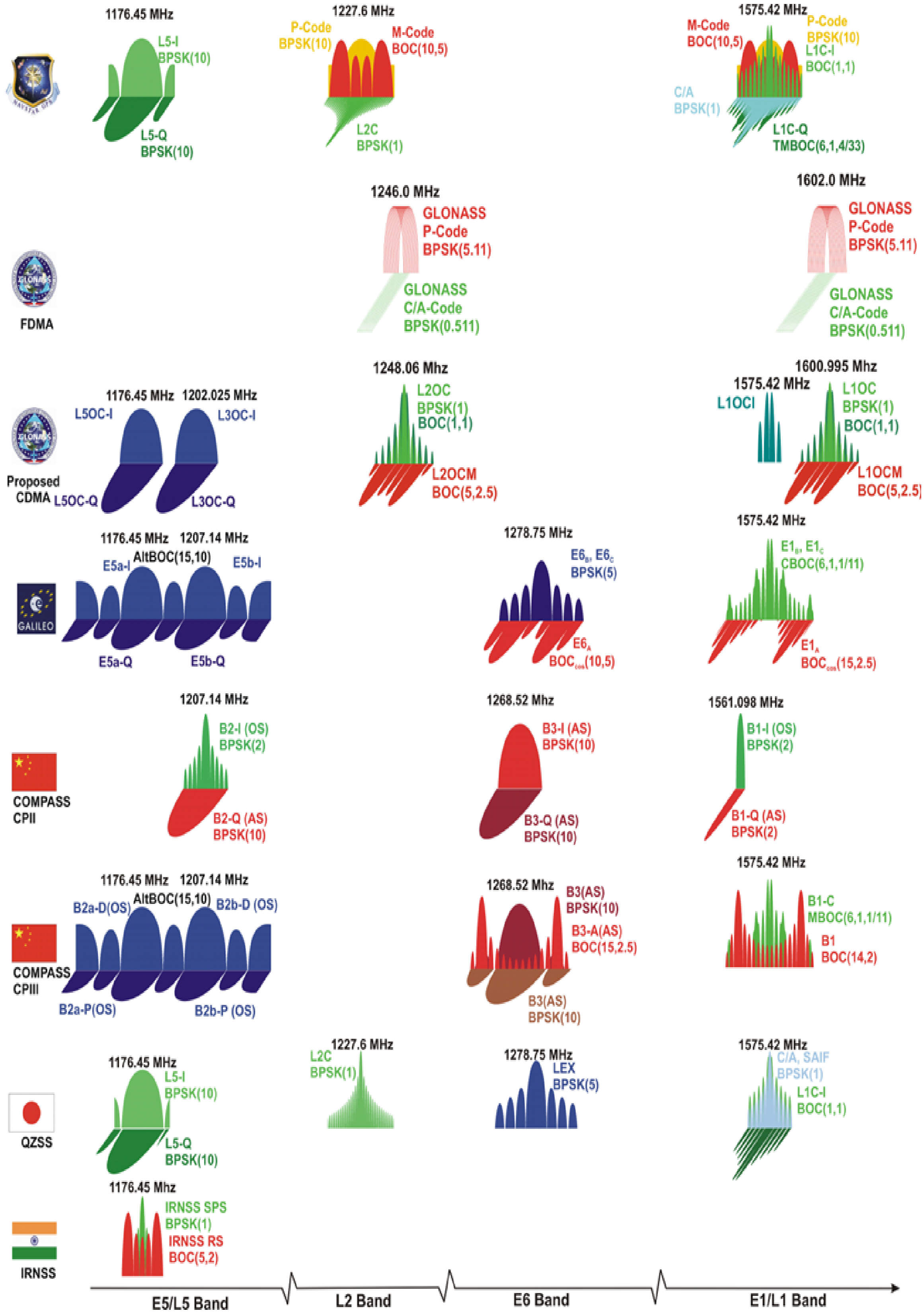
Figure 4-11
Satellite Navigation System Accuracy and Range



Source: European Space Agency

Figure 4-12

Navigation Satellite System Signal Frequencies



Source: European Space Agency

ifications, rather than defining equipage of specific navigation sensors.

4.4.1.1 Area Navigation (RNAV)

RNAV is a method of navigation that permits aircraft operation on any desired flight path within the coverage of ground or space-based navigation aids or within the limits of the capability of self–contained aids, or a combination of these. In the future, there will be an increased dependence on the use of RNAV in lieu of routes defined by ground-based navigation aids.

RNAV routes and terminal procedures, including departure procedures (DPs) and standard terminal arrivals (STARs), are designed with RNAV systems in mind. There are several potential advantages of RNAV routes and procedures:

- Time and fuel savings.
- Reduced dependence on radar vectoring, altitude, and speed assignment, allowing a reduction in required ATC radio transmissions.
- More efficient use of airspace.

Figure 4-13

Satellite Navigation Systems

System	Nominal constellation	Full operational capability	Number of operational satellites	Coverage	Civilian spectrum
GPS	24	1995	31 (2012)	Global	Current: L1 C/A, L2C, L5 Future: L1 C/A, L1C, L2C, L5
WAAS	3	IOC/2003 FOC/2008	3 (2012)	Regional, North America	Current: L1C/A, L5 Future: L1C/A, L5
GLONASS	24	1995 (GLONASS) 2010 (GLONASS-M)	24 (2012)	Global	Current 2007: L1PT, L2PT Future: L1PT, L2PT, L3PT,[a] L1CR,[a] L2CR,[a] L5R[b]
SDCM	2	2014 (Expected)	1 (2012)	Regional, Russian	SBAS L1 C/A
GALILEO	30 MEO	2014	2 (2012)	Global	E5 OS/SoL E6 CS/PRS E1 OS/SoL/PRS
EGNOS	3 Geostationary	2009 Open	3 (2012)	Regional,	Current: L1C/A
COMPASS /BeiDou	30 + 5 Geostationary	2020	5 Geosynchronous 5 Inclinded Geosynchronous 3 MEO (2012)	Global	1,559.052~1,591.788 MHz 1,166.22~1,217.37 MHz 1,250.618-1,286.423MHz
GAGAN/ IRNSS	3/7	2014	1 (2012)	Regional, India	GAGAN: L5, L1 IRNSS: S, L5 AND L1
MSAS	2 Geostationary		2 (2012)	Asia and Pacific	L1
QZSS	1 (Phase 1), 3 (Phase 2)[c]		1 (2012)	Regional, Asia and Oceania	L1 C/A, L1C, L2C, L5, L1-SAIF (L1 – submeter-class augmentation with integrity function), LEX (L-Band Experimental Signal)

a: Singal structure is under refinement.

b: Pending final decision.

c: The QZSS plan will proceed to the second phase of public-private cooperation after the evaluation of the results of technological verifications and demonstrations of the first flight phase.

Source: European Space Agency

4.4.1.2 Required Navigation Performance (RNP)

RNP is RNAV with on-board navigation monitoring and alerting and is also a statement of navigation performance necessary for operation within a defined airspace. A critical component of RNP is the ability of the aircraft navigation system to monitor its achieved navigation performance, and to identify for the pilot whether the operational requirement is or is not being met during an operation. This on–board performance monitoring and alerting capability therefore allows a lessened reliance on air traffic control intervention (via radar monitoring, ADS, multilateration, communications), and/or route separation to achieve the overall safety of the operation. RNP capability of the aircraft is a major component in determining the separation criteria to ensure that the overall containment of the operation is met.

The RNP capability of an aircraft will vary depending upon the aircraft equipment and the navigation infrastructure. For example, an aircraft may be equipped and certified for RNP 1.0 but may not be capable of RNP 1.0 operations due to limited navaid coverage. The following are navigational functional requirements of RNAV and RNP:

- Continuous indication of aircraft position relative to track to be displayed to the pilot flying on a navigation display situated in his primary field of view.
- Display of distance and bearing to the active (To) waypoint.
- Display of ground speed or time to the active (To) waypoint.
- Appropriate failure indication of the RNAV system, including the sensors.
- Navigation data storage function.

It may seem logical, for example, that an aircraft approved for Basic-RNP 1 be automatically approved for RNP 4; however, this is not the case. Aircraft approved to the more stringent accuracy requirements may not necessarily meet some of the functional requirements of the navigation specification having a less stringent accuracy requirement.

Figure 4-9 lists the different applications of navigation specifications by flight phase. The numbers given in the table refer to the 95 percent accuracy requirements. For any particular PBN operation, it is possible that a sequence of RNAV and RNP applications are used.

4.4.1.3 Airspace Concepts by Area of Operation

Oceanic and remote continental

Oceanic and remote continental airspace concepts are currently served by two navigation applications, RNAV 10[1] and RNP 4. Both of these navigation applications rely primarily on GNSS to support the navigation element of the airspace concept. In the case of the RNAV 10 application, no form of ATS surveillance service is required. In the case of the RNP 4 application, ADS contract (ADS-C) is used.

Continental enroute

Continental enroute airspace concepts are currently supported by RNAV applications. RNAV 5 has been in use in the Middle East and European regions, designated as B-RNAV (Basic RNAV) in Europe and RNP 5 in the Middle East. In the US, an RNAV 2 application supports an enroute continental airspace concept. At present, continental RNAV applications support airspace concepts which include radar surveillance and direct controller pilot communication (voice).

Terminal airspace: arrival and departure

Existing terminal airspace concepts, which include arrival and departure, are supported by RNAV applications. The European terminal airspace RNAV application is known as P-RNAV (precision RNAV). Although the RNAV 1 specification shares common navigation accuracy with P-RNAV, this regional

1 The existing RNP 10 designation is inconsistent with PBN RNP and RNAV specifications. RNP 10 does not include requirements for on-board performance monitoring and alerting.

navigation specification does not satisfy the full requirements of the RNAV 1 specification. The US terminal airspace application formerly known as US RNAV Type B has been aligned with the PBN concept and is now called RNAV 1. Basic-RNP 1 has been developed primarily for application in non-radar, low-density terminal airspace. In the future, more RNP applications are expected to be developed for both enroute and terminal airspace.

Approach

Approach concepts cover all segments of the instrument approach, i.e. initial, intermediate, final, and missed approach. They will increasingly call for RNP specifications requiring a navigation accuracy of 0.3 NM to 0.1 NM or lower. Three RNP applications are characteristic of this phase of flight:

- New procedures to runways never served by an instrument procedure.
- Procedures either replacing or serving as backup to existing instrument procedures based on different technologies.
- Procedures developed to enhance airport access in demanding environments.

The relevant RNP specifications for RNP approach applications are RNP APCH and RNP AR APCH. The following are types of RNAV GPS approaches and important terms and concepts associated with RNAV approaches.

- **APV**: Approaches with vertical guidance.
- **LNAV**: Lateral navigation.
- **VNAV**: Vertical navigation.
- **LPV**: Localizer precision with vertical guidance.
- **LP**: Localizer precision without vertical guidance.
- **Baro-VNAV**: Barometric vertical navigation.
- **Baro-Aiding**: Barometric aiding.

Further information on PBN can be found in ICAO Document 9613.

Key Points:

- All future navigation applications will identify the navigation requirements through the use of PBN performance specifications, rather than defining equipage of specific navigation sensors.
- The international aviation community has expressed a desire to have all enroute navigation, approach, landing and surface functions provided by a single system.

4.4.2 Current and Developing Global Navigation Satellite Systems

Navigation is evolving from ground-based navigation aids to satellite-based navigation systems. Global Navigation Satellite Systems (GNSS) provide standardized positioning information on a global basis to the aircraft for precise navigation. Satellite navigation systems consist of three main segments: space segment, control segment, and user segment.

Satellites in the core constellations broadcast a timing signal and a data message. Aircraft GNSS receivers use these signals to calculate their range from each satellite in view and also calculate 3-D position and precise time. Airlines are urging states to move from the current ground-based navigation systems to GNSS capable of being used in all airspace during all phases of flight.

Figure 4-11 shows the accuracy and applicable ranges of different satellite navigation systems currently in operation or developing. Russia is the only other country that has completed implementation of a GNSS system, with full restoration of GLONASS in 2011 completing global coverage. Additional GNSS and augmentation systems are in development. These new systems reduce dependence on foreign-controlled assets and provide additional accuracies and reliability. Figure 4-13 summarizes current and developing global, regional and augmentation systems.

4.4.2.1 Global Positioning System (GPS)

GPS is a constellation of orbiting satellites that provides navigation data to military and civilian users all over the world. The system is operated and controlled by the 50th Space Wing, located at Schriever Air Force Base, Colorado. GPS is a US-owned utility that provides users with positioning, navigation, and timing (PNT) services. The US Air Force develops, maintains, and operates the space and control segments. The Air Force Space Command declared full operational capability of GPS in April 1995.

Current Status

GPS is currently operating with 31 active space vehicles (SVs), as listed in Figure 4-14.

Figure 4-14

GPS Space Vehicles

SV#	PRN#	SLOT	PLANE	Launched	Clock
Type: Block IIA					
23	32	5	E	11/26/1990	RB
26	26	5	F	7/7/1992	RB
27	27	6	A	9/9/1992	CS
39	9	1	A	6/26/1993	CS
35	30	5	B	8/30/1993	RB
34	4	4	D	10/26/1993	RB
36	6	6	C	3/10/1994	RB
33	3	2	C	3/28/1996	CS
40	10	6	E	7/16/1996	CS
38	8	3	A	11/6/1997	CS
Type: Block IIR					
43	13	3	F	7/23/1997	RB
46	11	5	D	10/7/1999	RB
51	20	1	E	5/11/2000	RB
44	28	3	B	7/16/2000	RB
41	14	1	F	11/10/2000	RB
54	18	4	E	1/30/2001	RB
56	16	1	B	1/29/2003	RB
45	21	3	D	3/31/2003	RB
47	22	2	E	12/21/2003	RB
59	19	3	C	3/20/2004	RB
60	23	4	F	6/23/2004	RB
61	2	1	D	11/6/2004	RB
Type: Block IIR-M					
53	17	4	C	9/26/2005	RB
52	31	2	A	9/25/2006	RB
58	12	4	B	11/17/2006	RB
55	15	2	F	10/17/2007	RB
57	29	1	C	12/20/2007	RB
48	7	4	A	3/15/2008	RB
50	5	3	E	8/17/2009	RB
Type: Block IIF					
62	25	2	B	5/28/2010	RB
63	1	2	D	7/16/2011	RB

CS – Cesium, RB - Rubidium

Source: US Coast Guard

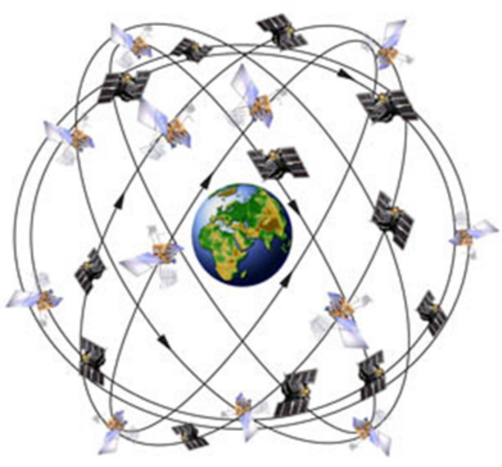
Technical Description

GPS is a satellite–based radio navigation system, which broadcasts a signal used by receivers to determine precise position anywhere in the world. The receiver tracks multiple satellites and determines a pseudorange measurement that is then used to determine the user location. A minimum of four satellites is necessary to establish an accurate three–dimensional position. Every satellite's orbital parameters (ephemeris data) are sent to each satellite for broadcast as part of the data message embedded in the GPS signal. The GPS coordinate system is the Cartesian earth–centered, earth–fixed coordinates as specified in the World Geodetic System 1984 (WGS–84).

GPS SVs' orbits are nearly circular, with eccentricity less than 0.02 and a semi-major axis of 26,560 km. The SVs have a speed of 3.9 km per second and a nominal period of 12 h sidereal time (11 h 58m 2 s), repeating the geometry each sidereal day. GPS SVs are arranged on six planes, each of them containing at least four slots. There is a spare satellite slot in each orbital plane. The present configuration allows users to have a simultaneous observation of at least four satellites in view worldwide, with an elevation masking angle of 15 degrees. GPS orbital planes and SVs are shown in Figure 4-15.

Figure 4-15

GPS Constellation



Source: www.gps.gov

Current and Planned Signals

The L1 frequency, transmitted by all GPS satellites, contains a coarse acquisition (C/A) code-ranging signal with a navigation data message available for peaceful civilian, commercial, and scientific use, and a precision P(Y) code ranging signal with a navigation data message available to users with valid cryptographic keys. GPS satellites also transmit a second P(Y) code-ranging signal with a navigation data message on the L1 and L2 frequencies. Figure 4-16 compares signal characteristics of the standard and precision signals.

Figure 4-16

SPS vs. PPS Signal Characteristics of note

	SPS	PPS
Presence	L1	L1 and L2
Code Length	1023 bits (1 SV)	~ 10^{12}12 bits (1 SV)
Repetition/PRN	1ms (1 SV)	7 days (1 SV)
Chip rate	1.023 MHz	10.23 MHz
Chip width	300m	30m
Rx Power, dBw	~ -160	~ -163 L1, -166 L2

Source: GPS World

The second civil signal, known as L2C, has been designed specifically to meet commercial needs. When combined with L1 C/A in a dual-frequency receiver, the L2C signal enables ionospheric correction, improving accuracy. For professional users with existing dual-frequency operations, L2C signals deliver faster signal acquisition, enhanced reliability, and greater operating range for differential applications. The L2C modulation also results in a signal that is easier to receive under trees and even indoors. This also supports the further miniaturization of low-power GPS chipsets for mobile applications.

The first GPS IIR-M satellite featuring L2C capabilities was launched in 2005. Every GPS satellite fielded since then has included an L2C transmitter. As of January 2010, there are seven GPS satellites broadcasting L2C signals.

The third civil signal, known as L5, is broadcast in a radio band reserved exclusively for aviation safety services and radio navigation satellite services. With a protected spectrum, higher power, greater bandwidth and other features, the L5 signal is designed to support safety-of-life transportation and other high-performance applications. Future aircraft will use L5 signals in combination with L1 C/A (also in a protected band) to improve accuracy via ionospheric correction and robustness via signal redundancy. The use of L5 signals will increase capacity, fuel efficiency, and safety in US airspace, railroads, waterways, and highways. When used in combination with L1 C/A and L2C, L5 will provide a very robust service that may enable sub-meter accuracy without augmentations and very long-range operations with augmentations. The operational L5 signal will launch with the follow-on series of GPS satellites, Block IIF.

The central focus of the GPS modernization program is the addition of new navigation signals to the GPS constellation. The new signals are being phased in as new GPS satellites are launched for replacement.

Operations and Levels of Service

Authorized access to the precise positioning service is restricted to the US Armed Forces, federal agencies, and selected allied armed forces and governments. The standard positioning service is available to all users worldwide on a continuous basis and without any direct user charge. The specific capabilities provided by the GPS open service are published in the *GPS Standard Positioning Service Performance Standards.* The US Department of Defense, as the operator of GPS, will continue enabling codeless/semi-codeless GPS access until December 2020, by which time the L2C and L5 signals will be available on at least 24 modernized GPS satellites.

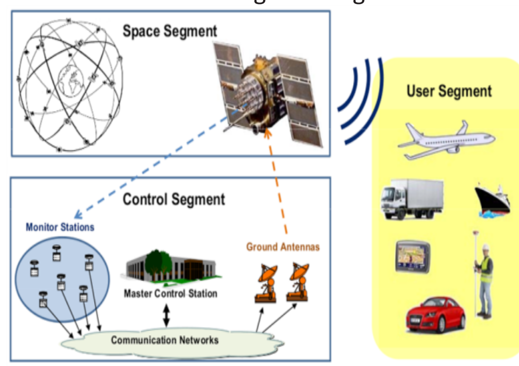
The FAA has granted approval for US civil operators to use properly certified GPS equipment as a primary means of navigation in oceanic airspace and certain remote areas. Properly certified GPS equipment may be used as a supplemental means of IFR navigation for domestic enroute, terminal operations, and certain instrument approach procedures (IAPs). This approval permits the use of GPS in a manner that is consistent with current navigation requirements as well as approved air carrier operations specifications.

GPS Segment Description

Since detailed descriptions of each segment of the GPS architecture have been widely published, a brief overview of each segment of the GPS architecture is presented for completeness. The overall GPS configuration is comprised of the space, user, and control segments as shown in Figure 4-17.

Figure 4-17

Satellite Navigation Segments



Source: European Space Agency

Space Segment

The GPS space segment consists of a constellation of satellites transmitting radio signals to users. The US Air Force manages the constellation to ensure the availability of at least 24 GPS satellites, 95 percent of the time. For the past several years, the Air Force has been flying 31 operational GPS satellites, plus three to four decommissioned satellites ("residuals") that can be reactivated if needed.

GPS satellites fly in medium earth orbit (MEO) at an altitude of approximately 20,200 km. Each satellite circles the earth twice a day. The satellites in the GPS constellation are arranged into six equally-spaced orbital planes surrounding the earth, each containing four slots occupied by baseline satellites. This 24-slot arrangement ensures there are at least four satellites in view from virtually any point on the planet. The latest generation of GPS satellites, Boeing Block IIF Space Vehicles, provide the following improvements over previous generations:

- Greater navigational accuracy through improvements in atomic clock technology.

- A new civilian L5 signal to aid commercial aviation and search and rescue operations.

- Improved military signal and variable power for better resistance to jamming in hostile environments.

- A 12-year design life providing long-term service and reduced operating costs.

- An on-orbit, reprogrammable processor that can receive software uploads for improved system operation.

User Segment

The user segment consists of receivers which process the transmitted data and ranging signals. An airborne receiver will typically track four or more satellites, each with a separate "channel" in the receiver in order to determine its position, velocity, and time (PVT).

Control Segment

The Operational Control System (OCS) is comprised of four major subsystems: a Master Control Station (MCS, soon to be replaced by a New Master Control Station [NMCS]), a Backup Master Control Station (BMCS, soon to be replaced by an Alternate Master Control Station [AMCS]), a network of four ground antennas (GAs), and a network of globally-distributed monitor stations (MSs). The functions of the MCS and the relations to monitor stations and ground antennas are shown in Figure 4-18.

The MCS is located at Schriever Air Force Base, Colorado, and is the central control node for the GPS satellite constellation. Operations are maintained 24 hours a day, seven days a week throughout the year. The MCS is responsible for all aspects of constellation command and control, to include:

- Routine satellite bus and payload status monitoring.

- Satellite maintenance and anomaly resolution.

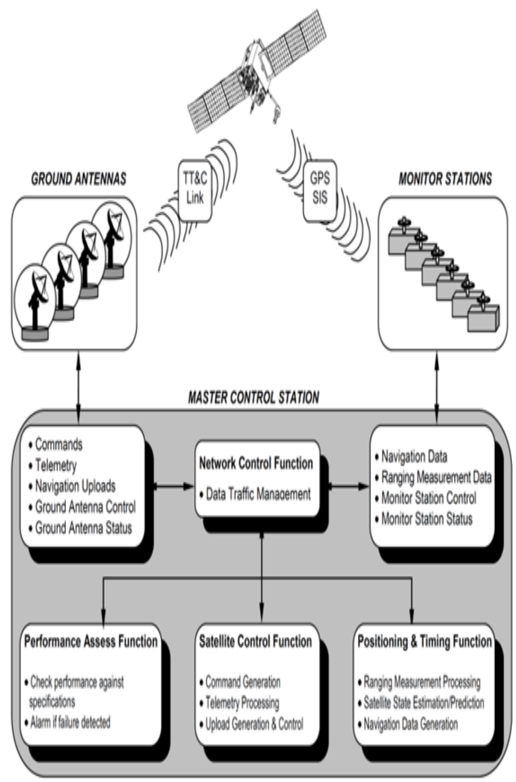
- Management of GPS SIS performance in support of all performance standards (SPS PS and PPS PS).

- NAV message data upload operations as required to sustain performance in accordance with accuracy and integrity performance standards.

- Detecting and responding to GPS SIS failures.

Figure 4-18

GPS Operational Control System



Source: www.gps.gov

General Performance

The basic GPS service provides users with approximately 7.8 meter accuracy, 95 percent of the time, anywhere on or near the surface of the earth. The GPS constellation of 24 satellites is designed so that a minimum of five is always observable by a user anywhere on earth. The receiver uses data from a minimum of four satellites above the mask angle (the lowest angle above the horizon at which it can use a satellite).

Selective Availability (SA) is a method by which the accuracy of GPS is intentionally degraded. This feature is designed to deny hostile use of precise GPS positioning data. SA was discontinued in May 2000, but many GPS receivers are designed to assume that SA is still active. New receivers may take advantage of the discontinuance of SA based on the performance values in ICAO Annex 10 and do not need to be designed to operate outside of performance.

4.4.2.1.7 Error Sources

Like all radio-based services, GPS is subject to interference from both natural and human-made sources. Error sources adversely affect signal propagation and must be mollified if not altogether eradicated in order for GPS to satisfy accuracy requirements for civil aviation navigation. Augmentation techniques used in order to remove anomalies are described in more detail in section 4.4.3. The error sources in the following sections also apply to the other satellite systems described in this report unless otherwise noted.

Interference Mitigation

Due to the low power of GPS signals, interference has been identified as a challenge related to the use of GPS. Despite this, the technical feasibility of using augmented GPS as the only means of navigation in the aircraft as well as the only navigation service provided by the Federal Aviation Administration (FAA) was confirmed as technically feasible in an independent study conducted by Johns Hopkins University Applied Physics Laboratory. However, the study did recommend efforts to mitigate the effects of intentional interference, unintentional interference, and atmospheric disturbances on GPS and its augmentation systems. The mitigation of interference is not only important to aviation, but to other GPS applications as well.

Figure 4-19

Satellite Positioning Error Sources

Error Source	**Typical or Maximum Error**
Ionosphere	10 Meters (30 feet)
Troposphere	1 Meter (3 feet)
Satellite Clock Synchronization	1 Meter (3 feet)
Electronic Noise	2 Meters (6 feet)
Multipath Error	0.5 Meters (1.5 feet)
Satellite Position (Ephemeris)	1 Meter (3 feet)
Intentional Degradation	0 Meters (0 feet) (currently)
Net RMS error	10 Meters (30 feet)
Typical Geometric Error (GDOP)	4 (Dimensionless factor)
Final RMS error (Net x GDOP)	**40 meters (120 feet)**
Actual Typical Error	**10 meters (30 feet)**

Source: www.PDHonline.org

4.4.2.1.7.2 Satellite-Based Errors

GPS positioning is dependent upon precise timing and satellite location relative to both space and time. Satellite-based errors are largely generated by errors in tracking individual satellites and predicting their orbital and clock characteristics (Figure 4-19). GPS tracking stations utilize both the L1 and L2 frequencies. In addition, they also use an uplink frequency of 1783.74 MHz for the transmission of ephemeris and clock updates that are continuously performed from multiple worldwide stations. Despite the fact that satellite station-keeping typically exceeds system specifications, the following residual errors exist:

- **Satellite Clock Error**: Satellite clock error is observed as a pseudorange bias with an error from one satellite's clock to another. This error may be as large as six meters and predominantly results from the measurement algorithms used to process ephemeris coefficients and compute clock drift. Where common satellites are in view, satellite clock error can be eradicated using differencing techniques;

- **Ephemeris Error**: This error is also observed as a pseudorange bias on the order of three meters per satellite, and as such, can also be differenced out. Contributors to ephemeris error include gravitational field variations, solar wind and pressure, and various diurnal effects. Ephemeris errors typically vary over longer time constants than clock errors, and are dramatically reduced when the satellite ephemeris data is periodically updated by ground control every few hours.

Atmospheric-Based Errors

Propagation delays result from signal refraction as it passes through the earth's atmosphere. The choice of frequency is important in analyzing atmospheric propagation delays. Frequency choice is important since L band frequencies are capable of penetrating dense clouds and precipitation without incurring substantial attenuation. Additional atmospheric errors are described in the following paragraphs:

- **Ionospheric Delay**: Propagation delays on the order of 30 meters during daytime and six meters at night occur as GPS signals pass through the earth's ionosphere. Ionospheric behavior is dependent on sunspot activity, latitude, and time of day. The fact that ionospheric dispersion is frequency-dependent is the prime reason for GPS satellites being equipped with multiple frequency (L1, L2, eventually L5) capability.

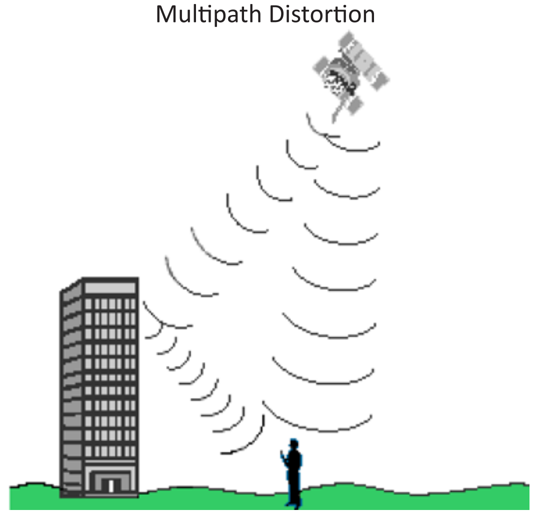
- **Tropospheric Delay**: Propagation delays due to signal passage through the troposphere vary as a function of distance, altitude, satellite elevation angle, and local weather conditions resulting in errors on the order of three to thirty meters. Unlike ionospheric error, troposphere error is mostly independent of radio spectrum frequency due to the water vapor and dry-gas components of the atmosphere. Tropospheric delay can be a significant source of error for wide area networks.

Receiver-Based Errors

Receiver-based errors can be caused by distortion of the signal, electrical interferences, or inherent errors in the receiver. The principal receiver-based error sources include the following:

- **Multipath** results when reflected, refracted, or deflected signals are received by a receiver shortly after the reception of the direct signal. Due to the small time delay of the reflected signal, the deflected signal and the direct signal are processed simultaneously by a receiver. The resulting signal distortion, or multipath, results from reflected, diffused, and refracted signals. While multipath cannot be eliminated, it can be controlled through better antenna pattern shaping and extreme receiver tracking loop time constraints. Error magnitudes can be on the order of three to five meters for C/A Code, and approximately 30 percent less for P Code tracking (Figure 4-20).

Figure 4-20
Multipath Distortion



Source: www.PDHonline.org

- **Antenna Cross-Coupling Error**, sometimes referred to as imaging, pertains to the effective shifting of an antenna's electronic center caused by other antennas located nearby, or from large reflective objects such as glass-fronted buildings. Error magnitudes on the order of several meters have been observed with code-based tracking, and several centimeters in carrier phase-based tracking.

- **Antenna Phase Center Movement** (offset) is typically of the order of two to three centimeters and varies according to satellite elevation or angle of incidence with the GPS antenna. Fortunately, this can be modeled with careful empirical analysis using a controlled anechoic environment.

- **Receiver Oscillator Drift** is due largely to the deficiencies of crystal clocks and temperature variations. It is a principal reason for the requirement of equipment to compute position using four or more satellites. Newer five, six ,or twelve channel receivers use low-cost crystal clocks and, although they exhibit excellent short-term drift characteristics (Allan variances), they require appropriate Kalman filter error modeling. Errors on the order of ten cm or less are typically encountered, constituting a significant source of error for carrier phase measurement instrumentation.

- **Tracking Delay** is a bias associated with GPS receiver tracking loop time constants, and a significant time-correlated error source associated with C/A Code equipment. For example, a typical GPS receiver might acquire a new satellite and immediately accept measurements from the satellite without having given the tracker time to "pull in" the signal so that the code correlation technique used to determine pseudorange yields long-term average integrity.

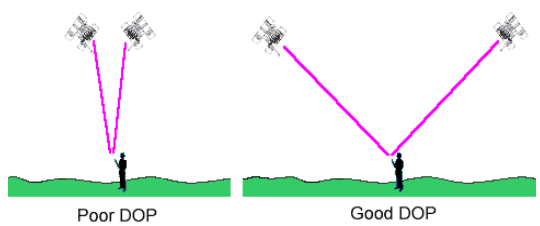
System-Based Errors

System-based errors have to do with the intentional design of the satellite configuration, its spatial and electronic or signal configuration.

- **Selective Availability**: Generates clock errors corresponding to about 30 meters in pseudorange and has the capability of inducing apparent ephemeris errors with similar effect. Selective Availability was turned off in May 2000.

- **Satellite Geometry**: Induces a smaller and more acceptable source of error with every new GPS satellite launch. Satellite geometry is characterized through geometric dilution of precision (GDOP, Figure 4-21), or its variations PDOP, HDOP, etc. This figure of merit is one indicator of the quality of position-fixing geometry, and periodically gives rise to singularities. A good rule of thumb is to multiply GDOP by the nominal pseudorange application error (i.e. error compensated) to arrive at an overall position error. A PDOP of three will translate a one-meter pseudorange error into a three-meter position fix error in three dimensions.

Figure 4-21
GDOP



Source: www.PDHonline.org

Mitigating Disruptions in Aviation Operations

The FAA will continue to operate and maintain a network of ground-based navaids for the foreseeable future; however, the FAA is committed to delivering satellite-based PNT service capable of supporting operations throughout the NAS without routine reliance on other navigation systems. Even when this goal is attained, many operators are expected to choose to retain other PNT receivers. Procedural means will also be used to maintain safe operations in the event of a loss of GPS. The FAA will update the navigation strategy as necessary to ensure safe and reliable air transportation. Critical issues to be addressed are discussed below.

Ionospheric scintillation during severe solar storms is also a concern but is expected to have only minimal impact on enroute, terminal, and non-precision approach operations. Ionospheric anomalies may cause periodic outages of LPV approach capability using

WAAS until an L5-capable GPS constellation is available.

A loss of GPS service, due to either intentional or unintentional interference, in the absence of any other means of navigation, would have varying negative effects on air traffic operations. These effects could range from nuisance events requiring standard restoration of capabilities to an inability to provide normal air traffic control service within one or more sectors of airspace for a significant period of time.

In addition to FAA plans of retaining a minimum network of VOR, DME, and ILS facilities to serve as an alternate means of navigation in the event of a GPS outage, several other solutions have been identified to help mitigate the effects of satellite navigation (SATNAV) service disruption:

- The L5 civil frequency planned for GPS will help mitigate the impacts of both solar activity and unintentional interference, but it may be 2018 before a full constellation of dual-frequency satellites (L1 and L5) is available. The dual frequency capability with L5 will address ionospheric scintillation by enabling receivers to calculate actual ionospheric corrections, thereby preserving LPV capability during severe ionospheric storms.

- Modern transport-category turbojet aircraft with inertial systems may be able to continue navigating safely for a period of time after losing PNT position updating depending on the route or procedure being flown. In some cases, this capability may prove adequate to depart an area with localized interference or, alternatively, the flight can proceed under visual flight rules in appropriate weather conditions. However, inertial performance without PNT updates degrades with time and will eventually fail to meet airspace requirements.

- Integrated GPS/inertial avionics, as well as improvements in antennas and algorithms, could provide increased interference resistance, effectively reducing the area affected by GPS jamming or unintentional interference. Industry research is proceeding to enhance these technologies, with an expectation that they might be marketed to a broader cross-section of the aviation community at some point in the future.

- FAA is currently developing requirements and recommendations for future alternative PNT solutions that address mitigations for GPS disruptions.

International Cooperation

In addition to participating in ICG, the Asia-Pacific Economic Cooperation forum, and the International Telecommunication Union (ITU), as well as standard-setting bodies such as ICAO and the International Maritime Organization, the US pursues its international GNSS objectives through bilateral cooperation with other system providers as follows:

- **The European Union**: In 2004 an agreement was reached providing the foundation for cooperation; a first plenary meeting was held in October 2008.

- **Japan**: Regular policy consultations and technical meetings on GPS cooperation began in 1996, leading to the 1998 Clinton-Obuchi joint statement. Both countries have benefited from a close relationship; the QZSS and the Multi-functional Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS) are designed to be compatible and interoperable with GPS.

- **The Russian Federation**: A joint statement issued in December 2004 and technical discussions have been ongoing through working groups on compatibility and interoperability, and on search and rescue.

- **India**: Policy and technical consultations on GPS cooperation have been under way since 2005; A joint statement on GNSS cooperation was issued in February 2007 in Washington, D.C.

Future Trends - GPS III

A major focus of the GPS modernization program is the addition of new navigation signals to the satellite constellation. The new signals are phasing in incrementally as the US Air Force launches new GPS satellites to replace older ones. Most of the new signals will be of limited use until they are broadcast from 18 to 24 satellites.

The US government is in the process of fielding three new signals designed for civilian use: L2C, L5, and L1C. The legacy civil signal, L1 C/A, will continue broadcasting in the future, for a total of four civil GPS signals.

Once L2C and L5 are fully operational, their features will obviate the need for codeless or semi-codeless GPS receivers, which many GPS professionals use today to attain very high accuracy. Such receivers work by exploiting characteristics of the encrypted military P(Y) signal at the L2 frequency to achieve dual-frequency capability.

The GPS modernization effort focuses on improving positioning and timing accuracy, availability, integrity monitoring support capability, and enhancement to the operational control segment. As these system enhancements are introduced, users will be able to continue to use existing receivers compliant with NAVSTAR GPS Space Segment/Navigation User Interfaces, as signal-backward compatibility is a requirement for both the military and civil user communities. Although current GPS users will be able to operate at the same, or better, levels of performance that they enjoy today, users will need to modify existing user equipment or procure new user equipment in order to take full advantage of any new signal structure enhancements.

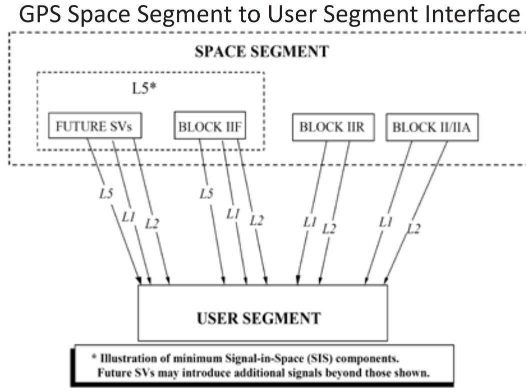
GPS modernization is a multi-phase effort to be executed over the next 15 or more years. The three additional coded civil signals to be added to the existing civil signal, L1 C/A, are:

- L1C, frequency 1575.42 MHz, to provide better performance than the current C/A signal being used by civilian receivers. This signal is being adopted by foreign providers and users as an international standard.
- L2C, frequency 1227.6 MHz to support dual-frequency civil PNT.
- L5, frequency 1176.45 MHz, to support dual-frequency PNT that meets the needs of critical safety-of-life applications, such as civil aviation.

In addition, a secure and spectrally separated military M-Code will be broadcast on the L1 and L2 frequencies. The first launch of an L2C capable satellite (GPS Block IIR-M) was in 2005, and the first satellite with operational L5 capability (GPS Block IIF) was launched in May 2010.

Figure 4-22

GPS Space Segment to User Segment Interface



Source: US Coast Guard

Twenty-four L2C-capable GPS satellites are projected to be in orbit by approximately 2017, and 24 GPS L5-capable satellites are projected to be in orbit by approximately 2019. Providing these second and third frequency civilian signals will allow dual frequency civilian users to directly compensate for ionospheric effects and thus achieve greater accuracy than previous reliance on a single frequency capability. These additional signals will also foster the development of tri-frequency GPS applications. The first launch of an L1C capable satellite (GPS Block III) is projected for 2014.

L5 will provide significant benefits above and beyond the capabilities of the current GPS constellation, even after the planned second civil frequency (L2) becomes available. Benefits include precision approach navigation worldwide, increased availability of precision navigation operations in certain areas of the world, and improved interference mitigation.

The US government commits to maintaining the existing GPS L1 C/A, L1 P(Y), L2C and L2 P(Y) signal characteristics that enable codeless and semi-codeless GPS access until at least December 31, 2020. To enable an orderly and systematic transition, users of semi-codeless and codeless receiving equipment are expected to transition to using civil-coded signals by this date.

In May 2008, the US Air Force awarded the development contract for the next generation GPS III satellites. These satellites will improve the overall accuracy, availability, and integrity of the GPS constellation, as well as provide increased anti-jam performance to meet the future needs of civil and military users.

GPS III SVs will introduce new capabilities to meet higher demands of both military and civilian users. It brings the full capability to use M-Code in support of warfighter operations. GPS III nominal M-Code capability exceeds maximum IIF/IIR M-Code capability (flex power without P(Y) Code). It expands international cooperation in the GNSS arena by fielding the L1C signal interoperable with Galileo, Quazi-Zenith Satellite System, and other GNSS systems. GPS III is needed to complete the deployment of L2C and L5 signal capabilities that began with the modernized GPS IIR-M and GPS IIF satellites. Using an incremental approach, new capabilities that require technical maturity or have greater risks of being properly integrated are deferred to later increments, ensuring low risk and high confidence delivery of capabilities (Figure 4-22).

The current operational control segment (OCS) is being upgraded, as it cannot presently support some capabilities of the newer satellites on orbit. The next generation control segment upgrade will support full modernized capabilities for the IIR-M and GPS IIF, and provide the foundation for GPS III. Next Generation Operational Control Segment (OCX) will also support existing and new interfaces, and together with GPS III and modernized Military GPS User Equipment (MGUE), will eliminate or mitigate existing shortfalls in the current GPS architecture.

Key Points:

- GPS is a US-owned utility that provides users with positioning, navigation, and timing (PNT) services. The US Air Force develops, maintains, and operates the space and control segments.
- New GPS signals are phasing in incrementally as the US Air Force launches new GPS satellites to replace older ones. Most of the new signals will be of limited use until they are broadcast from 18 to 24 satellites.
- The US government commits to maintaining the existing GPS L1 C/A, L1 P(Y), L2C and L2 P(Y) signalsuntil at least December 31, 2020.

4.4.2.2 Global Navigation Satellite System (GLONASS)

GLONASS is a radio-based satellite navigation system operated for the Russian government by the Russian Aerospace Defense Forces. It both complements and provides an alternative to GPS and is currently the only alternative navigational system in operation with global coverage and of comparable precision._The GLONASS ground segment consists of a system control center; a network of five telemetry, tracking, and command centers; the central clock; three upload stations; two satellite laser ranging stations; and a network of four monitoring and measuring stations, distributed over the territory of the Russian Federation. Six additional monitoring and measurement stations are to start operating on the territory of the Russian Federation and the Commonwealth of Independent States in the near future.

Current Status

The current generation of satellites, GLONASS-M, were developed beginning in 1990 and first launched in 2003. The aft payload structure houses 12 primary antennas for L-band transmissions. Laser corner-cube reflectors are also carried to aid in precise orbit determination and geodetic research. On-board cesium clocks provide the local clock source. As with the previous generation, the second generation spacecraft were launched in triplets using Proton-K Blok-DM-2 or Proton-K Briz-M boosters. There are currently 30 GLONASS-M satellites and one GLONASS-K in orbit as shown in Figure 4-23.

Figure 4-23

Glonass Current Status

Total satellites in constellation:	31 SC
Operational:	24 SC
In flight tests phase: (GLONASS-K)	1 SC
In commissioning phase:	0 SC
In maintenance:	2 SC
Spares:	4 SC
In decommissioning phase:	0 SC

Source: www.glonass-ianc.rsa.ru

Technical Description

The nominal baseline constellation of GLONASS comprises 24 GLONASS-M satellites uniformly deployed in three roughly circular orbital planes at an inclination of 64.8° to the equator. The altitude of the orbit is 19,100 km. The orbit period of each satellite is 11 hours, 15 minutes, 45 seconds. The orbital planes are separated by 120° right ascension of the ascending node.

Eight satellites are equally spaced in each plane with 45° argument of latitude. Moreover, the orbital planes have an argument of latitude displacement of 15° relative to each other. GLONASS orbital planes and SVs are shown in Figure 4-24.

Figure 4-24

Glonass Constellation

Source: www.spacecorp.ru

The GLONASS orbit makes it especially suited for usage in high latitudes (north or south), where getting a GPS signal can be problematic. A fully operational constellation with global coverage consists of 24 satellites, while 18 satellites are necessary for covering the territory of Russia.

The latest GLONASS-K1 satellites to be launched in 2011–2012 will introduce an additional open CDMA signal for testing purposes, located in the L3 band at 1202.025 MHz. GLONASS-K2 satellites, to be launched in 2013–2015, will relocate the L3 signal to 1207.14 MHz and add an additional open CDMA signal located at 1575.42 MHz in the L1 band; subsequent GLONASS-KM satellites to be launched after 2015 will feature additional open CDMA signals — one on existing L1 frequency, one at 1242 MHz in the L2 band, and one at 1176.45 MHz in the L5 band.

Technical Issues

The GLONASS constellation has coverage problems similar but opposite to those of GPS. Because of the higher inclination angle of the satellites, the coverage of the GLONASS constellation is much better in the northern latitudes. The high inclination which improves performance in the higher latitudes also causes the coverage near the equator to be much worse.

Operational Issues

GLONASS operates using the PZ-90 (Earth Parameters 1990), in which the precise location of the North Pole is given as an average of its position from 1900 to 1905. This is in contrast to the GPS's coordinate datum, WGS-84, which uses the location of the North Pole in 1984. As of September 2007, the PZ-90 datum has been updated to differ from WGS-84 by less than 16 inches in any given direction.

Institutional Issues

Although the format and modulation of GLONASS CDMA signals are not finalized, preliminary developments indicate that the new signals are essentially GPS/Galileo/COMPASS format signals placed at the same frequencies. The open signal in the L1 band will use binary offset carrier (BOC)(1,1) modulation centered at 1575.42 MHz, similar to corresponding modernized GPS signals in L1 band and Galileo/COMPASS signal E1. The open signal in the L5 band will use BOC(4,4) modulation centered at 1176.45 MHz, the same as the GPS safety-of-life (L5) and Galileo signal E5a; the open signal in the L3 band will use QPSK(10) modulation centered at 1207.14 MHz, the same frequency as Galileo/COMPASS signal E5b. This arrangement will allow easier and cheaper implementation of multi-standard GNSS receivers.

Future Trends

GLONASS has a US$11.81 billion budget approved through 2020, by which time the system is scheduled to have 24 satellites transmitting both the new CDMA and legacy FDMA signals.

GLONASS-K is the latest satellite design intended as part of GLONASS. Developed by Reshetnev Information Satellite Systems and first launched in Februay 2011, it is a substantial improvement of the previous GLONASS-M second-generation satellites, having a longer lifespan and better accuracy.

GLONASS-K is the first unpressurized GLONASS satellite—all of its equipment is able to operate in a vacuum. Due to this, the satellite's mass has been substantially reduced: GLONASS-K has a mass of just 750 kg compared to its predecessor GLONASS-M, which had a mass of 1,450 kg. The new satellite has an operational lifetime of ten years, three years longer than that of GLONASS-M and seven years longer than the lifetime of the original GLONASS satellite.

GLONASS-K will transmit additional navigation signals to improve the system's accuracy. Existing FDMA signals, two military and two civilian, will be transmitted on the L1 and L2 bands, and additional civilian CDMA signal will be transmitted in the L1, L2, L3 and L5 bands. The third generation GLONASS-K satellites are expected to double GLONASS' accuracy when fully operational.

Key Points:

- GLONASS is a radio-based satellite navigation system operated for the Russian government by the Russian Aerospace Defense Forces.
- It has a US$11.81 billion budget approved through 2020, by which time the system is scheduled to have 24 satellites transmitting both the new CDMA and legacy FDMA signals.

4.4.2.3 GALILEO

Galileo is Europe's program for a global navigation satellite system, providing a highly accurate, guaranteed global positioning service, interoperable with the US GPS and Russian GLONASS systems. Galileo's modern and efficient design will increase Europe's technological independence and help to set international standards for GNSS. Galileo is being developed in collaboration between the European Union and the European Space Agency (ESA). When operational, it will use two ground operations centers near Munich, Germany and in Fucino, Italy.

The use of basic (low-precision) Galileo services will be free and open to everyone. The high-precision capabilities will be available for paying commercial users and for military use. Galileo is intended to provide horizontal and vertical position measurements within one meter precision and better positioning services at high latitudes than other positioning systems. As a further feature, Galileo will provide a unique global search and rescue (SAR) function. Satellites will be equipped with a transponder which will relay distress signals from the user's transmitter to the Rescue Co-ordination Centre, which will then initiate the rescue operation. At the same time, the system will provide a signal to the users, informing them that their situation has been detected and that help is on the way. This latter feature is new and is considered a major upgrade compared to the existing GPS and GLONASS navigation systems, which do not provide feedback to the user.

Galileo will provide to its users not only a global positioning service, but also the associated integrity information for safety-of-life services. This is an important contribution of Galileo against the GPS or GLONASS systems, where safety-of-life integrity must be provided by augmentation systems. Thanks to integrity, the users are constantly aware of whether transmitted signals can be trusted; receiving timely alert messages in case of failures and data to compute the integrity risk for the decision to start a critical operation.

Current Status

In October 2011, the first two of four operational satellites were launched to validate the system. The first satellites will prove that the space and ground segments meet many of Galileo's requirements and will validate the system's design in advance of completing and launching the rest of the constellation.

The next two are scheduled for launch in 2012. Once this in-orbit validation (IOV) phase has been completed, additional satellites will be launched to reach initial operational capability (IOC) around mid-decade. Full completion of the 30 satellite system (27 operational + 3 active spares) is expected by 2019.

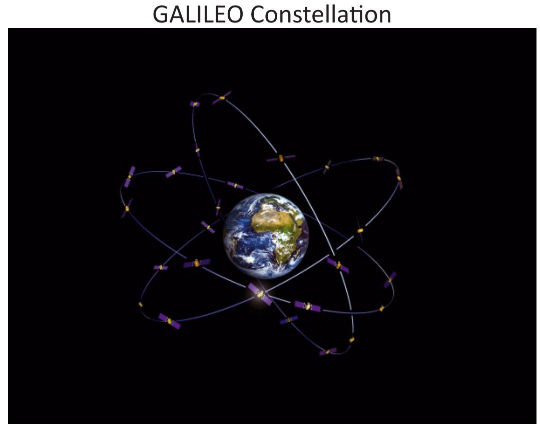
Technical Description

When Galileo is fully operational, there will be 30 satellites in Medium Earth Orbit (MEO) at an altitude of 23,222 km. Ten satellites will occupy each of three orbital planes inclined at an angle of 56° to the equator. The satellites will be spread evenly around each plane and will take about 14 hours to orbit the Earth. One satellite in each plane will be a spare, on stand-by, should any operational satellite fail. The Galileo full infrastructure will be composed of:

- A constellation of 30 satellites in Medium-Earth Orbit (MEO). Each satellite will contain a navigation payload and a search and rescue transponder.
- 30 - 40 sensor stations.
- Three control center.
- Nine mission uplink stations.
- five telemetry, tracking and command (TT&C) stations.

GALILEO orbital planes and SVs are shown in Figure 4-25.

Figure 4-25
GALILEO Constellation

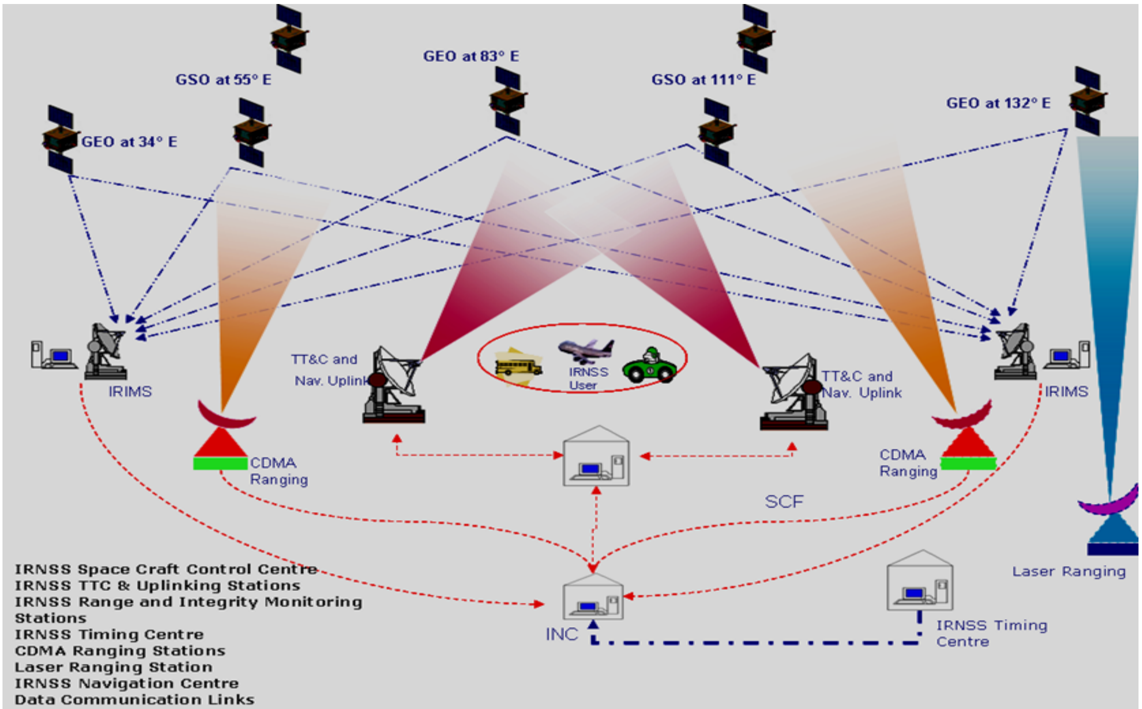


Source: European Space Agency

Operational Issues

Like GPS, Galileo will establish a dedicated terrestrial reference frame, Galileo Terrestrial Reference Frame (GTRF), which will be an independent realization of the international terrestrial reference system ITRS. According to Galileo requirements, the three-dimen-

Figure 4-26
IRNSS Architecture



Source: European Space Agency

sional differences of the position compared to the most recent ITRF should not exceed three cm.

Institutional Issues

In the latest of a series of setbacks for the Galileo navigation satellite project, China is set to claim a frequency that the European Commission wants to use for a security-oriented portion of the service.

In a January 2011 update on Europe's Galileo satellite navigation system, the European Commission suggested that efforts to persuade China to move away from frequencies planned for Galileo's Public Regulated Service (PRS) have gone nowhere. PRS is Galileo's equivalent to the US GPS military code, which is encrypted and reserved for defense and security customers.

China is under no legal or regulatory obligation to steer clear of PRS for its COMPASS/Beidou navigation system, now being deployed, because a signal overlap will not prevent users of either system from accessing their services.

The overlap will make it impossible for China or Europe to jam one another's signals without disabling their own service. This is an issue the US and Europe spent several years negotiating before European authorities agreed to place PRS on a radio frequency some distance from the GPS military code.

Future Trends

The European Parliament and the Council have allocated the management of the Galileo program to the European Commission. The European Commission is in the process of setting up a consultative group of GNSS experts called the Mission Evolution Advisory Group (MEAG). MEAG aims at providing EC with independent advice and recommendations on potential evolutions of the mission objectives and the service definitions for the European satellite navigation programs Galileo and EGNOS.

The group is expected to critically assess changes of both user needs and scope of space-based PNT, both on the European and international scale. Changes in the mission and service requirements for the Galileo and EGNOS program will be analyzed too, proposing suitable updates of the mission and service baseline. MEAG members include experts from GNSS user communities, GNSS industry sectors, academia, national space agencies, and other recognized experts from member states. The MEAG meets on a regular basis with an indicative number of three meetings per year. The expert group may establish on an ad-hoc basis working groups to provide specialist support as required to carry out its activities. The MEAG shall further record and report its work results and recommendations on a yearly basis to the Commission.

Key Points:

- Galileo is Europe's program for a global navigation satellite system, providing a highly accurate, guaranteed global positioning service, interoperable with the US GPS and Russian GLONASS systems.
- In the latest of a series of setbacks for the Galileo navigation satellite project, China is set to claim a frequency that the European Commission wants to use for a security-oriented portion of the service.
- The next two are operational satellites are scheduled for launch in 2012.

4.4.2.4 COMPASS/BeiDou-2

The COMPASS system (also known as Beidou-2, BD2) is a project by China to develop an independent global satellite navigation system. COMPASS is not an extension to the previously deployed Beidou-1, but a new GNSS similar in principle to GPS and Galileo.

According to the construction schedule, COMPASS will, as a first step, cover China and the nearby area in the initial operational phase, and full deployment of the system will be completed between 2015 and 2020.

Current Status

Compass currently has three MEOs, five GEOs, and five inclined geostationary orbit (IGSO) satellites in orbit, although not all of them are currently transmitting healthy signals. One of the GEOs launched in 2009 has not been stabilized and is drifting in orbit.

The current plans call for a fully operational constellation of 35 satellites to be in place by 2020, including five geostationary orbit satellites, 27 MEOs, and three in IGSO. A regional service is planned to begin in 2012 over China and the surrounding region.

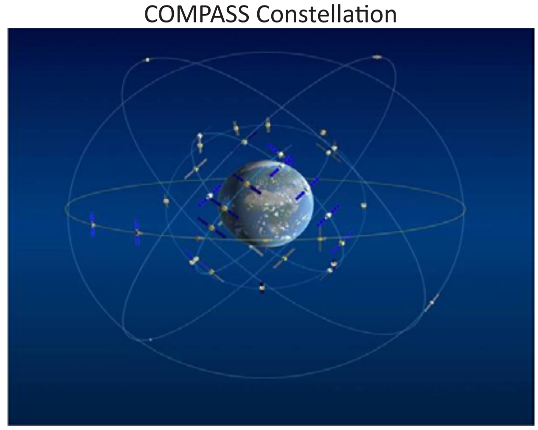
COMPASS can provide two types of service at the global level: open service and authorized service. Through its open service, it provides free positioning, velocity and timing services. Through its authorized service, it provides safer positioning, velocity and timing services, as well as system integrality information, for authorized users.

COMPASS can provide two kinds of authorized services, including a wide-area differential service (with a positioning accuracy of one m) and a short-message communication service in China and nearby areas.

Technical Description

The COMPASS/BeiDou Navigation Satellite System consists of five geostationary satellites and 30 non-geostationary satellites. The geostationary satellites are located at 58.75° E, 80° E, 110.5° E, 140° E and 160° E. COMPASS orbital planes and SVs are shown in Figure 4-27.

Figure 4-27
COMPASS Constellation



Source: European Space Agency

The orbital parameters of COMPASS satellites are given in Figure 4-28. The inclined geosynchronous orbit intersect node is 118° E.

Figure 4-28

COMPASS Orbital Parameters

Orbital Parameters	GEO	IGSO	MEO
Semi-Major Axis (Km)	42,164	42,164	27,878
Eccentricity	0	0	0
Inclination (deg)	0	55	55
RAAN (deg)	158.75E, 180E,210.5E,240, 260E	218E,98E, 338E	--
Argument Perigee	0	0	
Mean anomaly (degrees)	0	218E:0,98E: 120, 338E:240	
Number of Satellites	5	3	27
Orbit Planes	1	3	3

Source: European Space Agency

The frequency bands of COMPASS include:

- B1: 1559.052~1591.788 MHz
- B2: 1166.22~1217.37 MHz
- B3: 1250.618~1286.423 MHz

Operational Issues

Current frequency filings made by China to the ITU indicate that COMPASS will broadcast signals on four frequency bands that will overlap GPS, Galileo, and GLONASS signals. This increases potential benefit for users by increasing interoperability and user performance. However, radio navigation L-bands are already congested, causing concerns of interference. Development of COMPASS needs to be done with respect to existing and future systems, especially Galileo.

Institutional Issues

COMPASS will achieve frequency compatibility with other satellite navigation systems under the ITU framework through bilateral or multilateral coordination. Presently, COMPASS has facilitated coordination meetings with GPS, Galileo, GLONASS, and QZSS.

Future Trends

The COMPASS system is planned to be developed and deployed in three phases:

Phase 1 (2003+): Phase 1 consists of an experimental regional navigation system, BeiDou-1, which provided active navigation service.

Phase 2 (2012+): BeiDou-2 consists of a reduced satellite constellation and provides open service over China. This phase aims at deploying a system with passive positioning and timing capability over a regional area.

Phase 3 (2020+): By 2020, COMPASS would reach full operational capability with a Walker constellation of 27 MEOs plus 5 GEOs and the existing 3 IGSOs satellites of the regional system.

4.4.2.5 GNSS Transitional Issues

GNSS navigation represents a fundamental departure from traditional ground-based navigation systems with respect to aviation operations. Ground-based systems provide services that are limited by location and support point-to-point navigation. GNSS supports area navigation (RNAV) and RNP operations, reducing the need for terrestrial-based navaids. During the transition to GNSS operations, a heterogeneous fleet of aircraft and capabilities will manifest at different rates in different regions. All types of users will need to be accommodated.

Key Points:

- Mixed usage of satellite and ground-based navaids must be accommodated during transition to a single system.
- Interoperability of GNSSs provides additional benefits to users in terms of availability, reliability, and integrity of signal.

4.4.3 Current Regional Satellite Navigation Systems

Regional satellite navigation systems offer additional benefits and capabilities to limited areas or regions. Regional systems are also less costly to implement and maintain compared to constellations designed for global coverage.

4.4.3.1 Indian Regional Navigation Satellite System (IRNSS)

IRNSS will be an independent and autonomous regional navigation system with a service area of about 1,500-2,000 km around India's landmass. The system will be under complete Indian control, with the space segment, ground segment, and all user receivers built in India.

Current Status

The first satellite of the proposed constellation is expected to be launched during 2012-2013, while the full constellation is planned to be realized around 2014.

Technical Description

The nominal baseline of the IRNSS constellation comprises seven satellites, some of which are geostationary. Three satellites will be placed in geostationary orbit, at 34° E, 83° E and 131.5° E, respectively, and two satellites will be placed in geosynchronous orbit with an equator crossing at 55° E and 111.5° E, respectively, with an inclination of 29°. The constellation provides continuous regional coverage for positioning, navigation and timing services. The architecture of the system is shown in Figure 4-26.

The ground segment is responsible for the maintenance and operation of the IRNSS constellation. This segment comprises nine IRNSS telemetry, tracking and command stations, two spacecraft control centers, two IRNSS navigation centers, 17 IRNSS range and integrity monitoring stations, two IRNSS timing centers, six CDMA ranging stations, and two data communication links.

A summary of the signal frequency plan for IRNSS is shown in Figure 4-29.

Figure 4-29

IRNSS Signal Frequency Plan

GNSS System	IRNSS	IRNSS	IRNSS	IRNSS
Service Name	L-band	L-band	L-band	S-band
Centre Frequency [MHz]	1191.795	1191.795	1191.795	2491.75
Frequency Band	L5 A	L5 B	L5 C	S
Access Technique	CDMA	CDMA	CDMA	CDMA
Spreading modulation	BOC(10,2)	BPSK(10)	BPSK(10)	N/A
Sub-carrier frequency	10.23 MHz	-	-	N/A
Code frequency	2.046 MHz	10.23 MHz	10.23 MHz	N/A
Signal Component	Data	Data	Pilot	N/A
Primary PRN Code length	N/A	N/A	N/A	N/A
Code Family	N/A	N/A	N/A	N/A
Secondary PRN Code length	N/A	N/A	N/A	N/A
Data rate	N/A	50 bps /100 sps	N/A	50 bps /100 sps
Minimum Received Power	N/A	N/A	N/A	N/A
Elevation	N/A	N/A	N/A	N/A

Source: European Space Agency

IRNSS will offer two types of services:

- Special positioning service (SPS)
- Precision service (PS)

Both services will be carried on L5 (1176.45 MHz) and S band (2492.08 MHz). The navigation signals would be transmitted in the S-band frequency (2–4 GHz) and broadcast through a phased array antenna to keep required coverage and signal strength.

The data structure for SPS and PS is under study; it is being planned to take advantage of the fact that the number of satellites is reduced, seven instead of the 30 used in other constellations, to broadcast ionospheric corrections for a grid of 80 points to provide service to single frequency users. The clock, ephemeris, and almanac data of the seven IRNSS satellites will be transmitted with the same accuracy as in legacy GPS, GLONASS, and Galileo.

The Indian government approved the project in May 2006, with the intention of completing and implementing the system by 2015. The first satellite of the proposed constellation is expected to be launched in 2012.

4.4.3.2 Quasi-Zenith Satellite System (QZSS)

The Quasi-Zenith Satellite System (QZSS) is a regional navigation satellite system commissioned by the Japanese Government as a National Space Development Program.

QZSS was authorized by the Japanese government in 2002. The system was initially developed by the Advanced Space Business Corporation (ASBC) team, which included Mitsubishi Electric Corp., Hitachi Ltd., and GNSS Technologies, Inc. In 2007, ASBC collapsed, and the work was taken over by the Japan Aerospace Exploration Agency (JAXA) together with the Satellite Positioning Research and Application Center (SPAC).

Current Status

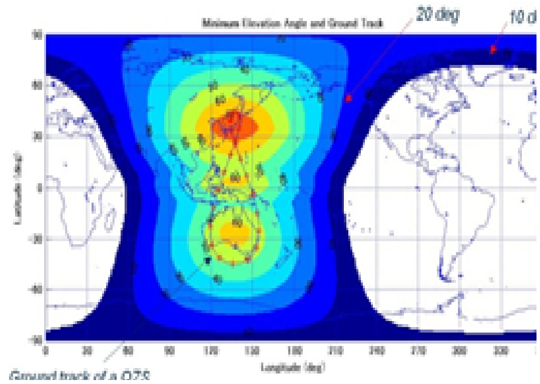
The initial phase operation started in September 2010 with the launch of the first quasi-zenith satellite, Michibiki, and was completed in 2011, with all functions of the satellite and the ground segment confirmed.

During the initial phase, technical verifications and application demonstrations showed that automobile traffic in the Tokyo area received a ten percent improvement in position reporting versus GPS alone.

Technical Description

The space segment will consist of three satellites placed in periodic highly elliptical orbit (HEO). The perigee altitude is about 32,000 km and apogee altitude about 40,000 km, all having the same ground-track. QZSS is designed so that at least one satellite out of three exists near zenith over Japan. Given its orbit, each satellite appears almost overhead most of the time (i.e., more than 12 hours a day with an elevation above 70°). The design life of the quasi-zenith satellites is ten years. The expected coverage area of the full constellation is shown in Figure 4-30.

Figure 4-30
QZSS Coverage Area and Ground Track



Source: European Space Agency

The ground segment is composed of a master control station (MCS), tracking control stations (TT&C), laser ranging stations and monitoring stations. The network of monitoring stations covers the East Asia and Oceania regions, with stations in Japan (Okinawa, Sarobetsu, Koganei, and Ogasawara) and abroad: Bangalore (India), Guam, Canberra (Australia), Bangkok (Thailand), and Hawaii (US). The MSC is responsible for the navigation message generation uplinked to the quasi-zenith satellite via a TT&C station in Okinawa. There are six signals planned for the QZSS system:

L1-C/A (1575.42 MHz): Used by combining with GNSS; increased availability of PNT services.

L1C (1575.42 MHz): Used by combining with GNSS; increased availability of PNT services.

L2C (1227.6 MHz): Used by combining with GNSS; increased availability of PNT services.

L5 (1176.45 MHz): Used by combining with GNSS; increased availability of PNT services.

L1-SAIF (1575.42 MHz): Submeter-class Augmentation; interoperable with GPS-SBAS.

LEX (1278.75 MHz): QZSS experimental signal for high precision (three cm level) service; compatible with Galileo E6 signal.

Further details on planned signals are shown in Figure 4-31.

Figure 4-31

QZSS Planned Signal Frequencies

GNSS System	QZSS	QZSS		QZSS
Service Name	C/A	L1C		SAIF
Centre Frequency	1575.42 MHz	1575.42 MHz		1575.42 MHz
Frequency Band	L1	L1		L1
Access Technique	CDMA	CDMA		CDMA
Spreading modulation	BPSK(1)	BOC(1,1)		BPSK(1)
Sub-carrier frequency	-	1.023 MHz		-
Code frequency	1.023 MHz	1.023 MHz		1.023 MHz
Signal Component	Data	Data	Pilot	Data
Primary PRN Code length	1023	10230		1023
Code Family	Gold Codes	Weil Codes		Gold Codes
Secondary PRN Code length	-	-	1800	-
Data rate	50 bps	50 bps	-	250 bps
Symbol rate	50 sps	100 sps	-	500 sps
Minimum Received Power [dBW]	-158.5	-157		-161
Elevation	5°	5°		5°

Source: European Space Agency

The multi-constellation GNSS interoperable signals (L1 C/A, L2C, L5, and L1C), are to be provided on the basis of no direct user fee. Compatibility is a mandatory requirement for the QZSS system, working in the same frequency bands among the multi GNSS systems without harmful interference. For the GNSS augmentation signals, L1-SAIF and LEX, a charging policy is under examination. SPAC leads the investigation for L1-SAIF (submeter class) and LEX (centimeter class) user terminals.

Compared to stand-alone GPS, the combined system GPS + QZSS will improve positioning performance via correction data provided through submeter-class enhancement signals L1-SAIF and LEX. It will also improve reliability by means of failure monitoring and system health data notifications (Figure 4-32).

Figure 4-32

QZSS Specification Performances

Signal-in-space user range error	Less than 1.6 m (95%), including time and coordination offset error.
Single frequency user positioning accuracy (positioning accuracy combined GPS L1_C/A and QZSS L1_C/A)	21.9 m (95%).
Dual frequency user (L1-L2) positioning accuracy	7.5 m (95%).
L1-SAIF signal users (using WDGPS correction data) positioning accuracy	1m (1 sigma rms) except in cases of large multipath error and large ionospheric disturbance.

Source: European Space Agency

Future Trends

In 2011 the government of Japan decided to accelerate the QZSS deployment in order to reach a four-satellite constellation by late decade, while aiming at a final seven-satellite constellation in the future.

Key Points:

- The Quasi-Zenith Satellite System (QZSS) is a regional navigation satellite system commissioned by the Japanese government as a National Space Development Program.
- In 2011 the government of Japan decided to accelerate the QZSS deployment in order to reach a four-satellite constellation by late decade, while aiming at a final seven-satellite constellation in the future.

4.4.4 Current and Developing Augmentation Systems

An augmentation system is any system that aids a core satellite system by providing accuracy, integrity, availability, or any other improvement to positioning, navigation, and timing that is not inherently part of the satellite system itself. A wide range of different augmentation systems has been developed by both the public and private sectors. The three main types of augmentation systems are satellite, ground and aircraft-based. Each system has different advantages and disadvantages that suit different types of aircraft in various airspaces.

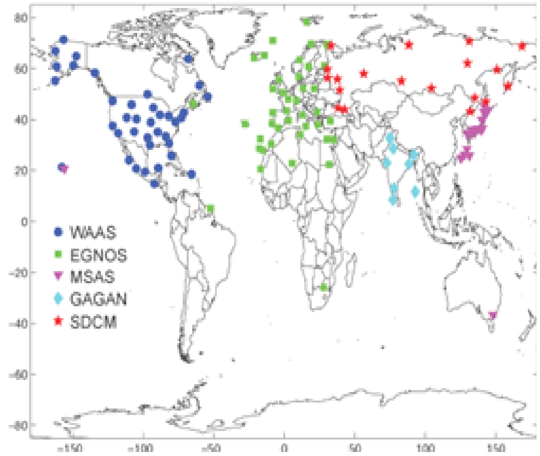
4.4.4.1 Satellite-Based Augmentation System (SBAS)

SBAS is a civil aviation safety-critical system that supports wide-area or regional augmentation — even continental scale — through the use of GEO satellites which broadcast the augmentation information. A SBAS augments primary GNSS constellation(s) by providing GEO ranging, integrity, and correction information. While the main goal of SBAS is to provide integrity assurance, it also capable of increasing accuracy with position errors below one meter.

The ground infrastructure includes accurately-surveyed sensor stations which receive the data from the primary GNSS satellites and a processing facility which computes integrity, corrections, and GEO ranging data forming the SBAS SIS. The SBAS GEO satellites relay the SIS to the SBAS users which determine their position and time information. For this, they use measurements and satellite positions both from the primary GNSS constellation(s) and the SBAS GEO satellites and apply the SBAS correction data and its integrity. Reference stations for the five major SBASs are shown in Figure 4-33.

Figure 4-33

Reference Station Networks of SBASs



Source: GPS World

Wide Area Augmentation System (WAAS)

WAAS provides an augmentation signal to GPS, delivered free of direct user fees, that provides correction and integrity information intended to improve positioning navigation and timing (PNT) service over the US and portions of Canada and Mexico. WAAS is the first operational implementation of an ICAO-compliant SBAS.

Current Status

The WAAS program started in 1992 and is being carried out by the FAA. WAAS was specially designed and developed for the civil aviation community. The system, which was declared operational in late 2003, currently supports thousands of aircraft instrument approaches in more than one thousand airports in USA and Canada.

Technical Description

WAAS works by processing GPS data collected by a network of reference stations to generate the SBAS message which is uploaded to GEO satellites. The GEO satellites broadcast this information to the user receivers, which compute the aircraft positioning and inform on potential alert messages. The WAAS system components are divided into three main segments similar to a GNSS.

The WAAS ground segment is composed of the following:

Thirty-eight widely-spaced wide-area reference stations (WRS): Located in North America (Mexico, Canada, and the US) and Hawaii: the WRS stations collect GPS data.

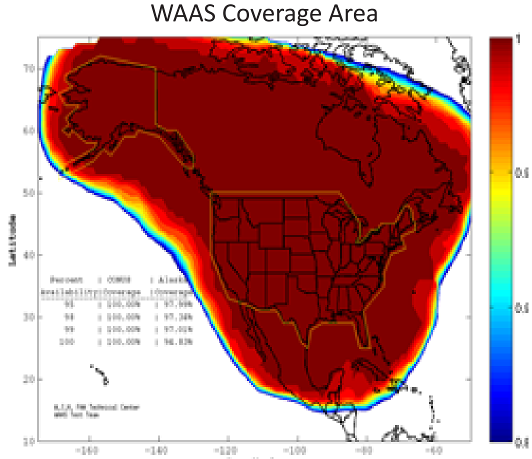
Three WAAS master stations (WMS): The WRS-collected data are forwarded to the WAAS master station (WMS) via a terrestrial communications network. At the WMS, the WAAS augmentation messages are generated.

Ground uplink stations (GUS): GUSs are in charge of the transmission of the WAAS messages generated by WMS stations to the navigation payloads on geostationary communications satellites for rebroadcast to the users.

Two operational control centers (OCC): OCC are used to monitor the system performance and to carry out the necessary corrective and periodic maintenance operations.

The WAAS space segment is currently composed of three GEO satellites in charge of broadcasting the WAAS augmentation message over the WAAS service area. The typical coverage area and availability is shown in Figure 4-34.

Figure 4-34
WAAS Coverage Area



Source: GPS World

The WAAS user segment consists of the GNSS receivers that combine GPS information with the SBAS signal-in-space broadcast by the WAAS GEO satellites. As such, the user segment is not under the control of the WAAS service provider (the FAA), and it is driven by the GNSS application market. Although the prime target of WAAS is the civil aviation user community, most GPS receivers nowadays can be configured to receive and process WAAS SIS, so they can benefit from the enhanced accuracy and/or integrity offered by WAAS.

The WAAS SIS has been designed to minimize standard GPS receiver hardware modifications. Therefore, a WAAS-GPS receiver is like a GPS receiver but with special software inside that allows the receiver to lock onto the code used by the WAAS GEOs satellites and compute the WAAS corrections to the GPS signals. Apart from this, the receiver is just like a GPS receiver.

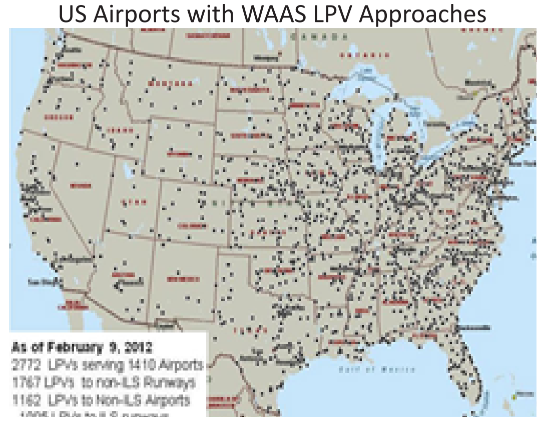
Applications

At present, WAAS supports enroute, terminal and approach operations down to a full LPV-200 (similar to CAT-I) for the WAAS service area. Currently, WAAS supports the following flight procedures:

- LNAV
- LNAV/VNAV
- LP
- LPV

Figure 4-35 shows the airports in the continental US that support WAAS LPV approaches.

Figure 4-35
US Airports with WAAS LPV Approaches



Source: FAA

Future Trends

The WAAS program is continuously in evolution. Two development phases have been already covered; a third is in progress, and there are plans to improve the capability of the system in parallel with the evolution of the SBAS standards towards a dual-frequency augmentation service. The four WAAS development phases are:

- Phase I: Initial operating capability (IOC). Completed in 2003.
- Phase II: Full LPV performance. Completed in 2008.
- Phase III: Full LPV-200 performance. Planned for 2009 - 2013.
- Phase IV: Dual frequency operations. Planned for 2014 - 2028.

For Phase IV, WAAS would operate with dual frequency (L1-L5). This would imply:

- Complete transition to SBAS L1/L5 dual frequency service.
- Provision of the SBAS-L1 single-frequency legacy service until 2028.
- Maintaining a robust, reliable, and sustainable LPV-200 capability.
- High availability performance, with steady operations and smooth maintenance.
- Improved service during severe solar activity.

In November 2011, the FAA approved operations specifications for RNP 0.3 for regional air carrier Horizon Air. This is the first RNP AR using a SBAS platform, more specifically WAAS. The number of operators and airports will increase as developments for approval procedures and potential benefits mature.

European Geostationary Navigation Overlay Service (EGNOS)

EGNOS is the first pan-European satellite navigation system. The EGNOS satellite system is a supplementary system which substantially increases the accuracy and reliability of satellite navigation systems.

EGNOS is a joint project of ESA, the European Commission, and EUROCONTROL. It is Europe's first activity in the field of satellite navigation and is a precursor to Galileo. After the successful completion of its development, ownership of EGNOS was transferred to the European Commission in April 2009. EGNOS operations are now managed by the European Commission through a contract with an operator based in France, the European Satellite Services Provider.

Consisting of three geostationary satellites and a network of ground stations, EGNOS achieves its aim by transmitting a signal containing information on the reliability and accuracy of the positioning signals sent out by GPS. It allows users in the European Civil Aviation Conference (ECAC) Region to determine their position to within 1.5 meters.

Current Status

EGNOS was put into operation in October 2009, and safety-of-life service was officially declared available for aviation in March 2011.

Technical Description

In addition to the three main segments of satellite navigation systems, EGNOS identifies a fourth segment, the support segment. The support segment contains off-line facilities supporting activities such as performance analysis, troubleshooting, maintenance, and qualification.

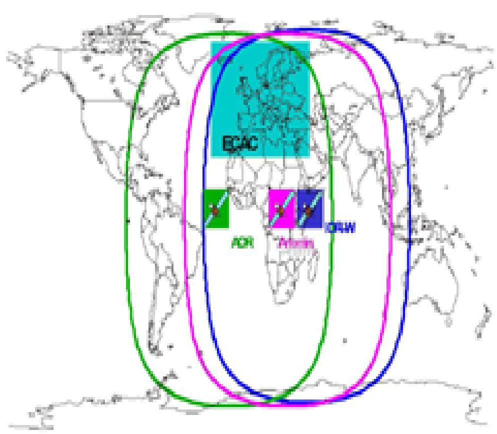
The EGNOS space segment comprises three GEO satellites broadcasting corrections and integrity information for GPS satellites in the L1 frequency band (1575.42 MHz). This configuration provides a high level of redundancy over the whole service area in case of a geostationary satellite link failure. The EGNOS operations are handled in such a way that, at any point in time, typically two of the three GEOs broadcast an operational signal. Since it is only necessary to track a single GEO satellite link to benefit from the EGNOS safety-of-life, this secures a switching capability in case of interruption and ensures a high level of continuity of service.

The three satellites that currently constitute the space segment and their locations are:

- Inmarsat-3 AOR-E (Atlantic Ocean Region East) stationed at 15.5° W.
- Inmarsat-3 IOR-W (Indian Ocean Region West) stationed at 25.0°E.
- ESA-Artemis stationed at 21.5° E.

The EGNOS satellite footprint is shown in Figure 4-36.

Figure 4-36
EGNOS Satellite Footprint



Source: European Space Agency

It is intended that the EGNOS space segment will be replenished over time in order to maintain a similar level of redundancy. The exact orbital location of future satellites may vary, though this will not impact the service offered to users. Similarly, different PRN code numbers may be assigned to future GEOs. However, all SBAS user receivers are designed to automatically detect and use any code in a pre-allocated set reserved for SBAS. Such evolutions will therefore be transparent for end users and will not necessitate any human intervention or change of receiving equipment.

The EGNOS ground segment comprises a network of Ranging Integrity Monitoring Stations (RIMS), four Mission Control Centers (MCC), six Navigation Land Earth Stations (NLES), and the EGNOS Wide Area Network (EWAN). Two additional facilities are also deployed as part of the ground segment to support system operations and service provision, namely the Performance Assessment and Checkout Facility (PACF) and the Application Specific Qualification Facility (ASQF), which are operated by the EGNOS Service Provider (ESSP SAS).

Future Trends

The European Parliament and the Council have assigned the management of the EGNOS program to the European Commission. The European Commission is defining the roadmap for the evolution of the EGNOS mission. This roadmap is expected to cope with legacy and new missions:

- **2011-2030:** Enroute/NPA/APV1/LPV200 service based on augmentation of GPS L1 only. The safety-of-life service offered by EGNOS will be guaranteed up to 2030 in compliance with ICAO SBAS SARPS. In order to grant this timeframe, it is still needed to achieve a programmatic commitment based on secured funds.

- **2020+:** It is planned that EGNOS will experience a major evolution by 2020, EGNOS V3, including the fulfillment of the SBAS L1/L5 standard, expansion to dual-frequency, and evolution toward a multi-constellation concept.

To support this mission roadmap, EGNOS will need to evolve. This evolution is divided into minor updates of the current EGNOS version, EGNOS V2, and a major evolution leading to the provision of new services, EGNOS V3.

The minor evolutions in the current EGNOS version are performed in a regular basis at an approximate pace of one update per year, and aim at solving infrastructure obsolescence issues, at supporting the LPV200 service beyond APV1, and at improving the operation of the system.

The major evolution requires a full dedicated engineering cycle, starting from the definition of the system mission, and highly coupled with a technical feasibility analysis in coordination with the evolution of the SBAS standards.

The European Commission and the European Space Agency are very active in SBAS standardization and interoperability, ensuring the co-ordination of the EGNOS evolution with that of the other SBASs in the world.

Multi-Functional Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS)

MSAS provides GPS augmentation information for the civil aircraft onboard satellite navigation systems under the FUKUOKA flight information region.

MSAS offers three advanced functions. In the event of a GPS failure, the health status of GPS is transmitted via the integrity function of MSAS, while the differential correction function provides ranging error data. MSAS also employs a ranging function to generate GPS-like signals and enable aircraft to use MTSAT as an additional GPS satellite. In order to ensure the reliability of this function, MSAS is monitoring MTSAT/GPS signals, ranging for determinate MTSAT satellite orbit and estimating ionospheric delay on a 24-hour-a-day, seven-day-a-week basis.

Current Status

MTSAT-1R was successfully put into orbit in February 2005 and MTSAT-2 in February 2006. The satellites have a planned lifespan of five years. MTSAT-1R and MTSAT-2 are respectively controlled by Kobe MCS and Hitachiota MCS.

MSAS was declared operational for aviation use in September 2007.

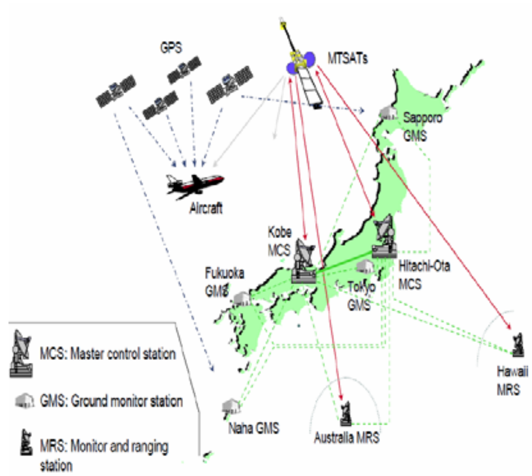
Technical Description

MSAS provides navigation services for all aircraft within Japanese airspace via two geostationary satellites: MTSAT-1R, which is at 140°E, and MTSAT-2, which is at 145°E.

MSAS consists of two geostationary satellites and a ground network made up of two master control stations (one at Kobe and one at Hitachioota), two monitoring and ranging stations (one in Australia and one in Hawaii), and four ground-monitoring stations (at Sapporo, Tokyo, Fukuoka and Naha).

The master control stations generate augmentation information based on the GPS and MTSAT signals received at the ground-monitoring stations and the monitoring and ranging stations. The ground-monitoring stations monitor GPS satellite signals and transfer the information to the monitoring and ranging stations which monitor the MTSAT orbits. They also have the GMS function and transfer the information to the monitoring and ranging stations. An overview of the MSAS architecture is shown in Figure 4-37.

Figure 4-37
MSAS Architecture



Source: Japan Aerospace Exploration Agency

MSAS navigation signals transmit from the L1 C/A satellites at a center frequency of 1575.42 MHz and are compliant with ICAO SARPs. Figure 4-38 provides greater detail on current MSAS signals.

Figure 4-38

MSAS Signal Characteristics

Parameter (units)	L1 C/A
Carrier frequency (MHz)	1575.42
PRN code chip rate (Mcps)	1.023
Navigation data bit/symbol rates (bps/sps)	250/500
Signal modulation method	BPSK(1)
Polarization	RHCP
Minimum received power level at input of antenna (dBW)	–161.0
Frequency bandwidth (MHz)	2.2

Source: Japan Aerospace Exploration Agency

Future Trends

MSAS is planning to expand bandwidths for L1 and L5. This implementation is under study, in accordance with the improvement schedule for the Wide-area Augmentation System of the US. Future improvements in MSAS are aligned with achieving compatibility and interoperability between the different SBAS and GNSS constellations.

GPS- Aided Geo-Augmented Navigation (GAGAN)

GAGAN is an SBAS implementation by the Indian government. In August 2001, the Airports Authority of India and the Indian Space Research Organization (ISRO) reached an agreement for the establishment of the GAGAN system.

Figure 4-39

Augmentation Applications

Augmentation element/operation	Oceanic enroute	Continental enroute	Terminal	Instrument approach and landing*
Core satellite constellation with ABAS	Suitable for navigation when fault detection and exclusion (FDE) is available. Pre-flight FDE prediction might be required.	Suitable for navigation when receiver autonomous integrity monitoring (RAIM) or another navigation source is usable.	Suitable for navigation when RAIM or another navigation source is usable.	Suitable for non-precision approach (NPA) when RAIM is available and another navigation source is usable at the alternate aerodrome.
Core satellite constellation with SBAS	Suitable for navigation.	Suitable for navigation.	Suitable for navigation.	Suitable for NPA and APV, depending on SBAS performance.
Core satellite constellation with GBAS	N/A	GBAS positioning service output may be used as an input source for approved navigation systems.	GBAS positioning service output may be used as an input source for approved navigation systems.	Suitable for NPA and precision approach (PA) Category I (potentially Category II and Category III).

* Specific aerodrome infrastructure elements and physical characteristics are required to support the visual segment of the instrument approach. These are defined in ICAO Annex 14 - Aerodromes and Aerodrome Design Manual (Doc 9157).

Source: FAA

GAGAN is planned for full operation by 2014. It will be able to help pilots navigate in Indian airspace with an accuracy of three meters. The first GAGAN transmitter was integrated into the GSAT-4 geostationary satellite and had a goal of being operational in 2008. Following a series of delays, GSAT-4 was launched in April 2010. However, it failed to reach orbit due to a launch vehicle malfunction.

Current Status

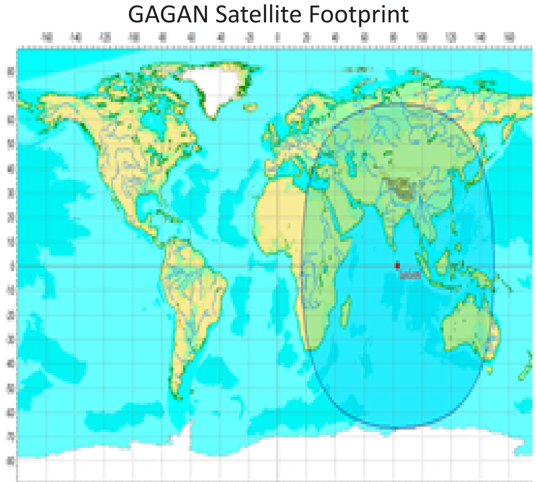
The space segment will consist of three operational GEO satellites. The first GAGAN transmitter to successfully reach orbit was aboard the GSAT-8 satellite, launched in March 2011. The other two are expected to be launched in the 2012-2014 timeframe.

Technical Description

GSAT-8 is currently in geosynchronous orbit located at 55° E. The two remaining GAGAN payloads will be launched on GSAT-9 and GSAT-10 communication satellites. GAGAN's proposed satellite footprint is shown in Figure 4-40.

Figure 4-40

GAGAN Satellite Footprint



Source: Indian Space Research Organization

The ground segment involves establishment of 15 Indian reference stations (INRES), three Indian navigation land uplink stations (INLUS), three Indian Mission Control Centers (INMCC), and installation of all associated software and communication links. The SBAS message generated by the INMCC is uplinked to the GEO satellite through its corresponding (INLUS).

Operational Issues

One of the main concerns about an SBAS implementation in India is the ionospheric behavior at these latitudes, as India is located in the equatorial ionospheric anomaly belt. The ionosphere near the geomagnetic equator has physical processes and features that rarely affect mid-latitudes. These include the Appleton geomagnetic anomaly, plasma bubbles, and scintillations.

Free from adverse ionospheric effects, current SBAS in the mid-magnetic latitudes provides vertical guidance for the single frequency users. The ionosphere equatorial anomaly and the ionospheric phenomena typically found at equatorial latitudes produce large spatial gradients and temporal gradients in the ionospheric delay. This significantly challenges SBAS to meet the stringent requirements associated with precision guidance. The macroscopic effects (equatorial anomaly) are not well approximated with the 5 x 5 degree grid thin-shell model specified in the current SBAS standards. Also, the microscopic phenomena (plasma bubbles) cause sharp gradients during a short period of time (less than five minutes). If these small scale features are not observed or alerted by the SBAS system, it would be difficult to ensure integrity compatible with the precision approach alert limits. Finally, the user equipment and the reference stations of the SBAS system might suffer from tracking and noise problems because of scintillation, which is a particularly likely problem in equatorial latitudes depending on the season and time of day. All these problems are under study by several groups. Different approaches for a SBAS implementation in equatorial magnetic regions have been presented.

Future Trends

After FOC is achieved, GAGAN will be compatible with other major SBAS systems to provide seamless air navigation service across regional boundaries.

One essential component of the GAGAN project is the study of the ionospheric behavior over the Indian region. Continued study will lead to the optimization of the algorithms for ionospheric corrections in the region, offering users continuous and reliable coverage. Recent studies have suggested the use of additional ground reference stations in the region.

System for Differential Correction and Monitoring (SDCM)

GLONASS is being further improved with a satellite-based augmentation system. SDCM will use a ground network of monitoring stations and Luch geostationary communication satellites to transmit correction and integrity data. This enables the global integrity monitoring of radio navigation signals of both GLONASS and GPS satellites, gathering raw measurements of pseudorange and carrier phase in L1, L2, and L3/L5 bands. Based on these measurements, the SDCM central processing facility calculates orbits and clock corrections, and formulates SBAS messages.

Current Status

SDCM development is now entering its deployment and completion phase. The nework of reference stations is almost completely established.

SDCM will use transponders on the Luch Multifunctional Space Relay System geostationary communication satellites to transmit correction and integrity data using the GPS L1 frequency. The first of these satellites, Luch-5A, was launched in 12/2011. Luch-5A recently began transmitting GPS corrections on the L1 signal after completing a test phase.

Technical Description

Raw measurements (GLONASS and GPS L1 and L2 pseudorange and carrier-phase measurements) from the ground stations will be communicated to the SDCM CPF. The CPF calculates the precise satellite ephemerides and clocks, controls integrity, and generates the SBAS messages. The format of these messages is compliant with the international standard also used by WAAS, EGNOS, and MSAS.

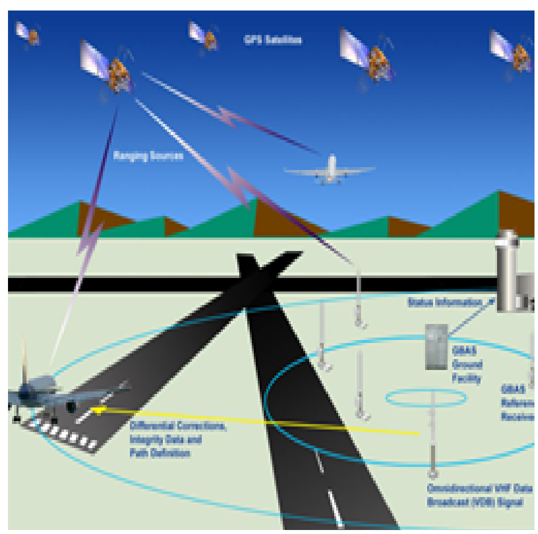
Future Trends

Further SDCM development is predicated upon the launch of two Luch satellites, planned in 2012 and in 2013, respectively. Also in the plans is the design of a new Luch-4 satellite with dual-frequency navigation transponder for a 2014 launch, completing the SBAS.

4.4.4.2 Ground Based Augmentation System (GBAS)

GBAS is a civil-aviation safety-critical system that supports local augmentation at the airport level of the primary GNSS constellation(s) by providing enhanced levels of service that support all phases of approach, landing, departure, and surface operations. While the main goal of GBAS is to provide integrity assurance, it also increases the accuracy with position errors below one meter. GBAS is intended to primarily support precision approach operations. Typical GBAS architecture is shown in Figure 4-41.

Figure 4-41
GBAS Architecture



Source: FAA

Local Area Augmentation System

The US version of GBAS has traditionally been referred to as the Local Area Augmentation System (LAAS). The worldwide community has adopted GBAS as the official term for this type of navigation system. To coincide with international terminology, the FAA is also adopting the term GBAS to be consistent with the international community. GBAS is a ground-based augmentation to GPS that focuses its service on the airport area (approximately a 20-30 mile radius) for precision approach, departure procedures, and terminal area operations. It broadcasts its correction message via a very high frequency (VHF) radio datalink from a ground-based transmitter. GBAS will yield the extremely high accuracy, availability, and integrity necessary for Category I, II, and III precision approaches, and will provide the ability for flexible, curved approach paths. GBAS demonstrated accuracy is less than one meter in both the horizontal and vertical axis.

4.4.4.3 Aircraft-Based Augmentation System (ABAS)

In the early 1990s, many aircraft operators were quick to adopt GNSS because of the availability of GPS receivers. Operators used these early receivers as an aid to VFR and IFR navigation. They quickly saw the benefits of having global RNAV capability, and demanded avionics that could be used for IFR navigation.

The civil aviation community imposes stringent requirements on the levels of precision, integrity, continuity of service, and availability provided by GNSS. One of the most essential aspects relies on integrity and its impact on safety, the major driver in civil aviation. Integrity in GNSS is the capability of providing timely warnings to the user when the service should not be used. These drivers have pushed the GNSS community to look for solutions that could guarantee integrity in the civil aviation domain.

ABASs augment and/or integrate GNSS information with information available on-board the aircraft to enhance the performance of the core satellite constellations.

RAIM

The most common ABAS technique is called receiver autonomous integrity monitoring (RAIM). RAIM requires redundant satellite range measurements to detect faulty signals and alert the pilot. The requirement for redundant signals means that navigation guidance with integrity provided by RAIM may not be available 100 percent of the time. RAIM availability depends on the type of operation; it is lower for non-precision approach than for terminal, and lower for terminal than for enroute. It is for this reason that GPS/RAIM approvals usually have operational restrictions.

RAIM algorithms require a minimum of five visible satellites in order to perform fault detection and detect the presence of an unacceptably large position error for a given mode of flight. FDE uses a minimum of six satellites not only to detect a faulty satellite but also to exclude it from the navigation solution so that the navigation function can continue without interruption.

A barometric altimeter may be used as an additional measurement so that the number of ranging sources required for RAIM and FDE can be reduced by one. Baro aiding can also help to increase availability when there are enough visible satellites, but their geometry is not adequate to perform integrity function. Basic GNSS receivers require the use of baro-aiding for non-precision approach operations.

Some states have approved the use of GPS as the only navigation service in oceanic and remote areas. In this case, avionics should not only have the ability to detect a faulty satellite (through RAIM), but it should also exclude that satellite and continue to provide guidance.

This feature is called fault detection and exclusion (FDE). Under such approval, aircraft carry dual systems, and operators perform pre-flight predictions to ensure that there will be enough satellites in view to support the planned flight. This provides operators with a cost-effective alternative to inertial navigation systems in oceanic and remote airspace.

INS

Another ABAS technique involves integration of GNSS with other airborne sensors such as inertial navigation systems (INS). Aircraft with existing INSs have used another ABAS technique which involves the integration of GNSS with the inertial data. The combination of GNSS fault detection (FD), or FDE, along with the short-term accuracy of modern inertial navigation systems, provides enhanced availability of GNSS integrity for all phases of flight.

A summary of the ABAS, SBAS and GBAS and their applicability to different operational phases are shown in Figure 4-39.

4.4.5 Terrestrial-Based Precision Navigation, Approach, and Landing Systems

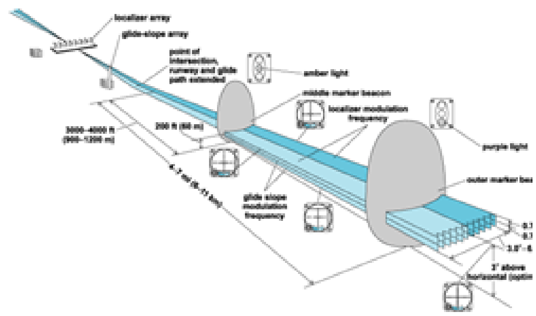
4.4.5.1 Instrument Landing System (ILS)

ILS is one of the current ICAO standard precision approach systems that has served the aviation community for over 60 years. ILS is designed to provide lateral and vertical guidance for approaching aircraft. ILS ground systems and avionics have continually evolved since initial inception, resulting in increased safety and improved airport access. Current ILS CAT III provides capabilities for aircraft to land under conditions with practically no visibility from the cockpit. Using such a precise system for approach does have drawbacks, reducing airport capacity due to increased separation between aircraft in order to reduce signal interferences.

The ILS generates a fixed localizer and glideslope angle that provides the pilot with lateral and vertical guidance and navigation information. Outer, inner, and middle marker beacons, indicating three discrete distances from the intended touchdown point, are either backed up or replaced, in most instances by distance measuring equipment (DME). Guidance signals are specified in angular terms with an average angular error of 0.05 degrees, such that absolute positioning error decreases as the aircraft approaches its touchdown point. Figure 4-42 shows a typical ILS installation.

Overall system accuracy parameters are specified by ICAO Annex 10, Volume 1.

Figure 4-42
ILS Glideslope



Source: FAA

As currently configured, the ILS can satisfy technical RNP performance parameters for accuracy, integrity, availability, and continuity for straight-in approaches. However, due to complex siting requirements and increasing pressure from other nearby users of the same frequency spectrum, the installation of ILS CAT II and III ground systems has proven difficult in certain locations. Siting requirements mandate the use of large flat surfaces at the end of the runway and large protection areas surrounding the airport property to avoid system performance degradation. Many of these difficulties have been documented in ICAO Annex 10, Attachment C, All Weather Operations Panel (AWOP) papers, and other international and national forums.

System Limitations

ILS has several limitations which undermine its future viability as the international standard for precision approach and landing systems. A primary issue is the availability of transmission frequencies. Channel limitation exists because too many transmitters are confined to a geographical area, and high-powered frequency modulation

(FM) broadcasts interfere with the adjacent low-power localize band.

The ILS signals can suffer interference from static and mobile sources in the transmission area. The growth in air travel since the 1970s has seen significant increase of airport aircraft movements and many building constructions around the airports. Hence, protection of the signal becomes more and more difficult. Furthermore, the ILS uses radio frequencies close to the FM radio stations, and the growth of these commercial enterprises puts pressure on the aviation industry.

Sustainability Issues

Currently, ILS generally operates very successfully in support of low visibility operations ranging from CAT I to CAT IIIb. However, in considering policy for future all-weather operations, it is necessary to predict what the situation will be in ten or fifteen years' time. This section is intended to identify the currently perceived threats to ILS, and to draw some preliminary conclusions concerning its capability for sustainment in the future.

The main factors that have been identified in determining the future sustainability of ILS operations are: multipath interference; radio interference, particularly from frequency modulation (FM) broadcast stations; and frequency congestion. Replacement planning of ILS facilities is also a factor in determining sustainability since many airport service providers have planned for the replacement of ILS with GNSS and augmentation systems. ILS systems will continue to operate into the foreseeable future as a redundant system as the new GNSS-based approaches are tested and verified.

It should be noted that some problems with ILS which were previously considered, while important, have not been discussed here. One example is the citing difficulties with ILS glide paths which depend on the terrain in front of the glide path antennas. Another example is the difficulties resulting from the glide path signal generation principle which requires costly and frequent flight checks, highly qualified personnel, and the protection of large critical and sensitive areas during low visibility operations. In general, it has been possible to provide glide path installations which meet the required category of performance through development of new glide path antenna designs for sites with poor terrain and environmental characteristics.

Multipath

The problem of multipath interference is well known and has been recognized since the early days of ILS. Both localizer and glide path systems may be affected. The effects of multipath may be classified in two main types:

Static multipath: Caused by large buildings such as hangers in the vicinity of the runway.

Dynamic multipath: Caused by aircraft taxiing close to the runway and glide path antenna or overflying the localizer antenna.

ICAO Annex 10 standards and SARPs delineate very tight tolerances on the ILS signal structure, particularly for Category III guidance down to and along the runway. Since specifications must be met for a combination of both static and dynamic multipath sources, it is necessary to affix tight tolerances on the allowable bends from both sources. Thus, in considering the effects of static multipath from proposed new development, it is always necessary to make some allowance for dynamic multipath.

Static Multipath

Clearly, the main mechanism available to prevent static multipath is to limit building development. In most states, mechanisms exist for airport operations to be notified of proposed developments, which are assessed for their potential impact on ILS using computer simulation and/or engineering techniques. Potential problems are then addressed either by modification to the original proposal, changes to the ILS facility or, in extreme cases, by objecting to the proposal. The extent to which ILS engineers can influence proposed development, however, varies from state to state.

Although static multipath problems mainly affect localizer performance, there have been a number of examples where the glide path performance has been of concern. At some airports, the glide path installation is close to the airport boundary, resulting in constraints on proposed developments, with the possibility of legal action by the developer. There are numerous examples of glides paths with special set-ups required to maintain the category of operation. As a specific example, the glide path antennas sometimes have to be turned towards the runway centerline to avoid illuminating adjacent hangars.

Dynamic Multipath

Dynamic multipath is caused by reflections from aircraft taxiing close to the runway or overflying the localizer, contaminating the signal. Protection against such interference is provided by procedural control of the ILS sensitive areas during low visibility operations. This is effective in ensuring the safety of operations but with the penalty of limiting the movement rate. For example, at one major airport the movement rate in good visibility is thirty-nine landings per hour, but falls to fifteen landings per hour when ILS-sensitive areas are protected. Clearly the need to protect ILS-sensitive areas is not the only constraint in low visibility conditions, but it is currently the major constraint. The disruption to operations becomes less acceptable as airport capacity is greatly reduced in low visibility conditions, while the demands of the suitably equipped operator remain the same.

Another safety concern is the use of autoland operations in good visibility without the ILS-sensitive area protection being in place. Pilots are warned that when carrying out autolands in conditions not requiring the introduction of low visibility procedures, they should closely monitor the path of the aircraft and be prepared to disconnect the autopilot if excessive disturbances occur during the approach. Nevertheless, a number of serious incidents have occurred during automatic landings in good visibility.

FM Broadcast

The extension to 108 MHz of the frequency band allocated to broadcasting in Europe resulted in the broad alignment of the radio regulations governing the use of this band in all three International Telecommunications Union (ITU) regions. As a consequence of this decision, studies and tests were carried out to determine the extent of any conflict between these services and the aeronautical services operating in the adjacent bands 108-137 MHz (ILS, VHF, VOR, and communications services).

It was established that under certain conditions the performance of airborne receivers could be degraded. The impact on ILS receivers was of particular concern, and it was found that interference could be caused by two main mechanisms:

Spurious emissions from the broadcast transmitter which could not be discriminated from wanted signals.

High level broadcast signals causing intermodulation and desensitization within the receiver.

Two points in particular should be noted. First, compatibility between FM broadcasting and aviation can only ever be achieved now and in the future by means of coordinated frequency planning between FM broadcast and aviation services. Second, at the time these problems were raised, the ILS/MLS transition date of January 1, 1998 had already been established, and it was expected, both by the broadcasters and by the aviation experts, that ILS would be withdrawn by the year 2000. The incompatibility between FM broadcasting and ILS was therefore considered to be a temporary problem. Because of failures in the implementation of MLS, the problem has now become more serious.

The introduction of new, digitally or partly digitally modulated broadcast signals in the band 87.5 to 108 MHz is going on. While the compatibility of analog FM-modulated broadcast signals in this band with aeronautical systems above 108 MHz is already well specified (ITU-R recommendations SM.1009-1 and IS.1140), there is a need to amend these recommendations to also cover the new broadcast signal types.

The VHF FM broadcast interference thresholds for analog aeronautical radio navigation receivers are defined in ITU-R Recommendations SM.1009-1. According to this recommendation, the maximum allowable error in the course display for VOR is 0.5°. For ILS (respectively, the ILS component of the tested combined VOR/ILS receiver), the maximum tolerable course error is defined as 7.5 µA in the analog course indicator display measured at a deflection 90 µA, corresponding to 0.093 DDM. (For comparison, the full-scale deflection is 150 µA).

Although a great deal of effort has been made within the ITU Task Group and by some individual states to resolve the problems, it must be realized that there is an inherent incompatibility between the relatively high power broadcasting services operating in a frequency band immediately adjacent to a low-power safety service. If ILS is to be retained, incompatibility with broadcasting services will need to be mitigated, and the mechanism for coordination between aviation and the broadcasting community will need to be continued.

Frequency Congestion

To date, it has been possible to find frequency assignments to meet ILS requirements. There is, however, now little scope for expansion in the most congested areas, especially in Europe. In addition, because of the interlocked nature of the ILS, DME, and FM broadcast frequency plans, it would be very difficult to find alternative ILS frequencies in some areas if cases of interference were reported at specific locations.

Replacement Planning

Many of the ILS systems currently in use were installed in the 1980s, or earlier, with a planned life of fifteen to twenty years. The expectation was that these systems would be replaced by MLS by the year 2000, and could then be withdrawn. If the decision is made to sustain ILS as a backup system after the transition to satellite and ground-based augmentation systems for precision approach procedures, it is certain that many airports will need to replace or service their older ILS facilities.

Current Research

Since there is little opportunity to improve the multipath performance of ILS, the main focus of R&D efforts on this topic is radio interference. Current Category III ground systems have already been optimized to minimize multipath interference, for example, by the use of wide aperture localizer antennas and two frequency clearances. There is little further development possible. Computer simulation is already available to assess the effects of proposed developments.

Future Trends and Conclusions

It may not be possible to maintain and fully protect the existing ILS services in some areas, although in the majority of other countries there are no difficulties foreseen in this regard. The attractiveness of ILS lies in the economy of its avionics costs and its wide international acceptance. The FAA continues to support (ground-based) ILS and will continue to procure and deploy new and replacement ILS for the foreseeable future. It is expected that ILS (ground-based) will be eventually replaced with some type of GPS landing system (GLS). The FAA currently operates more than 1,200 ILS systems, of which approximately 100 are CAT II or CAT III systems. In addition, the US Department of Defense (DOD) operates approximately 160 ILS facilities in the US.

As GPS-based augmentation systems are accepted and integrated into the navigation repository and user equipage and acceptance grows, the number of CAT I ILS may be reduced. The FAA does not anticipate phasing out any CAT II or III ILS systems until GBAS is able to deliver equivalent service and GPS vulnerability concerns are addressed. A reduction in the number of CAT II/III ILS may then be considered.

Current procedures to protect Category II/III ILS services from multipath interference during low visibility conditions must be maintained with their consequential adverse effect on movement rates in low visibility conditions until a new system with adequate reliability is adopted as the industry standard.

There is a continuing risk of interference to ILS operations from FM broadcasting. This risk will vary from country to country. Despite receiver immunity standards, compatibility between ILS and FM broadcasting depends on the international community undertaking and continuing to meet ICAO standards.

4.4.5.2 Microwave Landing System (MLS)

MLS is an all-weather, precision landing system originally intended to replace or supplement the ILS. MLS has a number of operational advantages, including a wide selection of channels to avoid interference with other nearby airports, excellent performance in all weather, and a small footprint at airports.

MLS consists of various subsystem transmitters that supply elevation, azimuth, and distance-to-threshold information. In addition, all MLS sites can provide supporting data via datalink, and certain MLS sites will provide departure or missed-approach guidance, or both. These subsystems transmit on two separate frequencies; one for angle (azimuth and elevation) guidance and data function, while the other provides distance-to-threshold information. MLS subsystems include:

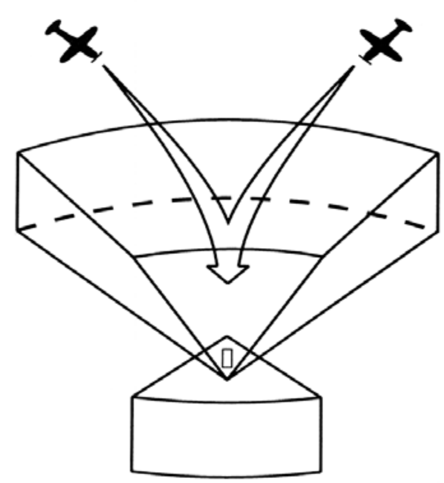
- Azimuth transmitter for approach azimuth guidance.
- Elevation transmitter for elevation guidance.
- Back azimuth transmitter for departure and missed approach.
- MLS datalink transmitter for supporting data.
- Precision DME (DME/P) transponder for distance data.

The azimuth station transmits MLS angle and data on one of 200 channels within the frequency range of 5031 to 5091 MHz. The equipment is normally located about 1,000 feet beyond the stop end of the runway, but there is considerable flexibility in selecting sites. The azimuth coverage, depicted in Figure 4-43, extends:

- Laterally, at least 40 degrees on either side of the runway centerline in a standard configuration.
- In elevation, up to an angle of 15 degrees and to at least 20,000 feet.
- In range, to at least 20 NM.

The back azimuth feature provides missed approach and departure guidance in a similar fashion. Unlike the ILS, MLS provides the capability to perform curved approaches within its service volume, which was a key operational requirement as defined by ICAO in 1972. MLS generally does not experience the frequency congestion and interference problems that are common with the ILS due to its higher transmission frequency which is protected via ITU and national regulations.

Figure 4-43
MLS Azimuth Coverage



Source: EUROCONTROL

Status

Although some MLS systems became operational in the 1990s, the widespread deployment initially envisioned by its designers never became a reality. GPS-based systems, notably GBAS, allowed the expectation of the same level of positioning detail with no equipment needed at the airport. GPS and GBAS dramatically lower the cost of implementing precision landing approaches, and since its introduction most existing MLS systems in North America have been turned off.

Sustainability Issues

Hardly any progress has been made with actual MLS implementation for regular air carrier operations. Despite some early encouraging results of cost/benefit studies for specific locations and scenarios, concerns were raised about the economic viability of MLS as a global replacement for ILS. The only remaining use for MLS may be the potential for seldom-needed CAT III autoland approaches performed by the major airlines at a handful of international hub airports.

The first microwave landing system (MLS) in the world to be approved for low visibility operations became operational at Heathrow Airport in 2009. British Airways supported the installation of MLS in order to sustain airport capacity during times of bad weather, particularly heavy fog.

Future Trends

The FAA and the rest of the civil aviation community are investigating potential aeronautical applications of the 5000 – 5150 MHz C-band for implementation because it is estimated by many that portions of this band will not be needed for future MLS assignments. These include:

- An extension of the tuning range of the Terminal Doppler Weather Radar (TDWR) in order to relieve spectral congestion within its present limited operating band.
- Weather functions of the planned multipurpose primary terminal radar that will become operational around the year 2013.
- An airport local area network, called AeroMACS, a surface network for communications at airports between ground-based and aircraft systems on the ground. It supports short range communications and location functions on the ground at airports. AeroMACS plans to use the 5000-5030 MHz and the 5091-5150 MHz C-bands.
- Future Unmanned Aircraft System (UAS) functions to be implemented in the 5030-5091 MHz C-band.
- The 5091-5150 MHz C-band is used for transmitting flight test telemetry data from aircraft to ground.

Key Points:

- An SBAS augments primary GNSS constellation(s) by providing GEO ranging, integrity, and correction information. While the main goal of SBAS is to provide integrity assurance, it also capable of increasing accuracy with position errors below one meter.
- ILS has several limitations which undermine its future viability as the international standard for precision approach and landing systems. A primary issue is the availability of transmission frequencies.
- MLS is an all-weather, precision landing system originally intended to replace or supplement ILS. MLS has a number of operational advantages, including a wide selection of channels to avoid interference with other nearby airports, excellent performance in all weather, and a small footprint at airports.

4.4.6 Terrestrial-Based Non-Precision Navigation, Approach, and Landing Systems

4.4.6.1 VOR/DME/TACAN

The VHF Omnidirectional Range System (VOR)/Distance Measuring Equipment (DME)/Tactical Air Navigation (TACAN) system is a short distance air navigation system. Historically, VOR, DME, and TACAN have comprised the basic infrastructure for aviation enroute and terminal navigation, and non-precision approaches. The ground components provide properly equipped aircraft with bearing, identification, and distance information referenced to the selected ground component.

VOR was developed between 1938 and 1945 by the US Civil Aeronautics Administration at the Technical Development Center in Indianapolis. VOR provides aircraft with azimuth information and ground-to-air communications. DME provides distance information. TACAN provides azimuth information primarily to military users and distance information to civil and military users. VOR/DME (or VORTAC with integrated military TACAN facilities) coverage is line-of-sight with rated ranges to 130 NM, although 200-mile operation is achieved at altitudes over 20,000 feet. Aircraft are guided to and from each VOR/TACAN ground facility, and the DME portion of the system is rated for operation of up to 100 aircraft.

The FAA operates more than 1,000 VOR, VOR/DME, and VORTAC stations. The DOD operates approximately 50 stations, located predominately on military installations in the US and overseas, which are available to all users.

4.4.6.2 VOR

VORs are assigned frequencies in the 108 to 118 MHz frequency band, separated by 100 kHz. A VOR transmits two 30 kHz modulations resulting in a relative electrical phase angle equal to the azimuth angle of the receiving aircraft. A cardioid field pattern is produced in the horizontal plane and rotates at 30 Hz. A non-directional (circular) 30 Hz pattern is also transmitted during the same time in all directions and is called the reference phase signal. The variable phase pattern changes phase in direct relationship to azimuth. The reference phase is frequency modulated while the variable phase is amplitude modulated. The receiver detects these two signals and computes the azimuth from the relative phase difference. For difficult siting situations, a system using the Doppler effect was developed and uses 50 instead of four antennas for the variable phase. The same avionics works with either type ground station.

Status

The current VOR services will be maintained at their current level to enable aviation users to equip their aircraft with satellite navigation avionics and to become familiar with the system. There is an FAA effort underway enabling a reduction in the VOR population, which will reduce VOR services by discontinuing facilities no longer needed.

VOR Error Sources

Multi-path induced errors in the azimuth subsystem caused by reflections off buildings and objects near the VOR have always limited its application, even with improved Doppler VOR. Vertical polarization of the VOR signal has also been a major cause of azimuth error. The VOR antenna array radiates mainly horizontally polarized energy, but small currents induced on the surface of the vertical pedestals supporting the sideband loops produce VOR indications which are at quadrature with the true bearing information. The small errors caused by this radiation are called vertical polarization errors. Aircraft receive the primary horizontally polarized wave, and when heading or attitude is changed, the ratio of vertically to horizontally polarized signal level changes, producing erroneous and time varying course indications.

Large numbers of VOR/TACAN/DME systems (usually located at airports) have also contributed to frequency congestion by limiting available voice frequencies for air traffic control use and for operation of the ILS system, which also uses the same frequency.

Future Trends

VOR services will be gradually discontinued in accordance with airway planning standard criteria after appropriate coordination. Service will be discontinued first at facilities where service is not needed or where satisfactory alternatives are available. VOR will remain in service throughout the transition to satellite navigation to support IFR operations as needed, and serve as an independent navigation source.

Figure 4-44

NAVAIDS and GNSS Technologies

Operational Services		Supporting Systems & Infrastructures			
		Ground-based NAVAIDs	GNSS	Self-contained On-board Systems	Airport Lighting
Non-Area Navigation Operations - Operations Referenced to Ground-based NAVAIDs	En Route	VOR (Victor and Jet routes) VORTAC (Victor and Jet routes) TACAN* DME (fix definition) NDB (in Alaska and for some offshore airways)	GPS, SBAS (approved as a substitute for NDB, DME)	Barometric altimetry, Inertial	N/A
	Arrival and Departure	VOR (SIDs, STARs) VORTAC (Victor and Jet routes) TACAN* (SIDs, STARs) DME (fix definition) NDB	GPS, SBAS (approved as a substitute for NDB, DME)	Barometric altimetry, Inertial	N/A
	Approach & Landing				
	Instrument Approach	ILS, Localizer, LDA VOR DME NDB TACAN* Radar approaches (ASR)*	N/A	Barometric altimetry	Lighting as required for type of operation and/or minima requirements. See AC 150/5300-13
	Vertical Guidance for Instrument Approach	ILS, PAR*	See "Area Navigation Operations" below	Barometric altimetry, radar altimetry, baroVNAV, EFVS/HUD***	Lighting as required for type of operation and/or minima requirements. See AC 150/5300-13
Area Navigation Operat	En Route	DME/DME** VOR/DME**	GPS, SBAS	Inertial (as part of a multi-sensor system)	N/A
	Arrival and Departure	DME/DME** VOR/DME**	GPS, SBAS	Inertial (as part of a multi-sensor system)	N/A
	Approach & Landing				
	RNAV and RNP Instrument Approach (horizontal guidance)	VOR/DME** RNAV approaches (limited application)	GPS, SBAS,GBAS	Inertial (as part of a multi-sensor system), barometric altimetry, baro-VNAV	Lighting as required for type of operation and/or minima requirements. See AC 150/5300-13
	RNAV and RNP Instrument Approach (with vertical guidance)	Baro VNAV in conjunction with ground-based NAVAIDs, e.g., DME/DME/INS RNAV.	SBAS, GBAS	Barometric altimetry, baro-VNAV, EFVS/HUD***	Lighting as required for type of operation and/or minima requirements. See AC 150/5300-13

* Primarily used by DoD

** Legacy and backup services

*** While not a navigation system, EFVS/HUD acts to mitigate risk and credit is given for its use in operational approvals

Source: FAA

Several potential aeronautical applications of the 108-117.975 MHz VHF band are being investigated for possible implementation after VOR has been partially decommissioned.

4.4.6.3 DME

DME provides the slant-range distance from the aircraft to the DME transmitter. At many sites, the DME function is provided by the TACAN system that also provides azimuth guidance to military users.

Two different types of DME interrogators are used for enroute and terminal area navigation: Narrow Band DME or DME/N, and the Precision DME or DME/P. Both interrogators adhere to the same basic principles of operation. A ground-based transponder operates in conjunction with an airborne interrogator to determine the slant range from the aircraft to the DME transponder.

An interrogation, consisting of a pair of appropriately spaced pulses, is transmitted from the interrogator on a selected frequency. The transponder, operating on the same channel, receives the transmission, waits for a precisely defined amount of time, called the zero mile delay (ZMD), and replies with appropriately spaced pulse pairs. The interrogator measures the total round-trip time, subtracts the ZMD, and calculates the range to the transponder based on the known propagation velocity of electromagnetic waves.

DME carrier frequencies are in the 960 to 1,213 MHz range, and the transmitted pulse power is between 50 and 1000 watts. The maximum range is about 230 miles, but at a flight level of 3,000-6,000 meters it is about 75 miles (only line-of-site propagation at these frequencies). The DME frequency range is subdivided into 126 interrogations and 126 reply channels with a channel separation of 1 MHz. The interrogation channels have been allocated to the frequency range 1025-1150 MHz and the reply channels to two frequency ranges, 962-1024 and 1151-1213 MHz. Each interrogation channel is coupled to a specific reply channel 63 MHz above or below, depending on the channel used. Each ground transponder has a fixed frequency, whereas the aircraft interrogator can be tuned to a number of frequencies.

DME pulses are transmitted in pairs with a specified pulse shape and separation. The system can operate in either the X- or

Y-mode; pulse separation is 12 ms for the X-mode (both interrogation and reply), and 36 ms (interrogation) and 30 ms (reply) for the Y-mode. The Y-mode which uses the same frequency range (1025-1150 MHz) for interrogations as well as replies is not used very much and can be regarded as a capacity reserve. The DME/N and TACAN systems use X and Y pulse-coding schemes, while DME/P can use any of four pulse-coding schemes (X, Y, Z, and W).

The DME/P and DME/N interrogators and transponders are interoperable. The key differences between the two are in their pulse shapes and signal detection techniques. DME/P, developed for use with the higher accuracy of the MLS, is capable of providing approximately 100-ft. accuracy for more precise autopilot-coupled approaches versus the 0.5 nautical mile accuracy achieved with DME/N. The basic source of inaccuracy encountered when using conventional DME/N as a terminal landing aid results from multipath reflections.

The problem is exacerbated by the relatively slow rise time of the pulses that were adopted when DME was envisioned for use only as an enroute navaid at moderately high altitudes. In conventional DME, the elapsed time between transmissions of a pair of interrogation pulses and receipt of a pulse-pair reply from the ground station is measured relative to a 50 percent threshold point in the pulses (the point where the received signal has reached half of its peak value). In proximity to the runway, reflections of the ground station's reply arrive soon after the desired pulse has arrived, distorting the latter. This introduces error into the elapsed-time measurement, which equates to error in distance measurement.

Status

The FAA plans to sustain existing DME service to support enroute navigation and to install additional low-power DME to support ILS precision approaches as recommended by the Commercial Aviation Safety Team.

Future Trends

The FAA plans to expand the DME network to provide RNAV capability for terminal area operations at major airports and to provide continuous coverage for RNAV routes and operations at enroute altitudes. Continued use of a substantial portion of the 960-1215 MHz ARNS band will be required to support DME.

The DOD Joint Tactical Information Distribution System/Multi-function Information Distribution System (JTIDS/MIDS) also operates in this band on a non-interference basis. The civil aviation community will use 978 MHz in the DME ARNS band to enable ADS-B services for segments of the aviation community not equipped with the 1090 MHz Mode S extended squitter. ADS-B is a function in which aircraft transmit four-dimensional (4-D) position and intent data derived from onboard PNT systems to other aircraft and to the ANSP's ground network.

4.4.6.4 TACAN

TACAN is a tactical air navigation system for the military services ashore, afloat, and airborne. It is the military counterpart of civil VOR/DME. TACAN provides bearing and distance information through collocated azimuth and DME antennas.

For reasons peculiar to military or naval operations (unusual siting conditions, the pitching and rolling of a naval vessel, etc.) the civil VOR/ DME system of air navigation was considered unsuitable for military or naval use. A new navigational system, TACAN, was therefore developed by the military and naval forces to more readily lend itself to military and naval requirements. As a result, the FAA has integrated TACAN facilities with the civil VOR/DME program. Although the theoretical or technical principles of operation of TACAN equipment are quite different from those of VOR/DME facilities, the end result, as far as the navigating pilot is concerned, is the same. These integrated facilities are called VORTACs.

TACAN ground equipment consists of either a fixed or mobile transmitting unit. The airborne unit in conjunction with the ground unit reduces the transmitted signal to a visual presentation of both azimuth and distance information. TACAN is a pulse system and operates in the ultrahigh frequency (UHF) band of frequencies. Its use requires TACAN airborne equipment and does not operate through conventional VOR equipment.

TACAN is a short-range UHF (9060 to 1,215 MHz) radio navigation system. TACAN is a line-of-site system which limits ground coverage to 30 NM or less. At altitudes of 5,000 feet the range will approach 100 NM; above 18,000 feet, the range approaches 200 NM. For distance information, 110 interrogators are considered reasonable for present traffic handling. Future traffic handling could be increased when necessary through reduced airborne interrogation rates and increased reply rates. Capacity for the azimuth function is limited. With the use of solid state electronics and remote maintenance monitoring techniques, the reliability of the TACAN system approaches 100 percent.

Status

The FAA and DOD currently operate more than 100 stand-alone TACAN stations in support of military flight operations within the NAS. The DOD also operates approximately 30 fixed TACAN stations that are located on military installations overseas, and maintains more than 90 mobile TACAN and two mobile VORTAC for worldwide deployment. The FAA and DOD continue to review and update requirements in support of the planned transition from land-based to space-based primary navigation.

Future Trends

The DOD requirement for land-based TACAN will continue until military aircraft are properly equipped with GPS; GPS PPS receivers are certified for all operations in both national and international controlled airspace; and the GPS support infrastructure, including published procedures, charting, etc., is in place. A phase-down of TACAN systems is planned for a future date, yet to be determined. Sea-based TACAN will continue in use until a replacement system is successfully deployed.

4.4.6.5 Non-Directional Radio Beacon (NDB)

NDB serve as non-precision approach aids at some airports; as compass locators, generally co-located with the outer marker of an ILS to assist pilots in getting on the ILS course in a non-radar environment; and as enroute navigation aids.

Aeronautical NDB operate in the 190 to 415 kHz and 510 to 535 kHz ARNS bands. (Note: NDB in the 285-325 kHz band are secondary to maritime radiobeacons.) Their transmissions include a coded continuous wave (CCW) or modulated continuous-wave (MCW) signal to identify the station. The CCW signal is generated by modulating a single carrier with either a 400 Hz or a 1,020 Hz tone for Morse code identification. The MCW signal is generated by spacing two carriers either 400 Hz or 1,020 Hz apart and keying the upper carrier to give the Morse code identification.

Status

The US NAS includes more than 1,300 NDB. Fewer than 300 are owned by the federal government; the rest are non-federal facilities owned predominately by state, municipal, and airport authorities.

Future Trends

FAA has begun decommissioning stand-alone NDB as users equip with GPS. NDB used as compass locators, or as other required fixes for ILS approaches (e.g., initial approach fix, missed approach holding), where no equivalent ground-based means are available, may need to be maintained until the underlying ILS is phased out. Most NDB that define low frequency airways in Alaska or serve international gateways and certain offshore areas like the Gulf of Mexico will be retained. Except in Alaskan airspace, no future civil aeronautical uses are envisioned for these bands after the aeronautical NDB system has been decommissioned throughout the rest of the NAS.

Figure 4-44 outlines ground-based navaids and GNSSs technologies described in previous sections and their use in various phases of operations.

Key Points:

- The VHF Omnidirectional Range System (VOR)/Distance Measuring Equipment (DME)/Tactical Air Navigation (TACAN) system is a short distance air navigation system. Historically, VOR, DME, and TACAN have comprised the basic infrastructure for aviation enroute and terminal navigation and non-precision approaches.

- The FAA plans to expand the DME network to provide RNAV capability for terminal area operations at major airports and to provide continuous coverage for RNAV routes and operations at enroute altitudes.

- TACAN is a tactical air navigation system for the military services ashore, afloat, and airborne. It is the military counterpart of civil VOR/DME. A phase-down of TACAN systems is planned for a future date, yet to be determined.

4.4.6.6 Alternative Positioning, Navigation, and Timing (APNT)

An increasing number of air, land, and sea stakeholders are transitioning to GNSS as the primary source of PNT. Users, however, need to be able to revert from GNSS- enabled PNT to an alternative source of PNT in the event of a disruption. Current aviation users can use existing VOR and DME systems, or receive radar vectors from ATC. Legacy VOR and DME systems support conventional navigation; however, they do not support PNT requirements for RNAV, RNP or provide position for ADS-B technology. The concept of operations for APNT is built on four pillars:

- Safe recovery (landing) of aircraft flying in IMC under IFR operation.

- Strategic modification of flight trajectories to avoid areas of interference and manage demand within the interference area.

- Continued dispatch of air carrier operations to deny an economic target for an intentional jammer.

- Flight operations continue without a significant increase in workload for either the pilot or the ANSP during an interference event.

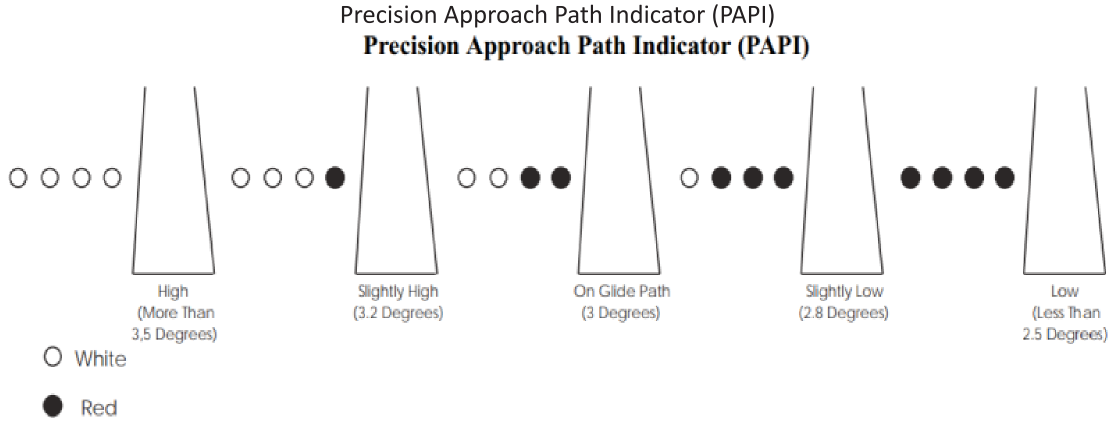
Maintaining limited APNT services that meet RNAV/RNP and/or ADS-B requirements for aviation users during an outage of GPS-enabled PNT is a basic goal of the Federal Aviation Administration's APNT initiative.

4.4.7 Airfield Lighting

Airfield lighting evolved soon after night flying was first introduced. At that time, most

Figure 4-45

Precision Approach Path Indicator (PAPI)



Source: FAA

airports consisted of an open area covered with either turf or cinders. Rotating beacons provided pilots with the general location of the airports but could not provide sufficient visual information to locate the cinder area and land. The introduction of airport boundary lighting solved this problem. As aircraft weight increased during the 1930s, most airports began to construct concrete runways to replace the cinder landing surfaces. Since airports had two or three runways, boundary lighting was no longer satisfactory to assist the pilot to identify the runway during night and low visibility operations. This marked the development of runway lighting.

4.4.7.1 Runway Lighting

Runway edge lights are placed on either side of the runway, spaced approximately 200 feet apart, outlining the edges of the runway. These lights are usually placed on short metal poles to elevate them from obstructions such as drifting snow or tall grass. Runway lights are white and usually covered with a Fresnel lens designed to focus the emitted light along and slightly above the horizontal plane of the runway's surface.

Runway threshold lights are installed on the last 2,000 feet of runways and used for instrument approaches utilizing lenses that are half white and half amber. These lights appear amber to a landing pilot, warning that the far end of the runway is fast approaching. The ends of the runway are clearly designated through the use of runway threshold lights, which are similar to runway lights but use red and green split lenses. As the pilot approaches the runway to land, the threshold lights on the runway appear green, while those on the far end of the runway appear red.

Runway light systems are normally operated from the control tower and are turned on during nighttime hours, during daylight whenever the visibility is less than two miles, or at the pilot's request. Whenever the control tower is not in operation, the lights are either left on or are operated using pilot-controlled lighting (PCL) systems. PCL systems permit pilots to switch on the lights by pressing their microphone switch a number of times in rapid succession, producing an audible click on the control tower frequency. The number of clicks controls both the operation and the intensity of the runway lighting system.

Runway light systems are classified according to the brightness they are capable of producing. Low-intensity runway lights (LIRL) are the least expensive to install and are typically equipped with 15-watt bulbs that operate on one intensity level. This intensity level is known as step one. The standard type of lighting for a runway used for instrument approaches is medium-intensity runway lighting (MIRL). MIRL is similar in construction to LIRL but are usually equipped with 40-watt bulbs. MIRL can be operated on three intensity levels: step one, step two, and step three. When operated on step one, medium-intensity lights produce the same light level as low-intensity lights. When functioning on step two, the lights operate at about 25 watts, and on step three they operate at maximum intensity (40 watts). During normal operations, MIRL is normally set to step one. Intensity is increased upon pilot request or whenever visibility decreases to less than three miles. Runways that are used heavily during periods of low visibility may be equipped with high-intensity runway lights (HIRL). HIRL operates on five steps ranging from 15 watts to 200 watts. At visibilities below five miles, steps are increased with step five reserved for visibility less than one mile.

Runways that are used extensively during periods of low visibility may be equipped with an assortment of embedded runway lights that provide the pilot additional visual cues when landing. These systems include touchdown zone lighting, runway centerline lighting, and taxiway turnoff lighting. Touchdown zone lighting is embedded in the runway and extends from the landing threshold to a point 3,000 feet down the runway. Touchdown zone lights use 100- to 200-watt bulbs and are placed in sets of three, on both sides of the runway centerline. Touchdown zone light intensities are stepped in conjunction with the runway edge lights.

Runway centerline lights provide additional directional guidance to enable pilots to accurately guide their aircraft along the runway centerline. Centerline lights are placed along the entire centerline at 75 foot intervals. Runway centerline lights are bi-directional: in the first part of the runway the lights are white, while the last 1,000 feet of centerline lights are red; in the 2,000 feet preceding the red lights, the centerline lights alternate red and white to warn pilots the runway end is approaching. Runway centerline lights are varied in intensity in proportion to the setting chosen for the runway edge lights.

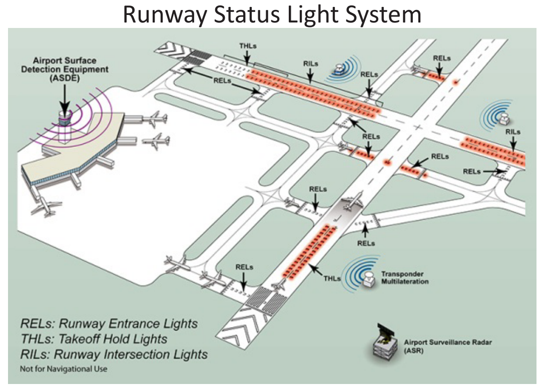
Taxiway turnoff lights are used to delineate the path that pilots should use for exiting the runway. Taxiway turnoff lights are inset into the runway's surface and are spaced at 50-foot intervals. The lights are green and extend from the runway centerline to the proper intersecting taxiway. Taxiway turnoff lights allow pilots to see runway turnoffs faster, which allow pilots to taxi faster, resulting in increased runway utilization capacity. Taxiway edge lights are blue and assist pilots navigate through large airports. Taxiway edge lights operate at different intensity levels and are usually operated from the control tower.

4.4.7.2 Runway Status Light System (RWSL)

RWSL is a fully automated system that provides runway status information to pilots and surface vehicle operators to clearly indicate when it is unsafe to enter, cross, takeoff from, or land on a runway. The RWSL system processes information from surveillance systems and activates runway entrance lights (REL), takeoff hold lights (THL), runway intersection lights (RIL), and final approach runway occupancy signal (FAROS) in accordance with the position and velocity of the detected surface traffic and approach traffic. REL, THL, and RIL are in-pavement light fixtures directly visible to pilots and surface vehicle operators. FAROSs alert arriving pilots that the approaching runway is occupied by flashing the precision approach path indicator (PAPI). FAROS may be implemented as an add-on to the RWSL system or implemented as a stand-alone system at airports without a RWSL system. RWSL is an independent safety enhancement that does not substitute for or convey an ATC clearance. Clearance to enter, cross, takeoff from, land on, or operate on a runway must still be received from ATC. Although ATC has limited control over the system, personnel do not directly use and may not be able to view light fixture activations and deactivations during the conduct of daily ATC operations. Figure 4-46.

Figure 4-46

Runway Status Light System



Source: FAA

4.4.7.3 Approach Light Systems

Approach light systems are designed to help pilots transition from instrument to visual flying as the aircraft nears the touchdown zone. Approach lights are placed along the extended centerline of the runway and usually extend from the runway threshold out to a point where the pilot can make the transition from instrument to visual flying. Approach light systems are designed to provide pilots with visual clues that will permit accurate aircraft control during the final approach and landing phase of the flight.

Approach light systems consist of a series of high-intensity white lamps placed five abreast, extending from the runway threshold out to a distance of 2,400 to 3,000 feet. These light bars are spaced 100 feet apart. At a point 1,000 feet from the end of the runway, a triple set of light bars provides the pilot with both roll guidance and a definite, unmistakable distance indication. The threshold of the runway is delineated with a series of four red light bars and a continuous line of green threshold lights.

To provide for identification of the approach light system, a high-intensity strobe light is placed on each of the light bars that extend beyond the 1,000-foot mark. The strobe lights flash in sequence, at a rate of two times per second, and appear to the pilot as a moving ball of light leading to the runway. These sequenced flashing lights (SFL) are also referred to by the slang name “the rabbit.” This combination approach lighting system has become the standard for runways equipped with CAT I ILS and is known as approach light system type 1 (ALSF-1). ALSF-2 is similar to ALSF-1 but includes additional lighting during the last 1,000 feet for aircraft during CAT II/III approaches. ALSF-2 provides a supplemental set of white light bars 500 feet from the runway threshold to provide aircraft with additional distance indication. Red light bars are also placed on both sides of the centerline, providing pilots with aircraft roll guidance during the last 1,000 feet. ALSF-2 approach light systems are wired such that the additional lights can be switched whenever CAT I ILS approaches are being conducted. The system is operated in the ALSF-2 configuration only when the pilot requests or when the visibility decreases below three-quarters of a mile. ALSF-1 and ALSF-2 systems are similar to high-intensity runway light systems in that they can be set to one of five intensity steps, depending upon visibility.

ALSF-1 and ALSF-2 systems are expensive to install, operate, and maintain. Therefore, only airports that use this type of equipment routinely can justify the costs. Less expensive systems are used by airports with less stringent requirements. These systems consist of only sequenced flashing lights spaced 200 feet apart and are known as runway alignment indicator lights (RAIL). Other less costly systems are described as follows:

Simplified Short Approach Lighting System (SSALS): A version of ALSF-1 that is only 1,200 feet long with lighting spaced at 200 foot intervals.

Simplified Short Approach Lighting System with RAIL (SSALR): Consists of a SSALS system but with runway alignment indicator lights out to a distance of 2,400 feet.

Medium-Intensity Approach Lighting System with RAIL (MALSR): Operates with only three steps of intensity, using medium-intensity white lamps. MALSR systems extend 2,400 feet from the runway threshold, with the light bars spaced at 200-foot intervals.

4.4.7.4 VFR Approach Light Systems

At airports located in densely populated areas or lacking contrast with surrounding terrain, it may be extremely difficult for a pilot flying VFR to identify the location of the runways. In these areas, positive means may be required for pilots to locate the runway. If the area has noise abatement restrictions, then aircraft are required to fly a specific path to the runway. Two types of identifier lights have been developed for these purposes: runway end identifier lights and omnidirectional approach lights.

Runway end identifier lights (REIL): Provide pilots with rapid identification of the runway end. The system consists of a pair of synchronized flashing lights located laterally on each side of the runway threshold. REILs may be either omnidirectional or unidirectional facing the approach area.

Omnidirectional Approach Light System (ODALS): Used to delineate the flight path that should be used by a pilot approaching a specific runway. ODALS consist of seven omnidirectional flashing lights located in the approach area of a non-precision runway. Five lights are located on the runway centerline extended with the first light located 300 feet from the threshold and extending at equal intervals up to 1,500 feet from the threshold. The other two lights are located, one on each side of the runway threshold, at a lateral distance of 40 feet from the runway edge, or 75 feet from the runway edge when installed on a runway equipped with a VASI.

Vertical guidance systems provide an inexpensive way of installing glide path indication at smaller airports. Two such systems are described as follows:

Visual Approach Slope Indicator (VASI): System lights are designed to be installed on runways with or without ILS approaches and can provide accurate glide path information as far as 20 miles from the runway. VASI uses either two or three light units arranged to provide visual glide path. The light units are next to the runway, with the first located approximately 700 feet and the second approximately 1,200 feet from the approach end. Each VASI unit projects a narrow beam of light filtered such that the upper portion (above the glide path) of the beam is white and the lower portion (below the glide path) is red. Pilots flying a VASI light know that aircraft is too high if they see a white light and too low if they see a red light. The two VASI units are installed such that a pilot on the desired glide path is above the near VASI (white beam) but below the far VASI (red beam). A pilot who is too high will see the white light from both units, while the pilot who is too low will see the red beams from both. The glide path provided by the standard two-light VASI system is of insufficient altitude for large aircraft (e.g., DC-10s, 747s) conducting approaches to the runway. At airports servicing these type aircraft, a third light bar is installed farther down the runway. Larger aircraft use the middle and far VASI units and smaller aircraft use the near and middle VASI units.

Precision Approach Path Indicator (PAPI): Units are similar to VASI units but are installed in a single row. Each light unit emits a white and a red beam but at progressively higher angles. Aircraft more than a half degree above the desired flight path will observe all the light units emitting white light. As the aircraft descends to a lower angle, the system appears to emit red light from the unit nearest the runway. When half the lights are red and the other half white, the aircraft is on the desired glide path. If all the light units appear red, the aircraft is in excess of a half degree below the desired glide path and should begin to climb immediately (Figure 4-45).

4.4.7.5 Technical Issues

Integration of airfield lighting systems with airport surface movement systems is essential in the modern CNS/ATM environment. Therefore, lighting control system interfaces must be developed and implemented that are able to function with current automation standards. Common parts and subsystems need to be developed that can function with a wide range of airfield lighting elements.

4.4.7.6 Operational Issues

A significant impact resulting from GNSS and GLS is that smaller airports without ILS systems will be afforded the opportunity to provide precision approaches. These airports must upgrade their current runway lighting systems as part of requirements to provide CAT I precision approach capability.

4.4.7.7 Future Trends

Airfield lighting industry trends include reducing life-cycle costs and environmental impacts by implementing low power lamps that reduce energy costs and protract lamp life, which also reduces labor charges associated with installation and re-lamping. Common parts that can be used in a variety of lighting systems also reduce costs by reducing inventories of spares. Airfield lighting monitoring systems have been developed to indicate the status and monitor the brilliance of each light, allowing total airfield uniformity regardless of the age of luminaries. The new systems are designed as an integral component in surface movement guidance systems with necessary fault detections to meet ICAO standards for CAT III operations.

Key Points:

- Integration of airfield lighting systems with airport surface movement systems is essential in the modern CNS/ATM environment. Therefore, lighting control system interfaces must be developed and implemented that are able to function with current automation standards.
- Airfield lighting industry trends include reducing life-cycle costs and environmental impacts by implementing low power lamps that reduce energy costs and protract lamp life, which also reduces labor charges associated with installation and re-lamping.

4.5 Surveillance Systems

The first ATC systems relied on aircraft following their flight plan and pilots reporting their position accurately. Any lack of precision in either flight planning or position reporting would seriously compromise aircraft separations and safety. This situation changed with the advent of radar. Radar provided air traffic controllers with the ability to independently maintain positive control of aircraft separations without relying on pilot position reports. In its early stages, radar indicated to the controller the position of all aircraft within the area of coverage, but did not allow the controller to identify a particular aircraft. This problem was solved by the development of secondary surveillance radar (SSR). Upon interrogation by the SSR transmitter, the suitably equipped aircraft automatically transmits an identification code and its altitude which provides the controller with the total situation.

Radar, however, suffers from the same limitation as VHF for communication and navigation. It has limited range, and there are large areas of the world, especially over oceans, where radar coverage cannot be provided. This limited range capability has spurred the current transition from radar to satellite-based surveillance. It is possible for an aircraft to automatically transmit its position, derived from its onboard navigation system, via satellite to a ground control station, and for the station to communicate directly with the aircraft, also via satellite, to ensure that separation is maintained. Therefore, a method exists for tactical control of aircraft, similar to radar control, even when aircraft are outside of radar coverage. This section addresses primary, SSR, and other specialized surveillance systems. It also provides an overview of communications-based surveillance systems (i.e., ADS) and the future surveillance environment.

4.5.1 Primary Radar

Primary radar operates by radiating electromagnetic energy and detecting the presence and character of the echo returned from reflecting objects. Radar is termed an active device because it uses its own energy to detect the target and does not depend on the energy radiated by the target. The two primary attributes of radar are its ability to detect a target at relatively large distances and to locate target position with a high degree of accuracy.

Radar can operate on frequencies of a few megahertz (HF) to the ultraviolet frequency range (laser radars). The basic principles and operation of different types of radar are the same. The radar signal, usually consisting of a repetitive train of short pulses (pulse train), is generated by a transmitter and radiated into space by an antenna. The antenna is used for transmission and reception. Targets reflect a portion of the radar signal back to the radar antenna where it is detected by the receiver. Target information such as location, shape, and motion are determined after comparison of the returned signal with the transmitted signal. The information is then displayed on a cathode ray tube (CRT) to an operator (air traffic controller).

The form of the electromagnetic signal radiated by the radar depends on the desired information about the target. A pulse radar for aircraft surveillance, for instance, may generate a repetitive train of short pulses, each a few microseconds in width, at a repetition rate of several hundred per second. If an accurate range measurement is required, the transmitted signal should occupy a wide spectral bandwidth, as does, for example, a short pulse. The shorter the pulse width the greater the spectral bandwidth. To accurately determine the Doppler frequency shift introduced in the reflected signal by a moving target, the signal waveform must be long in duration. An example is the continuous-wave (CW) Doppler radar. In addition to the widely used pulse train, there are many possible waveforms, including CW with frequency modulation, pulses with frequency or phase modulation, and bursts of pulses. The shape of the transmitted waveform is not important for detection as long as it contains sufficient energy to detect the smallest target at the maximum range.

Radar range is proportional to the fourth root of the radar transmitter power. This means that an increase in radar range means a tremendous increase in transmitter power. A significant part of high-power radar operating expenses is the cost of prime power to operate the transmitter. The transmitter generates the waveform at low power before amplification. Power amplifiers can be klystrons, traveling wave tubes, grid-controlled tubes, or crossed-field amplifiers. Many types of radar generate the signal directly without using an amplifier by modulating a power oscillator such as the magnetron. The power oscillator is usually used where simplicity and mobility are important, and the power amplifier is usually used where high power and/or stable waveforms are desired for moving target indicator (MTI), pulse-Doppler, or precision measurements.

Radar performance is generally determined by average power rather than peak power. Ground-based ATC surveillance radars have average powers in the range of about several kilowatts. The transmitter power is radiated into space by an antenna which directs the energy into a narrow beam. The narrow, directive beam characteristics of radars allows more energy to be concentrated on the target and also permits a measurement of target direction because of the localization of energy in space. ATC surveillance radars usually use a mechanically rotated reflector antenna with a fan-shaped beam, narrow in the azimuth dimension and broad in the elevation plane. Movement of the antenna beam may also be accomplished electrically with a phased array without mechanical motion.

The size of the antenna depends on the frequency, the antenna platform on which it will operate, and on the operating environment. Physically large antennas are associated with lower frequencies. UHF frequency radar antenna may be larger than 100 feet in diameter, while radars that operate in the upper microwave frequencies (X-band) may have diameters of about 10-20 feet.

Radars receive echoes from surrounding objects such as the ground, large bodies of water, or rain. Unwanted echoes are called clutter and can severely interfere with the detection of desired targets. If the desired target is moving and the clutter is not near the ground, it is possible to use the Doppler frequency shift produced by the moving target to tune out the undesired stationary echoes not shifted in frequency. This is the basis of MTI, pulse-Doppler, and CW radars.

Enroute primary radar provides positive control and separation of aircraft flying in enroute airspace. As such, enroute primary radar coverage is usually between 200 to 300 NM. Most existing enroute primary radars are based on tube type technology and are at or have exceeded their estimated life-cycle. Therefore, these radars are very expensive to operate. Newer solid-state radars are being implemented. However, the cost of continued procurement of these systems versus the cost of ADS for enroute surveillance cannot be justified. Enroute traffic densities can be easily handled by ADS operations. Establishing enroute primary radars to provide coverage of vast unpopulated areas of rugged terrain also poses significant operations and maintenance issues. The only remaining operational uses of enroute type radars after implementation of ADS appears to be in support of military surveillance operations. These types of operations do not require sophisticated ATC radar surveillance capabilities. Therefore, radars procured for this purpose are less expensive than their civil counterparts.

The advent of solid-state systems has given airport terminal primary radar systems sales a boost, making them cheaper and more flexible than earlier generations. Product differentiation between radar manufacturers is not extreme because of the new trends in open architectures. The economic benefits of solid state versus Klystron tube radars are overwhelming. With compatible performance, solid state systems are approximately 40 percent less because the package and board count decrease. The new systems also reduce maintenance costs. Fault isolation and diagnostics are much simpler and the line replacement unit (LRU) maintenance philosophy does not require sophisticated technicians to be readily available. Conventional tube-type radars have higher maintenance costs and require highly skilled technicians on site to perform repairs.

4.5.1.1 Technical Issues

One of the problems facing both radar suppliers and operators is the fast pace of technical change, especially in hardware capacity. Development can take a long period of time (up to ten years), and the hardware can become quickly outdated. Suppliers and operators are now more willing to wait to the end of a radar development cycle to finalize the data processing hardware (e.g., microprocessors, controllers, and associated hardware). Three generations of central processing units may occur before a radar progresses from the initial design phase to system implementation. This strategy is currently being employed on the Canadian Automated Air Traffic System (CAATS) project.

4.5.1.2 Operational Issues

Terminal primary radar ATC/ATM operations are today's standard method of operations. Operations, training, and maintenance issues are familiar, and mechanisms exist to address problems in any one of these areas. Even with the advent of ADS, there is general agreement in the ATC community and industry that terminal primary surveillance radar will still be needed on the airport in the foreseeable future. CAT II/III GNSS approaches may still be up to ten years away and terminal radar is the proven solution.

4.5.1.3 Institutional Issues

The policy of most major military powers still seems to favor large primary surveillance radars for air defense purposes (e.g., military operations, borders, oceanic areas, and ground-controlled intercepts). This trend appears likely to continue in the long term (at least the next 20 years). Although not a large market (declining), the best remaining markets for enroute radar appears to be in the Middle East, China, and Russia. China and Russia in particular will be the largest markets because of the large border area between the two countries and continued dominant military influence on their respective civil ATC/ATM structures.

4.5.1.4 Future Trends

Radar buyers in the current market are prone to buy systems that use a majority of commercial-of-the-shelf hardware and software because of its inherent flexibility. End users' needs tend to change during a systems life-cycle, making configurability critical to the end user organization. In the traditional process, a small configuration change may require a complete rebuild, which is very costly. Commercially available components bring more configurability to the end user organization. Commercial-off-the-shelf (COTS) products are very standards-oriented and users can swap one piece of hardware or software with another vendor's version of the same product. In contrast, a highly customized piece of hardware or software that fails would have to be replaced by the same product. COTS provides more control over cost and module replacement.

With the advent of ADS, primary enroute radar will be phased out as these systems approach the end of their system life-cycle. Savings and cost avoidance for countries that now operate the ground systems should be significant. Terminal primary radar appears likely to remain in highly congested terminal environments.

Key Points

- Primary radar is well understood and reliable, but has significant shortcomings such as limited range and significant maintenance costs.
- Many military applications still favor primary radar and will continue to serve as markets for suppliers in the near midterm.
- While no longer state-of-the-art technology, primary radar will likely continue to be a focus of terminal operations for the near future.

4.5.2 Secondary Surveillance Radar

Secondary surveillance radar (SSR), unlike primary radar, does not use transmitted energy reflected off the skin of aircraft to detect targets. SSR systems consist of a ground station that interrogates transponder-equipped aircraft, providing a two-way datalink on separate transmit and reply frequencies (Figure 4-47). Beacon systems offer advantages over primary radar systems because:

- Beacon reply pulses are stronger than primary radar echoes.
- Separate transmit and reply frequencies eliminate ground-clutter and weather return problems.
- Scintillation and dependence on radar cross section are eliminated.
- Interrogation and reply-path coding provide discrete target identification and automatic altitude reporting.

Figure 4-47

SSR Operations

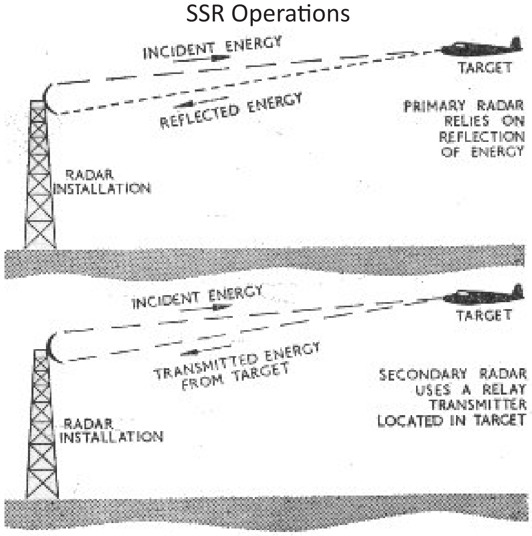
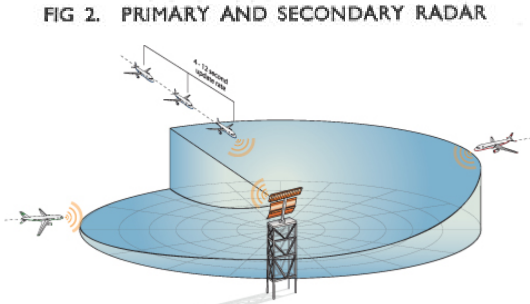


FIG 2. PRIMARY AND SECONDARY RADAR



Source: FAA

Today's civil SSR system, sometimes referred to as an ATC beacon system, is a direct outgrowth of the World War II identification friend or foe (IFF) system. The interrogator transmitter operates at L band at 1030 MHz, and the airborne transponder operates at 1090 MHz. The DOD offered this system for civil use in 1953 so that civil and military aircraft could operate on the same frequency channel to provide ATC information by using compatible airborne devices in the aircraft. The SSR was implemented in the US in the early 1960s, and by 1967 complete implementation of all commercial jet aircraft had taken place, and all military aircraft contained transponder equipment.

The SSR directionally interrogates transponder-equipped aircraft with coded-pulse pairs (at 1030 MHz) whose spacing denotes whether identify or altitude replies are being requested. The elicited reply (at 1090 MHz) comprises up to 16 pulses spaced at multiples of 1.45 msec. Two of the pulses are always present to define the code train, and the other pulses contain the code data. Generally, either 12 data-pulse positions provide up to 4,096 discrete identity codes, or 11 data-pulse positions provide altitude information in 100-foot increments referenced to 29.92 inches of mercury in accordance with the ICAO standard atmosphere.

The positions of the scanning antenna and the elapsed time between the interrogations and receipt of the transponder reply yield the azimuth and range of the aircraft. Therefore, range, azimuth, identity, and altitude can be derived. In addition, special code provisions enable pilots to declare an emergency or a communications failure. One of the pulses can be used for special identification if requested by ATC (ATC request referred to as "squawk IDENT.")

One of the inherent problems in beacon systems is that a transponder reply can be triggered from sidelobes at considerable distances from the ground station. This shows up on the controller's plan position indicator (PPI) as ring-around with subsequent loss of azimuth accuracy and resolution and increased interference. Modern beacon systems have side-lobe suppression systems

(SLS) to eliminate sidelobe interrogations within the airborne transponder. Reflections or multipath can cause a problem as serious as sidelobes, which cause transponders to reply. The beacon system may also suffer from overinterrogation on the single transmission frequency.

An airborne transponder may be within line-of-sight of many ground stations and hence will receive many interrogations. Monopulse processing is the latest technique used on modern SSR systems. Monopulse SSR (MSSR) systems uses a sum, omni, and delta pattern to interrogate aircraft which greatly improves azimuth accuracy.

Key Points

- Secondary surveillance radar provides a major improvement over primary radar in that it can provide identification of targets.
- The area still has technology and latency concerns with SSR, leaving considerable opportunity for more precise surveillance, such as ADS.

4.5.2.1 Mode S

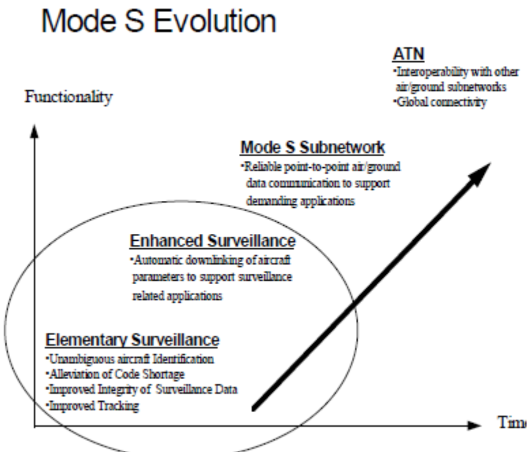
The existing SSR has a number of deficiencies which limit its ability to meet the demands presented by the increasing automation of the ATC system, particularly in an environment of increasing air traffic density. The inherent limitations of SSR, because of its signal structure and the nature of the system, result in transponder replies to all received interrogations. In a typical high density terminal area there are many aircraft responding to many interrogators, leading to a high level of interference that results in lost or garbled replies, as well as false targets. In addition, replies from aircraft closely spaced in range and/or azimuth will overlap and interfere with each other.

Mode S is an SSR system designed to overcome these problems. Mode S is comprised of three elements: the ground sensor, the airborne transponder, and the signals in space that form the link between them. The fundamental surveillance difference between Mode S and older SSRs is the manner of addressing aircraft or selecting which aircraft will respond to an interrogation. In SSR systems, all transponder-equipped aircraft within the main beam of the interrogator antenna signal respond. In Mode S, each aircraft is assigned a unique (discrete) address code.

Aircraft within the main beam of the antenna respond to interrogations if the aircraft's address code is included in the interrogation. Mode S includes the capability of calling all (or selectively, all non-Mode S) aircraft at a much lower interrogation rate. The addition of monopulse processing improves azimuth determination accuracy and allows reduction of the number of interrogations, since the monopulse system provides the positional accuracy required for Mode S from a single reply.

Three major advantages accrue from the use of discrete address for surveillance. First, an interrogator can limit its interrogation to only those targets for which it has surveillance responsibility. This prevents system saturation caused by all transponders responding to all interrogators within line-of-sight. Second, appropriate timing of interrogations ensures that responses from aircraft do not overlap, eliminating mutual interference from overlapping replies from closely-spaced aircraft. Third, discrete address in interrogations and replies permits the inclusion of messages to or from a particular aircraft, thereby providing the basis for a ground-to-air and air-to-ground digital datalink (Figure 4-48).

Figure 4-48
Transition to Mode S



Source: EUROCONTROL

Mode S employs a number of design features which minimize interference. Each Mode S-equipped aircraft has an assigned unique address. Messages to and from an aircraft discretely addressed do not result in responses from another aircraft. A reduced interrogation rate is possible through use of an antenna having a sum and difference pattern (monopulse antenna). The interrogation is transmitted on the sum pattern. Replies are received on both the sum and difference patterns. A monopulse estimate is made to establish the angular difference between the target and the antenna pointing angle. While it is possible to determine target position with a single reply, the Mode S sensor interrogation rate is a site-adaptable parameter depending on the interrogation mode (Mode S or SSR interrogation and replies) within the antenna beamwidth for operation with existing SSR-equipped aircraft.

The monopulse estimates for each reply pulse readily identify the reply to which each of the received pulses belong when overlapping replies are received from different angles within the antenna beam. Monopulse degarbling continues to operate into regions of pulse overlap that could not be resolved by pulse timing alone. Therefore, it reduces the susceptibility of the SSR mode to synchronous garble from aircraft which are near the same range and azimuth. A Mode S-equipped aircraft responds to interrogations containing its discrete address. This eliminates unnecessary replies to adjacent facilities and to interrogations which are intended for acquisition of other aircraft not on file. The SSR processor determines target azimuth by marking the center of the received string of replies, which may not necessarily reflect the actual position of the aircraft. The monopulse direction-finding technique has proven to be much more accurate in determining the angle of arrival of the reply signals.

The capability for an evolutionary transition from SSR to Mode S has been achieved by providing a high degree of compatibility between Mode S and current SSR systems. Mode S uses the same interrogation and reply frequencies as current SSR systems. In addition, the Mode S ground station performs the SSR functions as well as the Mode S functions. This degree of compatibility permits a smooth transition in which Mode S ground stations provide surveillance of standard SSR transponder-equipped aircraft and Mode S transponders' reply to SSR ground stations.

4.5.2.2 Technical Issues

Primary technical issues are related to upgrading MSSR to Mode S. Since all aircraft reply on the same frequency of 1090 MHz, a ground station will also receive aircraft replies originating from responses to other ground stations. These unwanted replies are known as FRUIT (false replies unsynchronized with interrogator transmissions or, alternatively, false replies unsynchronized in time). Several successive fruit replies could combine and appear to indicate an aircraft which does not exist. As air transport expands and more aircraft occupy the airspace, the amount of fruit generated will also increase. Also, fruit replies can overlap with wanted replies at a ground receiver, thus causing errors in extracting the included data.

4.5.2.3 Operational Issues

To support ADS-B Out, aircraft must be equipped with a GPS receiver as the position source, and a datalink transmitter to actually send the ADS-B data. The datalink transmitter that most aircraft will use is a Mode S transponder, using a feature called "extended squitter. The Mode S transponder with extended squitter is the international standard for ADS-B output.

Universal Access Tranceiver (UAT) solutions will almost certainly be more expensive than a Mode S-based solution, because the Mode S is built into many existing ATC transponders, whereas the UAT solution is a separate datalink radio. The key difference between the two solutions is that UAT has spare uplink bandwidth, whereas Mode S extended squitter only has the capacity for ADS-B position reporting. That means that a UAT radio can receive additional data streams, in addition to the traffic information.

4.5.2.4 Institutional Issues

In the US, the FAA attempted to mandate Mode A/C transponders upgrades to Mode S, but this move was strongly resisted by general aviation groups. At present, the rules to force the transition to Mode S have been put on indefinite hold, and aircraft that aren't required to be TCAS-equipped (which includes most of our owner-flown airplanes) continue to use the older and far less expensive Mode C units.

The FAA is providing a weather reporting function using the spare datalink bandwidth of the UAT radio and is hoping that this "added value" feature will encourage GA operators to install ADS-B equipment sooner than they otherwise might.

4.5.2.5 Future Trends

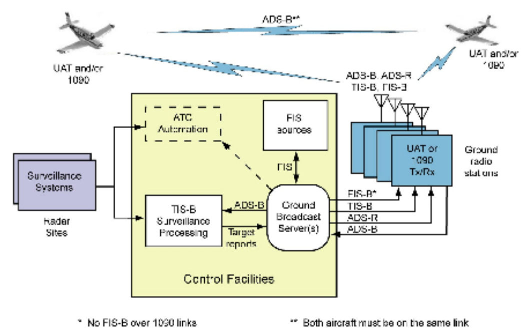
Widespread mandates for ADS-B are forecast between now and 2020. The biggest is already in place — the FAA has mandated ADS-B Out in all US airspace where transponders are currently required, with a deadline of 2020. Until then, there is not much airspace where ADS-B is actually required, especially for GA aircraft. Over the next few years other countries will roll out their ADS-B plans, but it is difficult to forecast when this will start to impact GA operators. Nevertheless, the expected lifetime of the avionics being installed today extends into the ADS-B deployment period, and it is worth taking into account future capabilities when buying equipment now.

4.5.3 Automatic Dependent Surveillance (ADS)

Automatic Dependent Surveillance (ADS) is a concept that combines GPS/GNSS and digital communications. GPS/GNSS-equipped aircraft will continually transmit their positions, obtained from GNSS satellites, to ground controllers over digital datalinks. ADS relies on downlink reports from an aircraft's avionics that occur automatically whenever specific events occur, or when specific time intervals are reached. ADS does not require an independent surveillance source, such as a radar antenna, to operate. Due to this capability, ADS can provide accurate surveillance reports in remote and oceanic areas that, for a variety of reasons, will never be inside radar coverage. The ADS reports are converted by datalink-equipped ground stations into an ADS track and presented on the controller's air situation display to provide enhanced situational awareness and the potential for reduced separation standards (Figure 4-49).

Figure 4-49

ADS Environment



Source: FAA

The ICAO Manual of ATS datalink applications identifies the following ATC functions that can be improved with ADS information. There will be more improvements in the future.

Position monitoring: The automation system processes incoming ADS messages to verify their validity and match them to the appropriate flight plan.

Conformance monitoring: The ADS reported position is compared to the expected aircraft position, which is based on the current flight plan. Longitudinal variations that exceed a predefined tolerance limit will be used to adjust expected arrival times at subsequent fixes. Horizontal and vertical deviations that exceed a predefined tolerance limit will permit an out-of-conformance alert to be issued to the controller.

Conflict detection: The ADS data can be used by the ground system automation to identify violation of separation minima.

Conflict prediction: The ADS future position data can be used by the automation system to identify potential violations of separation minima.

Conflict resolution: ADS reports may be used by the automation system to develop possible solutions to potential conflicts when they are detected.

Clearance validation: Data contained in ADS reports are compared to the current clearance, and discrepancies are identified.

Tracking: The tracking function is intended to extrapolate the current position of the aircraft based on ADS reports.

Wind estimation: ADS reports containing wind data may be used to update wind estimations and hence expected arrival times at waypoints.

Flight management: ADS reports may assist automation in generating optimum conflict-free clearances to support fuel-saving techniques such as cruise climbs.

The precise aircraft position location provided by ADS will allow controllers to reduce the separations between aircraft which would result in an overall ATC system increase in efficiency and capacity. In addition to position reports, ADS will provide aircraft intention and operational data that support air traffic management and collision avoidance tools.

Airlines expect ADS to provide substantial time and fuel savings over oceanic routes by quickly obtaining clearance to climb to higher altitudes to change routing to optimize flight conditions. Currently, track systems over the Pacific and North Atlantic Oceans are adjusted daily in response to forecasted winds. More precise navigation capabilities provided by GPS/GNSS and ADS will enable decreased longitudinal separation between aircraft, helping to reduce delays in congested flight tracks, particularly over the North Atlantic.

4.5.3.1 Automatic Dependent Surveillance–Broadcast (ADS-B)

If aircraft broadcast this information omnidirectionally to all listeners within range to receive, it is referred to as ADS-broadcast or ADS-B. ADS-B relies on the regular and frequent transmission of position reports via a broadcast datalink. The position reports are sent periodically by the aircraft with no intervention from the ground function. Position reports may be received by any recipient in range of the transmitting aircraft. Recipients may be communications receivers (data acquisition units) on other aircraft, ground vehicles, or at fixed ground sites. If received by a data acquisition unit, the position report will be processed with other surveillance data and may be forwarded to a controller/pilot display.

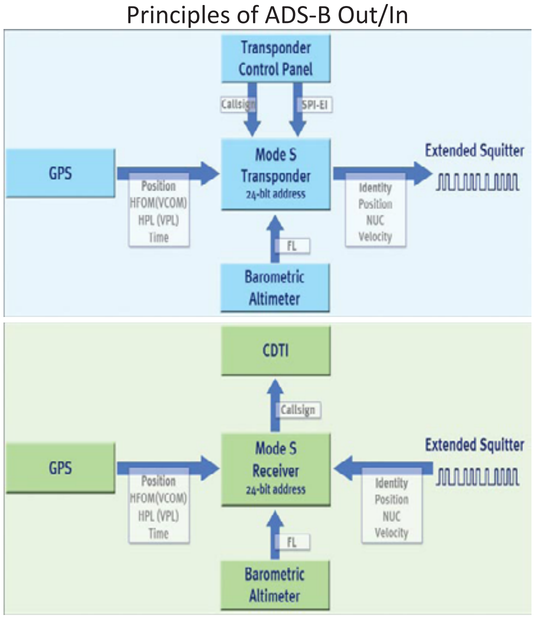
ADS-B offers data delivery from aircraft-to-aircraft or from aircraft-to-ground. Transmitting data directly from air-to-air means that there is no need for a ground infrastructure to be present for airborne surveillance. By using position reports received from surrounding aircraft, a traffic surveillance picture can be generated in the cockpit of all aircraft. This potentially allows new applications or new maneuvers to be performed by pilots. This concept of air-to-air surveillance in ADS-B is not available with ADS-C.

The transmitting aircraft does not know which, if any, recipients are receiving and processing the position reports. Unlike a point-to-point link, position reports are not acknowledged.

ADS-B transmissions lie outside of the ATN or ACARS, which only provide point-to-point communications. Three technologies are available: 1090 MHz extended squitter (which has been selected as the initial link for Europe), VDL Mode 4 (very high datalink), and UAT (Universal Access Tranceiver). Figure 4-50 depicts the principles of ADS-B Out/In.

Figure 4-50

Principles of ADS-B Out/In



Source: Airport-Int.com

ADS-B will offer increased safety, efficiency, and environmental awareness for pilots and air traffic controllers at a lower overall cost than the current radar system. Companies have already begun selling and developing aircraft hardware systems to allow general aviation aircraft owners to equip at an affordable cost. These companies include Avidyne, Aviation Communication and Surveillance Systems (a joint venture of L-3 Communications and Thales), Garmin, Intelcan, Rockwell Collins, and FreeFlight Systems.

ADS-B enhances safety by making an aircraft visible, real-time, to ATC and to other appropriately equipped ADS-B aircraft with position and velocity data transmitted every second. ADS-B data can be recorded and downloaded for post flight analysis. ADS-B also provides the data infrastructure for inexpensive flight tracking, planning, and dispatch.

4.5.3.2 Automatic Dependent Surveillance – Contract (ADS-C)

ADS-C reporting is controlled by the ground station in all situations other than emergency contracts. Only the flight crew can declare and cancel ADS emergency reporting. Although the crew can initiate the emergency reporting mode, the aircraft cannot initiate a contract. If there are no current contracts with a ground station, the pilot can "arm" the mode and then the mode will affect any subsequent contracts. ADS-C is most likely to find application to sparsely trafficked transcontinental or transoceanic crossings.

4.5.3.3 Automatic Dependent Surveillance – Rebroadcast (ADS–R)

ADS–R is a datalink translation function of the ADS–B ground system required to accommodate the two separate operating frequencies (978 MHz and 1090 ES). The ADS–B system receives the ADS–B messages transmitted on one frequency, and ADS–R translates and reformats the information for rebroadcast and use on the other frequency. This allows ADS–B In equipped aircraft to see nearby ADS–B Out traffic regardless of the operating link of the other aircraft. Aircraft operating on the same ADS–B frequency exchange information directly and do not require the ADS–R translation function.

4.5.3.4 Technical Issues

A concern for any ADS-B protocol is the capacity for carrying ADS-B messages from aircraft, as well as allowing the radio channel to continue to support any legacy services. For 1090ES, each ADS-B message is composed of a pair of data packets. The greater the number of packets transmitted from one aircraft, the smaller the number of aircraft that can participate in the system, due to the fixed and limited channel data bandwidth. System capacity is defined by establishing a criterion for what the worst environment is likely to be, then making that a minimum requirement for system capacity.

Additionally, ADS-B transmissions face integrity concerns, as ADS-B messages can be produced with simple low cost measures, which spoof the locations of multiple phantom aircraft to disrupt safe air travel. There is no foolproof means to guarantee integrity, but there are means to monitor for this type of activity. This problem is, however, similar to the usage of ATCRBS/MSSR where false signals also are potentially dangerous (uncorrelated secondary tracks).

4.5.3.5 Operational Issues

The airlines, ATC controllers, and the general aviation community all have different needs and financial resources. ADS-B messages can be used to know the location of an aircraft, and there is no means to guarantee that this information is not used inappropriately.

4.5.3.6 Institutional Issues

In the US, ADS–B equipped aircraft exchange information in one of two frequencies: 978 or 1090 MHz. The 1090 MHz frequency is associated with Mode A, C, and S transponder operations. 1090 MHz transponders with integrated ADS–B functionality extend the transponder message sets with additional ADS–B information. This additional information is known as an “extended squitter” message and referred to as 1090ES. ADS–B equipment operating on 978 MHz is known as the Universal Access Transceiver (UAT). The FAA has mandated ADS-B Out by 2020 on all aircraft operating in current Mode-C airspace (around class B and C airspace above 10,000 feet). The mandate allows either 1090-ES or UAT ADS-B Out on aircraft. The 1090-ES link is required for aircraft that fly above FL180.

The European mandate for ADS-B Out requires 1090ES ADS-B Out with a Mode-S transponder by 2015 for new aircraft and 2017 for retrofits, and only applies to aircraft greater than 12,500lbs or maximum cruise greater than 250 knots true air speed.

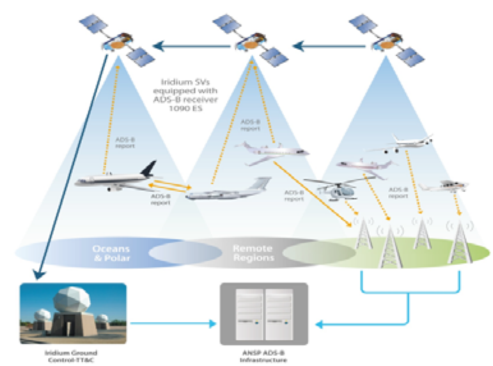
4.5.3.7 Future Trends

GNSS and ADS technologies will eventually replace primary radar for civil ATC enroute surveillance functions. GNSS/ADS technology offers the most significant cost advantages versus implementation and/or continued operations of ground based enroute surveillance radar.

Space-Based ADS-B

Installing ADS-B receivers on a cross-linked LEO constellation allows a relay of the aircraft ADS-B messages to the ATC operations centers with delays of only a few seconds. The global ADS-B reception will extend commercial aircraft coverage and surveillance over the oceans, the poles, and remote areas cost effectively, with enhanced coverage of mountainous areas. Both Iridium and Globalstar satellite constellations offer the potential for space-based capabilities (Figure 4-51).

Figure 4-51
Space-Based ADS-B



Source: IRIDIUM

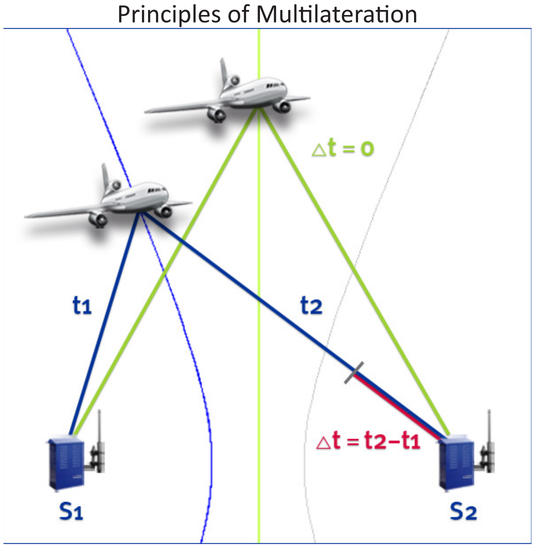
Key Points:

- ADS-B will offer increased safety, efficiency, and environmental awareness for pilots and air traffic controllers at a lower overall cost than the current radar system.
- ADS-B offers data delivery from aircraft-to-aircraft or from aircraft-to-ground.
- The emergence of space-based ADS-B may remove the ground station requirement for less congested traffic areas, such as oceans, polar regions, and remote or mountainous terrain.

4.5.4 Multilateration

Multilateration (MLAT) employs a number of ground stations, which are placed in strategic locations around an airport, its local terminal area, or a wider area that covers the larger surrounding airspace. These units listen for "replies," typically to interrogation signals transmitted from a local SSR or an MLAT station. Since individual aircraft will be at different distances from each of the ground stations, their replies will be received by each station at fractionally different times. Using advanced computer processing techniques, these individual time differences allow an aircraft's position to be precisely calculated (Figure 4-52).

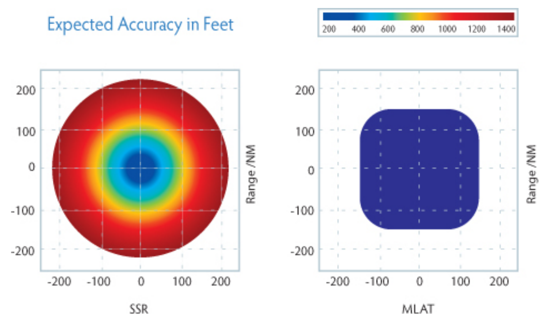
Figure 4-52
Principles of Multilateration



Source: Airport-Int.com

MLAT requires no additional avionics equipment, as it uses replies from Mode A, C ,and S transponders, as well as military IFF and ADS-B transponders. Furthermore, while the radar and multilateration "targets" on a controller's screen are identical in appearance, the very high update rate of the multilateration-derived targets makes them instantly recognizable by their smooth movement across the screen. A screen displaying MLAT information can be set to update as fast as every second, compared with the four to twelve second position "jumps" of the radar-derived targets. Unlike measurements of absolute distance or angle, measuring the difference in distance results in an infinite number of locations that satisfy the measurement. When these possible locations are plotted, they form a hyperbolic curve. To locate the exact location along that curve, a second measurement is taken to a different pair of stations to produce a second curve, which intersects with the first. When the two are compared, a small number of possible locations are revealed, producing a "fix" (Figure 4-53).

Figure 4-53
Comparison: SSR vs. MLAT



Source: EUROCONTROL

4.5.4.1 Technical Issues

Bandwidth and performance of the 1090 MHz datalink is dependent upon the complexity of the scenarios envisaged and could be a significant issue in high density areas. Also, 1090MHz interference sources can be malicious or accidental and can occur intermittently or for an extended period. The interference can be a localized source causing, for example, a "co-channel interference" problem up to a military denial of airspace operation involving active jamming. Also, multiple sites each require power and data communication paths. Additional issues to consider are site access, land rental or ownership, and technical maintenance capability to add multiple sites.

4.5.4.2 Operational Issues

The position determined by MLAT can be different from the position reported by radar or other systems. When more than one input type is received, these positions will need to be reconciled so that only one position (preferably the most accurate position possible) is displayed for a single aircraft. This can be achieved by the use of a multi sensor (e.g. MLAT, ADS-B, SMR, ASR) data processor. Controllers need to know which aircraft are being tracked by which system when the type of surveillance affects how they control that aircraft, or the quality of the reported position, so that appropriate separation standards can be applied. Depending on the application and limit of MLAT coverage, controllers may also need to know other capabilities of the displayed aircraft, such as RNP, ADS-B, and CDTI (cockpit display of traffic information). All of this adds information to be integrated into the present displays.

4.5.4.3 Institutional Issues

There are common types of institutional issues regardless of the state implementing MLAT. These include such things as legal issues (e.g. separation standards), radio spectrum allocation/management, and certification issues. Each state will have to resolve these, but global harmonization needs to be considered for consistency.

4.5.4.4 Future Trends

As the need for traffic surveillance expands over areas not presently covered by conventional secondary radar, many ANSPs are taking advantage of the cost benefits of multilateration versus new radar installations (Figure 4-54).

In wide area multilateration (WAM), the stations are spread much further apart, at distances of up to 100 km. In some locations, multilateration provides superior range over secondary radar, more accurate tracking, significantly lower costs, and significantly earlier operational readiness following contract award. The system has also been chosen in situations where existing "legacy" secondary radar has had to be replaced. In Armenia, for example, cost and performance analyses showed the clear advantages of multilateration over replacing the earlier secondary radar, and the wide area solution was chosen.

Figure 4-54
Global MLAT Adoption

Source: EUROCONTROL

In Australia, WAM became operational in June 2010, using a network of 14 widely-dispersed ground stations to provide coverage in Tasmania. This is one of the largest geographical deployments of WAM in the world to date. A multilateration system was also installed in 2010 at Sydney/Kingsford Smith Airport to replace the existing conventional radar precision runway monitor for the close-spaced parallel ILS approaches.

WAM could be expected to expand over some non-radar controlled airspace, thereby reducing procedural ATC while increasing capacity and throughput. Also, it now appears to be generally accepted that even when the world's civil air fleet is completely ADS-B equipped, there will still be a need for a backup system to cater to SSR or GPS failures, an application potentially well suited for WAM.

Key Points:

- Multilateration employs a number of ground stations and advanced computer processing techniques to measure variations in timed interrogation replies, allowing an aircraft's position to be precisely calculated.
- MLAT requires no additional avionics equipment, as it uses replies from Mode A, C, and S transponders, as well as military IFF and ADS-B transponders.
- With no major infrastructure investment, MLAT is fast becoming of interest

to many countries and ANSPs as a technology with superior range over SSR.

4.5.5 Surface Surveillance

Currently, airport surface surveillance is conducted through specialized primary radars at large high traffic density airports. Surface detection radar provides air traffic controllers with position information of aircraft, delivery trucks, baggage carts, and other equipment in very low visibility conditions. However, the controller needs to identify the aircraft in order to guide traffic in and around a busy ramp. In busy airport environments this task is virtually impossible without positive identification.

Other surface surveillance equipment has been developed by several different companies that determine identification and location of vehicles equipped with either Mode S or SSR transponders. Several SSR sensors are installed at various areas of the airfield such as runways, taxiways, and ramps. Each sensor interrogates a small area during a short period of time and enables the system to scan the entire surface of the airport in about one second. Aircraft or vehicle positions are determined by performing a multilateration calculation on asynchronous replies.

The sensors time tag the received responses, transmit the reports to a master work station for the multilateration position calculation, and display the target report on an airport digital display map. The master work station can present target identification, position, and velocity at a rate of one update per second. The master work station can also provide data for display at the airport authority, ground handling companies, airlines, and other interested parties. The major drawback to this method is that ground vehicles will also have to be equipped with transponders to determine their position. Installation, maintenance, and operating costs of adding additional airport sensors and the requirement for equipping airport vehicles with transponders will also increase resistance by service operators to this type of system.

Airport surface surveillance functions can also be provided by ADS systems using navigation inputs from DGNSS. VHF or UHF datalinks, in conjunction with DGNSS receivers, are used to transmit precise navigation information from the DGNSS receivers. This information can be processed in an automated ATC/ATM system and used by controllers to identify and monitor aircraft and surface vehicle movement. Of course, this means that vehicles must also be equipped with GNSS receivers and VHF or UHF datalink transmitter receiver units, which may be a prohibitive cost.

4.5.5.1 Airport Surface Detection Equipment - Model X (ASDE-X)

The potential for collisions on airport runways and taxiways increases every year as airports become busier. To combat the impact of this trend, the FAA is deploying the Airport Surface Detection Equipment - Model X (ASDE-X), a new runway-safety tool. ASDE-X is a multi-sensor surface surveillance system the FAA is acquiring for airports in the US. This system provides high-resolution, short-range, clutter-free surveillance information about aircraft and vehicles, both moving and fixed, located on or near the surface of the airport's runways and taxiways under all weather and visibility conditions. The system consists of:

- **A primary radar system**: ASDE-X system coverage includes the airport surface and the airspace up to 200 feet above the surface. Typically located on the control tower or other strategic location on the airport, the primary radar antenna is able to detect and display aircraft that are not equipped with or have malfunctioning transponders.
- **Interfaces:** ASDE-X contains an automation interface for flight identification via all automation platforms and interfaces with the terminal radar for position information.
- **ASDE-X Automation:** A multi-sensor data processor (MSDP) combines all sensor reports into a single target which is displayed to the air traffic controller.

- **Air traffic control tower display:** A high resolution, color monitor in the control tower cab provides controllers with a seamless picture of airport operations on the airport surface.

ASDE-X enables air traffic controllers to detect potential runway conflicts by providing detailed coverage of movement on runways and taxiways. ASDE-X collects data from a variety of sources to track vehicles and aircraft on the airport movement area and obtain identification information from aircraft transponders. The ASDE-X data comes from surface movement radar located on the air traffic control tower or remote tower, multilateration sensors, ADS-B sensors, the terminal automation system, and aircraft transponders. By fusing the data from these sources, ASDE-X is able to determine the position and identification of aircraft and transponder-equipped vehicles on the airport movement area, as well as aircraft flying within five miles of the airport.

Controllers in the tower see this information presented as a color display of aircraft and vehicle positions overlaid on a map of the airport's runways, taxiways, and approach corridors. The system creates a continuously updated map of the airport movement area that controllers can use to spot potential collisions. This technology is especially helpful to controllers at night or in bad weather when visibility is poor.

4.5.5.2 Technical Issues

Surface movement systems must be able to function with a wide number of diversely equipped aircraft and vehicles throughout major airports worldwide. This implies that an equally varied mix of surface surveillance systems will also be implemented. In order to ensure that aircraft can operate in a diverse environment, ADS surface surveillance systems must be developed that operate on either standard Mode S or VHF message formats.

4.5.5.3 Operational Issues

Surface surveillance information must be operationally integrated with ATC/ATM operations to achieve total system efficiency. Airport information, commercial airlines, and air traffic controllers must all be able to input and process information in order to make the system work efficiently. Information from all airport sensors must be displayed to appropriate ATC personnel. Therefore, new operations procedures must be developed to maximize the new capabilities obtained from automating the surface surveillance process.

4.5.5.4 Institutional Issues

Surface surveillance systems are being developed that use existing technologies. Therefore, individual states or airport operators will have the flexibility to choose a suitable technology to support their specific ground surveillance operations, without protests from diverse aviation groups. However, forcing implementation of Mode S transponders on airport vehicles, if this ever occurs, would cause a major backlash.

4.5.5.5 Future Trends

Integrated Mode S/VHF/GNSS systems will dominate the future market. Ground surveillance systems will only be required in the most high density airport environment, which initially means most large international airports and large domestic airports. The majority of these type of airports will be equipped with either Mode S or VHF capabilities because of the dense traffic environment. Methods of tagging primary ground surveillance radar data will be developed to ensure positive identification of aircraft and ground vehicles.

Key Points:

- Currently, airport surface surveillance is conducted through specialized primary radars at large high-traffic density airports, but other alternatives can now determine identification and location of vehicles equipped with either Mode S or SSR transponders.
- Surface surveillance information must be operationally integrated with ATC/

ATM operations to achieve total system efficiency.

- Integrated Mode S/VHF/GNSS systems will dominate the future market.

4.5.6 Airborne Collision Avoidance

An airborne collision avoidance system (ACAS) is an aircraft system that operates independently of ground-based equipment and air traffic control in warning pilots of the presence of other aircraft that may present a threat of collision. If the risk of collision is imminent, the system indicates a maneuver that will reduce the risk of collision. ACAS standards and recommended practices are mainly defined in Annex 10, volume IV, of the Convention on International Civil Aviation.

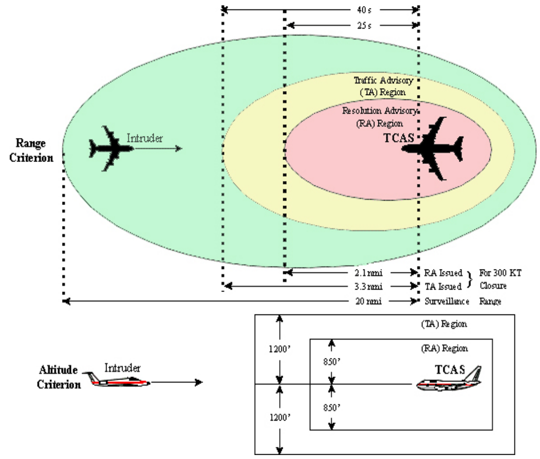
4.5.6.1 Traffic Collision Avoidance System (TCAS)

A traffic collision avoidance system or traffic alert and collision avoidance system (both abbreviated as TCAS) is designed to reduce the incidence of mid-air collisions between aircraft. It monitors the airspace around an aircraft for other aircraft equipped with a corresponding active transponder, independent of air traffic control, and warns pilots of the presence of other transponder-equipped aircraft which may present a threat of mid-air collision. It is a type of airborne collision avoidance system mandated by ICAO to be fitted to all aircraft with a maximum take-off mass of over 5700 kg (12,586 lbs) or authorized to carry more than 19 passengers.

TCAS creates a surveillance bubble stretching 30 NM ahead and approximately 10 NM either side of aircraft, and at least 3,000 feet above and below. This bubble, which is smaller in dense traffic, is scanned once a second by a transmitter/receiver which triggers transponders on any aircraft within the bubble. An onboard processor analyzes aircraft tracking (up to 30 aircraft maximum) within the bubble and decides if there is likely to be any conflict. Flight-deck displays vary, but usually the aircraft carrying TCAS is shown as an outline in the center (Figure 4-55).

Figure 4-55

Principles of TCAS



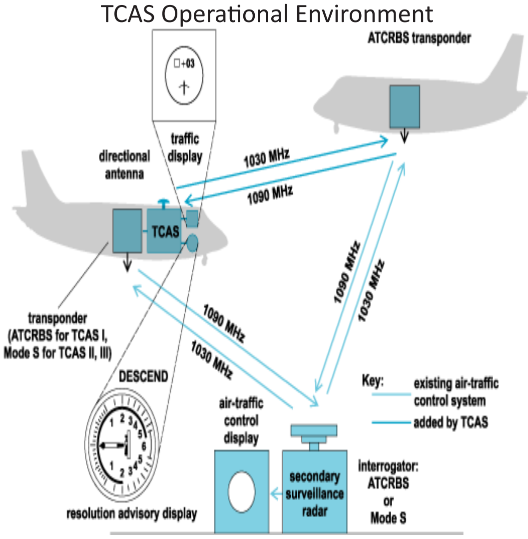
Source:Wikipedia

Any aircraft within the bubble not on a collision course appears as a hollow, pale blue diamond. Its relative altitude is shown as a plus or minus followed by two digits indicating hundreds of feet (e.g., +12 indicates an aircraft 1,200 feet above). If that aircraft comes within six NM and 1,200 feet, it is classed a proximity intruder and the diamond becomes solid. If the processor decides the aircraft will come too close in the next 35 to 45 seconds, the diamond changes to a yellow circle with an arrow showing climb or descent. The pilot is then given a traffic advisory (TA) which is an audible warning. If the system decides the aircraft will become dangerously close within 20 to 30 seconds, the yellow circle changes to a red square and the system gives a "resolution advisory" (RA), telling the pilot to take evasive action. TCAS information is usually displayed in the center of the aircraft's vertical speed indicator. When an RA is triggered, red and green areas around the VSI are illuminated to show the pilot the necessary climb or descent rate. Figure 4-56 depicts a TCAS operational environment.

The TCAS includes a datalink so that when two TCAS-equipped aircraft are flying too close to each other, the advice provided by the TCAS to the pilots is not contradictory. TCAS II does have limitations. It can only see transponder-equipped aircraft, and it can only solve a problem by requiring an altitude change. This is only possible if the intruding aircraft's transponder is transmitting altitude. TCAS cannot anticipate any directional changes. It may also issue a warning if two aircraft approach each other on a collision course, (e.g., one climbing and the other descending), but each intends to level out with correct separation.

Figure 4-56

TCAS Operational Environment



Source:McGraw Hill

TCAS II equipment, which includes a Mode S transponder, is intended for installation in transport and high performance general aviation aircraft. All TCAS II units have the capability to downlink RAs to Mode S ground stations. The ground station is notified that an RA is displayed (or was displayed within the last 18 seconds) by a bit set in the standard surveillance reply from the Mode S transponder in the TCAS aircraft. The RA information is then extracted by the ground station using Mode S datalink communications. This RA information could be displayed to the air traffic controller responsible for the airspace occupied by the TCAS aircraft. The purpose would be to improve the controller's awareness of TCAS operations and to notify her/him of possible flight path deviations in response to RAs.

A new version of the TCAS II collision avoidance logic designated version 6.04A has been developed. The new version was developed to eliminate flaws in the earlier version as follows:

- Eliminate altitude-crossing RAs issued against intruders leveling off at altitudes 1,000 feet away.
- Eliminate "bump-ups" caused when an intruder levels off from a high vertical rate 1,000 feet away in altitude.
- Eliminate unnecessary RAs generated at low altitudes (e.g., during approach to multiple parallel runways).
- Eliminate unnecessary corrective RAs generated against VFR intruders 500 feet away in altitude.

TCAS III attempts to use the TCAS directional antenna to assign a bearing to other aircraft, and thus be able to generate a horizontal maneuver (e.g. turn left or right). However, it was judged by the industry to be unfeasible due to limitations in the accuracy of the TCAS directional antennas. The directional antennas were judged not accurate enough to generate an accurate horizontal-plane position, and thus an accurate horizontal resolution. By 1995, years of testing and analysis determined that the concept was unworkable using available surveillance technology (due to the inadequacy of horizontal position information), and that horizontal RAs were unlikely to be invoked in most encounter geometries. Hence, all work on TCAS III was suspended and there are no plans for its implementation.

The concept has later evolved and been replaced by TCAS IV. TCAS IV uses additional information encoded by the target aircraft in the Mode S transponder reply (i.e. target encodes its own position into the transponder signal) to generate a horizontal resolution to an RA. TCAS IV replaced the TCAS III concept by the mid 1990s.

One of the results of TCAS III experience was the discovery that the directional antenna used by the TCAS processor to assign a bearing to a received transponder reply is not accurate enough to generate an accurate horizontal position, and thus a safe horizontal resolution. TCAS IV uses additional position information encoded on an air-to-air datalink to generate the bearing information, so the accuracy of the directional antenna would not be a factor.

TCAS IV development continued for some years, but the appearance of new trends in datalink such as ADS-B have pointed out a need to reevaluate whether a datalink system dedicated to collision avoidance such as TCAS IV should be incorporated into a more generic system of air-to-air datalink for additional applications. As a result of these issues, the TCAS IV concept was abandoned as ADS-B development started.

4.5.6.2 Technical Issues

Algorithms designed to instruct pilots not only to climb, but also to turn to avoid conflicts need to be developed to significantly improve the current system. This would eliminate many of the current alerts in safe encounters. Although the system occasionally suffers from false alarms, pilots are now under strict instructions to regard all TCAS messages as genuine alerts demanding an immediate, high-priority response. Wind shear detection and ground proximity warning system (GPWS) alerts and warnings have higher priority than the TCAS. Additionally, TCAS II will automatically fail if the input from the aircraft's barometric altimeter, radio altimeter, or transponder is lost.

4.5.6.3 Operational Issues

In modern glass cockpit aircraft, the TCAS display may be integrated in the navigation display (ND) or electronic horizontal situation indicator (EHSI); in older glass cockpit aircraft and those with mechanical instrumentation, such an integrated TCAS display may replace the mechanical vertical speed indicator (which indicates the rate of aircraft descent or climb).

TCAS is not fitted to many smaller aircraft mainly due to the high costs involved (between $25,000 and $150,000). Many smaller personal business jets, for example, are currently not legally required to have TCAS installed, even though they fly in the same airspace as larger aircraft that are required to have proper TCAS equipment on board. The TCAS system can only perform at its true operational potential once all aircraft in any given airspace have a properly working TCAS unit on board.

4.5.6.4 Institutional Issues

ICAO has circulated an amendment for formal member state agreement which recommends TCAS II Change 7.1 adoption by January 2014 for forward fit and January 2017 for retrofit. Following the feedback and comments from airline operators, EASA proposed the following dates for the TCAS II version 7.1 mandate in European airspace: forward fit (for new aircraft) March 2012, and retrofit (for existing aircraft) December 2015.

4.5.6.5 Future Trends

Research and development efforts are continuing to develop a low-cost proximity warning system for general aviation using GNSS technology. Existing technologies include:

Portable Collision Avoidance System (PCAS): An aircraft collision avoidance system to notify pilots of the nearest transponder-equipped aircraft, its relative height and distance and, most importantly, if the distances are closing or increasing. More advanced systems can integrate with EFIS, overlaying nearby aircraft on the GPS map with relative height information.

FLARM ("flight alarm") obtains its position from an internal GPS and a barometric sensor and then broadcasts this with forecast data about the future 3D flight track. Its receiver listens for other FLARM devices within three to five km and processes the information received.

Key Points:

- Collision avoidance systems monitor the airspace around an aircraft for other aircraft equipped with a corresponding active transponder, independent of air traffic control, and warns pilots of the presence of other transponder-equipped aircraft which may present a threat of mid-air collision.

- TCAS is considered an expensive retrofit for existing aircraft, and since not all aircraft are mandated for TCAs capability, the system will not work at optimum service levels. Retrofit of TCAS over the next ten years will require considerable investment on behalf of operators worldwide.

4.6 Weather Systems

Accurate and timely weather information increases aviation safety during all phases of flight. As flight operations transition from structured routing to user-preferred routing, weather observation and prediction systems will need to incorporate more technological advancements combined with user-friendly features. These new automated weather systems will become essential equipment for the aviation community as weather information from both ground and airborne instruments are incorporated into daily flight operations. This section describes aviation weather systems and presents relevant issues and trends related to the status of the technology and industry. Aviation weather user needs include:

- **Weather information content**: Weather information content needs to be increasingly sufficient in terms of accuracy, timeliness, detail, and resolution consistent with the evolving NextGen functional and performance requirements.

- **Weather information availability:** There needs to be consistent and universal (ubiquitous) access to weather information by aviation decision makers and other users.

- **Weather information consistency:** Even when weather information is available, it can be inconsistent in content or message. There is a need for weather information parity for more effective collaboration across multiple decision makers.

- **Weather translation:** There is a need to translate and integrate weather information and its uncertainties within decision-support constructs to meet evolving ATM operational missions and NAS user business models.

- **Weather predictability:** NAS users find it difficult to interpret and/or understand and effectively plan using current descriptions of weather uncertainty. There is a need to support ATM resource predictability and availability within the context of weather uncertainty.

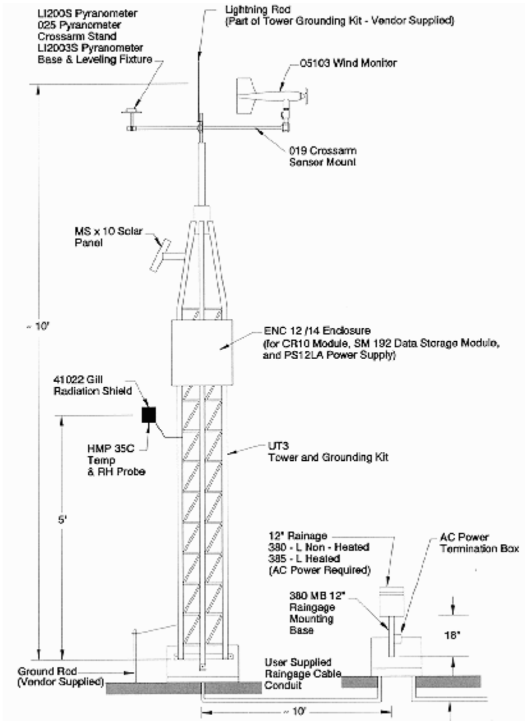
- **Weather information framework:** There needs to be an informational architecture for weather that facilitates growth, flexibility, and tailoring to support NextGen constructs.

4.6.1 Automated Weather Stations

Modern weather observation systems are able to improve the quality of weather data and provide support to, or partly replace, the human observer. Modern automatic weather stations (AWSs) report parameters including: wind speed, wind direction, visibility, runway visual range (RVR), weather type, precipitation, cloud coverage, cloud type, cloud height, temperature, humidity, and air pressure. The function of the airport AWS consists of automatic acquisition, validation, processing, display and distribution of meteorological reports and messages. Figure 4-57 depicts a typical AWS architecture.

AWS systems consist of two basic types of weather sensors: analog and digital. Analog sensors are gradually being replaced by digital. When automating the process of data acquisition and dissemination, it is desirable to use one type of sensor only. Digital sensors are preferable because they make it possible to avoid the conversion of analog to digital signals. The AWS must be capable of interfacing with any combination of sensors to which the following general requirements apply:

Figure 4-57
AWS Architecture



Source: US DOT

- Sensors should not require individual site adjustments.
- Sensors should conform to all fixed transfer functions (although the sensor outputs do not have to be linear).
- Sensors should have a serial digital interface.
- Sensors should have the capability of being tested internally via serial interface.
- Sensors should be operated independently by an AWS so that the failure or replacement of any sensor will not affect the performance of the remaining sensors or the software of the central processing unit.

Transmissometers are used for the measurement of meteorological optical range (MOR), which is necessary for the assessment of runway visual range. Forward scattermeters could also be used for this purpose. The meteorological visibility can be estimated by forward scattermeters. The problem with this method is the requirement to report the lowest visibility when the visibility is not the same in different directions, which is difficult to automate. Furthermore, MOR may not be representative of meteorological visibility during darkness. However, in practice, MOR is measured by the instruments generally used in the AWS visibility reports. For determining cloud height, laser ceilometers are recommended.

The measurement of the present weather is the most problematic. In fact, the sensor for present weather should allow for the assessment not only of visibility but also the type, amount, and duration of precipitation.

Currently, it is necessary for human observers to insert their visual observations of the present weather in the reports. Also, it is important to note that no sensor is currently available for the assessment of cloud coverage. Different studies now underway envisage the use of a combination of data from ceilometers, satellite, and weather radar for this purpose.

Lightning information can be derived from several types of sensors. For aviation, detection of cloud-to-cloud strikes is as important as cloud-to-ground strikes. The software for processing the data is specific for the task and forms part of the lightning detection system often used outside and AWS. Various national meteorological services are developing or have already developed software to present lightning data in an overlay on the presentation of the weather radar data.

The preprocessing of data is partly done in the sensor interface, a small autonomous microcomputer system linking the sensor and the central processing unit. The output from the interface represents a standard message containing the following: raw data produced by the sensor (used for maintenance purposes), calculated data, such as one-minute average or extreme values for the different databases, and sensor status data (used for operational and maintenance purposes). Sensor status data provide judgment on the functioning of the sensor itself. The human observer can overrule the sensor data only when it is evident that the sensor produces faulty values.

The interface should be constructed so that when changing a sensor for another type, only the input module of the interface has to be changed. That means that the software of the interface must also be designed in a modular way. The advantage of this approach is that the sensor replacement does not affect software. Data communication between sensors and the CPU can be achieved, for example, by repeating messages or using special protocols. The CPU is the heart of the system and automatically collects data from field sensors, performs calculations and coding, generates and distributes messages, and serves user interfaces.

Data storage is also required. Data from different airports and observation stations should be stored at only one location, in a central database having a safety backup. The central database can be connected by a network of fixed lines to the various data acquisition systems. The data communications, the sensor interface, and data acquisition processor software must be built so that remote maintenance of sensor, interface, and processor can take place from one central office.

The software in every sensor interface module and data acquisition system used in automated observation should be identical regardless of location or country. However, nearly every country has, or is developing, software specified to its own special needs. Therefore, while it is desirable, it is very difficult to standardize the processing software.

Weather data reports and messages are distributed to a variety of users and systems. Message transmission hardware can be a switching system which is part of a larger network extending beyond the airport boundaries. Data communication to external devices should use a standard protocol. Data is presented on CRTs or printers at different locations. Color graphics monitors are replacing analog recording devices. The color graphics display enables the observer and the aeronautical meteorological forecaster to obtain swift access to the date required for his/her evaluation and subsequent development of trend forecasts. Master control interventions can be prompted by the operator.

4.6.1.1 Technical Issues

The automated observation of ceiling as well as cloud type, cloud coverage, weather type and meteorological visibility remain a problem for which suitable algorithms have yet to be developed. Humans are still needed for observing those parameters which cannot be measured automatically and also for controlling the automatic observation process and performing the validation of its results.

4.6.1.2 Operational Issues

As AWS systems continue to proliferate, especially at international airports, these systems must be able to disseminate information not only to other ground facilities, but also to the aircraft. Therefore, airports must ensure that system utility is maximized by implementing only open system architectures capable of transmitting information on future air-to-ground datalink systems such as VHF TDMA or Mode S.

4.6.1.3 Institutional Issues

The software in every sensor interface module and data acquisition system used in automated observation systems should be identical, regardless of location or country. Standards need to be developed by international working groups in this area to reduce interoperability issues and lower costs by promoting standard COTS software and firmware.

4.6.1.4 Future Trends

Open architectures will be the prime feature that dominates the AWS market within five years. Modular design for system expansion and interoperability with other weather sensors and sources will be prime features. User-friendly, graphical color displays operating in a windows environment will also be an important feature. Certain information from future AWS systems will need to be available for other airport systems to ensure aviation safety. For example, wind speed, direction, and visibility should eventually be integrated with airport configuration management software to automatically suggest appropriate runway configurations or activate relevant airfield lighting equipment.

4.6.2 Wind Shear and Air Turbulence Detection Systems

US National Transportation Safety Board (NTSB) statistics indicate that the total number of turbulence-related accidents over the past 30 years, while declining slightly, is still quite substantial. The financial cost incurred by the airlines due to turbulence is also large. Based on some rough estimates by air carriers, which took into consideration passenger and flight attendant injury claims, a single serious encounter can cost an airline up to $1 million. Gust loading is a significant component in the structural design and certification of aircraft. A number of considerations must be taken into account in this process: catastrophic failure due to extreme encounters; lifetime accumulated fatigue; and satisfactory performance qualities. In order to simultaneously meet these design needs, adequate knowledge of the turbulence environment must be available.

Turbulence has a significant impact on flight efficiency in the tactical and strategic use of airspace. This impact is directly related to the aircrew's desire to avoid impending turbulence encounters and the lack of definitive planning information to help pilots know where to expect these encounters. Results include delays as aircraft change routes and altitudes to avoid encounters, accompanying increases in fuel consumption, and additional workload for pilots and controllers as they coordinate these changes. Current systems do not have the capability to conduct effective strategic and tactical airspace management planning. Routes that appear to be clear of turbulence can begin to experience problems with no warning, often providing traffic managers with major blocks of unusable altitudes after aircraft are enroute. The breakdown in planning is passed on to pilots and controllers to handle on a reactive basis with large numbers of aircraft competing for the available routes and altitudes.

One of the keys to reducing the impact of atmospheric turbulence on aviation is the ability to provide timely and accurate detection information to pilots, airline dispatchers, and ATC personnel. Currently, the only available source of detection data is pilot reports. Automated reporting of meteorological data from commercial aircraft is an extremely valuable source of information for the operational aviation community. Currently, the ACARS and SITA provide access to wind and temperature measurements from commercial aircraft. Advances in datalink technologies, combined with the future implementation of ADS, will provide wider access to this data. Augmenting the qualitative, intermittent, and subjective pilot reports with quantitative, automated, and aircraft-independent turbulence measurements is a high priority within both the air traffic and meteorological communities.

A critical weather service function is the prediction of wind shears in terminal areas. Airport wind shear detection systems consist of a series of anemometers at fixed positions around an airfield which alert controllers to sudden windspeed changes of more than 30 knots. Systems which are currently being implemented consist of a wind sensor located at center field, five sensors near the periphery of the airport, and a computer which processes sensor information. The alert systems provide an alarm to the controllers specifying the location of the wind-shear above the runway and the loss or gain in air speed caused by the occurrence. Controllers then relay this information by voice to pilots. Long-term modifications planned for this system include adding more sensors, correcting sensor height to reduce sheltering, developing improved algorithms, providing runway-oriented wind shear information, and providing new data/alert displays.

An active wind shear detection device is the Doppler weather radar. Doppler radars give controllers one or two minutes warning of a possible microburst with a 98 per cent detection rate. Doppler radars also provide controllers with gust-front and wind-shift predictions, giving tower staff 40-50 minutes warning when changes in the wind profile are likely. By using the information to reconfigure approaches, aircraft will reduce their fuel burn rate by avoiding problematic conditions.

4.6.2.1 Doppler Radars

Doppler radars have shown great potential in accurately detecting a wide variety of turbulent phenomena. Doppler radars are active detection systems that transmit electromagnetic or acoustic energy and estimate turbulence parameters from information contained in the back-scattered signal. There is a direct correlation between radar characteristics (e.g., transmitted frequency or power) and the atmospheric regimes that can be probed (e.g., convective boundary layer or clear-air, upper atmosphere).

The electromagnetic Doppler systems are further categorized by the wavelength of the transmitted signal: microwave, UHF, or VHF, infrared and optical. The characteristics of a given radar system determine both the type (e.g., clear-air or precipitation-environment) and the area coverage of turbulent airspace that can be detected. For example, a compact airborne optical radar (LIDAR) system would most likely be low-power, hence its coverage range in front of the aircraft would be correspondingly limited. A high-power, ground-based microwave Doppler radar may have a large coverage area and provide good information concerning cloud dynamics, yet only provide limited clear-air information.

A network of ground-based, scanning, microwave Doppler radars called weather surveillance radar (WSR) is a primary source of weather information. Modern weather radars are mostly pulse-Doppler radars, capable of detecting the motion of rain droplets in addition to the intensity of the precipitation.

NEXRAD (Next-Generation radar) is a network of 159 high-resolution, S-band Doppler weather radars operated by the National Weather Service, an agency of the National Oceanic and Atmospheric Administration (NOAA) within the US Department of Commerce. Its technical name is WSR-88D, which stands for Weather Surveillance Radar, 1988, Doppler.

NEXRAD detects precipitation and atmospheric movement or wind. It returns data which when processed can be displayed in a mosaic map showing patterns of precipitation and its movement. The radar system operates in two basic modes, selectable by the operator — a slow-scanning, clear-air mode for analyzing air movements when there is little or no activity in the area, and a precipitation mode, with a faster scan for tracking active weather. NEXRAD has an increased emphasis on automation, including the use of algorithms and automated volume scans.

These radars provide excellent coverage of wind shear information and general lower level atmospheric information involving precipitation. Recognizing the potential for obtaining turbulence information from these radars, numerous research studies and algorithm development efforts have been conducted. These efforts have shown promise. However, a reliable operational turbulence algorithm has yet to be developed.

A fundamental issue with the WSR-88D radars is the ability to detect turbulence at the cruise altitudes flown by commercial transports. Obtaining reliable wind information from microwave Doppler radars requires a sufficient amount of a certain class of atmospheric scatterers such as precipitation. The ability to detect turbulence with convective systems has been successfully demonstrated. Sufficient clear-air return is in general limited to the lower elevations. Therefore, the detection of clear-air turbulence at cruise altitude with the WSR-88Ds is problematic.

These vertically-pointed radars, also known as wind profilers, are currently providing valuable wind information to the operational meteorological community. The wind profilers transmit beams in three directions: vertical, and 16 degrees from the vertical to the north and east, respectively. Research is underway to develop operational algorithms that can extract turbulence information from these profilers. While the wind profilers will be able to detect clear-air turbulence at the cruise altitudes of commercial aircraft, the spatial extent of this detection region will be quite limited. In contrast to the WSR-88D systems, which scan a relatively large volume of the atmosphere, the three-beam profiler will only provide information in a narrow region above the device.

Digital radar systems now have capabilities far beyond that of their predecessors. Digital systems now offer thunderstorm tracking surveillance. This provides users with the ability to acquire detailed information of each storm cloud being tracked. Thunderstorms are first identified by matching precipitation raw data received from the radar pulse to some sort of template preprogrammed into the system. In order for a thunderstorm to be identified, it has to meet strict definitions of intensity and shape that set it apart from any non-convective cloud. Usually, it must show signs of organization in the horizontal and continuity in the vertical: a core or a more intense center to be identified and tracked by digital radar tracking systems. Once the thunderstorm cell is identified, speed, distance covered, direction, and estimated time of arrival are all tracked and recorded to be utilized later.

4.6.2.1 Technical Issues

Reliable turbulence algorithms must be developed in order for ground-based Doppler radars to detect turbulence at the cruise altitudes flown by commercial transports. Numerous research studies and algorithm development efforts have been conducted with disappointing results.

4.6.2.2 Operational Issues

Wind shear and air turbulence information will continue to be provided with a wide range of systems in the long-term. Airline, airport, and ATC/ATM services must ensure that information from these systems is capable of being integrated and displayed in the cockpit and on the ground in a user -friendly manner to be useful.

4.6.2.3 Institutional Issues

Aviation and weather organizations must continue to work towards development of standard weather-data information formats to encourage innovative use of weather information and systems.

4.6.2.4 Future Trends

Many countries are experimenting with wind shear and turbulence warnings and prediction systems. The Low Level Wind Shear Alert System (LLWAS) is designed to detect low level wind shear conditions around the periphery of an airport. Terminal Doppler Weather Radar (TDWR) is a Doppler weather radar system used primarily for the detection of hazardous wind shear conditions on and near major airports in the US.

4.6.3 Weather Dissemination and Display Technology

Advances in computers, weather sensors, and software have created a significant expansion in weather technology. Advanced systems are required to present controllers, airlines, and operators with tremendous amounts of meteorological data from a wide variety of sources, including: radar, satellites, wind profilers, acoustic sounders, and manned and automated weather observation stations. These systems use satellite downlinks to provide high-speed transmission of graphic weather charts at low costs. For example, the World Area Forecast Center (WAFC) provides standardized, high-quality global forecasts of upper winds, temperatures, and significant weather, which is transmitted to the aviation community through satellite broadcasts.

Direct broadcast service (DBS) offers high-speed satellite transmission relays of continuous radar weather information from virtually any connected source. Aviation weather personnel can receive information from any location and receive continuous updates within one to two minutes. These transmission mediums provide weather information to display subsystems for analysis by appropriate personnel. The display systems display composite radar updates, a mosaic of many individual radars that are remapped to a common background. This capability allows observers to see and analyze the organization of weather systems by viewing precipitation on a very large scale (e.g., 600-800 NM wide) rather than just the display of one radar (240 NM wide).

Additional graphics capabilities include the ability to zoom and scroll across any graphic image to allow closer analysis of map details that may otherwise be overlooked, and the ability to position a cursor anywhere on the image and display information such as cloud top temperature and altitude. Special software enables interested users to identify atmospheric conditions which are potentially threatening to the aviation community so that appropriate warnings can be disseminated within a reasonable amount of time.

4.6.3.1 Technical Issues

System integration is a key technical issue. Aviation weather forecasters have access to a wide variety of weather system information from multiple sources. These systems must be capable of sharing information to validate data and provide the most accurate, timely, quantitatively derived forecast. Therefore, systems must be designed to be flexible for future integration with additional weather sensors and be able to receive and disseminate data via standard aviation datalinks.

4.6.3.2. Operational Issues

As ADS, GNSS, and the initial stages of TBO are implemented, a greater amount of user-specific weather information must be made available to ATC/ATM organizations and the airlines. Creating this user-specific information will require a greater amount of information from a greater variety of weather sensors and sources. User organizations must ensure that they procure compatible systems that can be networked to compile and disseminate weather information. Systems must be modular, flexible, and available as commercially available packages to reduce costs and increase utility.

4.6.3.4 Institutional Issues

Deregulation of aviation weather services will provide strong incentives to provide higher levels of customer service and innovation in the weather forecasting industry. Resources required to develop new and innovative products and services can be facilitated by greater deregulation.

4.6.3.4 Future Trends

The combination of greater computer processing power for less money, high-volume data communications, and focus on customer requirements is leading to innovative provision of tailored weather information to aviation users. For example, systems that compile weather information from various sources to target specific routes of flight and flight profiles are transforming standard weather data into specialized user forecasts. System vendors who can provide some type of value-added service by transforming standard weather information into tailored customer-specific needs by adapting software to run on common PC platforms will gain increasing market share.

Within NextGen, the Next Generation Network-Enabled Weather (NNEW) project aims to develop a four-dimension (all points, lateral, vertical, and time dimensions) weather data cube (4-D Wx data cube) from disparate contributors and locations. NNEW will provide fast access to weather information to all NAS users by the provision of the 4-D Wx data cube, which will consist of:

- A virtual weather network containing data from various existing databases within the FAA, NOAA, and the US DOD, as well as participating commercial weather data providers.
- The ability to translate between the various standards so that data can be provided in user required units and coordinated systems.
- The ability to support retrieval requests for large data volumes, such as along a flight trajectory.

Key Points:

- Weather information delivery is an increasingly important component of aviation, with major implications for both safety and cost.
- Predictive weather-modeling capabilities are highly valued by the aviation community and have the potential to add substantial value to future ATM.