Journal of Aviation/Aerospace Education & Research

Volume 13
Number 3 *JAAER Spring 2004*

Article 3

Spring 2004

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FORUM

EXISTING AND POTENTIAL IN-FLIGHT ENTERTAINMENT TRANSMISSION SYSTEMS – STRENGTHS AND WEAKNESSES

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ABSTRACT

In-flight entertainment is likely to greatly expand its content over the next few years, mirroring changes that are occurring in terrestrial digital entertainment and communication systems. Most in-flight entertainment systems have been based on either in-plane, aircraft-to-ground, or aircraft-to-satellite technologies. The expansion of content expected in the near future will require advanced transmission systems that will be both technically and commercially able to deliver broadband services. This paper explores the strengths and weaknesses of existing transmissions technologies and suggests aircraft-to-aircraft transmission technology may offer advantages that other systems do not.

While most people associate in-flight entertainment (IFE) with airplane video and audio channels accessed from an armrest, the types of entertainment available on commercial aircraft are likely to abruptly change over the next decade. Reflecting these likely changes, the World Airline Entertainment Association defines in-flight entertainment (IFE) as including communications (telephony, fax, e-mail, data links), information (news, weather, stock quotes, Web content), and interactive services (video games, shopping/e-commerce, surfing the Web), as well as the traditional audio and video entertainment. The increasing emphasis on new types of digital applications is an indication of the promise of IFE as a powerful marketing tool for commercial airlines, especially since the success of JetBlue Airline's 24-channel television network introduced in April 2000. Economic slowdown and the events of September 11, 2001 have negatively impacted the global and domestic demand for in-flight entertainment, particularly for commercial aircraft, but an upturn in the industry may be associated with the introduction of new IFE applications in an attempt to replicate the success of JetBlue Airlines. Frost and Sullivan Inc. estimate that by 2007, IFE revenue will grow to $7.4 billion (IPECC, 2002). United Airlines in their in-flight magazine suggest there might be operational cost and customer service synergies from IFE introduction too (Kim, 2003). This paper reviews how these future IFE applications will be transmitted to aircraft and suggests that current transmissions systems may not be the best conduit for them.

Background

There are two types of IFE applications from a content-provider perspective: in-plane and out-plane. In-plane content consists of those applications that can be provided from technology that is stored in the aircraft, such as video and DVD players, and computer servers. Out-plane content consists of applications that can only be provided by technology that exists outside the aircraft and is transmitted to the aircraft through wireless communications. Two types of out-plane communications are used today: aircraft-to-satellite-to-ground, and aircraft-to-ground.

Until 1984, all in-flight entertainment in commercial aircraft was in-plane. In 1984, Verizon Inc. introduced the 'Airfone', which offered passengers a wireless aircraft-to-ground telephone system for domestic flights, first from a location at the back of the airplane, then in a seatback version three years later. The technology to make the Airfone work is an antenna installed under the belly of the aircraft that communicates with a ground-based network of approximately 135 ground stations located around the U.S. to link the aircraft with the telephone network. Each transmitter has a reach of 200-250 miles.

Nearly 5,000 aircraft worldwide had telephone systems by 2000. The air telephone market showed great promise initially, but has recently declined due to the terrestrial cell phone revolution in the late 1990s, which enables passengers to make relatively cheap calls immediately before their flight and after they deplane. Also hampering the success of the airfone are the high connection and use charges, currently about $4 per connection and $4 per minute, and the relatively poor reception of in-flight telephone technology. This has led some airlines, including American and Southwest Airlines, to take out their seat-back telephones. However, since cellular telephones cannot be used during flight because of their perceived possible interference with aircraft navigation systems and their undoubted interference with ground telephone systems, there remains significant demand for telephone communication in-flight, especially on long trips. Unlike cellular phones, aircraft installed telephones' signals are shielded and rigorously tested by the FAA for interference, thus leading to a major expense associated with their use. Air-to-ground transmission can also now be used for sending e-mail. Tenzing, in association with Verizon, has developed a narrowband system where a passenger plugs their laptop computer into the aircraft telephone and dials an on-board server (Acohido, 2003). The laptop can transfer e-mail at 56 kbs to the server, which stores and compresses bundles of messages and then sends them every 10-15 minutes to a ground server and relayed to the Internet. Seven major airlines have demonstrated Tenzing's e-mail service. According to the WAEA, the airfone UHF-based system is limited in the bandwidth it can supply, due to the limited allocations made to them by the FCC, and broadband service is not possible under the existing system. To make broadband service available, new frequencies would have to be allocated by the FCC. Also fiber optic or T-1 cable lines that can deliver broadband would be required to hook up with the 135 ground stations. Fiber optic cable currently costs $3 million per mile to install. Antenna systems would also be very expensive, since antennas would need to track each aircraft across the sky.

Satellite Broadband Technology

The slow speed of data transmission and the high costs of aircraft-to-ground systems have led many to believe that future content applications will be based on satellite broadband technology. Companies such as SITA, Thales Avionics, General Dynamics, Rockwell Collins, Tenzing, and Connexion (a Boeing Inc. subsidiary) have all developed satellite-based technology that will bring applications such as text messaging, satellite television and radio, e-mail and full Internet service to commercial aircraft. Lufthansa and British Airways have already tested Connexion's Internet service, and American Airlines and Delta have been in negotiation with Connexion for future service.

Today's global satellite industry began in the 1950s as an urgent response by the United States to the threat of Soviet military power. Throughout the Cold War, satellite technology rapidly evolved for national security objectives, intelligence operations, and the detection and tracking of intercontinental ballistic missile launches. By the end of the Cold War in the 1990s, thousands of unwanted satellites were in orbit around the Earth and commercial wireless communications technology was recognized as a potential business opportunity to make use of them.

Three groups of satellites are often identified, GEO (geo-stationary Earth orbit), MEO (medium earth orbit) and LEO (low-Earth orbit) satellites. GEOs have an altitude of approximately 22,400 miles, a height that allows them to orbit at the same speed as the earth, thus giving the appearance of being stationary. MEOs orbit between 6,000 and 20,000 miles, (the global positioning system satellites orbit at about 12,000 miles) while LEOs orbit the Earth at an altitude of between 500 and 2,000 miles. The lifespan of all these satellites is limited because of the degrading impact that interference has on their orbits. LEOs have a life-span of about 5-10 years before they burn up in the Earth's atmosphere, MEOs have a life span of around 8-12 years and GEOs 12-17 years before they succumb to earth's gravity.

Each of these satellite types have strengths and weaknesses. GEOs are good at delivering broadcast signals like television to end users within a continent, and because of their high altitude need only three satellites to cover the entire earth. Advanced broadcast satellites are expected to have multiple beams, each delivering unique "local content" over a larger area. GEO satellites can also be very effective at transferring large data files across countries and between continents, if high latency is acceptable to the customer and high data rates are desired on a dedicated basis. Most communication satellites are GEOs because of the simple receiving antenna requirements, that can be pointed at satellites in a fixed position without the need to track.

MEO and LEO satellites orbit the Earth at a faster rate than the earth's rotation, and because of their proximity to the ground, have significant advantages over GEOs for voice and data communication. Because of their orbit speed, to offer uninterrupted data services, many satellites must be deployed in multiple rings, and special protocols are needed to "hand off" all of the end users from one satellite leaving the region to the next satellite entering that region. At any instant of time, several communication nodes of the MEO and LEO constellation will be over oceans, mountains, and deserts, and not over cities. To make inter-continental communication a reality, LEOs need a constellation of up to a hundred satellites in operation, while MEOs require 10-15, depending on their altitude, and consequently the network is more complex than a GEO satellite system. The financial commitment to make these constellations complete is large, as demonstrated by the bankruptcy problems faced by Iridium LLC that used a LEO constellation, and ICO that used a MEO constellation.

The GEO, MEO and LEO satellite constellations also have some similar problems. Satellites degrade steadily through the damaging effects of ionizing radiation of solar and cosmic rays, though LEOs are somewhat protected by the Van Allen belts above them, and from thermal stresses occurring when the satellite moves from Earth's shadow to direct sunlight and then back to Earth's shadow again every orbital period. This constant degradation has led to many satellite failures, requiring several back-up satellites in space. The cost of replacement through satellite launches is very expensive. Iridium satellites which were sent into a low-Earth orbit, had launching costs of about $20 million per launch (Kadish and East, 2000) and 60-70 are needed to cover Earth. GEO satellites have a much higher altitude and their launch costs are exponentially higher. Koelle (2003) estimates the average transportation cost of putting a GEO satellite in space to be $57.6 million at a rate of $36,000 per kilogram. There are even higher expenses for satellite manufacture, insurance, research, development and ground station financing. The slight wandering of a GEO satellite and the very narrow beam of the signal requires the continual pointing of the transmitting antenna to track the satellite, which makes a ground station extremely expensive. Kadish and East (2000) estimated total system costs for a GEO INTELSAT communications satellite at $1 billion, while Sturza (1995) noted the total contract cost of the 12-satellite ICO constellation in MEO orbit with Hughes Inc. at $2.6 billion. As mentioned previously, the lifespan of satellites is also low, which means that the high launch and development costs have to be repeated at regular intervals. Because of the harsh space environment, satellites can get zapped by solar flares, meteoroids can damage solar panels and antennas, and charged particles can damage integrated circuits. (Kadish & East, 2000).

Satellites also have a number of weaknesses from an operational perspective. Satellites are susceptible to noise and interference. Microwave signals travel through the Earth's atmosphere and ionosphere on the uplink to the satellite and on the downlink to an aircraft, and both have a negative impact on a signal strength, with an average loss of at least 200 decibels. The atmosphere contains air, water vapor, clouds, rain and snow, all of which can increase signal attenuation. GEO satellites, because of their high altitude, also have propagation delays associated with them that make them inappropriate for real-time applications that need low delay capabilities, such as video conferencing, and inconvenient for voice transmissions, although they are appropriate for one-way transmissions such as television broadcasting or one-way e-mailing. Consequently, GEO satellites are less desirable than terrestrial networks for cellular telephony or performing highly interactive collaborative work.

Bandwidth issues are also a problem with satellites. Satellite systems are shared networks and every use of the system consumes bandwidth; the more users there are, the less bandwidth there is for any single user. The competition for satellite bandwidth is global, so, as more users begin using a satellite service and more high-bandwidth streams for audio and video are transmitted, overall per user capacity will drop. To an end user, this means that although the downlink and uplink bandwidth is configured for a certain speed, the actual speed of data coming to the user from the satellite and vice versa depends on the total amount of bandwidth the satellite is handling at that moment and how much it can dedicate to the user. Stern (2003) illustrates this issue in describing the 2003 Iraq War information technology needs of the U.S. military, which has created a shortage of communication satellite bandwidth. Typically, to increase the power and bandwidth from a satellite requires a larger, and thus heavier, satellite (Nguyen, 2003). However, increasing the weight of the satellite adds to the cost of the launch. Indeed, the maximum weight of a satellite is often capped by the lift capability of the launch system. Satellite communications companies have not been able to compete effectively with terrestrially based telephonic companies. During the 1990s, satellite communications was solely telephony, and after failing to successfully compete with terrestrial companies in urban areas, satellite companies looked to find a niche in rural and third world countries without telephone service. However, because these areas are sparsely populated and/or poor, demand has been weak. ICO Global Communications filed for bankruptcy in August 1999 and was bought out of debt in November of the same year by Craig McCaw, part owner of Teledesic. Teledesic stopped operations in October 2002 without ever launching a satellite, while Iridium Inc. filed for Chapter 11 bankruptcy in December 2000. Iridium emerged in March 2001 free from the $5 billion debt incurred in launching satellites and with a $72 million contract from the U.S. Dept. of Defense (Trimble 2001). This combination of debt write-off and multi-year revenue guarantee has enabled it to survive, but unable to expand, especially with $3,000 telephone handsets (Bedell, 2001). Globalstar L.P. filed for Chapter 11 bankruptcy in November 2001 and is still operating under that status.

The promise for satellites is that they would be able to provide wireless broadband access to computers. The lack of demand for satellite service is due to the fact that wireless broadband applications have not yet become ubiquitous in the way that wireless telephone systems have, and that satellites have not competed successfully with terrestrial systems.

Satellite and Relay Applications for Aircraft

To-date, satellite applications that have been developed for commercial aircraft over the past few years reflect the applications developed on the ground.

Satellite communication systems require antennas on top of the aircraft to communicate with satellites orbiting over the Earth. The satellites, in turn, switch the frequency of the signal and relay it to a ground station, which is then sent to a standard terrestrial wireline network.

To send and receive a signal to GEO satellites, Connexion is using an antenna on top of the fuselage measuring approximately 5'x3'x2.5". Besides creating drag that reduces fuel efficiency, the antenna cannot maintain a signal beyond the 63 degree latitude. Boeing is working with Mitsubishi to build an antenna that will be able to maintain a signal as far as 75 degrees north, but will be a foot above the roof of the plane, creating more drag (Merritt, 2003).

An alternative to providing internet services by satellite or from the ground is to provide them to commercial aircraft via a string of connected aircraft linked to one ground station. The service would work by providing a microwave link from a ground station to a nearby commercial aircraft in the sky, then relay that link between aircraft along a corridor in a chain-like fashion, with each aircraft in the chain acting as a repeater. The range of a radio signal is limited to line-of-sight to the horizon and can be calculated as:

1.23 x sq. root (altitude of aircraft)

At 30,000 feet the horizon is 173 miles and at 40,000 feet it is 246 miles. Two aircraft at 40,000 feet can therefore potentially be linked by line-of-sight when they are 492 miles apart.

A chain of connected aircraft could be created between regions, with each aircraft thus able to offer the same range of digital entertainment that now can only be offered by satellite. Ultimately, a constellation of connected commercial aircraft could provide IFE to each aircraft within the system. Using the nation's busiest air corridor and the dominant airline in that corridor as an example (Jet Blue's north-south eastern seaboard corridor schedule), Table 1 below documents the gaps between two outbound north-eastern U.S. locations and seven destinations in Florida and Puerto Rico. With Jet Blue's current schedule, only three gaps exist that are greater than the range of a microwave signal at 30,000 feet. Thus with a minor schedule adjustments, Jet Blue could maintain a wireless communications corridor for all flights within the corridor.

Table 1

Jet Blue Schedule N.E. US – Florida/Puerto Rico

(March 6, 2004)

Flight #	Departure Time	Departure Loc'n	NYK Dep.	Gap (mins)	Dest'n
367	6:05	JFK	6:05		FLL
381	6:10	JFK	6:10		MCO
165	6:35	JFK	6:35		TPA
17	6:40	JFK	6:40		FLL
353	7:05	JFK	7:05		PBI
347	7:10	JFK	7:10		FLL
429	6:45	BOS	7:14		MLO
441	7:00	BOS	7:29		TPA
401	7:30	JFK	7:30		SJU
25	7:45	JFK	7:45		FLL
66	8:10	JFK	8:10		RSW
37	8:20	JFK	8:20		PBI
45	8:20	JFK	8:20		MCO
19	8:20	JFK	8:20		FLL
23	8:35	JFK	8:35		TPA
411	8:45	JFK	8:45		SJU
343	9:10	JFK	9:10		RSW
41	9:20	JFK	9:20		MCO
39	9:20	JFK	9:20		FLL
355	9:40	JFK	9:40		PBI
349	10:20	JFK	10:20		FLL
63	10:30	JFK	10:30		RSW
65	10:35	JFK	10:35		TPA
57	10:40	JFK	10:40		PBI
59	10:45	JFK	10:45		MCO
1	10:50	JFK	10:50		FLL
431	11:10	BOS	11:39		MLO
453	11:20	BOS	11:49		FLL

Flight #	Departure Time	Departure Loc'n	NYK Dep.	Gap (mins)	Dest'n
69	13:00	JFK	13:00	61	MCO
51	13:10	JFK	13:10		PBI
27	13:10	JFK	13:10		RSW
3	13:15	JFK	13:15		FLL
53	13:35	JFK	13:35		TPA
31	14:00	JFK	14:00		MCO
81	14:10	JFK	14:10		FLL
385	14:45	JFK	14:45		FLL
435	14:25	BOS	14:54		MLO
403	15:05	JFK	15:05		SJU
447	14:50	BOS	15:19		TPA
9	15:30	JFK	15:30		FLL
391	16:05	JFK	16:05		RSW
77	16:20	JFK	16:20		PBI
21	16:25	JFK	16:25		TPA
351	16:30	JFK	16:30		FLL
359	17:20	JFK	17:20		MCO
357	17:20	JFK	17:20		PBI
49	17:25	JFK	17:25		FLL
341	18:50	JFK	18:50	85	RSW
35	18:55	JFK	18:55		PBI
29	18:55	JFK	18:55		TPA
47	19:00	JFK	19:00		FLL
43	19:10	JFK	19:10		MCO
455	19:10	BOS	19:39		FLL
437	19:40	BOS	20:09		MLO
407	21:10	JFK	21:10	61	SJU
79	21:15	JFK	21:15		MCO
11	21:25	JFK	21:25		FLL

Inbound flights to JFK would likely be unable to communicate with outbound flights because of the doppler effects of a perceived increase in frequency as one object gets closer to another. Even with full cooperation between airlines, there are likely to be gaps for night-time flights, that would require extra ground stations to overcome. Research is required in this area to identify where gaps exist in the commercial aircraft constellation, and where extra ground stations or satellite back-up would be required to provide full coverage.

Table 2 below compares the strengths and weaknesses of aircraft-to-aircraft relay station technology with satellite and ground-to-aircraft technology. Typically, because of shorter distances and less equipment involved, aircraft-to-aircraft relay technology can provide a cheaper and better quality of service. Aircraft-to-aircraft relay technology is cheaper to install than satellite or ground-to-aircraft systems and would have lower operating costs. Launching costs of commercial aircraft would be essentially zero, since in the absence of relay equipment aircraft would be launched anyway to serve their primary function, that of carrying passengers. Also, because aircraft (unlike satellites) do not operate in a hostile space environment and are not aloft for years, communications equipment should be expected to last longer and maintenance and repair of equipment would become routine and be inexpensive. The quality of service would also be expected to be better. GEO satellites have a delay of half a second which is a significant disadvantage for audio and video communication and with existing Internet (TCP/IP) and data communication protocols used on computer networks.

However there are a number of problems with providing in-flight entertainment by aircraft-to-aircraft relay technology. The first is that in order for an aircraft to receive a microwave signal, it must be within approximately 500 miles of another aircraft receiving a signal. While this is likely to be the case if an aircraft is flying in a highly used corridor such as the U.S. East-coast north-south corridor, it is not the case if an aircraft is flying in North Dakota. Thus not all domestic aircraft are likely to be connected within one large constellation, and in order for all commercial aircraft to be able to offer in-flight entertainment, there would have to be a significant number of ground stations or back-up satellite system to service them.

Secondly, the number of aircraft in the air is dependent on the time of day. While during the rush hour periods in the morning and late afternoon, there is likely to be a large enough aircraft pool to form a large constellation, at other times of day the constellation may be significantly smaller. Similarly, aircraft are subject to many last-minute flight delays and cancellations. This makes individual flights very unreliable, though in the context of a large constellation, perhaps not catastrophic. Thus, because there are so many aircraft in the sky at one time, the signal path to individual aircraft can be quite flexible, and not necessarily dependent on a straight line corridor. Thirdly, like satellites, aircraft are subject to signal attenuation because of weather, although because distances between aircraft are shorter than satellite-to-aircraft distances, attenuation might be expected to be less.

Table 2

Comparison Between Aircraft-to-Aircraft, Ground-to-Aircraft and Satellite Connection

	Aircraft-to Aircraft Linkup	Satellite Linkup	Ground-to-Aircraft Linkup
Launch Cost	N/A	Very High	N/A
Installation Time	Low	Low	Low
Installation Risk	Low	Very High	Low
Installation Cost	Low	High	High
Maintenance Cost	Low	High	Low
Equipment Life	Long	Short	Long
Potential Bandwidth	High	Low	High
Propogation Delay	Good	Bad	Good
Data Integrity	Good	Poor	Poor
Voice Quality	Good	Poor	Good

Despite the weaknesses of aircraft-to-aircraft relay technology, the greatest advantages over satellite transmission are latency and cost. Without the expenses involved in launching, manufacturing, maintaining and insuring satellites, aircraft-to-aircraft relay technology can offer good service at a fraction of the cost of satellite in-flight entertainment and without the major problem of satellite-based IFE: latency. The greatest advantages of aircraft-to-aircraft over ground-to-aircraft are the fewer and simpler ground stations required, with a resultant cost advantage.

Latency will likely become a much larger problem with future IFE systems when video and audio communications become the norm. According to Scheets and Allen (1999), future Internet service is likely to be more multi-media based. They suggest that networks that can most effectively satisfy the user's requirements will provide the service at the lowest cost and that consumers will have low levels of tolerance for loss and delay of signal. Similarly, Bedell (2001) suggests that the future of wireless will be of convergence, with one operations platform carrying voice, video, and data. With one content provider to manage and maintain a system, training and human resource requirements will be reduced, and consequently costs will too. Beaulieu (2002) suggests that the many forms of communication (telephony, facsimile, e-mail, voice mail, web) will consolidate into one unified messaging system. If in-flight entertainment architecture reflects the convergence expected on the ground, satellites will not be able to provide all services and an alternative content provider will be necessary, and that content provider may be a company that can provide aircraft-to-aircraft relay service.

The future of IFE is likely to reflect the dramatic changes that are occurring in entertainment systems on the ground. The advances being made in wireless technology make new IFE applications technically possible today. The potential low cost and high quality of aircraft-to-aircraft relay systems may make this technology preferable to the aircraft-to-ground and aircraft-to-satellite systems being marketed today. In a future world, where latency in IFE is deemed intolerable, aircraft-to-aircraft relay systems may be the economic choice for commercial aircraft in-flight entertainment.

Keith Mew has been employed in the aviation industry for about 20 years, initially as an airport employee and consultant, working with and for the Chicago airport system, and later as a university professor. He is a graduate of Thames Valley University and Coventry University in England and the University of Warsaw, Poland where he obtained his Ph.D. From 1983-7 he was Assistant Professor of Aviation Administration at Indiana State University, and currently he is Professor of Aviation Administration in the Technology Department at California State University, Los Angeles. His research interests have been in the area of airport finance and more recently aviation communications.

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