satcom direct

AERO CONNECTIVITY CONSIDERATIONS IN A MULTI-ORBIT LANDSCAPE

ABSTRACT

Key considerations for evaluating aero connectivity solutions to optimize the longevity of your investment.

MARCH 2023

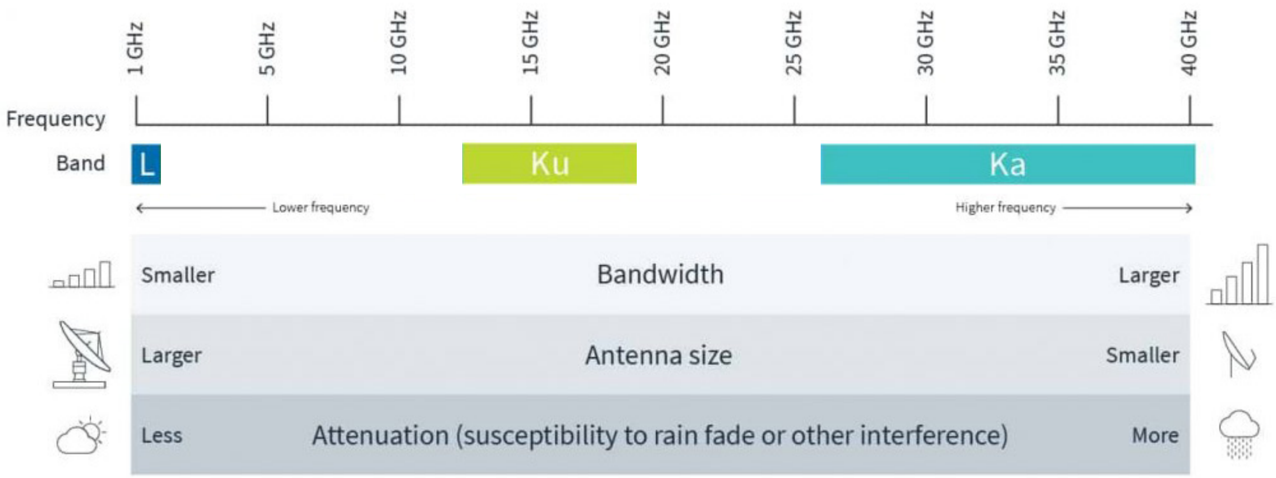
Introduction

Overview

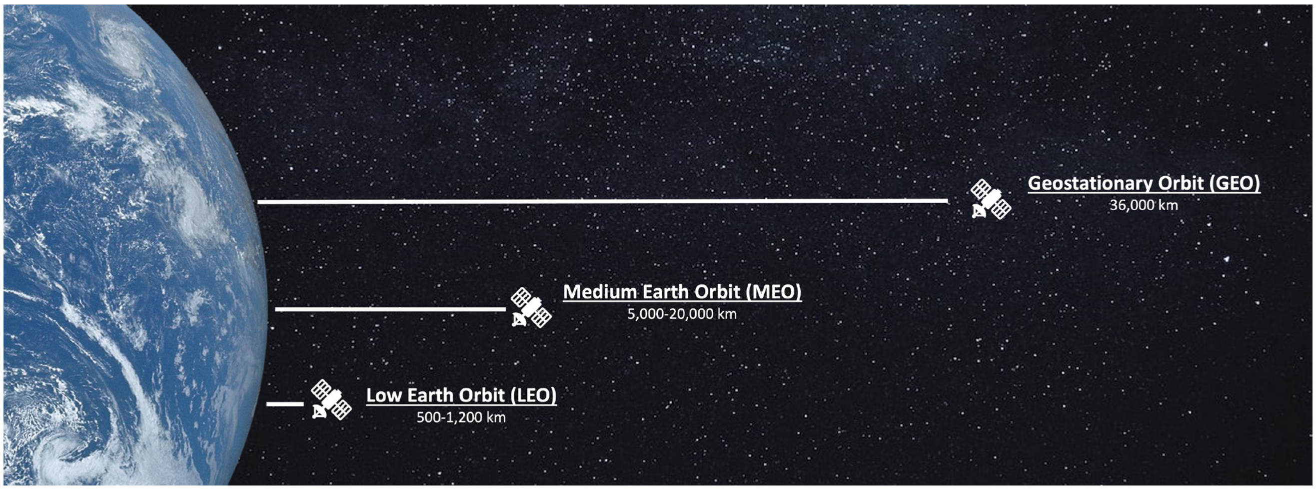
Consistent high performance airborne global connectivity is optimized through a layered solution. SD's approach is Plane Simple®; modular, upgradeable solutions that leverage constellations in different frequencies and orbits from multiple network operators to ensure longevity of the airborne connectivity. Combined with flexible pricing plans enabled by the industries best customer support organization, SD's airborne connectivity solutions are designed to operate with existing and future network constellations.

Technology

Aviation uses the L, Ku, and Ka frequency bands for satellite communications: L-band is the lowest frequency, has the lowest bandwidth, and the highest resistance to precipitation so it is typically used for cockpit communications. Ka and Ku operate at much higher frequencies which provides the greatest bandwidth with increased susceptibility to precipitation.



Satellite constellations are placed in three primary earth orbits: Geostationary (GEO), Mid-Earth (MEO), and Low-Earth (LEO).



LEO Satellites

Move relatively quickly across the sky, require many satellites to provide global coverage (600 to 3000+), and cost the most to implement and maintain the constellation due to the large number of satellites, relatively short ~ 5-year satellite lifespan, and the number of earth ground stations required.

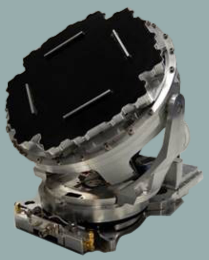
MEO Satellites

Higher than LEO but well below GEO. They require a few more satellites and ground stations than GEO constellations but nowhere near what is needed for a LEO constellation yet they offer almost the same latency as a LEO constellation.

GEO Satellites

Maintain a fixed position over a point on the earth, require the fewest satellites for global coverage (3 to 4), and cost the least to implement and maintain due to the 15–20-year longevity of individual satellites.

Airborne satellite antennas come in two primary categories, mechanically steered (gimbaled) or electronically steered antennas (ESA).



Mechanically Steered Antennas
Mature technology common in business aviation due to their compact size.

Electronically Steered Antennas
Seen most often as flat panels mounted on passenger jets, but the technology is migrating to smaller aircraft due to new LEO operators such as Kuiper, OneWeb & StarLink.

User Experience

Connectivity user's basis for comparison is what they experience in their homes or office, an experience characterized by a persistent, high bandwidth, low latency connection. Replicating this experience in an aircraft at 45,000 feet flying near 0.9Mach is a technical challenge. Unlike a house or office building, the aircraft is maneuvering, the antenna is in motion, the satellite is in motion, there are clouds and rain in between both, latency varies depending on how far away the satellite is (GEO, MEO, or LEO), and the connection can be interrupted as the system switches between satellite beams and/or between satellites.

For most uses, these technical challenges are transparent to the user. There are a couple of applications such as gaming or video teleconferencing that demand a persistent high bandwidth low latency connection that can be challenging to replicate in an airborne environment. An ESA using a LEO constellation provides a high bandwidth, low latency solution but is challenged by frequent beam and satellite switches that can adversely affect the overall user experience.

SD's Recommendation

Airborne connectivity represents a significant investment for an aircraft owner or operator. The result of that investment should be a system that supports the passenger's needs and aircraft's missions for 7-10 years.

SD's solution is Plane Simple®, a family of antennas that are modular, easy to install, frequency and network diverse, with a flexible system architecture that can adapt to future network changes. The ability to operate on different networks eliminates the risk of depending on a specific network operator or satellite generation.

Furthermore, SD will provide consultative services on helping aircraft operators determine the best combination of solutions for their aircraft. The decision on which solution to install on an aircraft is a factor of the mission requirements of the given aircraft: what are the passengers and crew trying to do and where are they flying and certain customers will benefit from a certain offering to best achieve their connectivity goals.

Satcom Direct's Connected Aircraft Vision

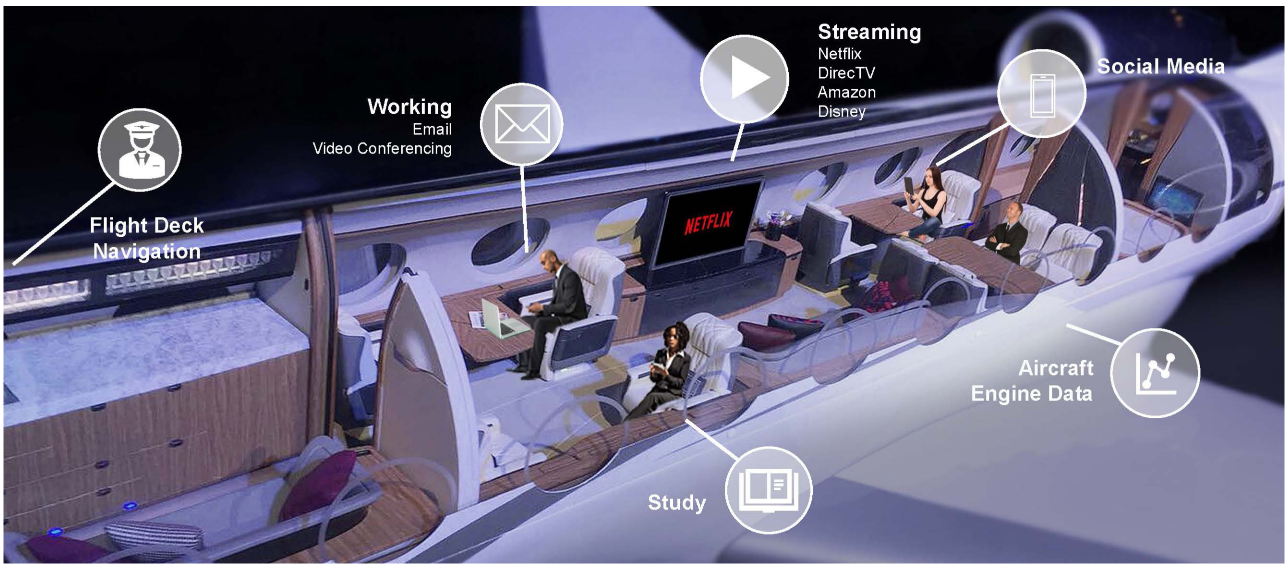
Satcom Direct's vision is to deliver consistent high performance airborne global connectivity and enable the digital transformation of flight operations. Achieving this vision requires continuous innovation, collaboration with key partners, and a dedicated focus on delivering our customers value. No single satellite network or proprietary technology can deliver on such ambitions. Operators require multiple connectivity solutions to achieve their performance and resilience requirements and protect their investment in an environment of rapid technological change and evolving network provider landscape.

There are three areas of focus for the connected aircraft that must be considered in this vision:

Passenger Experience – Ensuring that the proper bandwidth is available to support all applications for both passengers and crew.

Aircraft Data – Providing a path off the aircraft for non-safety aircraft data.

Situational Awareness – Ensuring that all personnel responsible for the operation of the aircraft have clear, near-real-time insight on the status of the connectivity system.



Space Segment Overview

Satellites

Satellites are the component that enable in-flight connectivity by reflecting information between the airborne antenna and the ground. A group of connected satellites is known as a "constellation". The distance and positional plane that a satellite is located from the earth is defined as the "orbit".

Communications satellites that are used for in-flight connectivity operate in one of four orbits and at one of three frequency bands. The orbits are Geostationary (GEO), Mid-Earth (MEO), High-Earth (HEO) and Low-Earth (LEO). Geostationary satellites maintain a fixed position over a point on the earth, require the fewest satellites for global coverage (3 to 4), and cost the least to implement and maintain the constellation due to the 15–20-year longevity of individual satellites. Furthermore, GEO satellites are optimal for delivering dedicated capacity to a defined region.

LEO satellites move relatively quickly across the sky, require many satellites to provide global coverage (300 to 3000+), and cost the most to implement and maintain the constellation due to the large number of satellites, relatively short lifespan of the satellites, typically 5 years or so, and the number of downlink ground stations required.

MEO satellites also move across the sky, but due to the higher orbit it is at a lower rate than LEOs. A global MEO constellation may only require 15-20 satellites as satellite covers a larger portion of the earth than LEOs.

HEO satellites are generally complementary to a GEO network to provide polar capacity. Only 2 satellites are needed to compliment this coverage as they will be on opposite sides of the orbit from each other and one will be active. They orbit north to south and are only active while over the northern hemisphere. Because these are used as a component of a GEO network, however, they will be considered part of the GEO constellations for the purposes of this paper.

Aviation uses three primary frequency bands for satellite communications: L, Ku, and Ka. L-band is the lowest frequency, has the lowest bandwidth, and the highest resistance to precipitation so it is typically used for cockpit communications. Ka and Ku are both used for high-speed connectivity services.

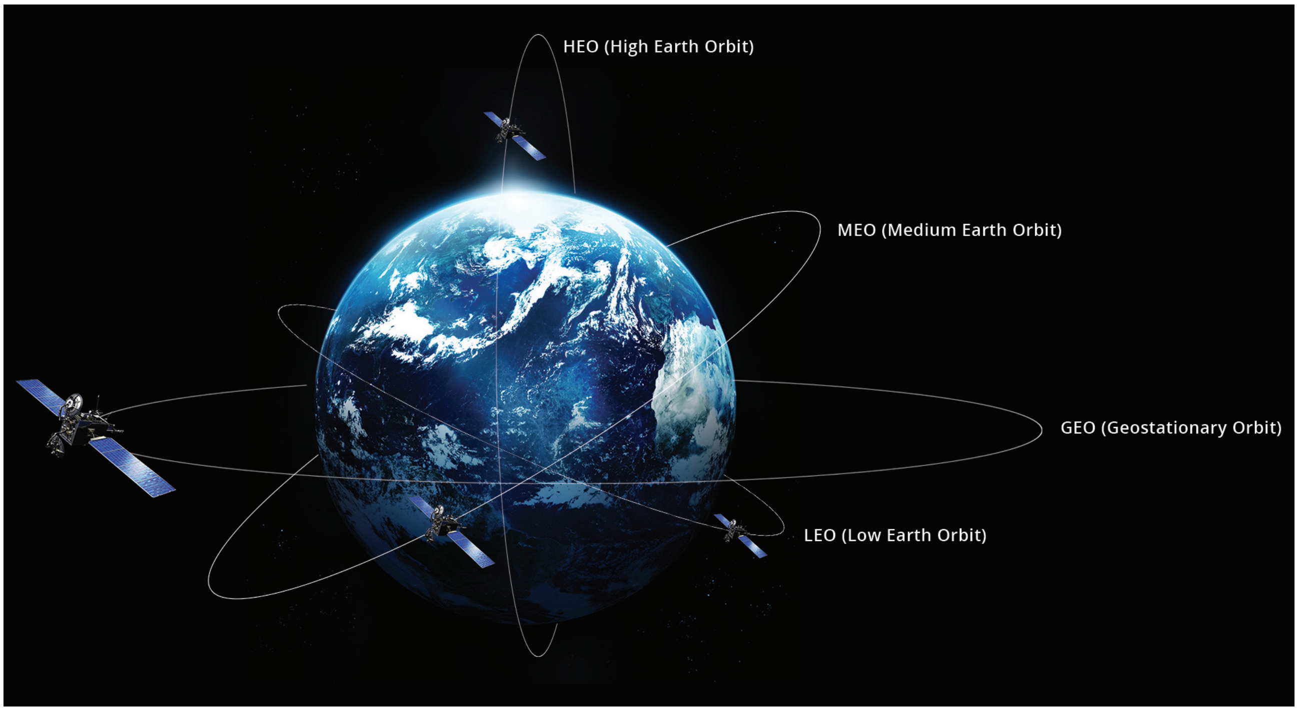
Impact of Orbits

There are three key considerations from a user-perspective when evaluating connectivity solutions; coverage, service capacity, latency, and the aircraft antenna.

All constellations can provide near global coverage, but GEOs are limited in the far northern and southern latitudes due to the fixed orbit. This is why they can be complemented with HEO satellites. LEOs and MEOs are able to provide complete global coverage if they have a full complement of satellites.

All satellites must be able to transfer data to and from a ground station, which are always located on a land mass. GEO satellites can always 'see' a ground station, but due to their lower altitude, LEO satellites cannot. Therefore, to provide coverage over the oceans, LEO satellites must be able to link with each other to move data to a LEO satellite that can see the ground. Some current LEO satellites don't have that capability and therefore cannot provide coverage over the oceans.

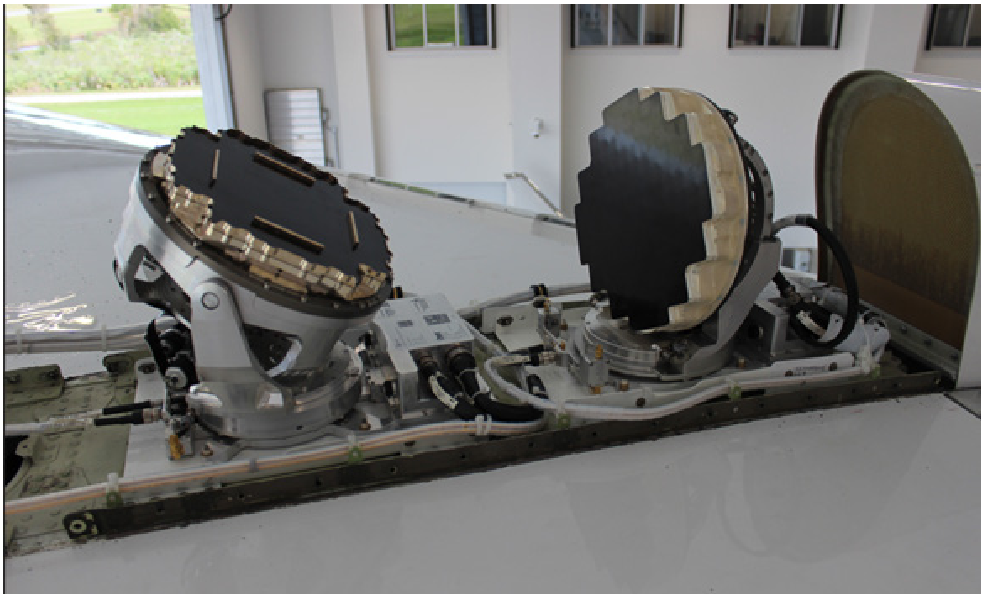
In highly congested areas, GEO constellations can augment capacity with additional satellites due to the stationary nature of their orbits. LEO and MEO constellations, on the other hand, must add capacity equally across the entire network.



Connectivity service capacity is the bandwidth performance available to enable applications on board the aircraft. Most airborne connectivity services contend for bandwidth with multiple verticals including commercial aviation, maritime, enterprise, and IoT, while only a few offer dedicated capacity to business aviation to ensure bandwidth demands are met.

The aircraft antenna is the final piece in moving data on and off the aircraft. The challenge with aircraft antennas is the limited amount of space to install them. Smaller antennas require more power from the satellite to achieve a given level of performance that a larger antenna would.

There are two main technologies in use today, the gimbaled antenna – which physically moves to point to the antenna – and electronically steered flat panel antennas (ESA – which steers the beam electrically with limited or no moving parts.) Mechanically steered antennas have been around a long time and are suitable for use with GEO networks where the look angle (the angle between the antenna and the satellite) can get very low.



LEO networks require an ESA antenna because they will change satellites frequently and this must be done nearly instantaneously to maintain the user session. Yet, because they struggle with low look angles, they are less suitable for GEOs. MEOs can operate with either, however, an ESA would be preferable to ensure a seamless user experience.

Capacity Considerations

Capacity refers to the amount of bandwidth that can be provided to, and used by, the aircraft antenna. The capacity may be limited by what the network can provide, by the connectivity plan in use, or by the antenna installed on the aircraft. Most consumer applications today demand multi-megabit-per-second (Mbps) bandwidth to meet the performance requirements of the passenger's applications.

Video applications such as streaming and videoconferencing have the highest bandwidth requirements today. As resolution has increased from Standard Definition to today's 4K, the bandwidth needed to deliver high resolution content continues to increase, with larger screen resolutions requiring upwards of 15-25Mbps for a quality experience.

Antenna size limits are one of the biggest challenges to increasing bandwidth on the aircraft. Most Super-Mid and Large-Cabin business jets have their satellite antennas installed on the top of the tail which limits the size of the antenna. To increase capacity with a fixed antenna size, the antenna needs to become more efficient. The microhorn technology used in SD Plane Simple antennas is inherently more efficient than legacy parabolic antennas which supports increased bandwidth within the existing tail space.

Capacity is also a function of what the network can provide and there are many factors at play. Some of those factors are technical and include the satellite design and operating frequency. Others are choices made by the network provider. For example, which user groups does the network provider support, e.g., commercial aviation, business aviation, maritime, land, and how are the needs of the various user groups prioritized. These factors are much more influential than operating frequency, i.e., Ka vs Ku, in the capacity available to a user.

Consistency of Aero Connectivity Service

Modern day home and office connectivity experiences set a users expectations for capacity, latency, and service consistency. For all practical purposes, home and office capacity is unlimited, latency is inconsequential, and the connection is uninterrupted. Replicating the home and office experience at 45,000 feet is a technical challenge and the physics involved require some compromises.

It can be difficult to maintain an uninterrupted connection during a flight. All satellites have beams that an aircraft transits during flight, and depending on the constellation and flight path, multiple satellites may be transited. LEO constellations require the most frequent beam and satellite changes, and as one would expect, GEO require the fewest. There are ways to minimize the impact of beam and satellite changes, such as buffering content as previously discussed. Minimizing the impact of beam and satellite swaps is the most challenging on video teleconferencing applications using a LEO network.

Like latency, satellite transitions do not impact all applications equally. Applications that are able to buffer content, such as video streaming, or that do not require a persistent connection, such as web browsing or email, will not be impacted by satellite transitions. The applications that require low latency, however, are most likely to be impacted by a satellite transition. Quicker satellite transitions may mitigate that impact.

Furthermore, the time to transition is not consistent across satellite types. The transition time is a function of how quickly the antenna can point to the new satellite and how quickly the network can re-establish the connection. Total transition times for GEOs will be on the order of 15-60 seconds (Plane Simple antennas being on the low end of that range). Total transition times for LEOs will be on the order of 400 microseconds to 25 milliseconds.

Service Latency

Latency is the amount of time it takes data to move from the aircraft to the satellite and then to the ground. Because the GEO satellite is relatively far away, it has the longest latency at ~700 milliseconds. LEO has the least latency, between 100-300 milliseconds. MEO is not far behind LEO at 200-400 milliseconds. For most applications, latency is not a factor and can be mitigated by techniques such as buffering where a block of data for a song or movie is downloaded ahead of it being needed.

Certain applications, however, can be impacted by latency. The below table identifies the target latency for certain applications and as noted, the ones where the latency of an airborne satcom system may impact performance include Automated Guided Vehicle (i.e. command and control), Augmented Reality, Interactive Gaming, Specialized Trading, and Video Conferencing. Other applications such as Web Browsing, Video Streaming, Social Media or Email would not realize any performance limitations due to the latency incurred by an aero connectivity system.

Application	Optimal Latency (milliseconds)	Acceptable Latency (milliseconds)
Automated Guided Vehicle	< 10	< 20
Augmented Reality	< 10	< 20
Interactive Gaming	< 30	< 100
Specialized Trading	< 30	< 300
Videoconferencing	< 100	< 500
Web Browsing	< 200	< 3000
Video Steaming (Over-the-Top)	< 1000	< 5000

Satellite Service Future Trends

History has proven that consumers and industries will continue to find ways to better utilize the connected world with innovative new applications. To support this, terrestrial networks continue to increase their capabilities. Given that aircraft operators expect their connectivity system to remain viable for 7-10 years, it is imperative that satellite operators and airborne terminal manufacturers follow suit.

The primary mechanism for accomplishing this is to add capacity to the global network through additional, more powerful satellites. Furthermore, software defined satellites (SDS) are emerging as a new technology that will allow the satellite operator to allocate capacity in those regions where it is demanded, as opposed to a static coverage area (though there will remain a coverage boundary).

In the LEO space, inter-satellite links will enable traffic to transfer from one satellite to another, thus limiting the number of ground stations required to support the network and to enable trans-oceanic coverage. While these added hops will add latency, the proximity of the satellites to each other and to the earth should minimize that impact.

Naturally, as the satellites evolve, the airborne terminals must also evolve. In order to minimize the invasive nature of antenna changes on an aircraft it is essential for the terminal architecture to be modular so as to minimize the impact of potential future changes. The airborne terminals must also consider future satellite designs to reasonably support any design changes in how the bandwidth is delivered to maximize the longevity of the airborne terminal through compatibility with satellite design updates.

The Plane Simple® terminals have been designed through collaboration with key network partners in both Ku-band and Ka-Band to ensure future compatibility with the satellite network roadmaps. This allows for continued growth in performance without the need to update the airborne terminal. Furthermore, the Plane Simple® terminal design is structured such that, in the event the antenna and/or modem is required to be upgraded due to changes in the satellite infrastructure, the key installation pain points such as wiring and mounting footprints are preserved, minimizing the upgrade cost and aircraft downtime.

Through this partner collaboration, the Plane Simple® airborne terminals deliver the most consistent business aviation connectivity performance today with performance growth to greater than 50Mbps on each gimbal, tail-mounted airborne terminal, and greater than 100Mbps on the ESA airborne terminals, all with the highest dedication to business aviation.

Selecting the Right Connectivity Solutions for Your Mission

As discussed throughout this paper, there are various advantages and disadvantages to satellite constellations in different orbits. No single solution will solve the problems for all users, so operators must ask themselves what option is best suited for their mission set.

The first step is to look at the critical applications that are needed as well as the most prevalent flight routes. Secondly, it's important to understand how many passengers are typically on board. This will help identify the key requirement in terms of capacity, latency, and consistency that are needed.

It is highly likely that the ideal connectivity solution(s) will be a combination of the offerings available vs a single one. In this case, the best course may be to install multiple systems on board an aircraft and allow the router to optimize the in-cabin network to best take advantages of each system.

Navigating this complex environment can be challenging, and SD has invested heavily and continues to do so in the development of solutions that maximize the investment of our customers in an ever-evolving landscape. The primary focus of SD's solution sets is to ensure the longevity of our customers connectivity selection through continuous performance improvements captivated by future-proof airborne terminal designs, network partner collaboration, and multi-dimensional mission enablement for the long-term. SD does not believe that such technological advancements can occur with one-dimensional, proprietary technology that does not focus on business aviation's operational needs.

SD is is here to support questions and provide consult on customer needs today and in the long run.

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