35th Space Symposium, Technical Track, Colorado Springs, Colorado, United States of America
Presented on April 8, 2019

A UAV USER'S GUIDE TO BEYOND LINE OF SIGHT CONNECTIVITY

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ABSTRACT

Current military operations rely on Unmanned Aerial Vehicles (UAVs) for a range of Command and Control (C2) and Intelligence, Surveillance, and Reconnaissance (ISR) missions. Many of these missions require Beyond Line of Sight (BLOS) communications links which can be implemented using a range of satellite communications (SATCOM) architectures. The range of sizes and capabilities of UAVs, the available satellite frequency bands, and the implemented communications architectures continues to expand. Just as users must choose the appropriate UAV for a given mission, BLOS options must be carefully considered as well. This paper provides a high-level overview of aeronautical terminal types and related connectivity that might be implemented in support of UAV mission data connections. The goal of this paper is to provide a helpful, high-level guide that correlates anticipated performance based on terminal size, weight, and power (SWaP). This will help a UAV user understand BLOS connectivity options for a specific platform of interest.

INTRODUCTION

Inmarsat has focused on BLOS connectivity for globally-distributed, mobile maritime users since 1979. These connectivity services initially focused on safety of life services that operate in L-band and require very high availability. As time has passed and Inmarsat capabilities have evolved, services have expanded and extended to include mobile connectivity services for a diverse array of terminals – including support for land, sea, and air users. These mobile connectivity services now provide a wide array of capabilities ranging from low-speed Internet of Things (IoT) messaging services through very high-speed services in L-band and Ka-band. This paper provides a high-level view of how these Inmarsat services might be used to provide connectivity to various UAVs Groups (Group 2-5). This paper serves as a helpful, fact-based input for trade space options associated with selecting a compatible BLOS aeronautical terminal solution for a specific UAV mission. Smaller UAVs with challenging SWaP constraints are considered (Group 2 UAVs). The ability of large UAVs that support larger aperture aeronautical terminals and extremely high data rates are assessed (Group 3, 4, and 5 UAVs). These assessments are all performed using Inmarsat L-band and Ka-band services on satellites that are on-orbit today and available worldwide (the GEO-visible earth).

INMARSAT L-BAND SERVICES

Inmarsat's most advanced L-band services are provided by four satellites that are on orbit today. An overview of these satellites and their areas of coverage is shown in Exhibit 1. These satellites include three Inmarsat 4 (I-4) satellites and one Alphasat satellite. The first I-4 satellite was launched in 2005. Alphasat, the last satellite in this series was launched in 2013. The I-4 satellites operate in standard L-band (1525MHz-1559MHz RX and 1626.5 -

1660.5MHz TX) and Alphasat operates in standard and extended L-band (1518MHz -1559MHz RX and 1626.5 - 1675MHz TX). A variety of services are supported by these satellites including the Broadband Global Area Network (BGAN) service. A very large number of UAVs leverage Inmarsat L-band services for command and control capability. These satellites also support lease services for unique (non-BGAN) applications. For lease services, a customer makes a power and bandwidth purchase and can then operate with waveforms tailored for their specific application. Next generation L-band services will be delivered by the Inmarsat 6 (I-6) series of satellites. The first I-6 satellite is planned for launch in 4Q2020.

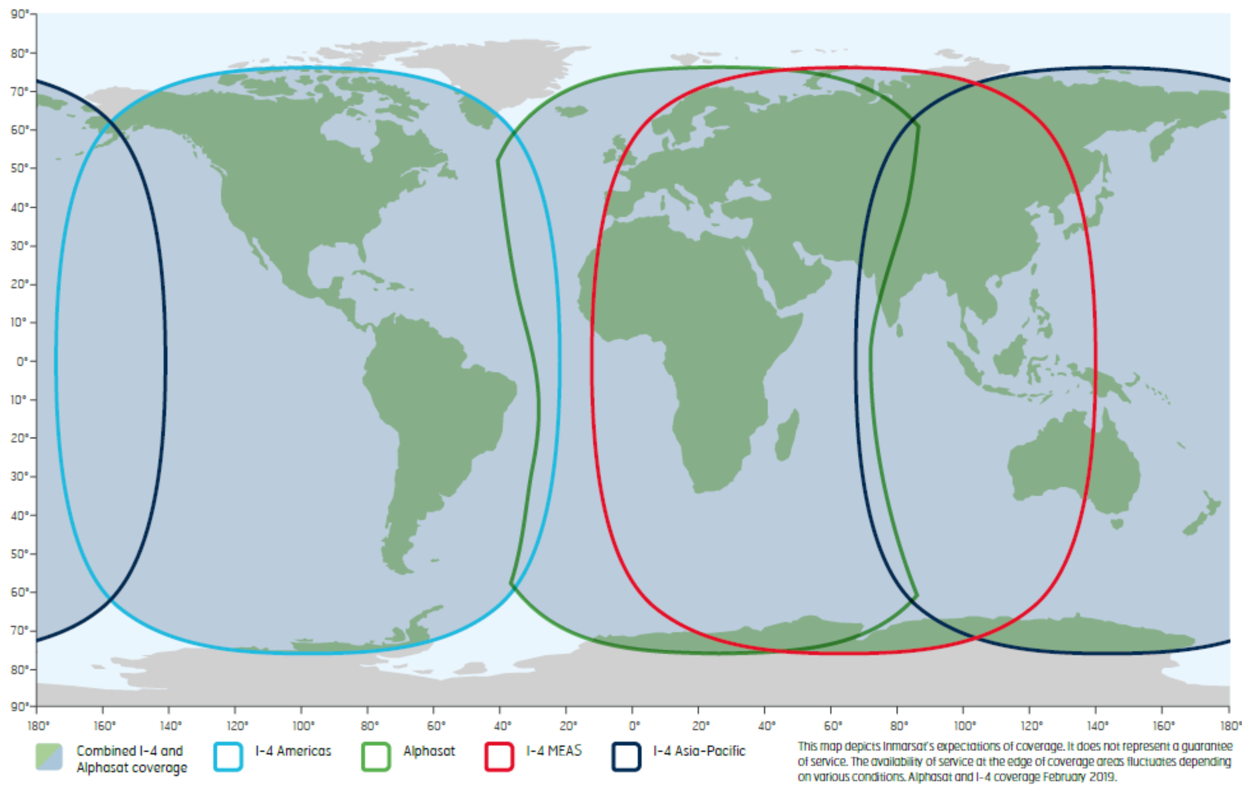

Exhibit 1: L-band Coverage Map. The Inmarsat 4s and the Alphasat satellites provide worldwide L-band coverage. These satellites support subscriptions services (e.g., BGAN) and lease services anywhere in the area of coverage.

INMARSAT KA-BAND SERVICES

Inmarsat Ka-band services are provided via four satellites that are on-orbit today. An overview of these satellites and their areas of coverage is shown in Exhibit 2. This constellation is comprised of four Inmarsat 5 (I-5) satellites. The first I-5 satellite, I-5 GX1, was launched in 2013. The last I-5 satellite, I-5 GX4, was launched in 2017. The I-5 satellites provide Ka-band capability worldwide. The GX service provides a subscription service for commercial Ka-band terminals. These satellites also provide high capacity steerable beams that are used to seamlessly augment GX services and to provide very high-performance military (mil) Ka-band connectivity. The GX services operate in the 29-30GHz TX and 19.2-20.2GHz RX band providing 32MHz transponder bandwidth worldwide. Mil Ka-band services (accommodated on the high capacity steerables) operate in the 30-31GHz TX and 20.2-21.2GHz RX band providing 1.2° steerable spot beam antennas with 40 to 730MHz of transponder bandwidth.

Next generation GX and mil Ka-band services will be delivered by the GX5 satellite and Inmarsat 6 (I-6) series of satellites (the I-6 satellites are L/Ka hybrids). Offering high capacity GX services in high demand regions, GX5 is due to launch in 4Q2019. The first I-6 is scheduled to launch in 4Q2020.

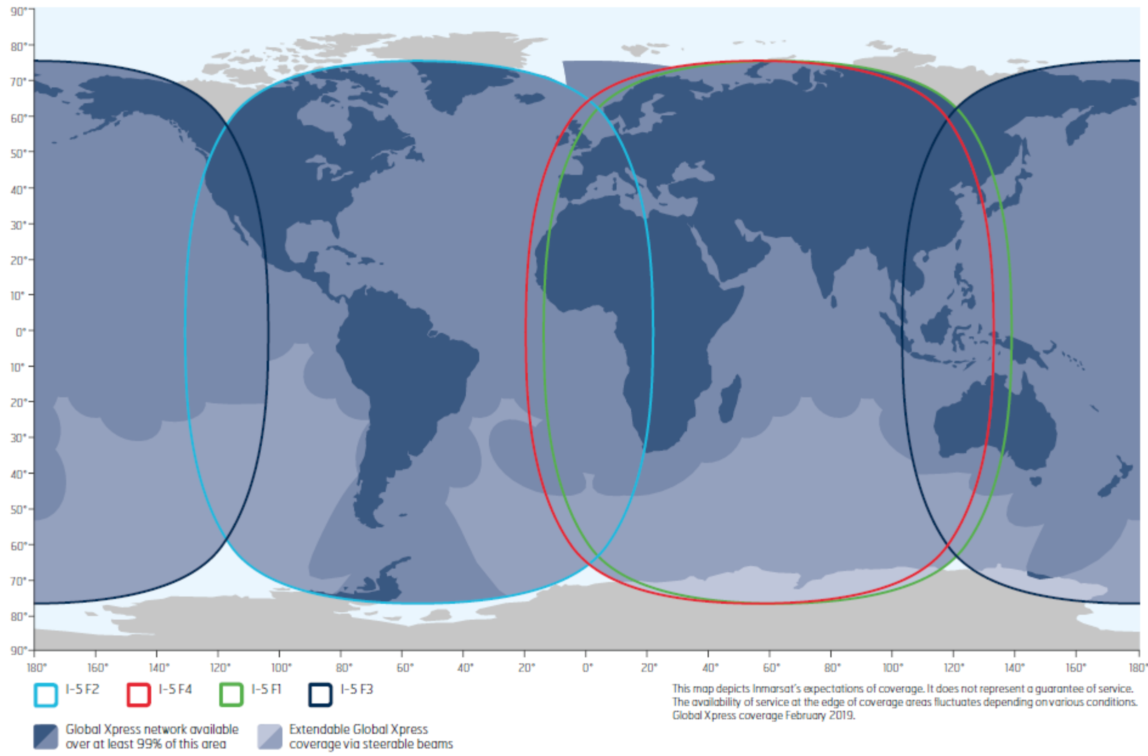

Exhibit 2: Ka-band Coverage Map. Inmarsat-5 satellites provide worldwide commercial Ka-band coverage and steerable spot beam military Ka-band coverage. These satellites support subscription services (e.g., GX SATCOM as a Service) or steerable beam lease services (e.g., mil-Ka lease) anywhere in the area of coverage.

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UAV GROUPS

For the purposes of this paper, we make use of the United States Department of Defense (DoD) Classification for UAV Groups shown Exhibit 3. This paper assesses connectivity options and applicable aeronautical terminals for Groups 2-5 UAVs. The sections below provide an overview of the general aeronautical terminal characteristics for the various UAV groups. Information includes antenna size, power amplifier size, plausible bands of operations, and expected forward (to the UAV) and return (from the UAV) link performance. This summary is not intended to be an exhaustive treatment. Instead it allows the reader to gain a general sense of plausible aeronautical terminals that may be employed for BLOS communications and the supported data rates.

Category	Size	Maximum Gross Takeoff Weight (MGTW) (lbs)	Normal Operating Altitude (ft)	Airspeed (knots)
Group 1	Small	0-20	<1,200 AGL*	<100
Group 2	Medium	21-55	<3,500	<250
Group 3	Large	<1320	<18,000 MSL**	<250
Group 4	Larger	>1320	<18,000 MSL	Any airspeed
Group 5	Largest	>1320	>18,000	Any airspeed

*AGL = Above Ground Level
**MSL = Mean Sea Level
Note: If the UAS has even one characteristic of the next level, it is classified in that level.
Source: "Eyes of the Army" U.S. Army Roadmap for UAS 2010-2035

Exhibit 3: DoD UAV Classification. United States Department of Defense (DoD) Classification for UAV Groups.

Group 2 UAV Terminals

Group 2 UAVs provide very constrained aeronautical terminal accommodations. The limited accommodations force a range of compromises among key attributes (size, weight, power, forward link data rate, return link data rate). Typically, these terminals have very small antennas. These small antennas impact the available transmit and receive gain making the link budget more challenging. Further, these small antennas yield a wide beamwidth making compliance with off-axis emissions requirements (regulatory) more difficult while also making the terminal more susceptible to adjacent satellite interference. Antennas for Group 2 UAVs typically range from 5cm to 20cm in diameter. Antennas for these UAVs are usually parabolic or flat panel in shape and the overall terminal is designed to be as lightweight as possible. Limited available platform power restricts RF power amplifiers to the range of 5W to 16W which effectively limits the Effective Isotropic Radiated Power (EIRP). Lower terminal EIRP yields lower return link (UAV to gateway) data rates. Operations for these UAVs generally occur at low altitude (under the weather) which requires careful consideration of band selection and management of link margins. Ideal band of operation for Group 2 UAV terminals when using Inmarsat resources is L-band. With the right terminal and link design, it is possible to use mil Ka-band to support connectivity.

Group 3 UAV Terminals

Group 3 UAVs provide ample aeronautical terminal accommodations. Aeronautical terminal antennas for Group 3 UAVs typically range in size from 23cm to 46cm in diameter. Terminals are usually parabolic or flat panel in shape. Available platform power supports RF power amplifiers in the range of 16W to 50W. Operations generally occur at medium to high altitude for these platforms. Ideal band of operation for Group 3 aeronautical terminals when using Inmarsat resources is commercial or military Ka-band. For special circumstances, it is possible to use L-band lease services for these terminals too.

Group 4 and Group 5 UAV Terminals

Group 4 and Group 5 UAVs provide the most significant aeronautical terminal accommodations of all the UAV categories. Aeronautical terminals for these UAVs are characterized by very large antennas (60cm to 1.2m diameter parabolic apertures), significant available platform power to support operations (utilizing 50W to 250W RF power amplifiers), and operations at high altitude (above most weather effects). Ideal band of operation for these terminals when using Inmarsat resources is commercial or military Ka-band.

UAV BLOS TERMINALS AND THEIR LINK PERFORMANCE

The sections that follow describe a series of sample terminals that operate in L-band and Ka-band and summarize expected link performance (supported data rates). In L-band, the terminals support subscription services at modest rates or hybrid subscription/lease service for the highest data rate applications. These hybrid terminals are referred to as LAISR terminals (L-band Airborne ISR). The data rates supported by the prospective L-band terminals are provided in the descriptions below. In Ka-band, the terminals discussed provide on-demand support for subscription services in commercial Ka-band and lease-based services in mil Ka-band. The data rates supported by the prospective Ka-band terminals are provided in the sections that follow.

Sample L-band Terminals

Cobham Aviator UAV 200

The Aviator UAV 200 is a recently developed aeronautical terminal solution that has been purpose built to meet UAV BLOS connectivity needs. This aeronautical terminal is comprised of a single, lightweight LRU and is much lighter than comparable offerings. The Aviator UAV 200 operates across a wide temperature range (-40°C to +55°C) and at altitudes up to 6,000m. Connectivity for this terminal is provided via Inmarsat's SwiftBroadband BGAN service. A single, purchased subscription provides worldwide access. A summary of the key characteristics of the UAV 200 terminal is shown in Exhibit 4.

	Cobham Aviator UAV-200
Antenna Class	Class 4
Antenna Type	Electronic Phased-Array
Antenna Mounting	Inside Aircraft Fuselage
Input Power	14-28 VDC
No. Components	One
Total Weight	3.2 lbs.
Dimensions (inches)	9.5 x 6.3 x 2.4
Total Size (Volume)	108 cu. Inch
Max Power Draw (@28VDC)	28 W
User Data Interface	Ethernet
NAV Interface	RS-232 or Ethernet
Supported Data Rates	Class 4 SwiftBroadband to 5 deg elevation ; Background IP to 200 Kbps; Streaming to 32 Kbps with Half HDR

Exhibit 4: Cobham Aviator UAV 200.

Cobham AviatorSP

The AviatorSP provides robust connectivity using Inmarsat's SwiftBroadband BGAN service. In a single channel configuration, the terminal consists of three LRUs as shown in Exhibit 5. The single channel terminal has been ruggedized to meet the demanding needs of the aircraft and helicopter environment and reliably supports duplex data rates of up to 432Kbps depending on the selected antenna. The AviatorSP Multi Channel System provides robust multi-channel connectivity using Inmarsat's SwiftBroadband BGAN service. The terminal is offered in two- and four-channel versions and is comprised of 4 LRUs. Exhibit 6 summarizes the key characteristics of the two-channel system; Exhibit 7 summarizes the key characteristics of the four-channel system. The only hardware difference between the two systems is the four-channel uses a slightly larger (ARINC-600 3 MCU form factor) SDU.

Cobham AviatorSP – Single Channel

The key characteristics of the Cobham Aviator-SP Single Channel terminal are shown in Exhibit 5 below. The terminal is offered with three variants – a Class 15, Class 7, and Class 6 version ("Class" is an Inmarsat means of binning user terminals by capability). The Class 15 variant has the lowest SWaP and features an omni-directional antenna that does not require the UAV to provide steering inputs. It can support data rates up to 200Kbps or streaming up to 32Kbps. The Class 7 variant uses an intermediate gain fuselage mounted antenna and can provide background data rates up to 332Kbps or streaming up to 128Kbps. The Class 6 variant features two high-gain antenna options; a fuselage mount phased-array and a tail-mount mechanically steered unit. The mechanically steered antenna is designed to be mounted inside a radome (tail or other suitable location); optionally a ruggedized version of the antenna allows for installation without requiring an additional radome. Both antennas provide the same data rate performance (up to 432Kbps background IP or streaming up to 256Kbps).

Antenna Class	Class 15	Class 7	Class 6	
Antenna Type	Omni	Electronic Phased-Array	Mechanical Helix	Electronic Phased-Array
				
Antenna Mounting	Fuselage - Blade	Fuselage Mount	Tail Mount	Fuselage Mount
No. Components	***Three individual pieces:*** Satellite Data Unit (SDU), HPA/DLNA (HLD), Antenna			
LRU Dimensions (L x W X H in inches)				
	SDU		HLD	
	13.1 x 7.6 x 2.0		7.8 x 7.5 x 2.4	
Antenna Dimensions (L x W x H in inches)	13.6 x 3.4 x 4.4	22.9 x 6.9 x 2.0	10.0 x 9.7 x 10.0	41.4 x 11.8 x 2.0
Total Weight	13.3 lbs.	19.6 lbs.	15.9 lbs.	32.9 lbs.
Total Size (Volume)	436 cu. Inch	412 cu. Inch	1180 cu. Inch	1182 cu. Inch
Input Power	20.5 - 32.2 VDC, nominal +28VDC			
Max Power Draw (@28VDC)	89 W	96 W	111 W	109 W
User Data Interface	Ethernet			
NAV Interface	Not Required	ARINC-429		
Background IP Data Rates	Up to 200Kbps	Up to 332 Kbps	Up to 432 Kbps	
Streaming IP Data Rates	8, 16, or 32 kbps	8, 16, 32, 64 or 128 Kbps	8, 16, 32, 64 , 128 Kbp or X-stream (up to 256 Kbps)	

Exhibit 5: Cobham AviatorSP Single Channel.

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Cobham AviatorSP – Two-Channel

The key characteristics of the Cobham Aviator-SP Two-Channel terminal are shown in Exhibit 6 below. The terminal is offered in two variants – a Class 7 version, and Class 6 version. Both variants use the same Class 6 and 7 antennas as used in the single-channel system; the differences are the two-channel systems uses a stand-alone HPA and DLNA, and an ARINC-600 two MCU form factor SDU. The terminal provides up to two channels of SwiftBroadband at the same per channel data rates as the single-channel system. The Class 6 variant can bond up to two channels to provide an aggregate throughput of 800Kbps.

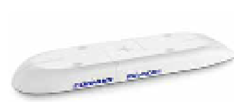
	Cobham Aviator-SP (Two-Channel)		
Antenna Class	**Class 7**	**Class 6**	
Antenna Type	Electronic Phased-Array	Mechanical Helix	Electronic Phased-Array
			
Antenna Mounting	Fuselage Mount	Tail Mount	Fuselage Mount
No. Components	***Four individual pieces:*** Satellite Data Unit (SDU), HPA-7450, DLNA, Antenna		
LRU Dimensions (L x W X H in inches)			
	SDU	**DLNA**	**HPA**
	12.6 x 2.4 x 7.6 (ARINC-600 2 MCU)	11.2 x 7.8 x 2.0	13.5 x 2.4 x 7.6 (ARINC-600 2 MCU)
Antenna Dimensions (L x W x H in inches)	22.9 x 6.9 x 2.0	10.0 x 9.7 x 10.0	41.4 x 11.8 x 2.0
Total Weight	30.9 lbs.	27.2 lbs.	44.2 lbs.
Total Size (Volume)	636 cu. Inch	1404 cu. Inch	1406 cu. Inch
Input Power	20.5 - 32.2 VDC, nominal +28VDC		
Max Power Draw (@28VDC)	277 W	293 W	290 W
User Data Interface	Ethernet		
NAV Interface	ARINC-429		
Background IP Data Rates	Up to 332 Kbps (per channel)	Up to 432 kbps (per channel)	
Streaming IP Data Rates	8, 16, 32, 64 or 128 Kbps (per channel)	8,16, 32, 64, 128 Kbps or X-stream (up to 256 Kbps) per channel; bonded service up to 800 Kbps	

Exhibit 6: Cobham Aviator-SP Two-Channel.

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Cobham AviatorSP – Four-Channel

The key characteristics of the Cobham Aviator-SP Four-Channel terminal are shown in Exhibit 7 below. The terminal provides up to four channels of SwiftBroadband at the same per channel data rates as the single-channel system. The terminal uses the same antennas and RF electronics as with the two-channel system; the only difference is that the four-channel system uses a larger ARINC-600 form factor SDU (three MCUs). The Class 6 variant can bond up to four channels to provide an aggregate throughput of 1600Kbps.

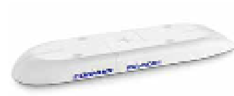
	Cobham Aviator-SP (Four-Channel)		
Antenna Class	Class 7	Class 6	
Antenna Type	Electronic Phased-Array	Mechanical Helix	Electronic Phased-Array
			
Antenna Mounting	Fuselage Mount	Tail Mount	Fuselage Mount
No. Components	***Four individual pieces:*** Satellite Data Unit (SDU), HPA-7450, DLNA, Antenna		
LRU Dimensions (L x W X H in inches)			
	SDU	DLNA	HPA
	13.5 x 3.7 x 7.6 (ARINC-600 3 MCU)	11.2 x 7.8 x 2.0	13.5 x 2.4 x 7.6 (ARINC-600 2 MCU)
Antenna Dimensions (L x W x H in inches)	22.9 x 6.9 x 2.0	10.0 x 9.7 x 10.0	41.4 x 11.8 x 2.0
Total Weight	32.7 lbs.	29 lbs.	46 lbs.
Total Size (Volume)	741 cu. Inch	1509 cu. Inch	1511 cu. Inch
Input Power	20.5 - 32.2 VDC, nominal +28VDC		
Max Power Draw (@28VDC)	297 W	313 W	310W
User Data Interface	Ethernet		
NAV Interface	ARINC-429		
Background IP Data Rates	Up to 332 Kbps (per channel)	Up to 432 kbps (per channel)	
Streaming IP Data Rates	8, 16, 32, 64 or 128 Kbps (per channel)	8,16, 32, 64, 128 Kbps or X-stream (up to 256 Kbps) per channel; bonded service up to 1600 Kbps	

Exhibit 7: Cobham Aviator-SP Four-Channel.

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Honeywell Aspire 200

The key characteristics of the Honeywell Aspire 200 terminal are shown in Exhibit 8 below. The terminal is offered in two variants – a Class 7 version, and Class 6 version. The terminal provides data rates up to 332Kbps (Class 7) or 432Kbps (Class 6). In addition, the terminal can support Inmarsat High-Data Rate (HDR) service. In this configuration, the Class 7 terminal can support data rates up to 500Kbps streaming and the Class 6 systems can support up to 650Kbps streaming.

	Honeywell Aspire-200		
Antenna Class	Class 7	Class 6	
Antenna Type	Electronic Phased-Array	Mechanical Helix	Electronic Phased-Array
			
Antenna Mounting	Fuselage Mount	Tail Mount	Fuselage Mount
No. Components	*Three individual pieces:* High-Speed Data Unit (HDU), HPA/DLNA (IPLD), Antenna		
LRU Dimensions (L x W X H in inches)			
	HDU	IPLD	
	14.8 x 2.4 x 7.8	7.5 x 7.5 x 2.5	
Antenna Dimensions (L x W x H in inches)	18.3 x 7.6 x 1.9	10.0 x 10.0 x 9.7	43.0 x 14.3 x 2.5
Total Weight	20.6 lbs.	18.9 lbs.	34.4 lbs.
Total Size (Volume)	420 cu. Inches	1194 cu. Inches	1498 cu. Inches
Input Power	20.5 - 32.2 VDC, nominal +28VDC		
Max Power Draw (@28VDC)	100W	110W	115W
User Data Interface	Ethernet		
NAV Interface	ARINC-429		
Background IP Data Rates	up to 332 Kbps	up to 432 Kbps	
Streaming IP Data Rates	8, 16, 32, 64 or128 Kbps; up to 500 kbps with HDR	8, 16, 32, 64 , or 128 Kbps; X-stream (up to 256Kbps); up to 650 kbps with HDR	

Exhibit 8: Honeywell Aspire 200**.**

LAISR

LAISR (L-band Airborne Intelligence, Surveillance, and Reconnaissance) is a subscription service designed to support UAV ISR applications. The service provides a DVB-S2X SCPC simplex return channel and a full-duplex low-speed Swift Broadband (SB) connection. The DVB-S2X return channel enables transport of high-throughput applications such as full-motion video (FMV), SAR, ELINT, and other bandwidth-intensive payloads from the UAV to the ground. The SB connection provides a low speed forward channel (up to 200Kbps) suitable to support C2 of the UAV platform. The service is designed to operate on the current I-4 satellite constellation (standard L-band) and Alphasat (both standard and extended L-band), as well as the future I-6 satellites.

The first-generation LAISR terminal is designed for installation on Group 3 UAVs. There are two different variants: single-antenna and dual-antenna. The single antenna variant combines the DVB-S2X return channel and the full-duplex SB connection onto a single high-gain antenna. The dual-antenna variant moves the SB link to its own dedicated low-gain antenna. In the dual-antenna configuration, the terminal's maximum EIRP is increased by 3dB, thus allowing higher data rates to be achieved. Both terminal variants consist of a standard single-channel SB terminal augmented by a DVB-S2X modem, High-Power Amplifier (HPA), and bandpass filter. The single-antenna variant adds a power combiner/splitter to enable both communication links to operate over a single antenna.

The DVB-S2X return channel is implemented using leased bandwidth and power in a narrow spot beam. Multiple contiguous narrow spot beams may be assigned to a subscription. As the UAV transitions through the coverage region, the return channel is automatically switched to the appropriate beam. This enables seamless communications over a large geographic area. First generation single-antenna LAISR terminals are currently fielded on Group 3 UAVs operating in the Alphasat region with return channel data rates of up to 2.5Mbps.

First Generation LAISR SWaP and Data Rates

The key characteristics of the single-antenna and dual-antenna LAISR terminals are shown in Exhibit 9 and Exhibit 10 respectively. Maximum power consumption is referenced to +28VDC and is the “worst-case” consumption based on the HPA being driven to full-output power. Actual power consumption may be significantly reduced depending on desired data rate. For IP throughput, the rates shown are the “worst-case” rates assuming a maximum bandwidth of 2MHz and terminal operations at Edge of Beam (EoB) with an elevation angle of 20 degrees. Higher data rates are possible at more favorable locations. This configuration has demonstrated a 10Mbps forward and 10Mbps return during development and demonstration testing.

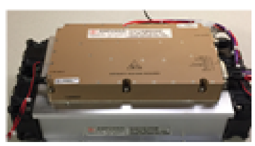
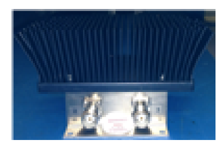
	Inmarsat Government Single-Antenna LAISR		
Antenna Type	Mechanical Helix		
			
Antenna Mounting	Tail Mount		
No. Components	***Eight individual pieces*** : Antenna plus LRU components shown below		
LRU Dimensions (L x W X H in inches)			
	SDU	**HLD**	**LAISR MODEM**
	13.1 x 7.6 x 2.0	7.8 x 7.5 x 2.4	18.6 x 13.4 x 1.75
			
	LAISR HPA	**Bandpass Filter**	**Power Combiner**
	10.75 x 5.25 x 3.75	7.96 x 1.25 x 1.65	5.0 x 4.5 x 2.75
			
	Management Router		
	6.75 x 6.25 x 2.66		
Antenna Dimensions (L x W x H in inches)	10.0 x 9.7 x 10.0		
Total Max Weight	**33.5 lbs.** *Optional configurations can result in configurations weighing less than 22lbs.		
Total Max Size (Volume)	**1683 cubic inches** *Optional configuratino s can reduce maxmum occupied space		
Input Power	28 VDC		
Max Power Draw (@28VDC)	**553 amps** *at HPA maximum output power; lower data rates can signficatnly reduce consumed power		
User Data Interface	Ethernet		
NAV Interface	ARINC-429		
Data Rates	**Forward:** up to 200 Kbps **Return:** up to 6150 Kbps (worst-case location); higher data rates possible depending on location		

Exhibit 9: Single-Antenna LAISR.

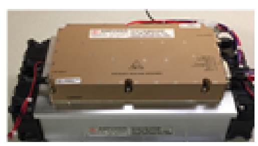
	Inmarsat Government Dual-Antenna LAISR		
	Mechanical Helix		Omni
Antenna Type			
Antenna Mounting	Tail Mount		Fuselage -Blade
No. Components	***Eight ndividual pieces*** : Antennas plus LRU components shown below		
			
	SDU	**HLD**	**LAISR MODEM**
	13.1 x 7.6 x 2.0	7.8 x 7.5 x 2.4	18.6 x 13.4 x 1.75
LRU Dimensions (L x W X H in inches)			
	LAISR HPA	**Bandpass Filter**	
	10.75 x 5.25 x 3.75	7.96 x 1.25 x 1.65	
			
	Management Router		
	6.75 x 6.25 x 2.66		
Antenna Dimensions (L x W x H in inches)	10.0 x 9.7 x 10.0		13.6 x 3.4 x 4.4
Total Max Weight	**33.9 lbs.** *Optional configurations can result in configurations weighing less than 22lbs.		
Total Max Size (Volume)	**1799 cubic inches** *Optional configuratino s can reduce maxmum occupied space		
Input Power	28 VDC		
Max Power Draw (@28VDC)	**553 amps** *at HPA maximum output power; lower data rates can signficatnly reduce consumed power		
User Data Interface	Ethernet		
NAV Interface	ARINC-429		
Data Rates	**Forward:** up to 200 Kbps **Return:** up to 7500 Kbps (worst-case location); higher data rates possible depending on location		

Exhibit 10: Dual-Antenna LAISR.

LAISR-LW (Lightweight)

The LAISR-LW (Lightweight) terminals, which are currently under development and will be available in 4Q2019, represent the second generation of LAISR terminals. These terminals feature reduced size and weight thus enabling extended loiter time and use of the LAISR service on smaller platforms. Some variations of this terminal will feature full-duplex DVBS2X links, thus allowing higher data rates to the UAV.

As an example, LAISR-LW variant 1 replaces the existing SB hardware with a "one-box" Class 4 SB terminal. The LAISR return channel is implemented with similar hardware to that of the first-generation terminal. Performance is expected to match that of the first-generation LAISR dual antenna terminal.

A second example is LAISR-LW variant 2. It also replaces the existing SB hardware with a "one-box" Class 4 SB terminal, but in addition substitutes the High-Gain Antenna with an omni-directional antenna. The result is a lower weight system with less complexity (i.e., steering inputs from the UAV are no longer a requirement) offset by lower achievable data rates.

Exhibit 11 lists key characteristics of the LAISR-LW future variants. As with the first-generation terminals, power consumption and return channel data rates are "worst-case" with lower power draws for lower data rates, and the potential for higher data rates at more favorable locations within the satellite footprint.

	Size and Weight		**Power Consumption (W)**	**Current Draw (A)**	**Data Rates (Kbps)**
Terminal Type	Volume (cubic in.)	Max Weight (lbs.)	Max Watts (@28VDC)	Max Amps (@28VDC)	Maximum Data Rates, Worst-Case Location, 2MHz
LAISR-LW (Variant 1)	TBD	TBD (est 11 -24)	492	17.6	7500
LAISR-LW (Variant 2)	TBD	TBD (est 11-14)	492	17.6	4000

Exhibit 11: LAISR-LW Specification

LAISR-ULW (Ultra Lightweight)

LAISR-ULW is a new terminal currently under development that is targeted at the smaller UAV classes and will be available in 4Q2019. ULW stands for ultra-lightweight and the threshold system weight is less than 5 pounds. LAISR-ULW will eliminate the SB forward channel and replace it with a DVB-S2X SCPC link. With a full-duplex DVB-S2X architecture, the terminal implements Adaptive Coding and Modulation (ACM) in order to maximize link throughput as link conditions change. Threshold rates are 120Kbps forward, 350Kbps return, though preliminary analysis and testing indicate data rates of up to at least 2Mbps are achievable (depending on location in the satellite footprint and allocated spectrum).

To simplify installation and operations, the terminal uses an omni-directional antenna to remove the need to have the UAV provide steering inputs. Two variants of the terminal are currently planned – a true "one-box" solution where the antenna is integrated into the electronics unit and a "remote" configuration where the antenna is mounted to the top of the UAV fuselage and connected to the electronics unit via coaxial cable.

LAISR-ULW Projected SWaP and Data Rates

Exhibit 12 shows the projected maximum weight, volume, power consumption, and data rates for LAISR-ULW. Max power consumption is referenced to +28VDC. For data rates, the rates shown are the "worst-case" rates assuming a maximum bandwidth of 200kHz, and terminal operations at Edge of Beam (EoB) with an elevation angle of 20 degrees. Higher data rates are possible at more favorable locations or with additional spectrum.

	Size and Weight		Power Consumption (W)	Current Draw (A)	Data Rates (Kbps)
Terminal Type	Volume (cubic in.)	Max Weight (lbs.)	Max Watts (@28VDC)	Max Amps (@28VDC)	Maximum Data Rates, Worst-Case Location, AF1, 200KHz
LAISR-ULW	<300	<5	<100	<3.5	Forward: 375 Kbps Return: 700 Kbps

Exhibit 12: LAISR-ULW Specifications**.**

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Sample Ka-band Terminals

A wide range of parabolic and flat-panel antenna have been developed and currently operate on the I-5 satellites. Additional terminals are in the development process to meet various user requirements. The following Exhibits are typical specifications for terminals of various sizes. The data rates are estimates based on factor such as using a modem with available symbol rates up to 90Msps and modulation and coding (MODCOD) rates of up to 64APSK-5/6, operating in clear sky conditions, using up to 100MHz of transponder bandwidth and/or power, and configuring transponder settings for optimum performance.

GetSAT MicroSAT

The GetSAT MicroSAT LW, is a small, lightweight satellite terminal that supports airborne connectivity. The design has emphasized efficient terminal SWaP characteristics. The terminal supports commercial and mil Ka-band and includes an embedded SCPC modem to support transmit and receive operations on mil Ka-band. More details regarding this terminal are shown in Exhibit 13.

Power	24-54VDC
Nav Interface	Internal INS
Mass	10.7kg
Dimensions	26cm x 30cm
Consumed Power	235W
Data Interface	Ethernet
RF Specs	EIRP: 44dBW G/T: 8.2dB/K
Data Rates (Commercial Service)	Up to 45Mbps Forward; 4Mbps Return
Data Rate (Military Ka-band Steerable Beam)	Up to 105Mbps Forward; 16Mbps Return

Exhibit 13: GetSAT MicroSAT LW Specifications.

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Using the commercial Ka-band subscription services, the GetSAT MicroSAT provides a forward link up to 45Mbps and a return link up to 4Mbps. An assessment of predicted maximum performance for a GetSAT MicroSAT terminal using the Global Xpress subscription service is described in Exhibit 14.

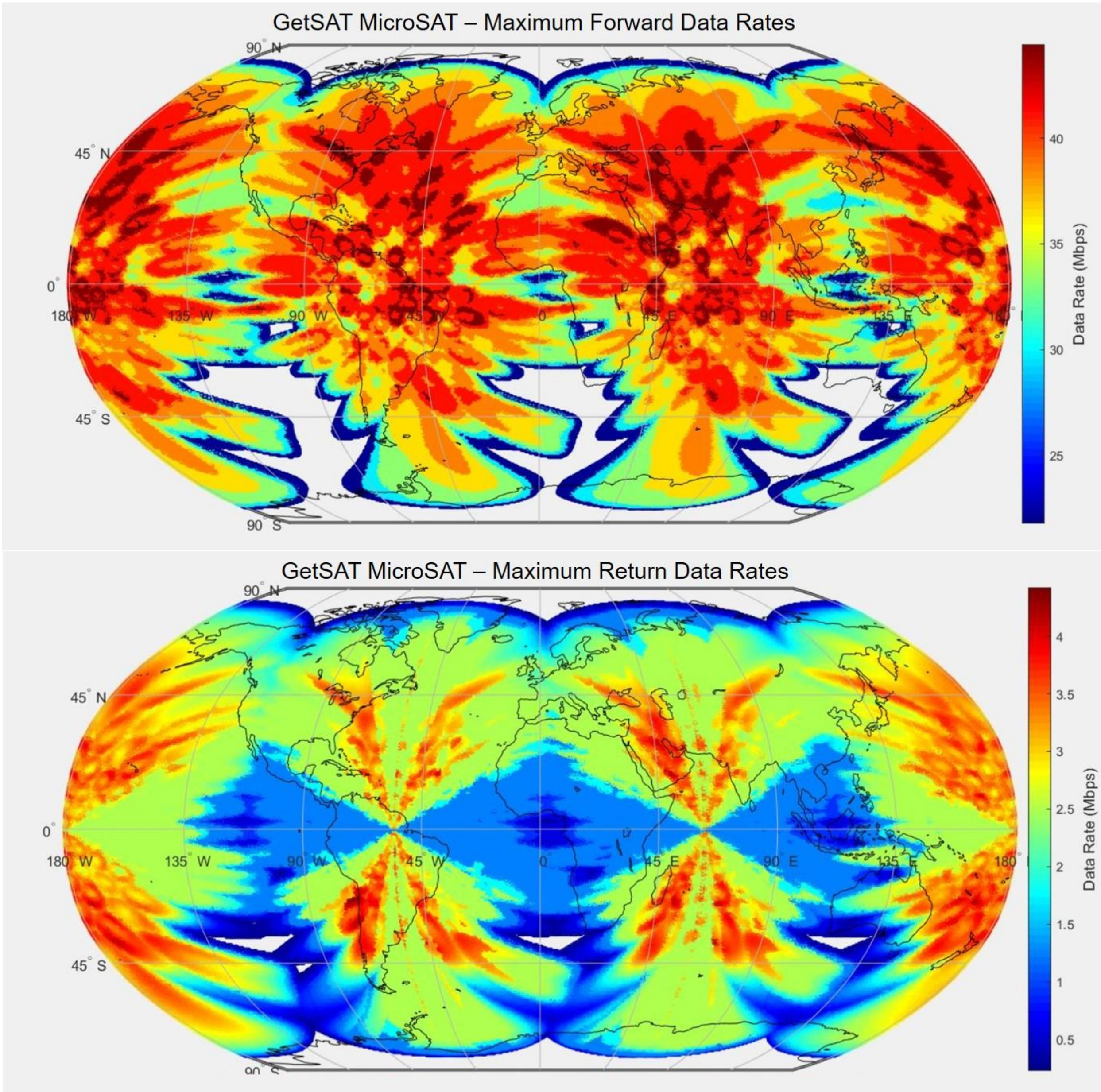

Exhibit 14: GetSAT MicroSAT Terminal Performance using Global Xpress Commercial Ka-band Subscription Services.

It is possible to operate the GetSAT MicroSAT terminal on an I-5 military Ka-band steerable beam. Exhibit 15 provides an overview of the forward and return link performance for this antenna using the High Capacity Cross-strapped (HCX) configuration (mil Ka-band user link with commercial Ka-band feeder link). HCX provides a 100MHz duplex transponder. Performance analysis is based on clear sky or above-the-clouds conditions and use a high-performance modem.

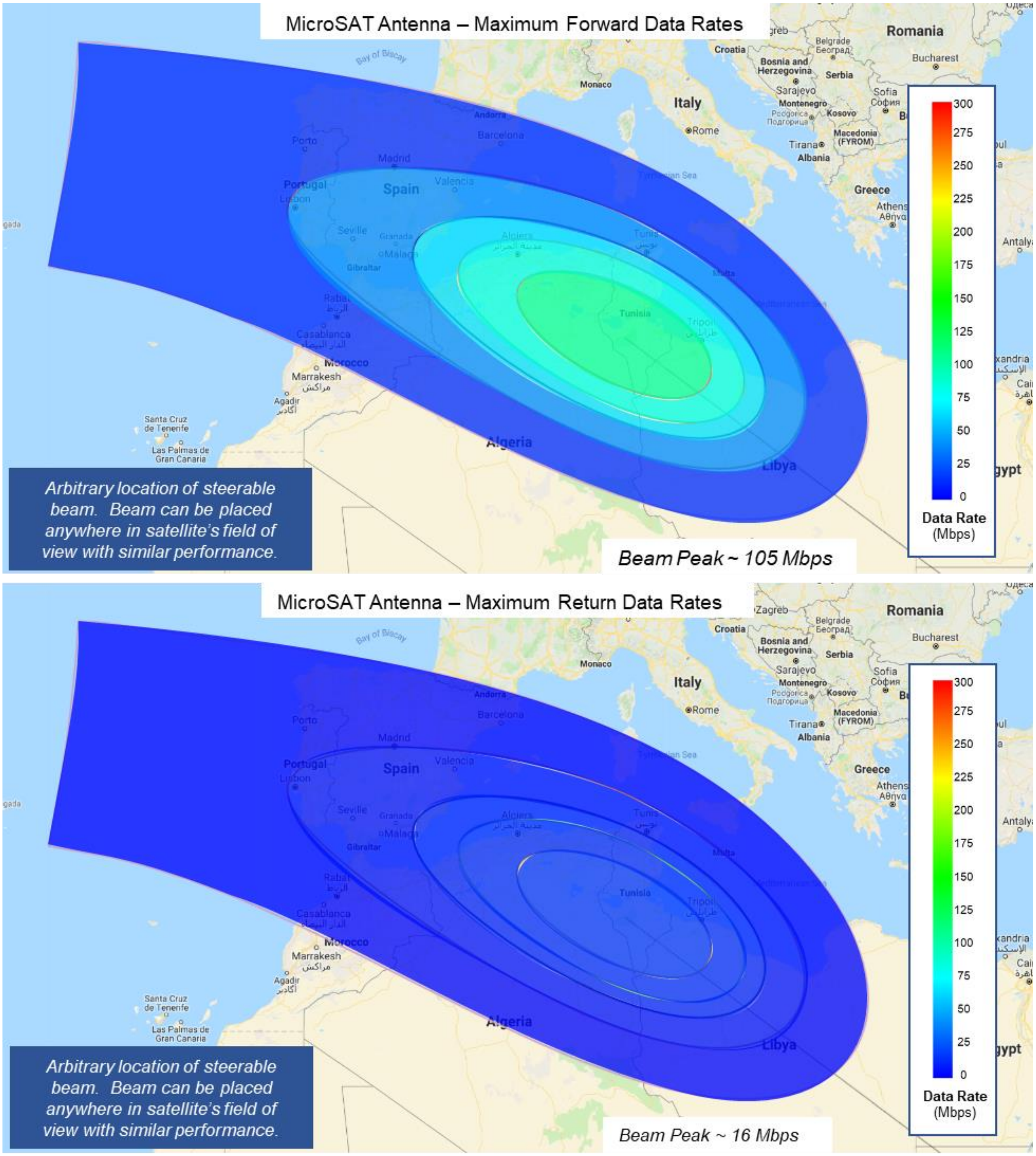

Exhibit 15: GetSAT MicroSAT Performance using I-5 Military Ka-band HCX.

30cm Parabolic

Exhibit 16 provides an overview of the characteristics for a sample 30cm terminal aeronautical terminal. This terminal supports commercial and mil Ka band and includes mil band and commercial band modems.

Power	28VDC
Nav Interface	External INS - ARINC 429
Mass	32kg
Dimensions	34.5cm x 30.5cm
Consumed Power	447W
Data Interface	Ethernet
RF Specs	EIRP: 47.7dBW G/T: 11dB/K
Data Rates (Commercial Service)	Up to 55Mbps Forward; 8Mbps Return
Data Rate (Military Ka-band Steerable Beam)	Up to 145Mbps Forward; 38Mbps Return

Exhibit 16: 30 cm Parabolic Antenna Specifications.

Using the commercial Ka-band subscription services, a 30cm antenna could provide a maximum forward link performance up to 55Mbps and a return link performance of up to 8Mbps. An assessment of forward and return link performance for a 30cm terminal is shown in Exhibit 17.

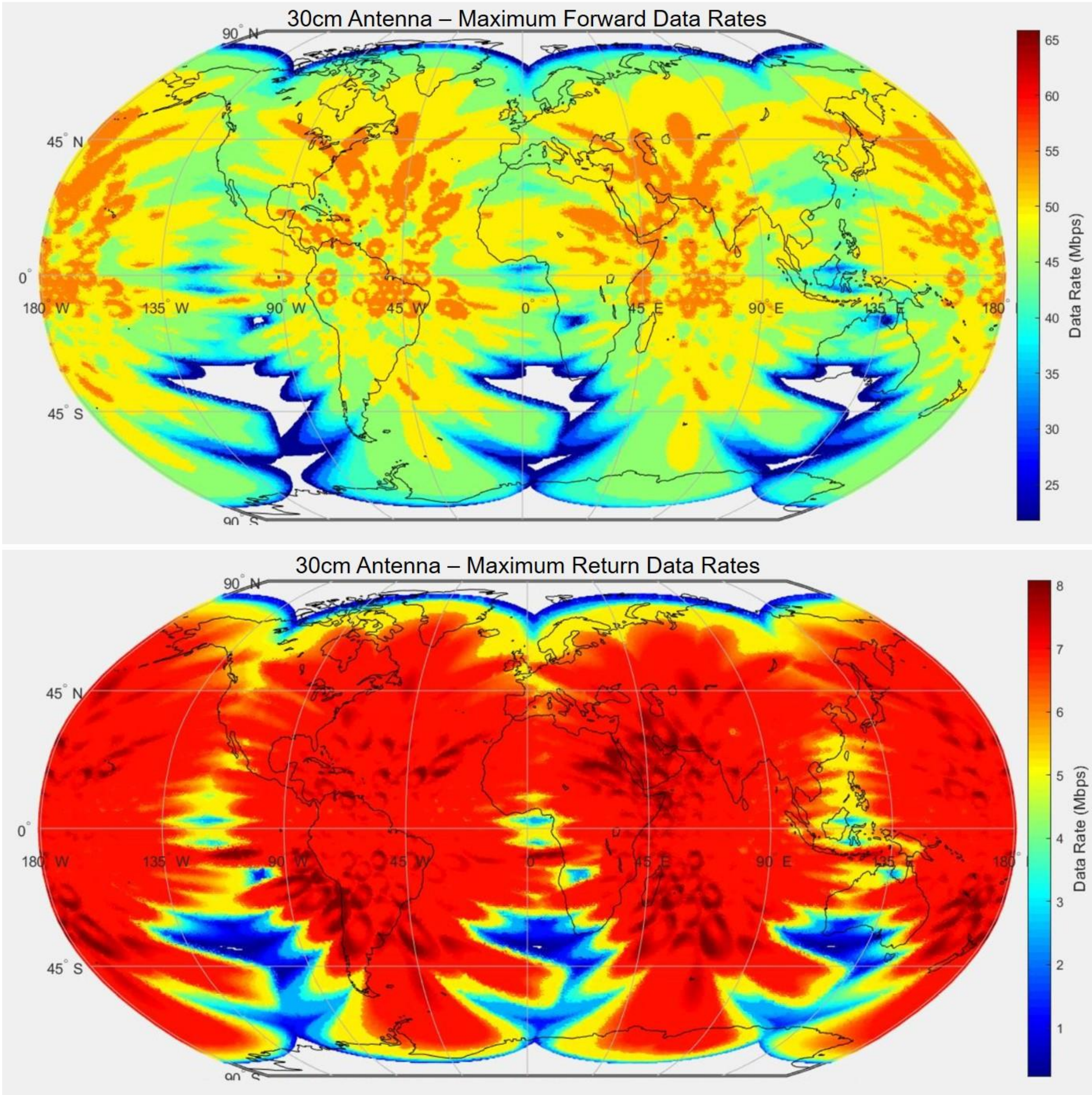

Exhibit 17: 30cm Terminal Performance using Commercial Ka-band Subscription Services.

It is possible to operate this 30cm terminal on an I-5 military Ka-band steerable beam. Exhibit 18 provides an overview of the forward and return link performance for this antenna using the HCX service (mil Ka-band user link with commercial Ka-band feeder link). HCX provides a 100MHz duplex transponder. Performance analysis is based on clear sky or above-the-clouds conditions and use of a high-performance modem.

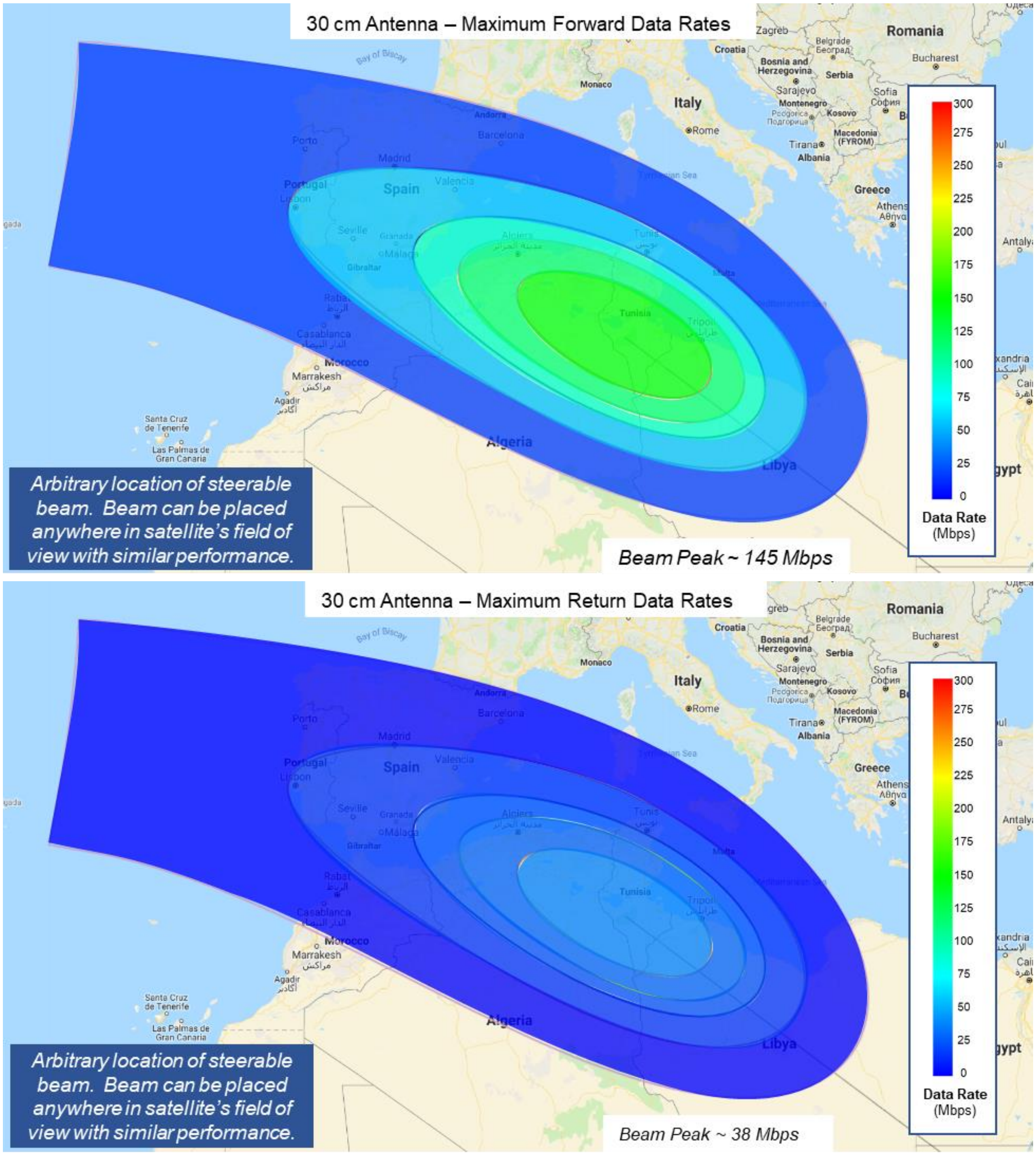

Exhibit 18: 30cm Antenna Performance using I-5 Military Ka-band HCX.

46cm Parabolic

Exhibit 19 provides an overview of the characteristics for the Orbit GX46 aeronautical terminal. This terminal supports commercial and mil Ka-band and includes mil band and commercial band modems.

Power	28VDC	
Nav Interface	External INS - ARINC 429	
Mass	21.4kg	
Dimensions	58cm x 50cm	
Consumed Power	527W	
Data Interface	Ethernet	
RF Specs, Typical	EIRP: 52dBW G/T: 12.2dB/K	
Data Rates (Commercial Service)	Up to 65Mbps Forward; 10Mbps Return	
Data Rate (Military Ka-band Steerable Beam)	Up to 174Mbps Forward; 92Mbps Return	

Exhibit 19: 46cm Parabolic Antenna Specifications.

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Using the commercial Ka-band subscription services, a 46cm diameter aperture provides a forward link up to 65Mbps and a return link up to 10Mbps. An assessment of predicted maximum performance for a 46cm terminal is described in Exhibit 20.

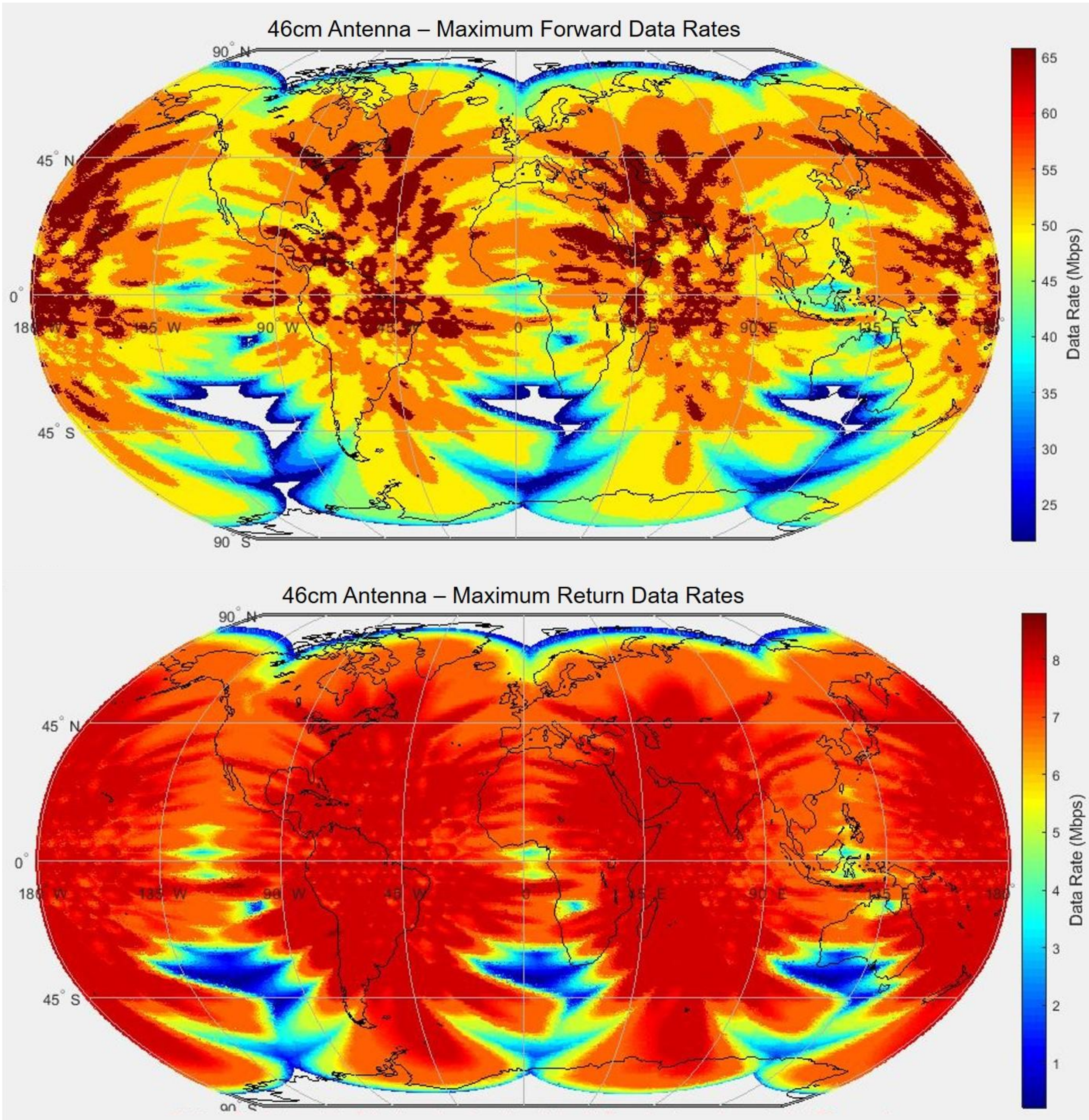

Exhibit 20: 46cm Terminal Performance using Commercial Ka-band Subscription Services.

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It is possible to operate this 46cm terminal on an I-5 military Ka-band steerable beam. Exhibit 21 provides an overview of the predicted maximum forward and return performance for this antenna using HCX. HCX provides a 100MHz duplex transponder. Performance analysis is based on clear sky or above-the-clouds conditions and use of a high-performance modem.

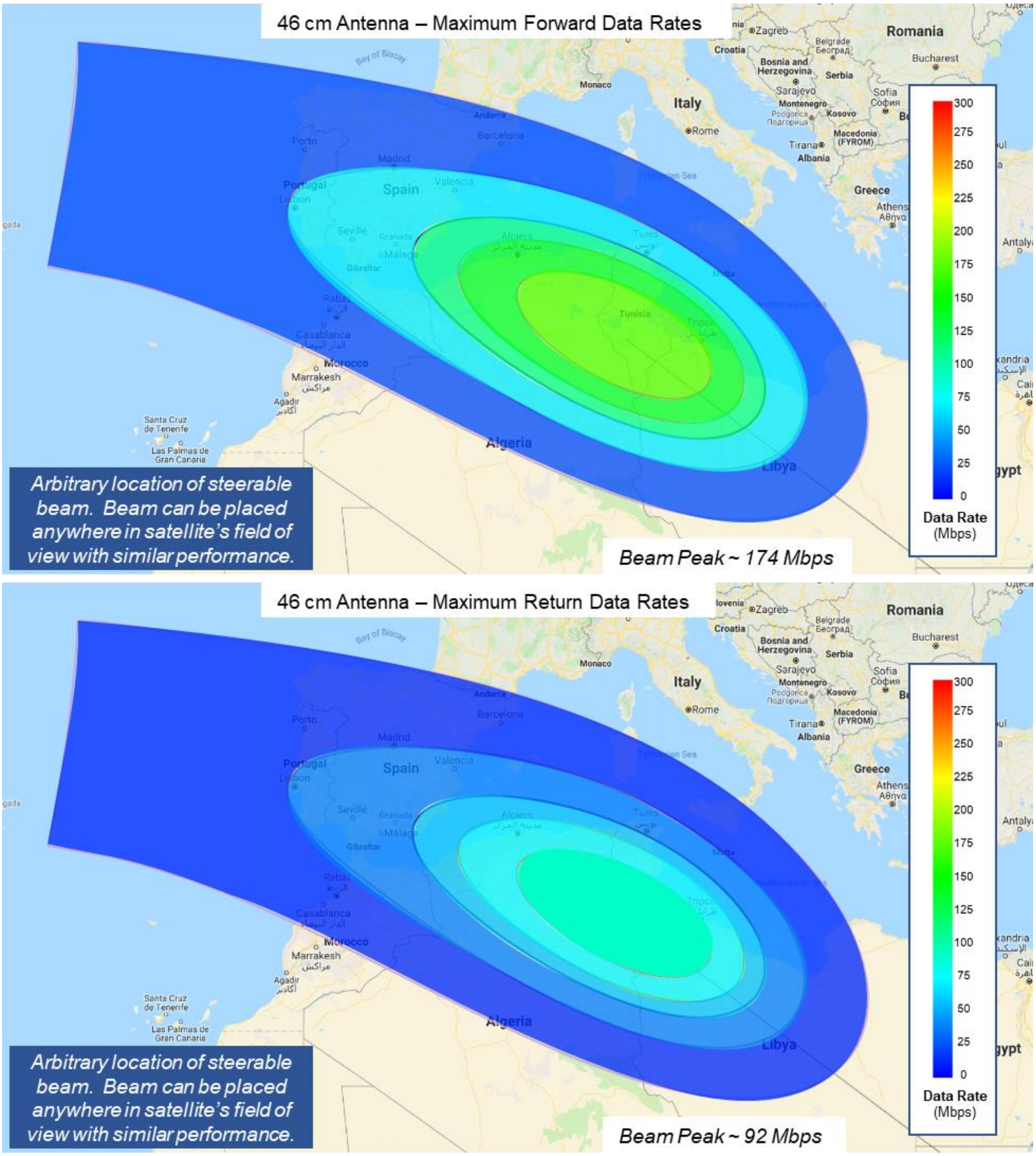

Exhibit 21: 46cm Antenna Performance using I-5 Military Ka-band HCX.

76cm Parabolic

Exhibit 22 provides an overview of the characteristics for a sample 76cm aeronautical terminal. This terminal supports commercial and mil Ka-band and includes mil band and commercial band modems.

Power	28VDC	No terminal picture available 
Nav Interface	External INS - ARINC 429	
Mass	31.5kg	
Dimensions	97cm x 100cm	
Consumed Power	597W	
Data Interface	Ethernet	
RF Specs, Typical	EIRP: 60dBW G/T: 17dB/K	
Data Rates (Commercial Service)	Up to 85Mbps Forward; 13Mbps Return	
Data Rate (Military Ka-band Steerable Beam)	Up to 250Mbps Forward; 219Mbps Return	

Exhibit 22: 76cm Parabolic Antenna Specifications.

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Using the commercial Ka-band subscription services, a 76cm diameter aperture would provide a maximum forward link performance up to 85Mbps and a return link performance of up to 13Mbps. An assessment of predicted maximum performance this terminal is shown in Exhibit 23.

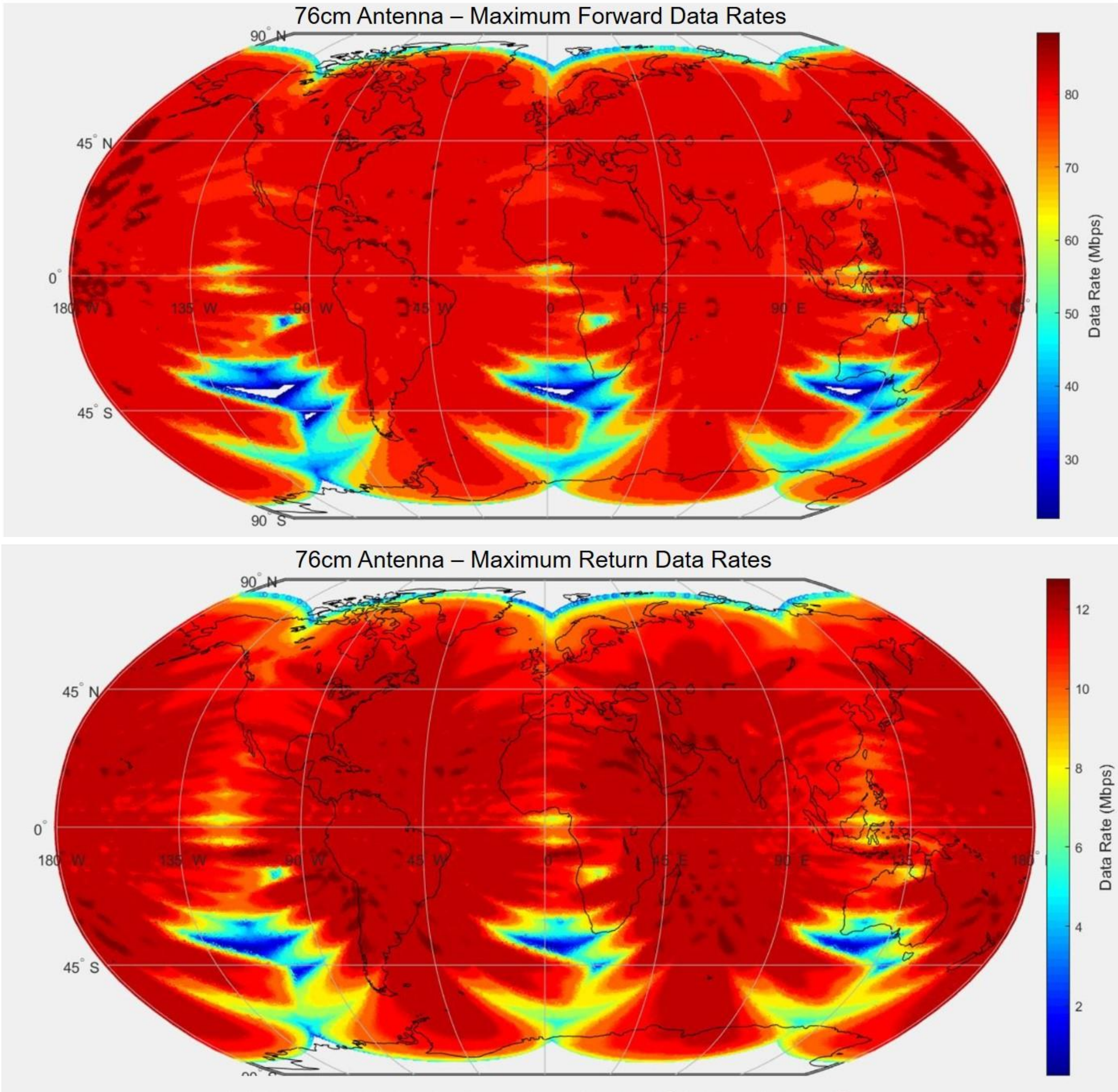

Exhibit 23: 76cm Terminal Performance using Commercial Ka-band Subscription Services.

It is possible to operate this 76cm terminal on an I-5 military Ka-band steerable beam. Exhibit 24 provides an overview of the predicted maximum forward and return performance for this antenna operating on. HCX provides a 100MHz duplex transponder. Performance analysis is based on clear sky or above-the-clouds conditions and use of a high-performance modem.

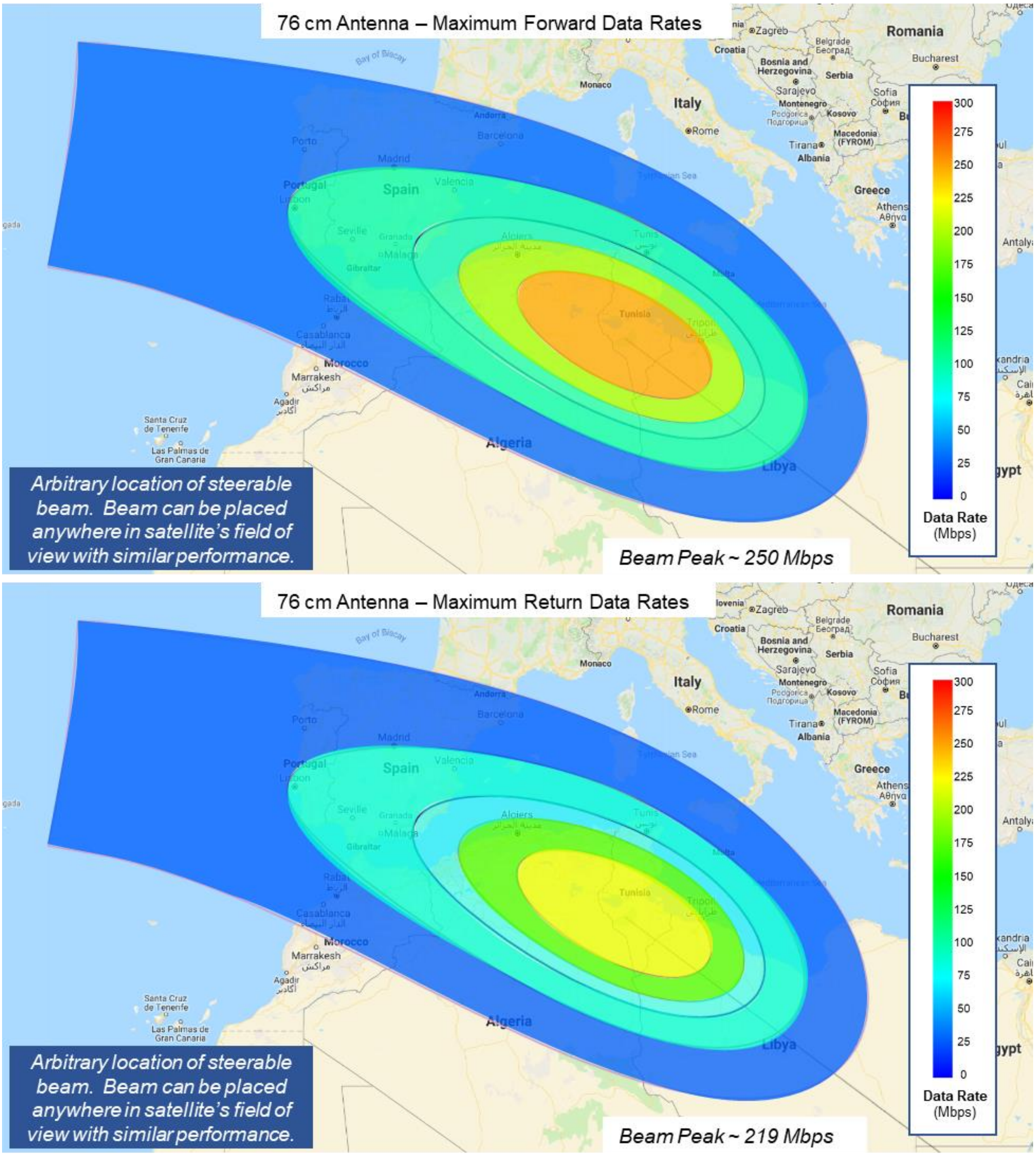

Exhibit 24: 76cm Antenna Performance using I-5 Military Ka-band HCX.

1.2m Parabolic

Exhibit 25 provides an overview of the characteristics for a sample 1.2m aeronautical terminal. This terminal supports commercial and mil Ka band and includes mil band and commercial band modems.

Power	28VDC
Nav Interface	External INS - ARINC 429
Mass	45.7kg
Dimensions	130cm x 137cm
Consumed Power	696W
Data Interface	Ethernet
RF Specs, Typical	EIRP: 66dBW G/T: 23dB/K
Data Rates (Commercial Service)	Up to 85Mbps Forward; 13Mbps Return
Data Rate (Military Ka-band Steerable Beam)	Up to 338Mbps Forward; 338Mbps Return

Exhibit 25: 1.2m Parabolic Antenna Specifications.

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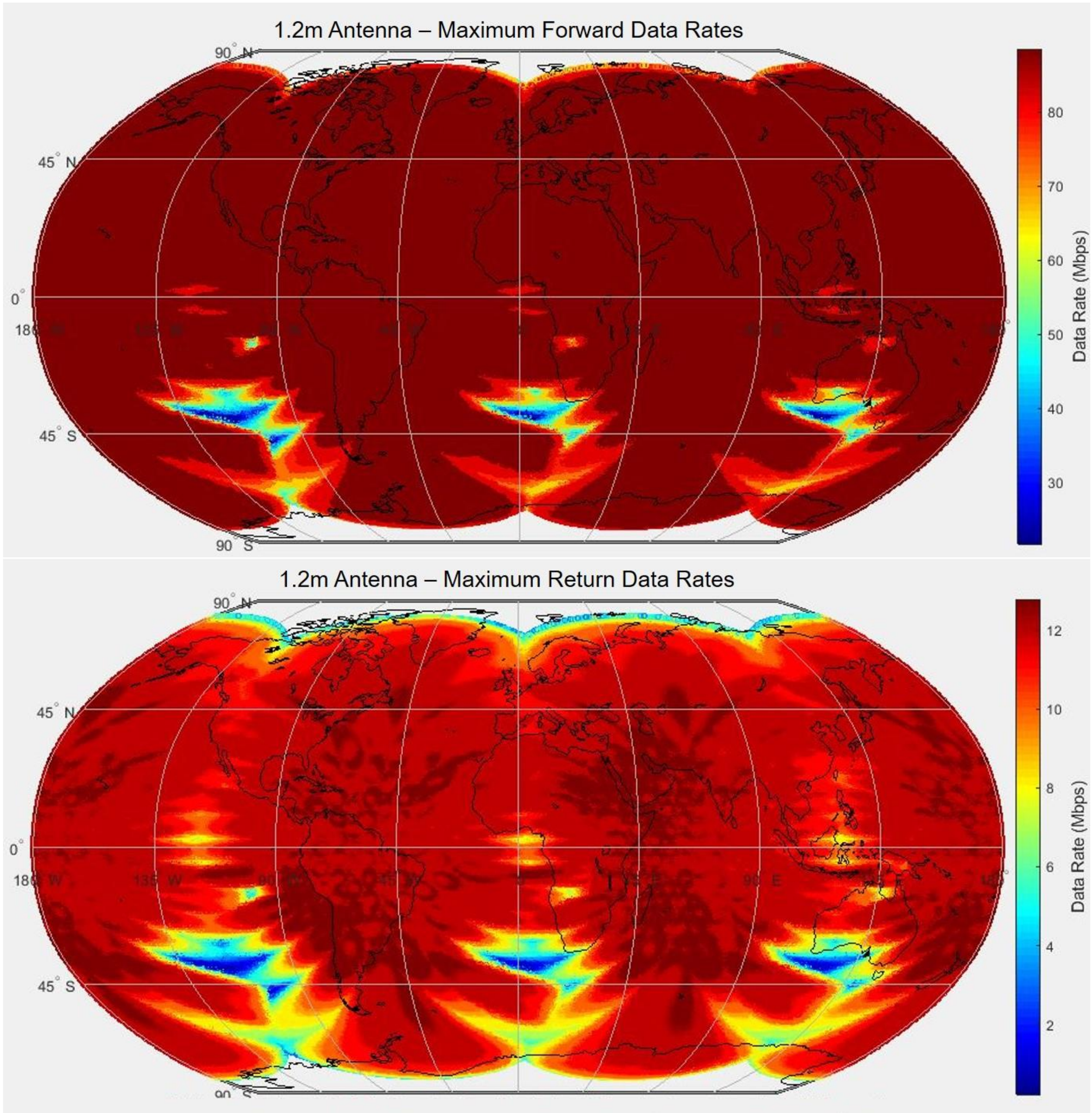

Exhibit 26: 1.2m Terminal Performance using Commercial Ka-band Subscription Services.

It is possible to operate this 1.2m terminal on the I-5 military Ka-band steerable beam. Exhibit 27 provides an overview of the predicted maximum forward and return performance for this antenna using the HCX configuration. HCX provides a 100MHz duplex transponder. Performance analysis is based on clear sky or above-the-clouds conditions and use of a high-performance modem.

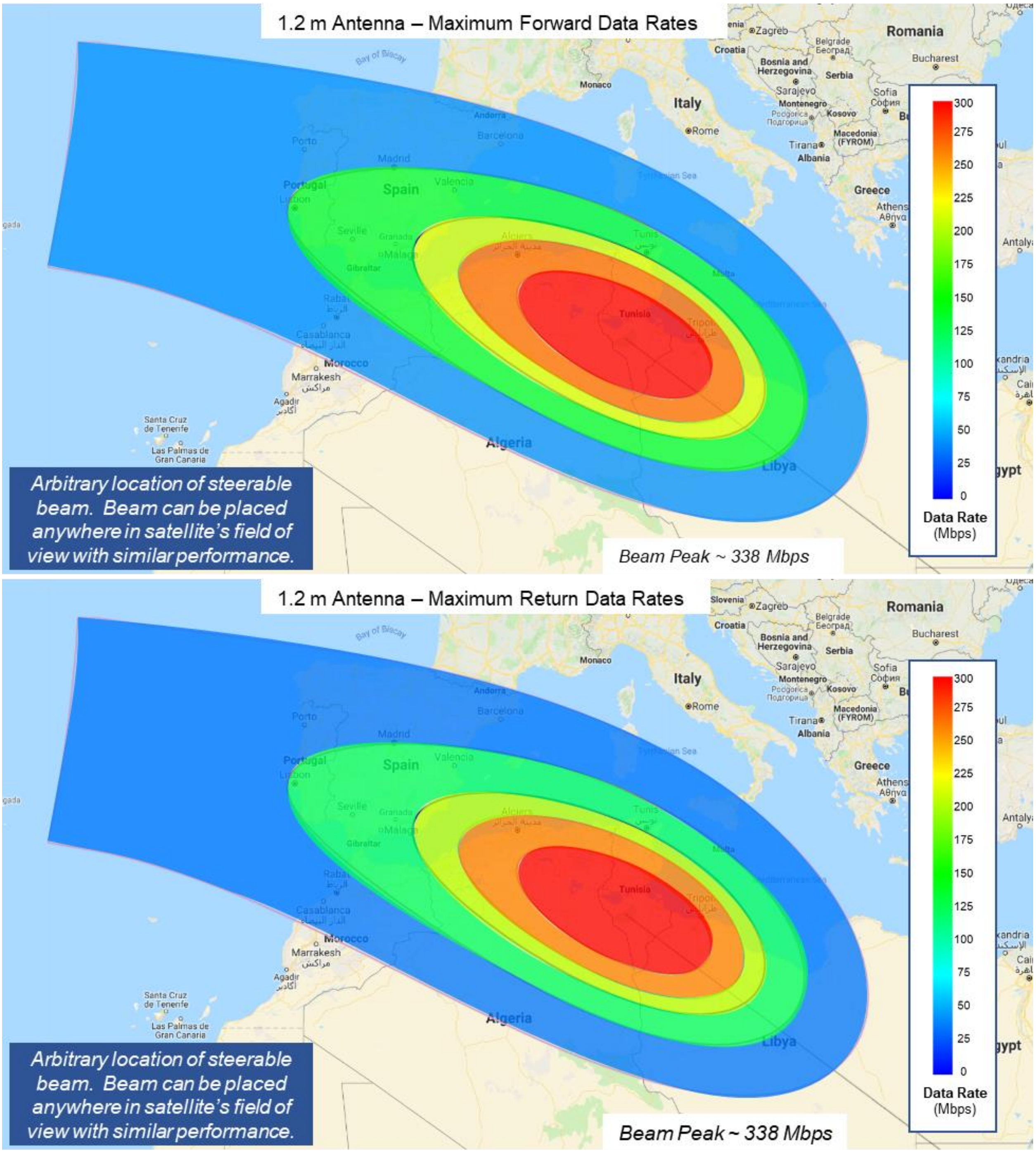

Exhibit 27: 1.2m Antenna Performance using I-5 Military Ka-band HCX.

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CONCLUSION

The applications of UAVs and their performance continue to expand. Investment and experience have allowed amazing accomplishments in the UAV realm in a relatively short period of time. Inmarsat's worldwide L-band and Ka-band solutions provide an excellent means of supporting BLOS communications for UAV platforms. Capabilities on the Inmarsat satellite constellations continue to expand and advance...which expands the "art of the possible" for UAVs whose missions are enhanced by BLOS communications. A reader of this paper will have gained an understanding of BLOS options for various Categories of UAVs. Connectivity performance models for L-band subscription services, leased L-band, Ka-band subscription services and leased mil Ka-band show scalable solutions across a resilient, global Inmarsat architecture. This understanding enables the formation of reasonable performance (data rate) and accommodation (SWaP) expectations for BLOS solutions. Unique applications and advanced terminal designs can expand or shrink the available trade space to a degree, but the information presented provides a solid guide for a UAV User seeking to expand their platform utility with BLOS connectivity.