In Reply Refer To: APG-NI-1111-0006

December 16, 2011

Mr. Anthony Serafini
Office of Engineering and Technology
Federal Communications Commission
445 12th Street SW, Washington, DC 20554

Subject: FCC Experimental Radio License Application for the Cygnus Spacecraft

Attachment(s):
(1) Cygnus FCC Form 442 Narrative
(2) Cygnus FCC Form 442 Telemetry Modes
(3) Cygnus Antenna Patterns
(4) Cygnus Concept of Operations
(5) Cygnus Orbital Debris

Submitted Separately:
(6) Cygnus NTIA Filing
(7) Cygnus Power Flux Density Summary (ITAR Controlled)

Dear Mr. Serafini,

This letter and its attachments form part of Orbital Sciences Corporation's (Orbital) application for an Experimental Radio License for the Cygnus spacecraft. Orbital is developing the Cygnus spacecraft for the NASA Commercial Orbital Transportation Services (COTS) Space Act Agreement and Commercial Resupply Services (CRS) contract. Orbital respectfully requests an expedited review and processing period in light of the recent decision to change frequency licensing from NTIA to the FCC. An expedited review is essential as initial RF testing at the Wallops Flight Facility for the Cygnus demonstration mission is scheduled to begin on 1 March 2012 in support of a 28 April 2012 launch date.

Orbital has used the OET Experimental Licensing System e-File Site to file the basic application:

FRN: 0016225740
Form 442 Confirmation Number: EL763271
Form 442 File Number: 0548-EX-PL-2011
Date of Submission: November 2, 2011

The Cygnus spacecraft transmitter parameters do not clearly match FCC Form 442. The attachments to this letter provide additional narrative and technical data to support the e-File form.

In Reply Refer To: APG-NI-1111-0006

Should you have any questions or require any additional information, please contact either Mr. Kevin Jackson or Mr. Michael Maguire:

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COTS/CRS Program
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Sincerely,

Frank DeMauro
COTS/CRS Program Director
Advanced Programs Group

Attachment 1
Cygnus FCC Form 442 Narrative

This document provides information in support of the Orbital Sciences Corporation's (Orbital) radio license application for the Cygnus spacecraft.

Specific data is supplied for each paragraph of the Administration and Technical Section of the FCC Form 442 application.

This design note and the FCC Form 442 application identify all modes and configurations of the Cygnus spacecraft communications transmitters.

In Table 1 FCC Form 442 Administration Section Narrative, the Section number matches the same field of the FCC Form 442.

Table 1 FCC Form 442 Administration Section Narrative

Section	Form	Response
1.	Mailing Address:	No additional information required
2.	Application Purpose:	No additional information required
3.	For Modification indicate below:	No additional information required
4.	Government contract:	Yes
4.a.	Government Agency:	NASA
4.b.	Project:	Orbital Sciences Corporation is under contract to NASA/Johnson Space Center to:
4.b.i.	Project (Sub-paragraph)	Develop a commercial cargo transportation system, the Cygnus spacecraft, for delivery of cargo to the International Space Station and perform one demonstration flight of this system. This is the NASA Commercial Orbital Transportation System (COTS) program; Note: the demonstration Cygnus flight is referred to as ORB-D1.
4.b.ii.	Project (Sub-paragraph)	Perform eight operational flights to deliver cargo to the International Space Station. This is part of the NASA Commercial Resupply Services (CRS) program. Note: the operational Cygnus flights are referred to as ORB-1 through ORB-8.
4.c.	Contract Number:	
4.c.i.	COTS program:	Space Act Agreement NNJ08TA32S
4.c.ii.	CRS program:	NNJ09GA02B
5.	Foreign Government User:	No additional information required
6.	Research Project:	No additional information required
7.	Exhibit:	No additional information required

Section	Form	Response
8.	Estimated Duration:	60 months. Orbital Sciences expects launch and operate 9 spacecraft over the next 3 to 5 years under contract to NASA. Each mission will last 7 to 180 days on orbit depending on NASA requirements. Orbital requests a single license to cover all missions: i.e. 60 month duration. Alternatively, at the discretion of the FCC, Orbital would request a 2 year term and update the license as necessary for each mission. See Technical Data §6 Frequencies, Emissions and Modulating Signals for details on the transmitters and modulation schemes for each mission. This data is also summarized in the spreadsheet attached to this application.
9.	Environmental Impact:	No additional information required
10.a.	Manufacturer:	Transmitter equipment:

Manufacturer	Model Number	Experimental
Thales Alenia Espana (Spain)	605051AA-50	No
Quasonix (USA)	QSX-VSR-000-20S-20-4D-ORBN	No
Mitsubishi Electric Co. (MELCO) (Japan)	F7F3413-G02	No

Section	Form	Response
10.b.	Quantity of Each Unit:	

	Thales	Quasonix	MELCO
Mission	605051AA-50	QSX-VSR-000-20S-20-4D-ORBN	F7F3413-G02
ORB-D1	2	0	2
ORB-1	2	0	2
ORB-2	1	1	2
ORB-3	0	2	2
ORB-4	0	2	2
ORB-5	0	2	2
ORB-6	0	2	2
ORB-7	0	2	2
ORB-8	0	2	2

Section	Form	Response
10.c.	Transmitter Description	
10.c.i		Thales Alenia Espana provides a spaceflight qualified S-Band transponder: it includes both a telecommand receiver and a telemetry transmitter. The transponder supports several different modulations and data rates as commanded from the spacecraft operations center. The transponder can operate in both Space-to-Earth (Cygnus spacecraft direct to ground) and Space-to-Space (Cygnus spacecraft via the NASA TDRSS to ground) modes. The transponder will be used in a dual redundant configuration for the ORB-D1 (demonstration) and ORB-1 missions. The transponder operates as the primary transmitter with the Quasonix transmitter as a spare on the ORB-2 mission. The transponder is not used on subsequent missions.
10.c.ii.		Quasonix provides a spaceflight qualified S-Band transmitter: it provides only telemetry transmit capability. The transmitter supports several different modulations and data rates as commanded from the spacecraft operations center. The transmitter can operate in both Space-to-Earth (ORB-spacecraft direct to ground) and Space-to-Space (ORB-spacecraft Space-to-Space via the NASA TDRSS) modes. The transmitter operates as a redundant transmitter to the Thales transponder on the ORB-2 mission. The transmitter will be used in a dual redundant configuration for the ORB-3 and all subsequent missions.
10.c.iii.		Mitsubishi Electric Company (MELCO) provides a spaceflight qualified S-Band transponder: it includes both a telecommand receiver and a telemetry transmitter: dual redundant systems are operated in hot standby. The Cygnus transponder is the Proximity Link System (PLS): the corresponding ISS system is the Proximity Communications System (PROX). PROX transmits forward link data and PRN code to PLS. PLS receives forward link data and passes to Cygnus command system. PLS receives return link data from Cygnus telemetry system and transmits telemetry and received PRN to PROX. PROX routes Cygnus telemetry to ISS.

Section	Form	Response
11.	Station ID:	No. The transmitters will not transmit the licensed call sign. All data is transmitted in randomized CCSDS (Consultative Committee on Space Data Systems) format.
12.	Applicant Type:	No additional information required
13.	Foreign Government:	No additional information required
14.	License Denied or Revoked:	No additional information required
15.	Owner and Operator:	No additional information required
16.	Contact Information:	No additional information required
17.	Drug Abuse Question:	No additional information required
18.	Certification:	Kevin Jackson

Table 2 FCC Form 442 Technical Section Narrative provides information responsive to the items in the FCC Form 442 Technical Section.

Table 2 FCC Form 442 Technical Section Narrative

Section	Form	Response
1.	Application Purpose:	No additional information required
2.	Transmitter Location:	Mobile is incorrect but is one of only two options in the on-line application form. This application is for an unmanned cargo spacecraft. The license should be considered ET – Space Operation Service. The spacecraft transmitters will be operational/non-operational as follows:
2.a.	Integration and Test Facility at Wallops Flight Facility	Telemetry and PLS operation at NASA Wallops Flight Facility during final integration and test under the control of the Wallops Spectrum Manager.
2.a.		i. Latitude: 37.8339° N ii. Longitude: −75.4877° E iii. Altitude: 25 ft
2.b.	Wallops Flight Facility Launch Pad	No telemetry or PLS operations on the launch pad. The spacecraft is covered by a fairing for launch therefore the spacecraft transmitters will not be active until the spacecraft is deployed on orbit.
2.c.	On-orbit	Telemetry operation on orbit following fairing separation from the Taurus Launch Vehicle and throughout operations to reach the International Space Station.
2.c.	The Keplerian orbital elements, using the Earth J2000 Coordinate System, for a typical mission will be:	i. Semi-Major Axis: 6779.02 km ii. RAAN: 210.373 deg iii. Eccentricity: 0.0004656438 iv. Argument of Perigee: 188.616 deg v. Inclination: 51.601 deg vi. True Anomaly: 296.031 deg vii. Orbit Period: 5400 s
2.d.	Orbital injection will occur at an altitude of approximately:	i. ORB-D1 through ORB-2: 260 to 280 km ii. ORB-3 to ORB-8: 300 km

Section	Form	Response
2.e.	ISS Operations	PLS operations with the International Space Station will occur within 30 km of the ISS at altitudes in the range:
2.e.		i. Minimum: 333 km ii. Maximum: 460 km.
2.f.	De-orbit	Telemetry operations following departure from the ISS until re-entry.
3.	Datum:	N/A
4.	Directional Antenna:	N/A
5.	Exhibit Submitted:	Antenna patterns for the spacecraft are included as an attachment to this application.
6.	Antenna Height:	Spacecraft will operate at altitudes from 260 km to 460 km with corresponding RF horizons of 1800 km to 2500 km.
7.	Frequencies, Emissions and Modulating Signals:	This data is also summarized in the spreadsheet attached to the application. All transmitters will operate in the 2200 to 2300 MHz band. This band is allocated in its entirety to US Government applications. Orbital had previously submitted an application to the NTIA for this spacecraft: the application was advanced to the final approval stage before it was determined that the Cygnus spacecraft fell under commercial (and hence FCC) purview despite supporting a NASA (US government contract). The NTIA application is submitted as a supporting document to this application. This data is also summarized in Attachment 2.

Section	Form	Response
7.a.	PLS Transmitter Mode 1: PLS-to-PROX	
7.a.i.	PLS Return Link	1. Antenna: Passively coupled Quadrifilar Helical and Monofilar Helical antenna pair (omnidirectional) 2. Frequency: 2205.0 MHz (Lower 2202.9 MHz, Upper 2207.1 MHz) 3. Bandwidth: 4.20 MHz 4. Mean Power (Transmitter Output): a. 2.1 W = 3.2 dBW (High Power) b. 7.7 mW = −21.1 dBW (Low Power) 5. EIRP: a. 0.11 W = −9.7 dBW (High Power) b. 0.41 mW = −34.0 dBW (Low Power) 6. Modulation: SS-USQPSK (Spread Spectrum Unbalanced Staggered Quadrature Phase Shift Keying) 7. I/Q Imbalance: 1 to 2.5 8. I channel (PRN Ranging) a. Data Rate: no data b. Coding: none c. Symbol rate: none d. Chip rate 2.97 Mchips/s 9. Q channel (Telemetry) a. Data Rate: 8 kbps b. Coding: Convolutional (R = ½ , K =7) c. Symbol Rate: 16 kbps d. Chip rate: 2.97 Mchips/s 10. Emission Designator: 4M20G1D

Section	Form	Response
7.b.	Cygnus to TDRSS	
7.b.i.	Telemetry Transmitter Mode 1: Space-to-Space: Spread Spectrum S-Band Single/Multiple Access (SSA/MA) (DG1 Mode 2)	1. Antenna: Quadrifilar Helix pair (omnidirectional) 2. Frequency: a. 2216 MHz (2213.0 to 2219.0 MHz) (ORB-D1 to ORB-D2) b. 2287.5 MHz (2284.5 to 2290.5 MHz) (ORB-3 to ORB-8) 3. Bandwidth: 6.0 MHz 4. Mean Power (Transmitter Output): a. 7.1 W = 8.5 dBW (ORB-D1 to ORB-2) b. 20.0 W = 13.0 dBW (ORB-3 to ORB-8) 5. EIRP: a. 6.4 W = 8.0 dBW (ORB-D1 to ORB-2) b. 17.9 W = 12.5 dBW (ORB-3 to ORB-8) 6. Modulation: SQPN (Staggered Quadrature Pseudorandom Noise) 7. I/Q imbalance: 1 to 1 8. I channel (Telemetry) a. Data Rate: 4 or 8 or 16 or 21 kbps b. Coding: Convolutional (R = ½, K = 7) c. Symbol Rate: 8 or 16 or 32 or 42 ksps d. Chip rate: 2.9816 Mchips/s 9. Q channel (Telemetry – duplicate) a. Data Rate: 4 or 8 or 16 or 21 kbps b. Coding: Convolutional (R = ½, K = 7) c. Symbol Rate: 8 or 16 or 32 or 42 ksps d. Chip rate: 2.9816 Mchips/s 10. Emission Designator: 6M00G1D

Section	Form	Response
7.b.ii.	Telemetry Transmitter Mode 2: Space-to-Space: S-Band Single Access (DG1 Mode 2)	1. Antenna: Quadrifilar Helix pair (omnidirectional) 2. Frequency: a. 2216 MHz (2215.975 to 2216.025 MHz) (ORB-D1 to ORB-D2) b. 2287.5 MHz (2284.5 to 2290.5 MHz) (ORB-3 to ORB-8) 3. Bandwidth: a. 8/16/32/42 kHz (ORB-D1 to ORB-2) b. 6 MHz (ORB-3 to ORB-4) 4. Mean Power (Transmitter Output): a. 7.1 W = 8.5 dBW (ORB-D1 to ORB-2) b. 10.0 W = 10.0 dBW (ORB-3 to ORB-8) 5. EIRP: a. 6.4 W = 8 dBW (ORB-D1 to ORB-2) b. 8.9 W = 9.5 dBW (ORB-3 to ORB-8) 6. Modulation: a. SQPSK(Staggered Quadrature Phase Shift Keyed) (ORB-D1 to ORB-2) b. SQPN (Staggered Quadrature Pseudorandom Noise) (ORB-3 to ORB-8) 7. I/Q imbalance: 1 to 1 8. I channel (Telemetry) a. Data Rate: 4 or 8 or 16 or 21 kbps b. Coding: Convolutional (R = ½, K = 7) c. Symbol Rate: 8 or 16 or 32 or 42 ksps d. Chip rate: i. 0 (not spread) (ORB-D1 to ORB-2) ii. 3.0778 Mchips/s (ORB-3 to ORB-8) 9. Q channel (Telemetry – Identical) (ORB-D1 to ORB-2) (Telemetry – Alternating) (ORB-3 to ORB-8) a. Data Rate: 8 or 16 or 32 or 42 kbps b. Coding: Convolutional (R = ½, K = 7) c. Symbol Rate: 16 or 32 or 64 or 84 ksps d. Chip rate: i. 0 (not spread) (ORB-D1 to ORB-2) ii. 3.0778 Mchips/s (ORB-3 to ORB-8) 10. Emission Designators: a. 8K00/16K0/32K0/42K0G1D (ORB-D1 to ORB-2) b. 6M00G1D (ORB-3 to ORB-8)

Section	Form	Response
7.c.	Cygnus to Ground	
7.c.i.	Telemetry Transmitter Mode 3: Space-to-Earth: Ground Station Telemetry	1. Antenna: Helical pair (omnidirectional) 2. Frequency: a. 2216 MHz (2214.5 to 2217.5 MHz) (ORB-D1 to ORB-D2) b. 2287.5 MHz (2286.0 to 2289.0 MHz) (ORB-3 to ORB-8) 3. Bandwidth: 8/16/32/42/3000 kHz 4. Mean Power (Transmitter Output): a. 7.1 W = 8.5 dBW (ORB-D1 to ORB-2) b. 0.5 W = −3.0 dBW (ORB-3 to ORB-8) 5. EIRP: a. 6.4 W = 8 dBW (ORB-D1 to ORB-2) b. 0.45 W = −3.5 dBW (ORB-3 to ORB-8) 6. Modulation: SQPSK (Staggered Quadrature Phase Shift Keying) 7. I/Q imbalance: 1 to 1 8. I/Q channel (Telemetry) a. Data format: alternating bit b. Data Rate: 4 or 8 or 16 or 21 or 3000 kbps c. Coding: Convolutional (R = ½, K = 7) d. Symbol Rate: 8/16/32/42/3000 ksps Note: 3000 kbps telemetry is not convolutional coded therefore bit rate equals symbol rate. e. Chip rate: 0 (not spread spectrum) 9. Emission Designators: 8K00/16K0/32K0/42K0/3M00G1D

Attachment 2
Cygnus FCC Form 442 Telemetry Modes

The tables below summarize the Cygnus spacecraft telemetry modes, modulations, data rates, center frequencies, and necessary bandwidths. Specific frequencies are assigned to be compatible with NASA allocations in the Space Operations Service S Band (2025 to 2110 MHz uplink; 2200 to 2300 MHz downlink).

Table 3 Telemetry Transmitter Mode 1 and PLS Mode Parameters

Thales TM Transmitter			Transmitter	EIRP		Frequency				Telemetry Transmitter Mode 1 : Space-to-Space : Spread Spectrum S-Band Single Access Return (SSA) : DG1 Mode 2 (Non-Coherent)																	
Mission	Qty	Polarization	Max	Max	Min	Center	Lower	Upper	Bandwidth	TDRSS	DSSS	PRN Code	Modulation	PN Chip Rate	Coding	Data Rate 1	Symbol Rate 1	Data Rate 2	Symbol Rate 2	Data Rate 3	Symbol Rate 3	Data Rate 4	Symbol Rate 4	Channel Format			Data Format
	Each		dBW	dBW	dBW	MHz	MHz	MHz	MHz			(NASA)		MHz		kbps	ksps	kbps	ksps	kbps	ksps	kbps	ksps	I Channel	Q Channel	I/Q Imbalance	
ORB-D1	2	RHCP	8.5	8.0	-	2216.000	2213.000	2219.000	6.000	SSA	Yes	25	SQPN	2.9816	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-1	2	RHCP	8.5	8.0	-	2216.000	2213.000	2219.000	6.000	SSA	Yes	25	SQPN	2.9816	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-2	1	RHCP	8.5	8.0	-	2216.000	2213.000	2219.000	6.000	SSA	Yes	25	SQPN	2.9816	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-3	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-4	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-5	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-6	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-7	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-8	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-

Emission Designator: 6M00G1D

Quasonix TM Transmitter			Transmitter	EIRP		Frequency				Telemetry Transmitter Mode 1 : Space-to-Space : Spread Spectrum S-Band Single/Multiple Access Return (SSA/MA) : DG1 Mode 2 (Non-Coherent)																	
Mission	Qty	Polarization	Max	Max	Min	Center	Lower	Upper	Bandwidth	TDRSS	DSSS	PRN Code	Modulation	PN Chip Rate	Coding	Data Rate 1	Symbol Rate 1	Data Rate 2	Symbol Rate 2	Data Rate 3	Symbol Rate 3	Data Rate 4	Symbol Rate 4	Channel Format			
	Each		dBW	dBW	dBW	MHz	MHz	MHz	MHz			(NASA)		MHz		kbps	ksps	kbps	ksps	kbps	ksps	kbps	ksps	I Channel	Q Channel	I/Q Imbalance	Data Format
ORB-D1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-2	1	RHCP	8.5	8.0	-	2216.000	2213.000	2219.000	6.000	SSA	Yes	25	SQPN	2.9816	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-3	2	LHCP	13.0	12.5	-	2287.500	2284.500	2290.500	6.000	MA	Yes	25	SQPN	3.0778	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-4	2	LHCP	13.0	12.5	-	2287.500	2284.500	2290.500	6.000	MA	Yes	25	SQPN	3.0778	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-5	2	LHCP	13.0	12.5	-	2287.500	2284.500	2290.500	6.000	MA	Yes	25	SQPN	3.0778	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-6	2	LHCP	13.0	12.5	-	2287.500	2284.500	2290.500	6.000	MA	Yes	25	SQPN	3.0778	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-7	2	LHCP	13.0	12.5	-	2287.500	2284.500	2290.500	6.000	MA	Yes	25	SQPN	3.0778	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-8	2	LHCP	13.0	12.5	-	2287.500	2284.500	2290.500	6.000	MA	Yes	25	SQPN	3.0778	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M

Emission Designator: 6M00G1D

MELCO PLS Transmitter			Transmitter	EIRP		Frequency				Proximity Link System (PLS) Transmitter Mode 1 : PLS-to-Prox (Space-to-Space)											
Mission	Qty	Polarization	Max	Max	Min	Center	Lower	Upper	Bandwidth	ISS	DSSS	PRN Code	Modulation	PN Chip Rate	Coding	Data Rate	Symbol Rate	Channel Format			Data Format
	Each		dBW	dBW	dBW	MHz	MHz	MHz	MHz			(NASDA)		MHz		kbps	ksps	I Channel	Q Channel	I/Q Imbalance	
ORB-D1	2	RHCP	3.2	-9.7	-34.0	2205.000	2202.900	2207.100	4.200	PROX	Yes	I = 11 : Q = 9	U-SQPSK	2.9668	R = ½ K = 7	8.0	16.0	Ranging	Telemetry	1:2.5	NRZ-L
ORB-1	2	RHCP	3.2	-9.7	-34.0	2205.000	2202.900	2207.100	4.200	PROX	Yes	I = 11 : Q = 9	U-SQPSK	2.9668	R = ½ K = 7	8.0	16.0	Ranging	Telemetry	1:2.5	NRZ-L
ORB-2	2	RHCP	3.2	-9.7	-34.0	2205.000	2202.900	2207.100	4.200	PROX	Yes	I = 11 : Q = 9	U-SQPSK	2.9668	R = ½ K = 7	8.0	16.0	Ranging	Telemetry	1:2.5	NRZ-L
ORB-3	2	RHCP	3.2	-9.7	-34.0	2205.000	2202.900	2207.100	4.200	PROX	Yes	I = 11 : Q = 9	U-SQPSK	2.9668	R = ½ K = 7	8.0	16.0	Ranging	Telemetry	1:2.5	NRZ-L
ORB-4	2	RHCP	3.2	-9.7	-34.0	2205.000	2202.900	2207.100	4.200	PROX	Yes	I = 11 : Q = 9	U-SQPSK	2.9668	R = ½ K = 7	8.0	16.0	Ranging	Telemetry	1:2.5	NRZ-L
ORB-5	2	RHCP	3.2	-9.7	-34.0	2205.000	2202.900	2207.100	4.200	PROX	Yes	I = 11 : Q = 9	U-SQPSK	2.9668	R = ½ K = 7	8.0	16.0	Ranging	Telemetry	1:2.5	NRZ-L
ORB-6	2	RHCP	3.2	-9.7	-34.0	2205.000	2202.900	2207.100	4.200	PROX	Yes	I = 11 : Q = 9	U-SQPSK	2.9668	R = ½ K = 7	8.0	16.0	Ranging	Telemetry	1:2.5	NRZ-L
ORB-7	2	RHCP	3.2	-9.7	-34.0	2205.000	2202.900	2207.100	4.200	PROX	Yes	I = 11 : Q = 9	U-SQPSK	2.9668	R = ½ K = 7	8.0	16.0	Ranging	Telemetry	1:2.5	NRZ-L
ORB-8	2	RHCP	3.2	-9.7	-34.0	2205.000	2202.900	2207.100	4.200	PROX	Yes	I = 11 : Q = 9	U-SQPSK	2.9668	R = ½ K = 7	8.0	16.0	Ranging	Telemetry	1:2.5	NRZ-L

Emission Designator: 4M20G1D

Table 4 Telemetry Transmitter Mode 2 Parameters

Thales TM Transmitter			Transmitter	EIRP	Frequency				Telemetry Transmitter Mode 2 : Space-to-Space : S-Band Single Access Return (SSA) : DG2 Mode 2 (Non-Coherent)																
Mission	Qty	Polarization	Max	Max	Center	Lower	Upper	Bandwidth	TDRSS	DSSS	Modulation	PN Chip Rate	Coding	Data Rate 1	Symbol Rate 1	Data Rate 2	Symbol Rate 2	Data Rate 3	Symbol Rate 3	Data Rate 4	Symbol Rate 4	Channel Format			Data Format
	Each		dBW	dBW	MHz	MHz	MHz	MHz				MHz		kbps	ksps	kbps	ksps	kbps	ksps	kbps	ksps	I Channel	Q Channel	I/Q Imbalance	
ORB-D1	2	RHCP	8.5	8.0	2216.000	2215.996	2216.004	0.008	SSA	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Alternating)		1:1	NRZ-M
ORB-1	2	RHCP	8.5	8.0	2216.000	2215.996	2216.004	0.008	SSA	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Alternating)		1:1	NRZ-M
ORB-2	1	RHCP	8.5	8.0	2216.000	2215.996	2216.004	0.008	SSA	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Alternating)		1:1	NRZ-M
ORB-3	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-4	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-5	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-6	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-7	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-8	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
												Emission Designator:		8K00G1D		16K0G1D		32K0G1D		42K0G1D					
														Worst Case PFD Calculation											

Quasonix TM Transmitter			Transmitter	EIRP	Frequency				Telemetry Transmitter Mode 2 : Space-to-Space : S-Band Single Access Return (SSA) : DG2 Mode 2 (Non-Coherent)																
Mission	Qty	Polarization	Max	Max	Center	Lower	Upper	Bandwidth	TDRSS	DSSS	Modulation	PN Chip Rate	Coding	Data Rate 1	Symbol Rate 1	Data Rate 2	Symbol Rate 2	Data Rate 3	Symbol Rate 3	Data Rate 4	Symbol Rate 4	Channel Format			Data Format
	Each		dBW	dBW	MHz	MHz	MHz	MHz				MHz		kbps	ksps	kbps	ksps	kbps	ksps	kbps	ksps	I Channel	Q Channel	I/Q Imbalance	
ORB-D1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-2	1	RHCP	8.5	8.0	2216.000	2215.996	2216.004	0.008	SSA	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Alternating)		1:1	NRZ-M
ORB-3	2	LHCP	10.0	9.5	2287.500	2284.500	2290.500	6.000	SSA	Yes	SQPN	3.0778	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-4	2	LHCP	10.0	9.5	2287.500	2284.500	2290.500	6.000	SSA	Yes	SQPN	3.0778	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-5	2	LHCP	10.0	9.5	2287.500	2284.500	2290.500	6.000	SSA	Yes	SQPN	3.0778	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-6	2	LHCP	10.0	9.5	2287.500	2284.500	2290.500	6.000	SSA	Yes	SQPN	3.0778	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-7	2	LHCP	10.0	9.5	2287.500	2284.500	2290.500	6.000	SSA	Yes	SQPN	3.0778	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
ORB-8	2	LHCP	10.0	9.5	2287.500	2284.500	2290.500	6.000	SSA	Yes	SQPN	3.0778	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	TM (I/Q Identical)		1:1	NRZ-M
						Emission Designator:		6M00G1D				Emission Designator:		8K00G1D		16K0G1D		32K0G1D		42K0G1D					
														Worst Case PFD Calculation											

Table 5 Telemetry Transmitter Mode 3 Parameters

Thales TM Transmitter			Transmitter	EIRP	Frequency				Telemetry Transmitter Mode 3 : Space-to-Earth (Ground Station Telemetry)																		
Mission	Qty	Polarization	Max	Max	Center	Lower	Upper	Bandwidth	Ground	DSSS	Modulation	PN Chip Rate	Coding	Data Rate 1	Symbol Rate 1	Data Rate 2	Symbol Rate 2	Data Rate 3	Symbol Rate 3	Data Rate 4	Symbol Rate 4	Data Rate 5	Symbol Rate 5	Channel Format			Data Format
	Each		dBW	dBW	MHz	MHz	MHz	MHz				MHz		kbps	ksps	kbps	ksps	kbps	ksps	kbps	ksps	kbps	ksps	I Channel	Q Channel	I/Q Imbalance	
ORB-D1	2	RHCP	8.5	8.0	2216.000	2215.996	2216.004	0.008	NEN/USN	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	3000.0	-	TM (I/Q Alternating)		1:1	NRZ-M
ORB-1	2	RHCP	8.5	8.0	2216.000	2215.996	2216.004	0.008	NEN/USN	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	3000.0	-	TM (I/Q Alternating)		1:1	NRZ-M
ORB-2	1	RHCP	8.5	8.0	2216.000	2215.996	2216.004	0.008	NEN/USN	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	3000.0	-	TM (I/Q Alternating)		1:1	NRZ-M
ORB-3	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-4	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-5	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-6	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-7	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-8	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
												Emission Designator:		8K00G1D		16K0G1D		32K0G1D		42K0G1D		3M00G1D					
														Worst Case PFD Calculation													

Quasonix TM Transmitter			Transmitter	EIRP	Frequency				Telemetry Transmitter Mode 3 : Space-to-Earth (Ground Station Telemetry)																		
Mission	Qty	Polarization	Max	Max	Center	Lower	Upper	Bandwidth	Ground	DSSS	Modulation	PN Chip Rate	Coding	Data Rate 1	Symbol Rate 1	Data Rate 2	Symbol Rate 2	Data Rate 3	Symbol Rate 3	Data Rate 4	Symbol Rate 4	Data Rate 5	Symbol Rate 5	Channel Format			Data Format
	Each		dBW	dBW	MHz	MHz	MHz	MHz				MHz		kbps	ksps	kbps	ksps	kbps	ksps	kbps	ksps	kbps	ksps	I Channel	Q Channel	I/Q Imbalance	
ORB-D1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
ORB-2	1	RHCP	8.5	8.0	2216.000	2215.996	2216.004	0.008	NEN/USN	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	3000.0	-	TM (I/Q Alternating)		1:1	NRZ-M
ORB-3	2	LHCP	-3.0	-3.5	2287.500	2287.496	2287.504	0.008	NEN/USN	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	3000.0	-	TM (I/Q Alternating)		1:1	NRZ-M
ORB-4	2	LHCP	-3.0	-3.5	2287.500	2287.496	2287.504	0.008	NEN/USN	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	3000.0	-	TM (I/Q Alternating)		1:1	NRZ-M
ORB-5	2	LHCP	-3.0	-3.5	2287.500	2287.496	2287.504	0.008	NEN/USN	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	3000.0	-	TM (I/Q Alternating)		1:1	NRZ-M
ORB-6	2	LHCP	-3.0	-3.5	2287.500	2287.496	2287.504	0.008	NEN/USN	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	3000.0	-	TM (I/Q Alternating)		1:1	NRZ-M
ORB-7	2	LHCP	-3.0	-3.5	2287.500	2287.496	2287.504	0.008	NEN/USN	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	3000.0	-	TM (I/Q Alternating)		1:1	NRZ-M
ORB-8	2	LHCP	-3.0	-3.5	2287.500	2287.496	2287.504	0.008	NEN/USN	No	SQPSK	-	R = ½ K = 7	4.0	8.0	8.0	16.0	16.0	32.0	20.98	41.96	3000.0	-	TM (I/Q Alternating)		1:1	NRZ-M
												Emission Designator:		8K00G1D		16K0G1D		32K0G1D		42K0G1D		3M00G1D					
														Worst Case PFD Calculation													

Attachment 3
Cygnus Antenna Patterns

The attached charts summarize the Cygnus spacecraft antenna patterns for telemetry (transmit) functions.

The Cygnus spacecraft will transmit in the Spacecraft Operations Service S-Band. This band is allocated to the US Federal Government and covers 2200 to 2300 MHz. The Cygnus spacecraft downlink frequencies have been chosen by NASA consistent with operations near the International Space Station. The Cygnus spacecraft telemetry operates with a variety of data rates and modulation schemes. These are detailed in Attachment 2.

This attachment and the FCC Form 442 application describe the standard Cygnus antenna configurations. See Attachment 5 for system block diagrams and antenna positions.

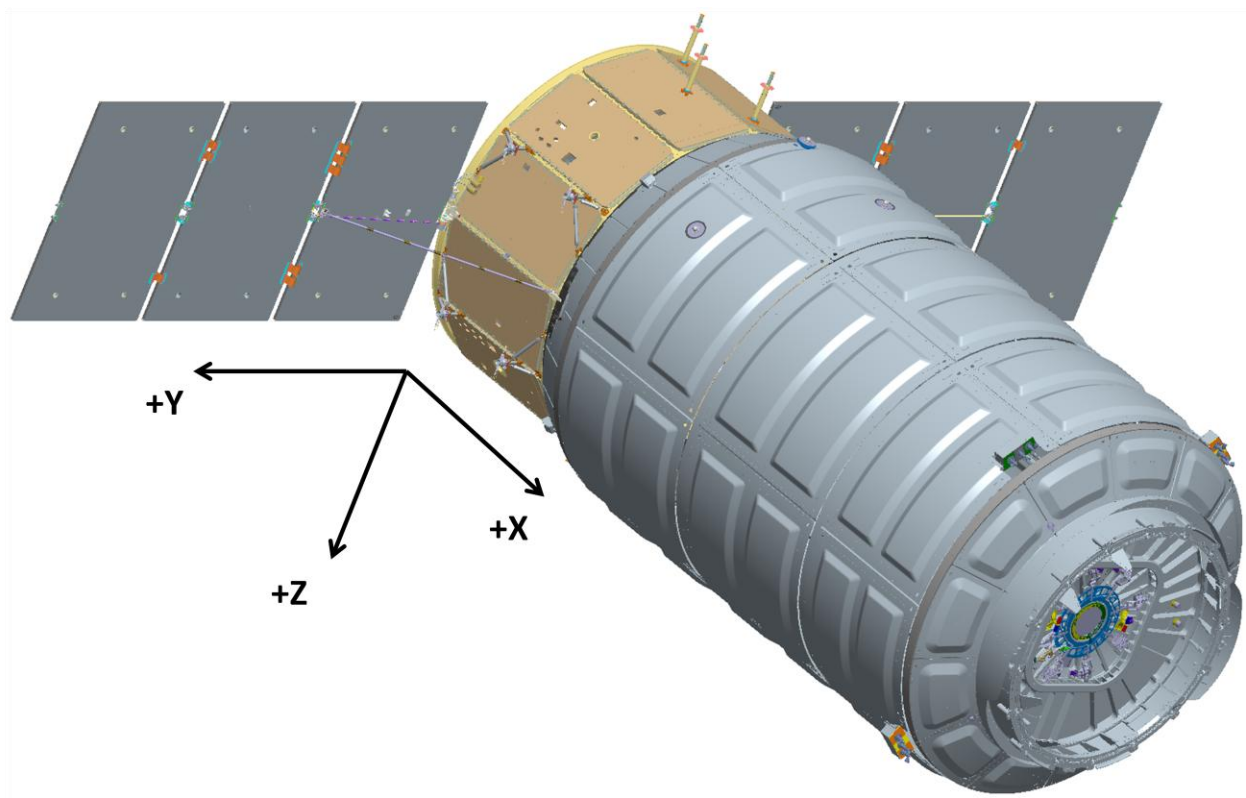

Figure 1 Cygnus Axes Defined

Figure 1 Cygnus Axes Defined shows the Cygnus vehicle axes. The –Z-axis shows three antennas. Each antenna is matched with an antenna on the +Z-axis to form an antenna pair. The antenna gain plots for these antenna pairs follow.

Cygnus will approach the ISS with the –Z-axis forward. This will improve antenna performance towards the ISS during the critical approach and departure phase. Cygnus-ISS communications are provided by the PROX/PLS hardware. Figure 2 Cygnus PROX/PLS Antenna Pattern shows the PROX/PLS antenna pattern. Details of the hardware configuration can be found in Attachment 5.

Cygnus will nominally fly in a solar inertial profile. From a communications perspective a receiving station will rotate once around the vehicle per orbit necessitating an omnidirectional antenna pattern. This will be required for both space-to-space and space-to-Earth links. Figure 3 Cygnus Telemetry Antenna Pattern shows the antenna pattern used for these telemetry links. Details of the hardware configuration can be found in Attachment 5.

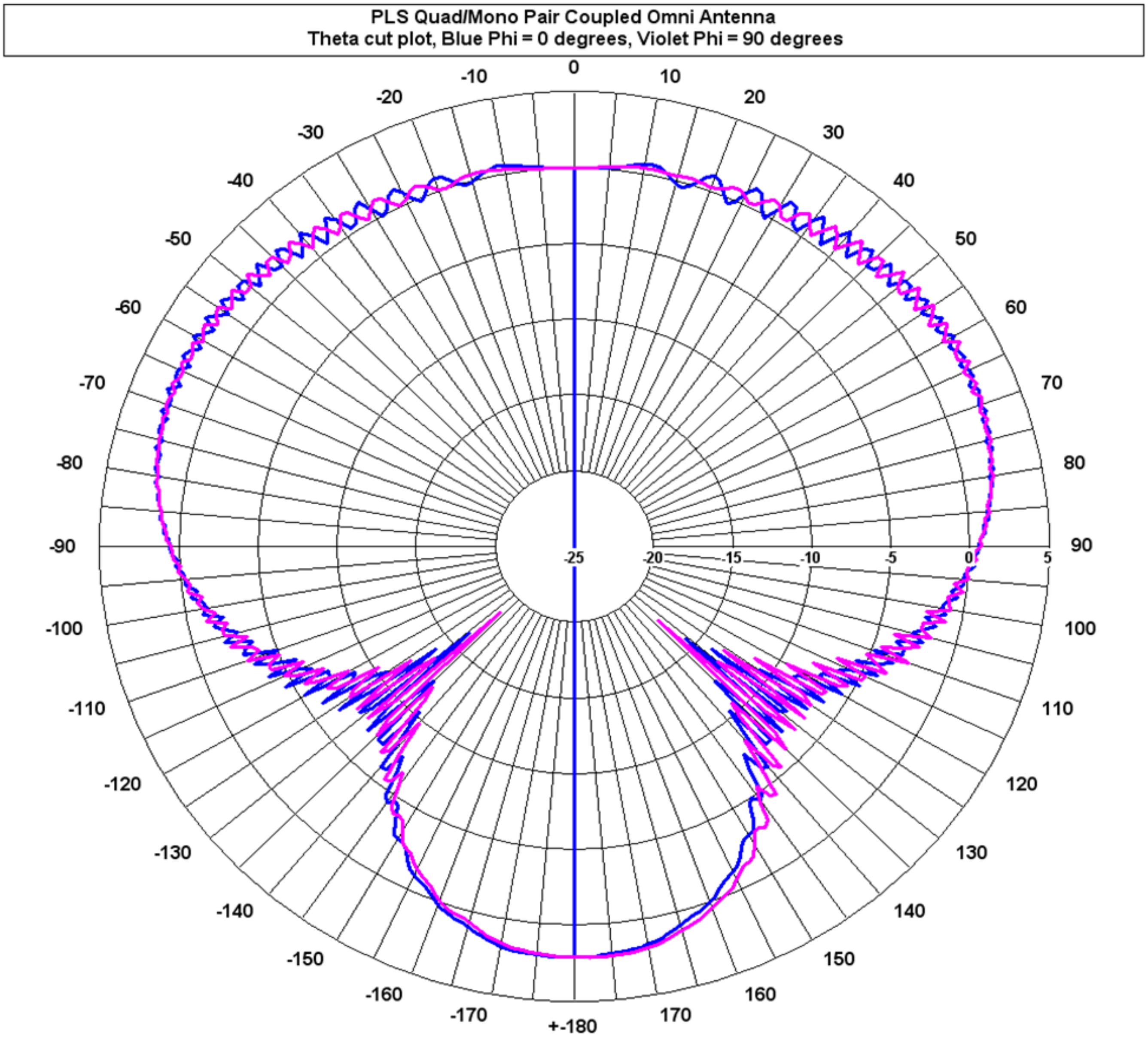

Figure 2 Cygnus PROX/PLS Antenna Pattern

In this plot, φ = 0° plots can be matched to the YZ-plane and φ = 90° can be matched to the XY-plane where 0° on the plot represents the –Z-axis.

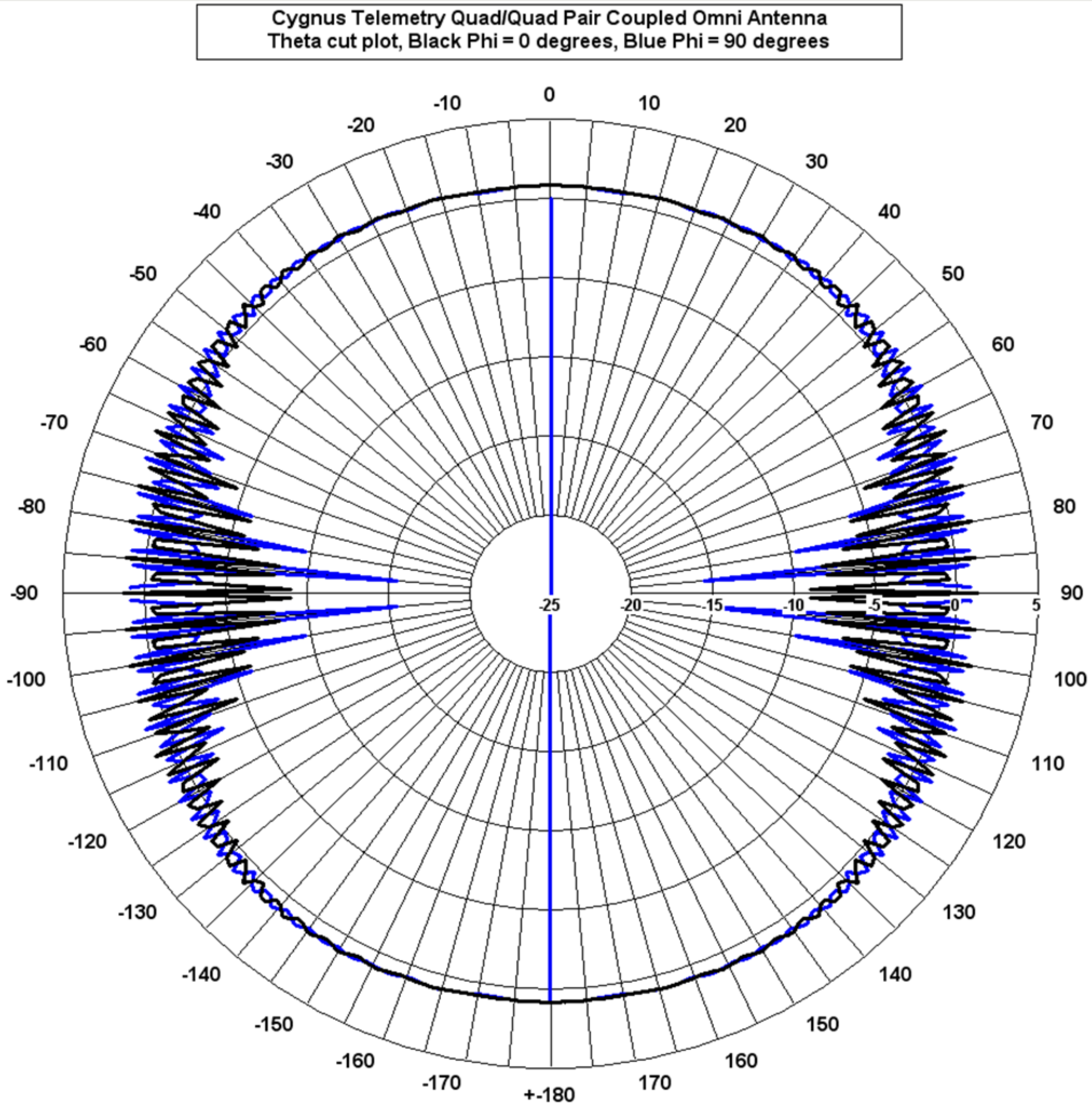

Figure 3 Cygnus Telemetry Antenna Pattern

In this plot, φ = 0° plots can be matched to the YZ-plane and φ = 90° can be matched to the XY-plane where 0° on the plot represents the –Z-axis.

Attachment 4
Cygnus Concept of Operations

This attachment describes typical mission architecture and basic scenarios for the Cygnus spacecraft communications systems. Orbital has developed the unmanned Cygnus spacecraft to support the NASA COTS/CRS programs. This document describes the basic Cygnus Concept of Operations in support of Orbital's FCC Experimental License application for the spacecraft. Radio licenses are required for all Cygnus transmitters to remain compliant with US and International Radio Regulations.

Orbital Sciences Corporation (Orbital) is under contract to NASA/Johnson Space Center to:

a. Develop a commercial cargo transportation system for delivery of cargo to the International Space Station (ISS) then perform a demonstration flight of this system. This is part of the NASA Commercial Orbital Transportation System (COTS) program. The COTS program is performed in accordance with the COTS Space Act Agreement NNJ08TA32S; and,

b. Perform eight operational flights to deliver cargo to the International Space Station (ISS). This is part of the NASA Commercial Resupply Services (CRS) program. The CRS program is performed in accordance with NASA Contract NNJ09GA02B.

The scope of operations for each NASA contract includes:

a. Mission planning and cargo integration operations prior to the mission;

b. Ground operations associated with spacecraft and launch vehicle processing and integration;

c. Launch operations;

d. Flight operations; and,

e. Post-flight analyses.

A total of 9 missions are planned:

a. COTS contract: ORB-D1 (demonstration mission)

b. CRS Contract: ORB-1 through ORB-8 (operational mission)

The International Space Station (ISS) provides a science and research resource for member (supporting) nations. Following the retirement of the Space Shuttle program the United States is left without a means to provide logistics support to the ISS. The NASA COTS/CRS programs are using commercial companies to develop US logistics capability for the ISS.

The COTS/CRS Concept of Operations encompasses a continuous production of flight elements that support multiple missions planning and integration activities. The CRS missions are authorized through one or more NASA contract Task Orders. The mission is complete after cargo delivery to and cargo disposal from ISS has been completed.

The COTS/CRS ground operations are supported by Orbital's production and processing facilities in Arizona and Virginia plus many supplier production facilities. The architecture elements are manufactured at multiple geographic locations and are delivered to the ground processing site at the NASA Wallops Flight Facility (WFF) for mission integration.

Cygnus integration and test at Wallops will include RF testing of each telemetry mode and configuration.

The overall COTS/CRS flight operations are depicted in Figure 4 COTS/CRS Flight Operations. The launch vehicle injects the Cygnus spacecraft into a nominal 200 by 300 km orbit at 51.6° inclination. Mission operations responsibility is passed from the Wallops Launch Control Center (LCC) to the Cygnus Mission Control Center Dulles (MCC-D) at spacecraft separation. Cygnus systems are monitored by MCC-D throughout the mission.

Cygnus performs several phasing maneuvers to rendezvous with the ISS. Cygnus approaches ISS along an R-bar approach corridor using automated rendezvous and proximity operations.

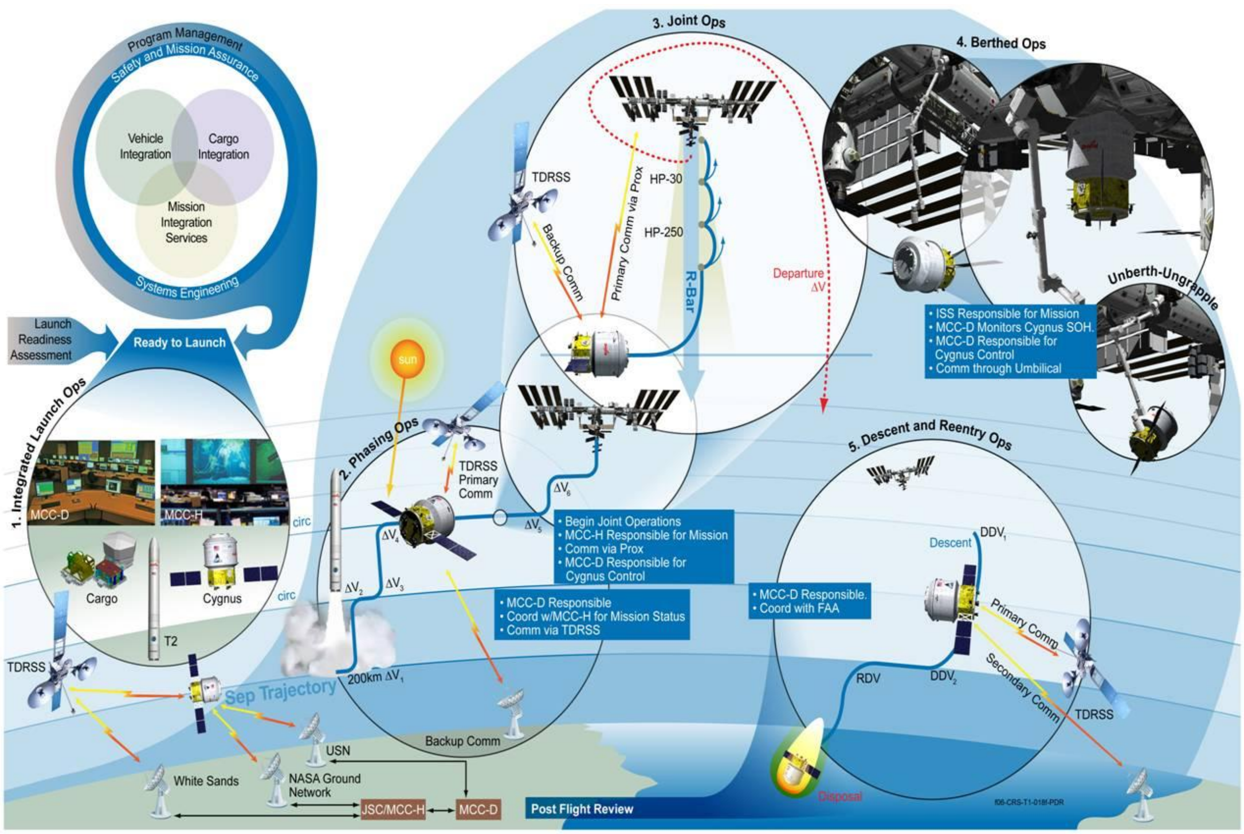

Figure 4 COTS/CRS Flight Operations

After berthing operations are completed, internal (pressurized) cargo is unloaded by the ISS crew and any ISS disposal cargo is loaded into the PCM. Cygnus maintains IVA compatible environments within the PCM while attached to the ISS. After the ISS crew completes installation of ISS disposal cargo, Cygnus is unberthed from ISS and activates its maneuvering systems to depart from the ISS. Once safely away from ISS, MCC-D maneuvers Cygnus to a pre-planned de-orbit location for a destructive reentry trajectory back to Earth.

All FAA de-orbit requirements have been met.

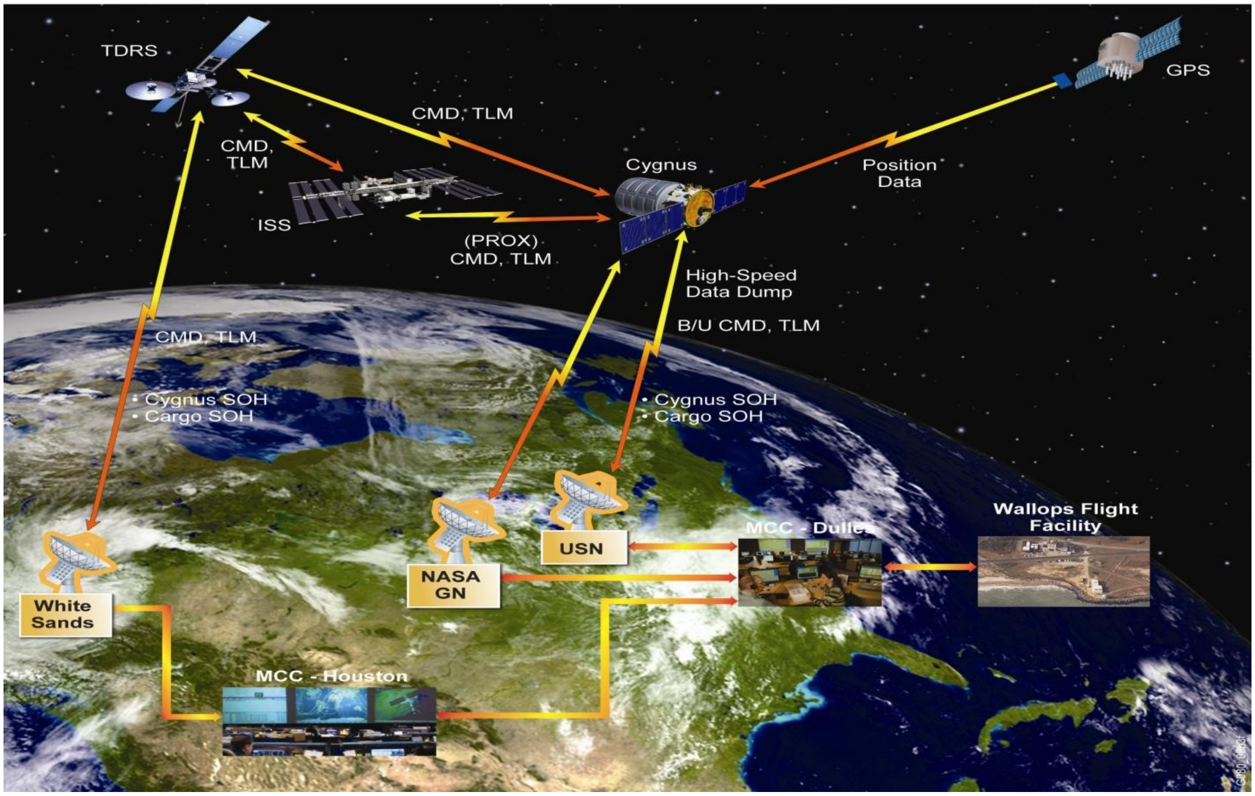

Figure 5 COTS/CRS Command and Control Systems

All Cygnus flight operations are directly controlled from MCC-D, which maintains continuous communication and coordination with NASA's MCC-H through multiple voice loops and direct data connections. The mission command and control communications systems are depicted in Figure 5 COTS/CRS Command and Control Systems.

Orbital's Cygnus spacecraft consists of a common Service Module (SM), and a Pressurized Cargo Module (PCM). The PCM provides a pressurized volume for transport of active and passive internal cargo to ISS. The Service Module provides propulsion, electrical power, guidance, navigation and control of the Cygnus spacecraft.

Figure 6 and Figure 7 show the Cygnus spacecraft with solar arrays deployed and the vehicle design axes marked. The SM is the smaller cylinder with its base at the origin of the coordinate system. The PCM is the larger cylinder further up the +X-axis.

Figure 6 Cygnus Spacecraft –Z View shows the Cygnus spacecraft with solar arrays deployed. On this view the communications antennas can be clearly seen as three pedestals and circular ground planes. Cygnus will approach the ISS along the −Z axis to provide line of sight visibility for the communications antennas.

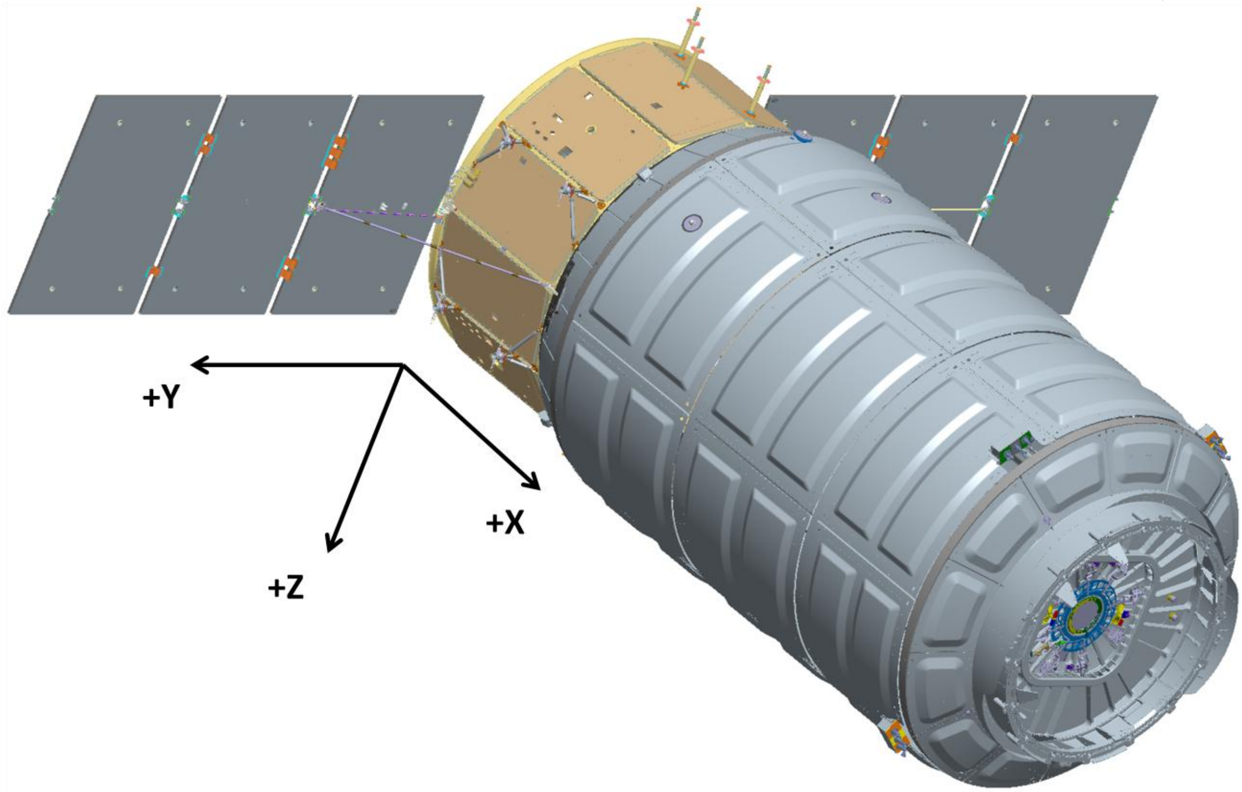

Figure 6 Cygnus Spacecraft –Z View

Three S-Band antennas are provided on the +Z and −Z axes. The antennas are grouped in three pairs: where a pair is one antenna on +Z and one on −Z. The first pair provides S-Band telecommand receive and telemetry transmit. The second and third pair are redundant S-Band forward and return link antennas for the PROX/PLS system. All antennas are broadband low gain helices. The TC/TM antenna pair is configured for omnidirectional coverage: the PLS antenna pairs are optimized for mission operations near the ISS.

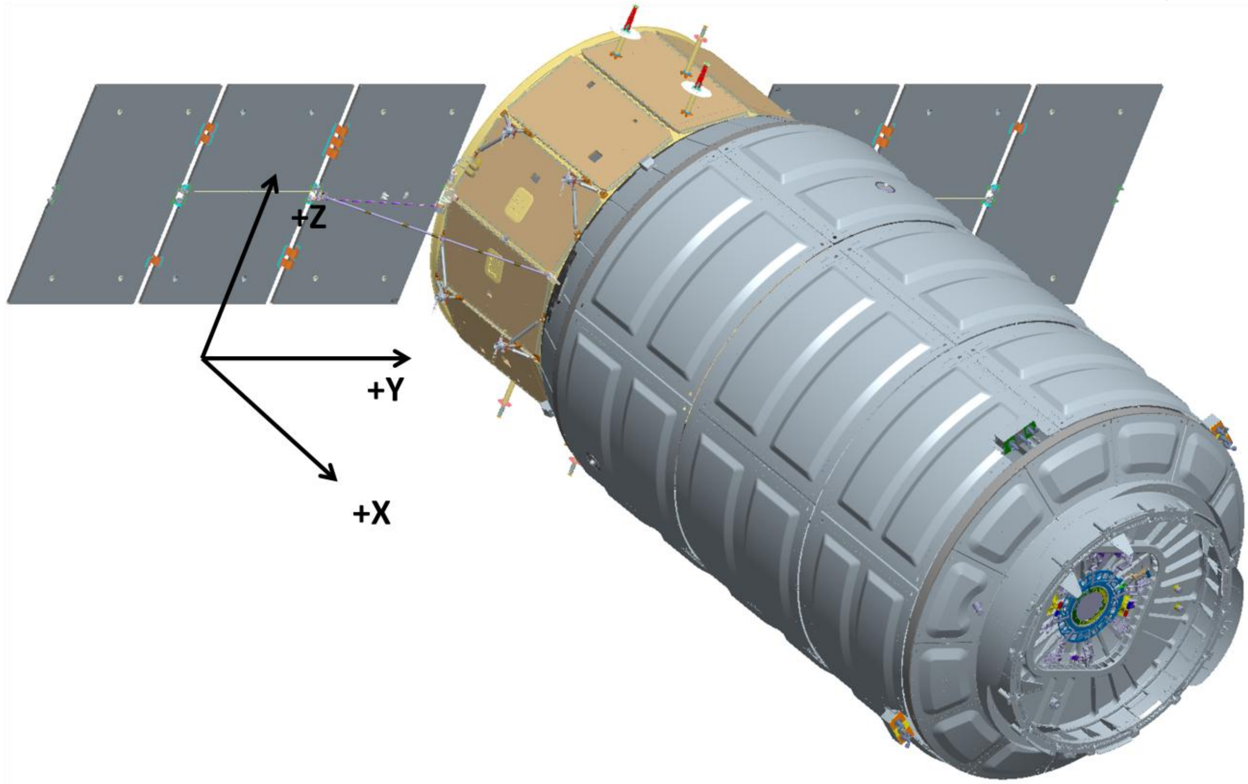

Figure 7 Cygnus Spacecraft +Z View

Figure 7 Cygnus Spacecraft +Z View shows the Cygnus spacecraft with solar arrays deployed. On this view the communications antennas can be clearly seen as three pedestals with circular ground planes.

Two distinct communications systems are employed on Cygnus:

a. NEN/SN/USN telemetry and telecommand as shown in Figure 8 Cygnus TC/TM Block Diagram. This subsystem provides TC/TM services through the NASA Near Earth Network (earth-to-space and space-to-earth), NASA TDRSS Space Network (space-to-space), and the commercial ground station Universal Space Network (earth-to-space and space-to-earth); and,

b. ISS telemetry and telecommand as shown in Figure 9 Cygnus PLS Block Diagram. This subsystem provides telecommand and telemetry services between the ISS and Cygnus (space-to-space).

Of note in Figure 8 Cygnus TC/TM Block Diagram is the design provides redundant hardware strings through a single coupler and antenna pair. As discussed above, two antennas are used to form an omnidirectional antenna pattern. Telecommand functionality is provided by spacecraft command receivers. No further discussion of the command receivers is required as they are not part of the radio licensing submission.

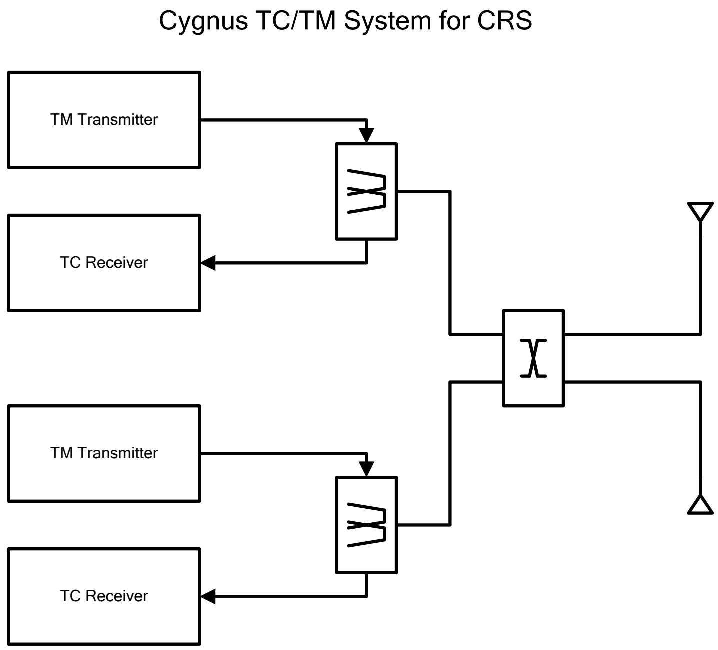

Figure 8 Cygnus TC/TM Block Diagram

Telemetry functionality is provided by dual redundant telemetry transmitters configured to operate through an omnidirectional antenna pair. Telemetry downlink can operate in any of three different modes:

1. TDRSS S-Band Single/Multiple Access (spread spectrum)
2. TDRSS/Ground S-Band Single Access (non-spread)
3. Ground S-Band Single Access (non-spread)

Each downlink mode supports multiple data rates.

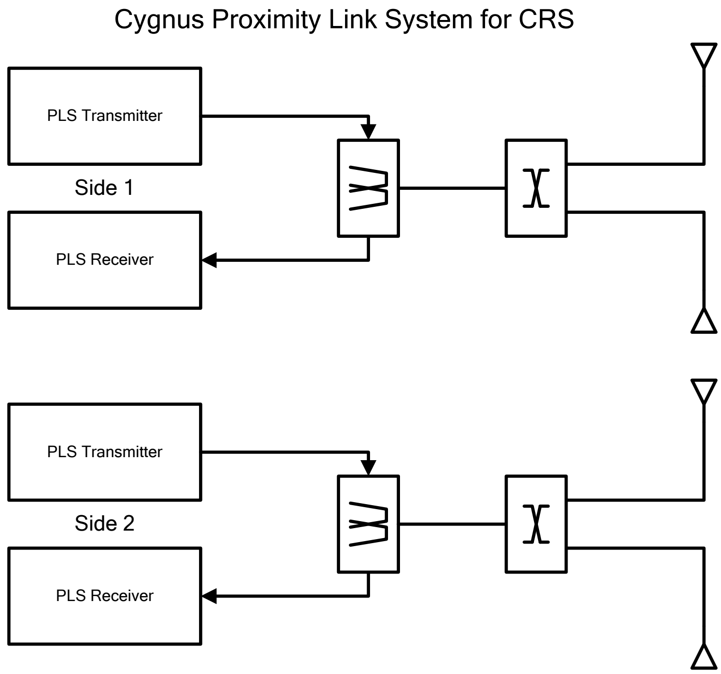

Figure 9 Cygnus PLS Block Diagram

The PLS design in Figure 9 Cygnus PLS Block Diagram provides fully redundant hardware strings that are operated in hot standby mode. The Proximity Link System (PLS) provides space-to-space communications between Cygnus and ISS during approach and departure. The ISS Proximity Communications System (PROX) and PLS provide bidirectional communications of data and commands.

Telecommand for the Cygnus spacecraft will not be addressed in this document. This document is to provide technical information for spacecraft transmitters requiring licensing. In all cases, the command uplink sites are responsible for radio licenses in support of Cygnus telecommand.

Attachment 2 identifies data for all missions, transmitters, frequencies, modes, modulations and data rates provided by the spacecraft transmitters.

The Orbital Mission Control Center in Dulles (MCC-D) is used for Cygnus ground operations, with direct communications to NASA's Mission Control Center in Houston (MCC-H). MCC-D includes the facilities and resources for real time mission planning and flight trajectory design, crew and flight control team training and flight operations of COTS/CRS missions.

The COTS/CRS program conducts the Cygnus and Taurus II launch operations from the Wallops Flight Facility in Virginia. The SM/PCM integrated operations utilize WFF infrastructure and utilities plus launch vehicle and Cygnus provided Ground Support Equipment (GSE) to perform the launch operations for CRS missions.

Attachment 5
Cygnus Orbital Debris Mitigation

Spacecraft Hardware Design, § 5.63(e)(1): Orbital has assessed and limited the amount of debris released in a planned manner during normal operations.

The Cygnus spacecraft incorporates a conservative design philosophy to reduce orbital debris. The overall design minimizes deployments and opportunities for orbital debris to be generated.

During a Cygnus mission there are two opportunities for generating orbital debris:

1. Clamp band. The Cygnus spacecraft is held by a clamp band to the Payload Adapter on the Launch Vehicle. At spacecraft separation, the clamp band tension is released allowing the spacecraft to move away from the Launch Vehicle. The clamp band is fixed to the Taurus II Launch Vehicle and releases no parts or debris when activated.

2. Solar arrays. Cygnus uses two solar arrays to provide electric power to the spacecraft bus. The solar arrays are folded along the sides of the spacecraft for launch. The solar array deployment is initiated by a thermal cutter cutting through a restraint. Springs then push the solar arrays into their final position. All components of the thermal cutter and the restraint are captured and not released from the vehicle.

There are no other deployments or mechanisms that can result in the separation of components from the Cygnus spacecraft.

The Cygnus spacecraft has been shown to be compliant with all NASA and FAA re-entry and orbital debris requirements.

Orbital has also assessed and limited the probability of the Cygnus spacecraft becoming a source of debris by collisions with small debris or meteoroids that could cause loss of control and prevent post-mission disposal. Orbital has designed Cygnus to be able to withstand Micro-meteoroid / Orbital Debris (MM/OD) events during mission operations. Cygnus is designed to be compliant to the Probability of No Penetration (PNP) and MM/OD requirements as defined in SSP 30425, Space Station Program Natural Environment Definition for Design. The high-level requirements are provided in Table 6 Parameters for Micrometeoroid and Orbital Debris Environments Definition.

Table 6 Parameters for Micrometeoroid and Orbital Debris Environments Definition

Altitude	216 Nautical Miles (400 km)
ISS attitude	Flight attitude envelopes defined in SSP 50699-03, ISS Certification Base Volume 3: Flight Attitudes, Table 4.3.3-1.
Orbital inclination	51.6°
Orbital debris density	0.10 lbm/in^3 (2.8 gm/cm^3) (1)
Notes: (1) For MM/OD critical items only.	

The MM/OD protection is implemented through the use of Kevlar blankets around key hardware components on the Cygnus spacecraft, such as the Hydrazine and Oxidizer propellant tanks.

Minimizing Accidental Explosions, § 5.63(e)(2): Orbital has assessed and limited the probability of accidental explosions during and after completion of mission operations. During the mission the items that may be able to cause a break up would be the propulsion tanks as well as the Pressurized Cargo Module. A Failure Mode Effects and Criticality Analysis for the Cygnus vehicle has been performed and shows no credible failures that will cause an unintentional break up of Cygnus.

The design of the Cygnus spacecraft is such that the risk of explosion is minimized both during and after mission operations. In designing and building the spacecraft, Orbital took steps to ensure that debris generation will not result from the conversion of energy sources on board the spacecraft into energy that fragments the spacecraft. Burst tests have been performed on all pressure vessels during qualification testing to demonstrate an adequate margin of safety. Bipropellant mixing is prevented by the use of valves that prevent backwards flow in propellant and pressurization lines. All pressures, including those of the batteries, are monitored by telemetry.

After completion of the Demo mission at ISS the Cygnus vehicle will depart and perform a controlled re-entry maneuver into an ocean. As part of acceptance of the Orbital re-entry plan an Orbital Debris Assessment Report (ODAR) will be completed and accepted by NASA showing that the Cygnus vehicle is limiting the amount of orbital debris generated during the mission.

No items on the Cygnus vehicle will be passivated for re-entry. To perform the controlled reentry the vehicle will need power and propulsion working in order to perform the final burns and to ensure that the Cygnus vehicle hits its re-entry target.

A Casualty Risk assessment has been performed based on a breakup model of the Cygnus structure, propellant and pressurant tanks, and other components. For purposes of this assessment, propellant dispersion at a high altitude is assumed (due to tank rupture) but without explosive effects. A separate analysis of the casualty risk resulting from accidental explosion during the re-entry phase has also been performed and is described below.

Safe Flight Profiles, § 5.63(e)(3): Orbital has assessed and limited the probability of the spacecraft becoming a source of debris by collisions with large debris or other operational space stations. All de-orbit and re-entry operations are coordinated with NASA-Johnson Space Center (NASA-JSC) Mission Control Complex at Houston (MCC-H) to prevent collisions with large debris or other operational space stations or systems.

Orbital has made an assessment of the Cygnus spacecraft potential for on-orbit collisions during the mission. Utilizing the NASA Debris Assessment Software (DAS) tool, the probability of collision with space objects larger than 10 cm was calculated for the ODAR. The design requires the probability must be less than 0.001. The inputs into DAS were:

Perigee: 425 km
Apogee: 425 km
Inclination: 51.6 degrees
Final Down Mass: 2766 kg
Mission Duration: 40 days
Area to Mass Ratio: 0.3641

The probability of collision per DAS is 0.00000, thereby meeting the ODAR requirement.

The Cygnus primary mission is to provide logistics support to the International Space Station. As the ISS is a manned space flight it takes priority over all other spacecraft in orbit parameters. Cygnus will be launched into the same orbital plane as the ISS and perform phasing maneuvers to raise altitude to match the ISS orbit.

The Cygnus spacecraft contains GPS receivers onboard that relay its position to the Mission Control Centers in both Houston and Dulles (MCC-D). Orbital will coordinate the Cygnus spacecraft's location with MCC-H in order to allow for a determination of separation between multiple orbiting space stations and systems. Orbital will provide the two line elements of the Cygnus spacecraft, such that its location is known at any given time. Orbital will work with MCC-H to monitor the risk of close approach of its spacecraft. If required, avoidance maneuvers will be performed to eliminate the possibility of collisions.

To determine the Cygnus orbit, the Cygnus Flight Dynamics Team (Orbits) will be using Raw GPS measurements. These raw measurements will be filtered on the ground to estimate the Cygnus orbit. The orbit determination process will then provide the estimated states for the maneuver planning process. Typical 3-sigma position errors for the raw GPS measurements utilized are in the order of 90 meters. The re-entry maneuvers are planned such that under the predictive orbit knowledge and maneuver execution errors, the debris field is placed in an uninhabited area in the Pacific Ocean.

Post-Mission Disposal, § 5.63(e)(4): Orbital will perform a controlled re-entry into either the Pacific or Indian Ocean once the mission is completed. NASA JSC assisted Orbital with an ORSAT (Object Reentry Survival Analysis Tool) analysis to determine the amount of debris that will survive.

Table 7 ORSAT Analysis Results provides the ORSAT estimates for:

1. Total Debris Casualty Area (DCA): The combined impact area for those debris elements expected to reach the ground, and with sufficient energy to result in human casualty. The ORSAT analysis assumes the planned Cygnus re-entry perigee altitude of 50 km. The DCA calculation includes all debris elements having energy greater than 15 joules.

2. Re-entry Foot Print: The dimensions of the debris field reaching the earth's surface. The debris field is calculated as the distance between the debris element having the smallest downrange impact (the debris field "heel") and the furthest downrange element (the "toe"). For purposes of calculating the foot print, only those debris elements having a potential for casualty risk (i.e. greater than 15 joules) are considered.

3. Population Density: The estimated average population density, in persons per km^2, at the Cygnus orbit inclination angle of 51.6°. The risk factor assumes a re-entry is initiated at a random location along the 51.6° orbit, and can be interpolated from the curves of population density vs. inclination shown in Figure 10 Population Density as a Function of Orbit Inclination (from NASA-STD-8719.14)

4. Human Risk Factor: The risk of human casualty, calculated as the product of Total Debris Casualty Area (DCA) and Population Density. For the December 2008 and March 2009 results,

the Risk Factor was provided by JSC with the ORSAT results; for the current CDR results, it is calculated using an interpolation of population density, from Figure 10 Population Density as a Function of Orbit Inclination (from NASA-STD-8719.14).

Figure 11 Plot of Cygnus Mass Demise Altitude (from Mission CDR Analysis) shows a graphic of the demise of components vs. their altitude and downrange location.

Orbital has analyzed segments of the Cygnus spacecraft that will survive re-entry and reach the surface of the Earth based on the ORSAT analysis as shown in Table 8 ORSAT Re-Entry Results (Surviving Debris Only). The demise factor and the associated downrange footprint upon re-entry are also calculated in Table 8

Table 7 ORSAT Analysis Results

Mass	Total DCA	Re-entry Foot Print	Population Density	Human Risk Factor
Based on COTS Mission CDR	19.94 m^2	547.9 km	15.5/ km^2	1:3235

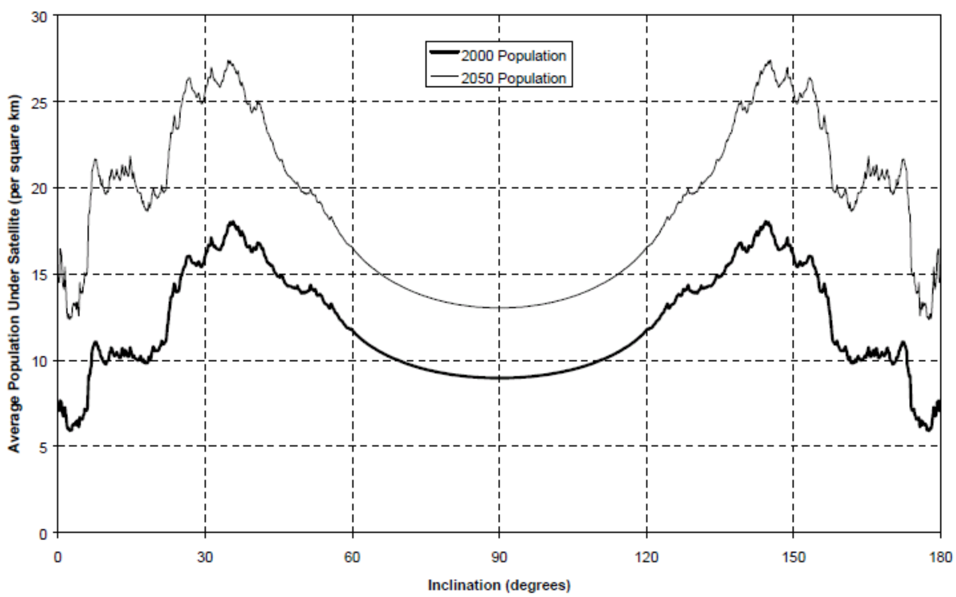

Figure 10 Population Density as a Function of Orbit Inclination (from NASA-STD-8719.14)

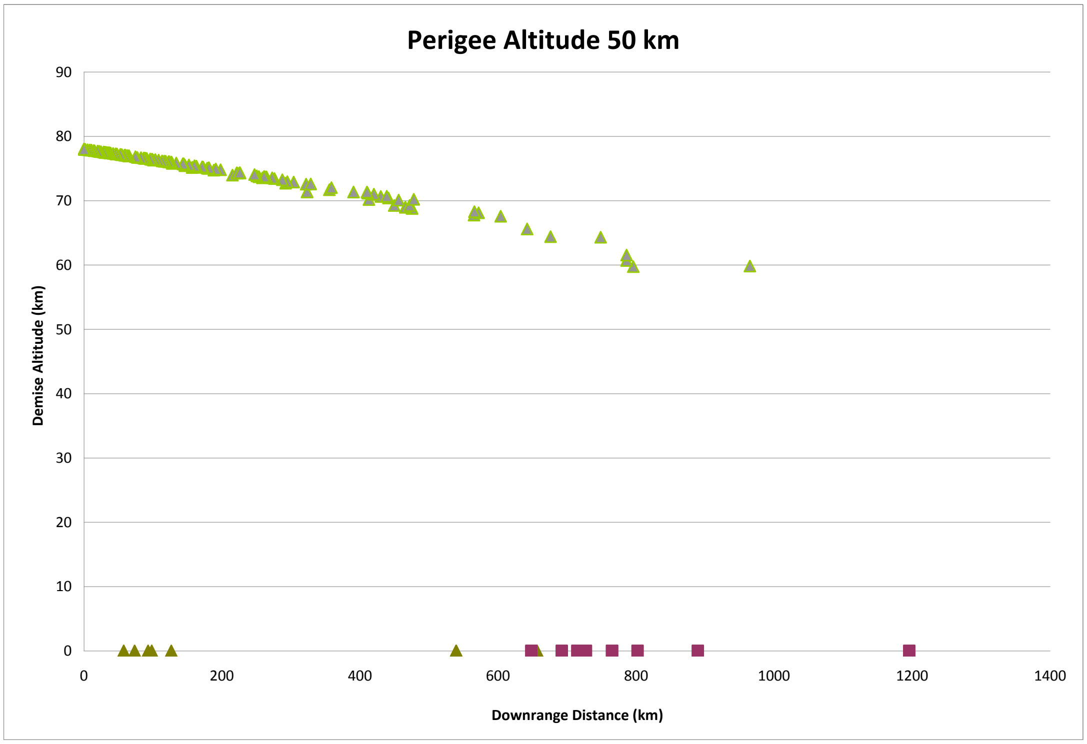

Figure 11 Plot of Cygnus Mass Demise Altitude (from Mission CDR Analysis)

Table 8 ORSAT Re-Entry Results (Surviving Debris Only)

Row Num	Name	Qty	Demise Altitude (km)	Demise Factor (%)	Debris Casualty Area (m^2)	Total DCA (m^2)	Downrange (km)	Impact Mass (kg)	Total Impact Mass (kg)	Kinetic Energy (J)	Ballistic Coefficient (kg/m^2)	Impact Velocity (m/s)
1	COTS	1				**19.941**			**178.4**			
21	Harness	1	0	92	1.56	1.56	889.577	23.43	23.43	14285.93	75.8	34.92
33	Grapple (PVGF and GRM)	1	0	43	1.404	1.404	1196.087	37.85	37.85	69348.96	225.2	60.53
54	Propellant Tank (Oxidizer)	1	0	62	2.282	2.282	765.347	29.27	29.27	10097.24	43	26.27
56	Check Valve (Ox)	1	0	95	0.45		539.387	0.05		6.08	14.1	15.04
57	Check Valve (Fuel)	1	0	95	0.45		539.387	0.05		6.08	14.1	15.04
60	Propellant Filter	2	0	92	0.478		656.727	0.09		10.88	14.6	15.29
61	Fuel Propellant Lines	13	0	54	1.081		126.577	0.19		2.12	1.4	4.66
62	Propellant Tank (Hydrazine)	2	0	62	2.282	4.564	765.337	29.27	58.54	10096.9	43	26.27
63	High Pressure Latch Valve	1	0	88	0.515	0.515	692.597	0.46	0.46	139.5	37.9	24.64
64	Low Pressure Latch Valve	11	0	90	0.503	5.533	727.617	0.46	5.06	156.33	42.6	26.12
65	Oxidizer Propellant Lines	13	0	54	1.081		57.507	0.06		0.19	0.4	2.56
66	Helium Pressurant Lines	13	0	54	1.081		98.157	0.13		0.93	0.9	3.8
67	Pressurant Tank (Gaseous Helium) - NOTE : Tan	1	0	62	1.242	1.242	802.277	10.68	10.68	4209.91	49.1	28.08
77	Delta-V Engine (DVE)	1	0	37	1.047	1.047	648.167	3.63	3.63	753.13	25.9	20.37
98	Heater, Flexible Spiral Wound Laminar Strip, 1/4	1	0	59	3.381		73.497	0.65		3.05	0.6	3.07
153	Power/Data to ISS	1	0	60	3.805		92.987	0.6		3.23	0.7	3.28
166	TAS-I Hatch	1	0	85	1.794	1.794	714.917	9.48	9.48	1753.96	23.1	19.24

Footprint Heel	648.17 km
Footprint Toe	1196.09 km
Footprint Length	547.92 km
Mass %	4.08%

Orbital has calculated the Casualty Risk Assessment of Cygnus during the re-entry phase of the mission. Based on ORSAT results, casualty risk calculations verify compliance with NASA and FAA requirements.

The casualty risk for controlled re-entry is calculated as:

$$E_C = \sum_{i=1}^{n} A_{Ci} D_{Pi}$$

Where:

- n is the number of possible events (debris elements that can reach the Earth's surface.
- A_{Ci} is the casualty area of the impacting debris in the i^{th} event, and,
- D_{Pi} is the population density of the area at risk in the i^{th} event.

The population density in the controlled re-entry debris field is considered equal to zero, resulting in casualty risk estimate:

$$E_C = 0$$

For uncontrolled re-entry resulting from a Cygnus vehicle anomaly, the Casualty risk is calculated as:

$$E_C = (1 - P_S) \times \sum_{i=1}^{n} A_{Ci} D_{Pi}$$

Where:

- P_S is the Cygnus Probability of Mission Success.

The Cygnus reliability analysis shows the probability of mission success is 0.9659. For purposes of the reentry calculation, however, a separate calculation is performed to include only those Cygnus functions required to successfully perform the reentry. These functions are shown in the reliability block diagram of Figure 12 Reliability Block Diagrams: Cygnus Re-entry Capability, with a summary of the subsystem and system calculations shown in Table 9 Reliability Results for Re-entry Capability. As described in Table 10 Prediction of Re-entry Casualty Risk, de-orbit and reentry is controlled from the ground and, therefore, the Orbital MMC-D and ground station are also included in the calculation. Based on these assumptions, the predicted probability of success for reentry is 0.9944.

The calculation of casualty risk is then:

$$E_C = (1 - 0.9944) \times \frac{1}{3235}$$

$$E_C = 1.73 \times 10^{-6}$$

Individual casualty risk is defined as the expected risk to any given individual. For uncontrolled reentry, this risk is equally spread across the population falling under the reentry debris footprint at 51.6° inclination: see Figure 10 Population Density as a Function of Orbit Inclination (from NASA-STD-8719.14). This population is directly proportional to the footprint area, with a length of 548 km per Table 7 ORSAT Analysis Results. From Orbital's reentry analysis, the minimum width of the debris footprint is 2 km but could be up to about 35 km due to wind effects and other dispersions. Taking the conservative value of 2 km (since individual risk will be inversely proportional to the debris field footprint), the footprint area is:

$$A_D = 2\text{ km} \times 548\text{ km} = 1096\text{ km}^2$$

And individual casualty risk is then calculated as:

$$E_{C\text{ (Individual)}} = \frac{E_C}{A_D D_P}$$

$$E_{C\text{ (Individual)}} = \frac{1.73 \times 10^{-6}}{(1096\text{ km}^2)\left({}^{15.5}/_{\text{km}^2}\right)}$$

$$E_{C\text{ (Individual)}} = 1.02 \times 10^{-10}$$

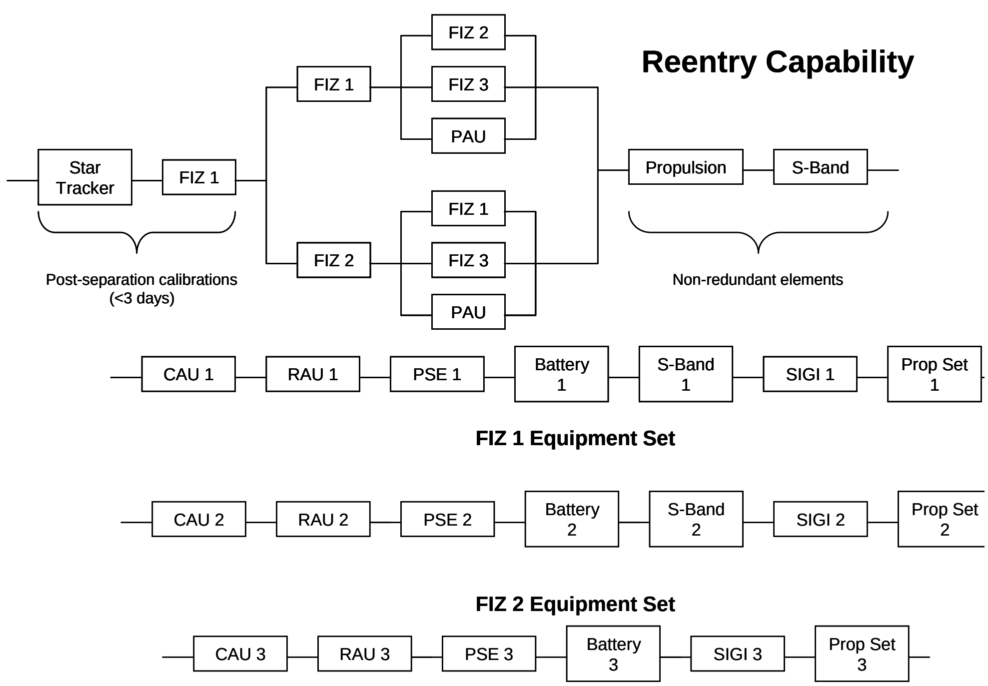

Figure 12 Reliability Block Diagrams: Cygnus Re-entry Capability

Table 9 Reliability Results for Re-entry Capability

Reentry Success Calculation		
Cygnus element	**Redundancy**	**Predicted Ps**
Fault Isolation Zone	FIZ 1 or 2 Required	0.9952
TT&C elements	Non-redundant	1.0000
Propulsion elements	Non-redundant	1.0000
Star Tracker	Non-redundant	0.9998
SM Total		0.9950
PCM	Not required	
Cygnus Total		0.9950
Taurus II	Included in Taurus II Risk	
Ground Station	Required	0.9994
	Reentry Ps	**0.9944**

Cygnus compliance with NASA and FAA requirements for re-entry is summarized in the Table 10 Prediction of Re-entry Casualty Risk.

Table 10 Prediction of Re-entry Casualty Risk

Case	Casualty Risk Requirement		Cygnus Prediction
	FAA 14CFR435	NASA NASA-STD-8919.14	
Uncontrolled re-entry	$< 30 \times 10^{-6}$	$< 30 \times 10^{-6}$	N/A
Controlled re-entry	$< 30 \times 10^{-6}$/mission $< 1.0 \times 10^{-6}$/individual	N/A	0.00
Uncontrolled (anomalous) re-entry	$< 30 \times 10^{-6}$/mission $< 1.0 \times 10^{-6}$/individual	$< 1.0 \times 10^{-4}$	1.73×10^{-6}/mission 1.02×10^{-10}/individual

In order to maximize the propellant available for reentry operations, and thus reduce the potential for an anomalous reentry, a Cygnus program decision has been made that no depletion of excess fuel or oxidizer from the tanks will be performed prior to starting the reentry phase. In this case, it is highly likely that explosive rupture will occur at the three Cygnus propellant tanks (two hydrazine and one oxidizer).

A separate, detailed, model and analysis of the effects of an explosion during re-entry on the expected Cygnus debris field has not been performed. However, applicable conclusions may be drawn from the results of such a study performed for the Automated Transfer Vehicle (ATV)[1], an ISS re-supply vehicle with a mission very similar to Cygnus.

[1] G Koppenwallner, B Fritsche, T. Lips, T. Martin and E. Pasquale, Analysis of ATV Destructive Reentry Including Explosion Events, Proceedings of the Fourth Conference on Space Debris, Darmstadt, Germany, 2005

From the ATV analysis results, the following conclusions can be made regarding their applicability to Cygnus:

1. Maximum reentry propellant mass for Cygnus (which occurs in the Demonstration Mission contingency case) is 907 kg vs. 2558 kg assumed for ATV. Therefore, the effects of an explosion on vehicle breakup can be expected to be less severe than for ATV.

2. For Cygnus, the debris mass reaching the earth's surface is expected to be greatly reduced if a reentry explosion occurs, compared with the nominal case. Even for those debris elements which survive, the percentage of those having significant casualty risk (i.e. greater than 15 joules) should also be significantly reduced.

3. It can be expected that an explosive reentry will result in a larger casualty footprint. Based on the ATV results, a worst case assumption is made that the footprint heel is reduced to 0 km, i.e. corresponding to the ground track coordinates at the reentry point. Comparison of the existing and proposed footprint is shown in Table 11 Cygnus Re-Entry Debris Footprint :

4. For both ATV and Cygnus, it must be emphasized that the predicted footprint increase due to explosion is a worst case, since the analysis assumes the explosion occurs in the contingency case of full propellant load still on-board. In all nominal mission cases, the remaining propellant load at end of mission will be much smaller (< 10%); in this case the worst case values in Table 11 Cygnus Re-Entry Debris Footprint can be considered to bound the expected characteristics of the debris footprint

Table 11 Cygnus Re-Entry Debris Footprint

Cygnus Debris Footprint	Current results (Table 7)	Worst explosion case
Footprint Heel:	648 km	0 km
Footprint Toe:	1196 km	1196 km
Footprint Length:	548 km	1196 km

Although these results show that the potential for explosive reentry of the Cygnus vehicle can significantly increase the size of the debris footprint, the reentry Casualty Risk from such an event is expected to be reduced. This is because an explosion is expected to significantly reduce the hazardous effects of any surviving debris fragments, both in terms of their total mass and their combined cross-sectional Debris Casualty Area (DCA). Compared with the non-explosive case, a higher percentage of Cygnus' total reentry mass will be either consumed in reentry, or will reach the earth's surface as non-hazardous fragments (i.e. with energy less than 15 joules). Further, the Cygnus' calculated Casualty Risk is based on the combined DCA of hazardous fragments spread over an average population density for the spacecraft trajectory. Therefore a reduction of the DCA will also result in reduction of the Human Risk Factor.