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ULA SmallSat / Hosted Rideshare Mission Accommodations

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Abstract— United Launch Alliance (ULA) EELV launch vehicles have a long history of providing high-value payload accommodations for a variety of customer spacecraft and missions, including planetary missions.

Rideshare - the approach of sharing available performance margin with a primary spacecraft, provides satellite developers the opportunity to get their spacecraft to orbit and beyond in a cost effective and reliable manner. Hosted experiments provide another opportunity to fly non-separating systems on the upper stage through disposal/re-entry that may take up to 5 years to complete. This opportunity of hosted experiments allows for data gathering in the space environment and/or for raising technology readiness levels.

This paper will give a brief overview of the rideshare capabilities that are available with current status. This includes the results from the NROL-36 launch of 8 PPODs in Sep of 2012. This presentation will focus on Rideshare delivery options for CubeSats/SmallSats and Hosted Experiments, with emphasis on support for command/control, sequencing, data collection, and data transport to ground stations for experiment data products.

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1. INTRODUCTION

The chart in Figure 1, gives a summary of ULA's current rideshare optional carrier systems and their current status. The smallest Cubesat systems are for 1U up to 3U PPODs and can also accommodate 6U variations in the Naval post Grad School Cube-sat Launcher (NPSCuL) box carrier. The concept is for the NPSCuL to be integrated by a third party and delivered to the launch site for final integration to the vehicle. SmallSats of 200 kg can be flown on the ESPA ring system provided by CSA/MOOG. Larger still, (up to 1000 kg) is the A-Deck system (or IPC stack) being developed by Adaptive Launch Solutions. This system fills the inside of a variable stack of adapter rings to give the desired height (up to 7 feet). The A-Deck deploys after the primary S/C has been delivered. The Dual Satellite Systems (DSS-4M, and DSS-5M) are being developed by ULA. As the naming implies, the 4M (or 4-meter) fits inside the 4-meter fairing, and same for the 5M system. The DSS-4M is designed to accommodate dual Delta II class payloads or 10,000 lbs upper and 5,000 lbs lower S/C. The DSS-5M is designed to support dual GPS III S/C.

2. OPPORTUNITIES

A summary of the current launch manifest for missions that have some residual mass margins that could accommodate rideshare or hosted experiments is shown is Figure 2. The chart gives the primary S/C, the rough orbit parameters, margin, and approximate launch dates. The difficulty with any chart of this type is matching system options to mission specifics. Any rideshare will have to be evaluated with mission design to access any option for viable conditions, desires, disposal requirements, and many other mission peculiar considerations. So this chart may look promising but mission specific rideshare designers need to evaluate requirements to determine any data solution.

3. CUBESATS AND PPODS

The NPSCuL Cubesat box is accommodated on the ULA Aft Bulkhead Carrier (ABC) shown in Figure 3. This plate and strut system is located on the aft of the Centaur upper stage. The ABC can support 80 kg of usable wt for separating or non-separating rideshare S/C. The advantage of the ABC is its position away from the primary S/C envelope. This means no security issues, no contamination issues, and the environment is a bit easier than on top. There is an ABC Users Guide available but it will be updated with actual flight data. The challenge of the ABC is that it is integrated very early and can be on the pad for several weeks prior to flight.

A populated PPOD configuration is shown in Figure 4, shows the OUTSAT spacecraft consisting of 8 PPODs in the NPSCuL box as it was readied for flight on the NRO-L36 mission out of VAFB.

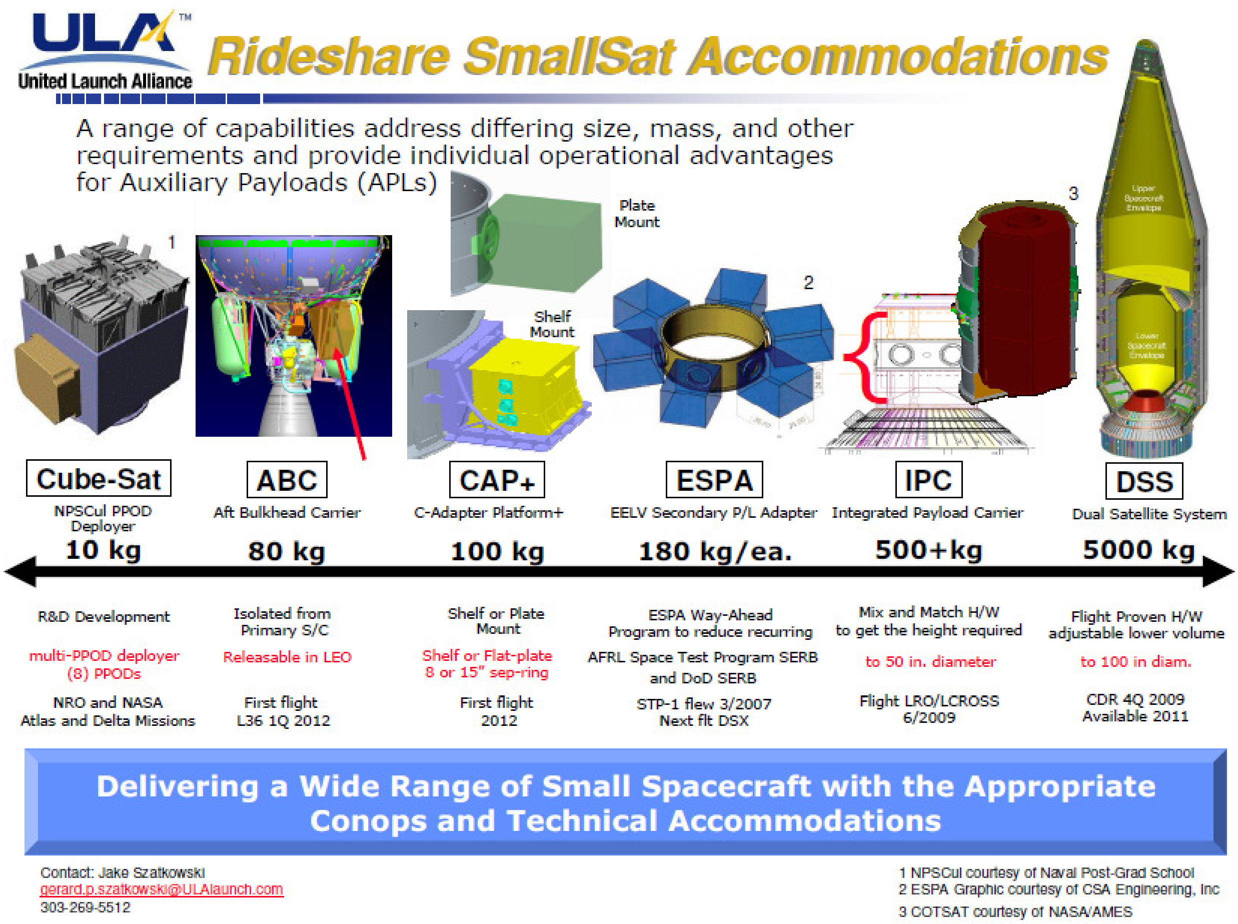

Figure 1, ULA Rideshare Carrier Systems

Mission	Customer	Vehicle	Site	Orbit	Margin, Excluding Disposal (kg)	FY15	FY16	FY17	Notes
GPS-IIF	USAF	401	ER	MEO – Direct	~600	IIF-4, IIF-6	IIF-7, IIF-8		Transfer orbits missions
GPS-III	USAF	411	ER	MTO	[~1100]		IIIA-2	IIIA-5	
SBIRS	USAF	401	ER	GTO	~100		GEO-3	GEO-4	
AFSPC	USAF	401	ER	GTO	TBD	AFSPC-8			
NRO	NRO	411	ER	GTO	TBD			L-61	
AEHF	USAF	531	ER	GTO	Performance Limited			AEHF-4	
MUOS	USAF	551	ER	GTO	Performance Limited	MUOS-4	MUOS-5		
GOES	NASA	541	ER	GTO	Performance Limited		GOES-R	GOES-S	
TDRS	NASA	401	ER	GTO	Performance Limited		TDRS-M	TDRS-N	
MMS	NASA	421	ER	GTO	Performance Limited	MMS			
Discovery	NASA	401	ER	Hyperbolic	TBD	D-12			Earth escape trajectories
ExoMars	NASA	421	ER	Hyperbolic	Performance Limited		EM		
Osiris Rex	NASA	401	ER	Hyperbolic	Performance Limited			OR	
Europa	NASA	551	ER	Hyperbolic	Performance Limited			EO	
Solar Orbiter	NASA	551	ER	Hyperbolic	Performance Limited			SO	
NRO	NRO	401	WR	TBD	TBD			L-79	LEO Missions Disposal TBD
NRO	NRO	541	WR	TBD	Performance Limited	L-67		L-42	
NRO	NRO	401	WR	TBD	TBD	L-55			
STP	USAF	401	WR	~700km 98 deg	>5,000			STP-3	
CLARREO	NASA	[Delta	WR	~600 km Polar	TBD			CLARREO	
ICESat	NOAA	[Delta	WR	Polar	TBD		ICESat-2		
DMSP	USAF	401	WR	~800km 99 deg	>4,000	DMSP-19/DSX	DMSP-20		
JPSS	NOAA	[Delta	WR	~800km 98deg	~900		JPSS-1		
GeoEye	GeoEye	401	WR	~700km 98 deg	>4,000			GEOEYE-2	
WorldView	Digital Globe	401	WR	~700km 98 deg	>4,000		WV-4		
Comm I-9	CLS	401	WR	TBD	>4,000		Comm I-9		

Figure 2, Mission Margins for Rideshare Opportunities

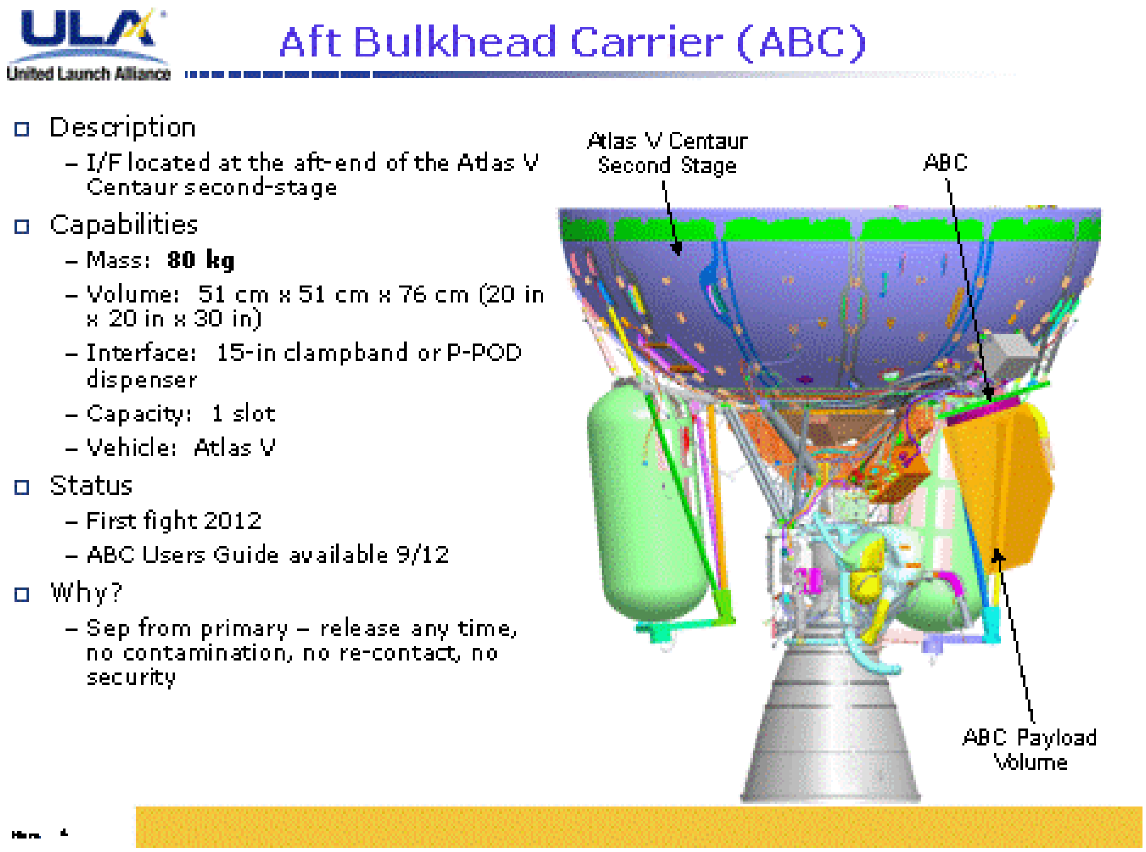

Figure 3, Aft Bulkhead Carrier

Figure 4, OUTSAT Spacecraft on NROL-36 Mission

4. ADAPTER DECK (A-DECK)

The A-Deck depicted in Figure 5, shows the initial concept of a platform inside of a stack of C-adapters. The A-Deck provides for a large volume, up to 1,000 kg in a 60 inch diameter, 7 ft tall format, where single or multiple satellites can be hosted. The A-Deck can be treated as a single spacecraft, even if multiple satellites are hosted. ULA and NRO funded ALS to develop this system as a viable rideshare option. This initial work has been completed through CDR. ALS is at present has completed the hardware qualification testing on the heavy deck version. The AQUILA system (courtesy of ALS) has 3 options - a light composite deck system, a medium metal-doubler system, and a 1000 kg capable metal-isogrid version. The AQUILA system can mount a single or multiple payloads onto the deck.

Figure 6 show the AQUILA system and stacking options.

5. HOSTED EXPERIMENTS SUPPORT

Besides rideshare accommodations, ULA would like to offer support for hosted experiments to technology developers. The concept is for non-separating hardware to be mounted to the Atlas upper stage Centaur system. These experimental packages will be exposed to the space environment for extended periods of time. Depending on the mission disposal orbit, the experiment could see recurring passes thru the Van Allen radiation belt in a geo-transfer (GTO) or polar orbits. The concept would serve to provide radiation, vacuum, and direct solar environment for electronics or solar panel systems to raise TRL levels and for flight verification data. ULA is working to provide basic services to the hosted experiments in limited power, sequencing commands, data capture/storage, and up/down link communications. Several hosting options are available depending on the size and complexity of the experiment hardware.

As part of the support system for hosted experiments and rideshare deployment systems, ALS is developing an Auxiliary Payload Support Unit (APSU). The APSU is based upon the Space Micro Inc board suite. ULA initiated the concept and funded the development of the requirements document, prototype units, initial SIL testing, and developmental qualification unit. The APSU is capable of providing distributed power to experiments or spacecraft for limited power requirements. It serves to sequence commands for separation systems or experiment actuations. It can provide data recording up to 10 GB worth of experimental data, spacecraft initialization data or video data thru a variety of interfaces. The APSU can downlink data thru the ULA Master Data Unit (MDU) for communication to the ground, as long as the Centaur avionics system is available. The APSU can also communicate with other communication systems as well. Figure 7, gives a summary of the APSU capabilities.

The APSU will provide the following functions:

- Operate with redundant launch vehicle power
- Operate with redundant launch vehicle discrete enables
- Programmable deployment sequencer for separation events (up to 32)
- Power switching for auxiliary payload system
- Data comm interface for transmission to ground
- Launch powered or unpowered and initiate operations after primary S/C deployment
- Small size (4.0 x 4.2 x 6.7 inches), light weight (<1.2 kg) and low power (10.5 watts)
- Extensible architecture
- COTS solution - customizable capabilities and requirements fit

ULA is working with Space Micro to adapt their communication equipment to support the needs of hosted experiments data communications to ground receivers. Multiple options are available for data communication, including Space Micro's X-Band and S-Band transmitter systems. One of these communication systems can be integrated to downlink data from the APSU in the hosting support suite. Figure 8 shows the Space Micro data sheets on their S-Band transmitter systems. The comm systems can be selected depending on the disposal orbit the Atlas upper stage is assigned.

Further, there is a need for a ground station that can be relied upon to receive and process the data from the experiment. The selection of the ground receiver needs to match the orbital parameters and be coordinated with the orbital period. The transceiver system can coordinate with a variety of ground stations.

NASA uses the Spacecraft Tracking and Data acquisition Network (STDN), established to service the data requirements for long-duration, high-available space-to-ground communications. Real time operational control and scheduling of the network is provided by the Network Operations Control Center (NOCC) at the Goddard Space Flight Center (GSFC) in Greenbelt Maryland.

A sample experiment based upon a NASA fiber optical sensing system requires 1.5 GB of data collected during launch. This provides a data-point as to the requirements of the downlink communication system. Once collected, downlink can take place over a period of up to 6 months. Table-1 below calculates the necessary transmission rates for downlink periods from 4 to 6 months.

A link budget for this sample experiment was calculated to determine basic feasibility of the configuration for the candidate S-Band downlink. The communication system configuration consists of two half omni antennas on the adapter ring to create full omni (-3 dBi) coverage communicating to a typical ground station antenna (>5m size with 30 dBi gain). Typical system losses were used in the calculation with Reed-Solomon (255, 223) forward error correction and a system 3 dB margin desired. The calculations were based upon basic link budget analysis as defined by Sklar[1].

Margin = EIRP(dBW) + Gr(dBi) – Eb/No(dB) – R(dB-bit/s) – kT (dBW/Hz) – Ls(dB) – Lo(dB)

Where terms are defined as:

- Margin: calculated link margin
- EIRP: Effective Isotropic Radiate Power
- Gr: Gain of receiving antenna
- Eb/No: Energy per bit to noise power spectral density ratio
- R: Data rate
- kT: product of Boltzmann constant and temperature
- Ls: Free space loss
- Lo: Other losses

A simple spreadsheet calculation was performed to the above equation. Setting the desired margin to 3 dB and the previous condition set provides for the calculated results shown in Table 2 below. Using Reed-Solomon encoding and a data rate of 317.6 kbps using BPSK modulation, the data can be transmitted using a power amplifier of less than 5 watts within 90 days. Overall, this creates a communication system with reasonable (easily producible) characteristics.

Table-1,. Sample Experiment Downlink Rates

Data Collected	1.5	1.5	1.5	GB
Data Collected	12	12	12	Gbit
Downlink Time per Day	10	10	10	Minutes
No. of Days for Downlink	120	150	180	Days
Downlink Minutes Available	1200	1500	1800	Minutes
Downlink Seconds Available	72000	90000	108000	Seconds
Information Data Rate Desired	166,667	133,333	111,111	Bits/Second
ECC Factor (Overhd rqrd FEC)	2	2	2	
Transmission Rate (# days)	333,333	266,667	222,222	Bits/Second

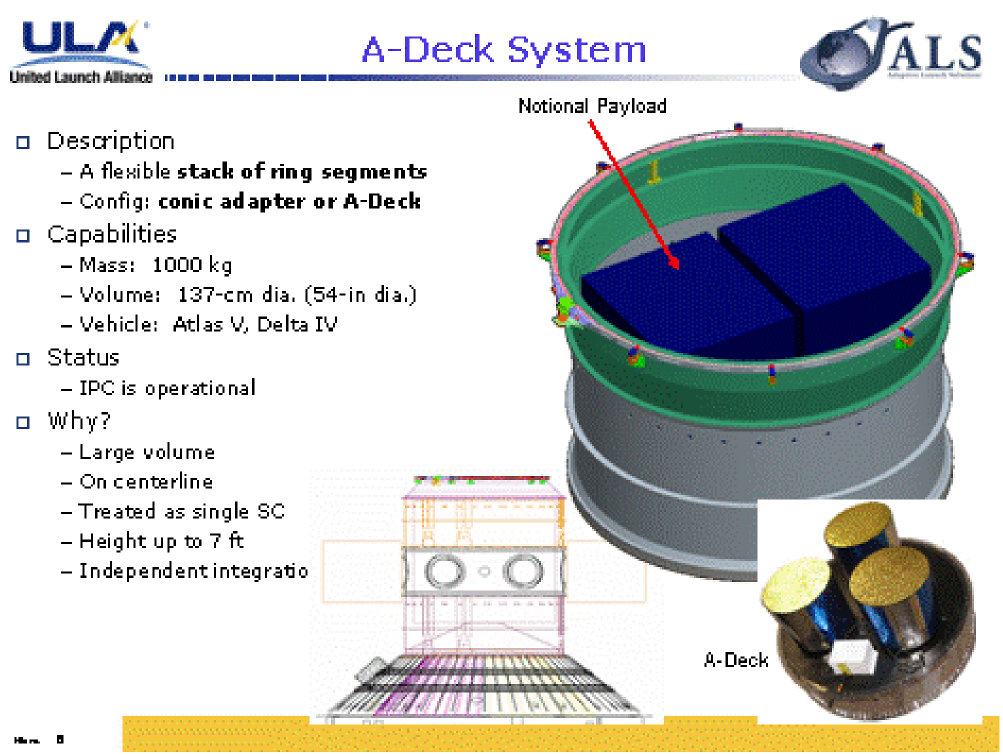

Figure 5, A-Deck Configuration from Adaptive Launch Solutions [x]

An experiment of this type can be serviced with data rates of less than 512 kbps, well within the S-Band transceiver system capabilities. S-Band transceivers are also desirable due to the abundance of available ground stations and standard waveforms. NASA supports STDN (Spacecraft Tracking and Data Network) waveforms with its Tracking and Data Relay Satellite System (TDRSS), Near Earth Network and Deep Space Networks and Air Force supports SGLS (Space/Ground Link Subsystem) waveforms with its Air Force Satellite Control Network. Both waveform types are supported on Space Micro's S-Band transceivers.

As an alternative, if a rough pointing antenna system can be used the transmit requirements can be greatly improved. This however requires vehicle attitude control. If the experiment period is beyond the Centaur mission duration, then this options is not available.

6. SUMMARY

In summary, ULA would like to re-iterate that rideshare missions are possible within the existing launch manifest for polar, MEO, and GTO types orbits. That we have developed (or through partnerships have developed) a suite of rideshare carrier options that can meet the demand from the rideshare community. And further, that with our partners, ULA can offer some unique options to the Hosted Experiment community to provide: power, telemetry, cmd/cntl and data storage services.

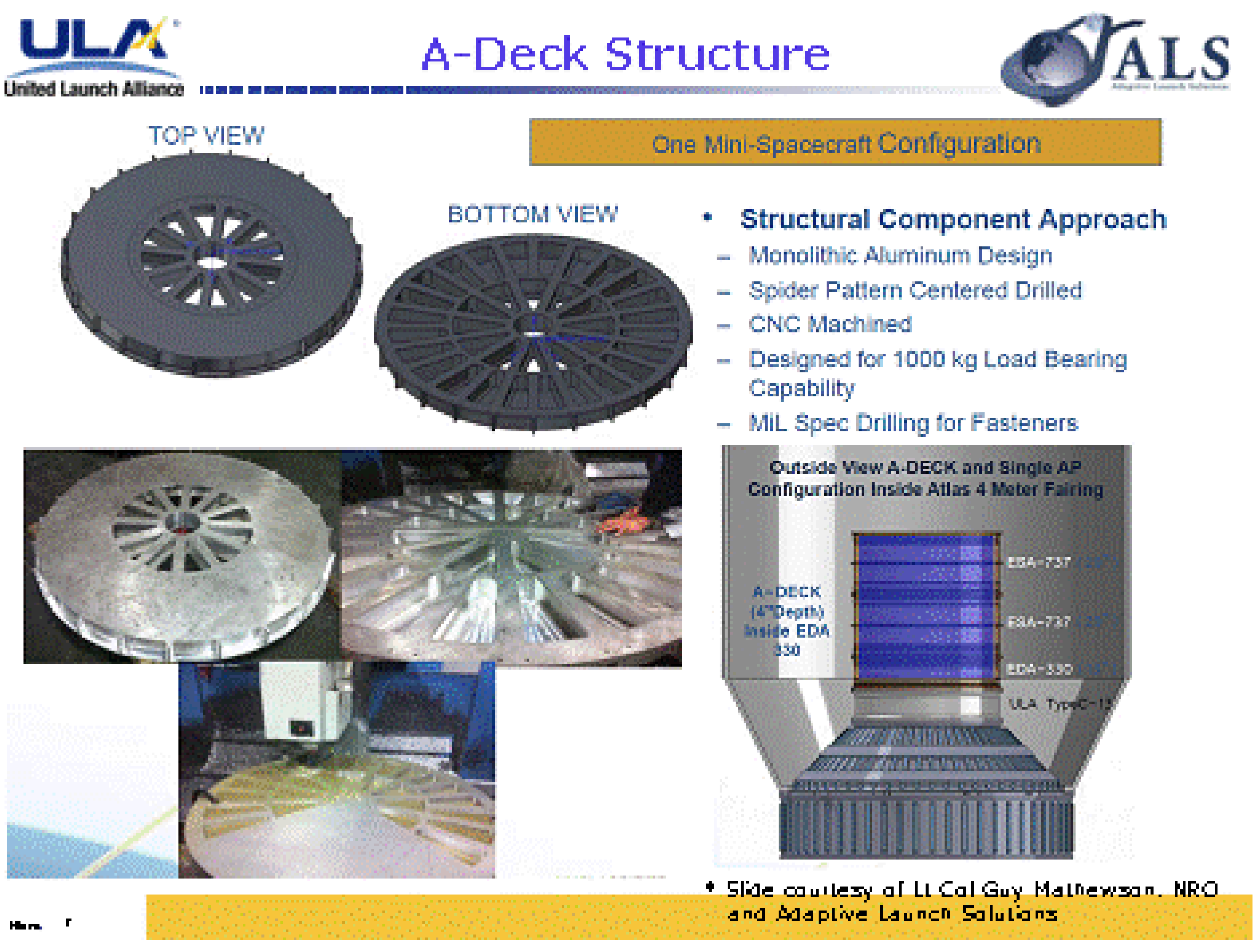

Figure 6, AQUILA Structure and Stack Options [x]

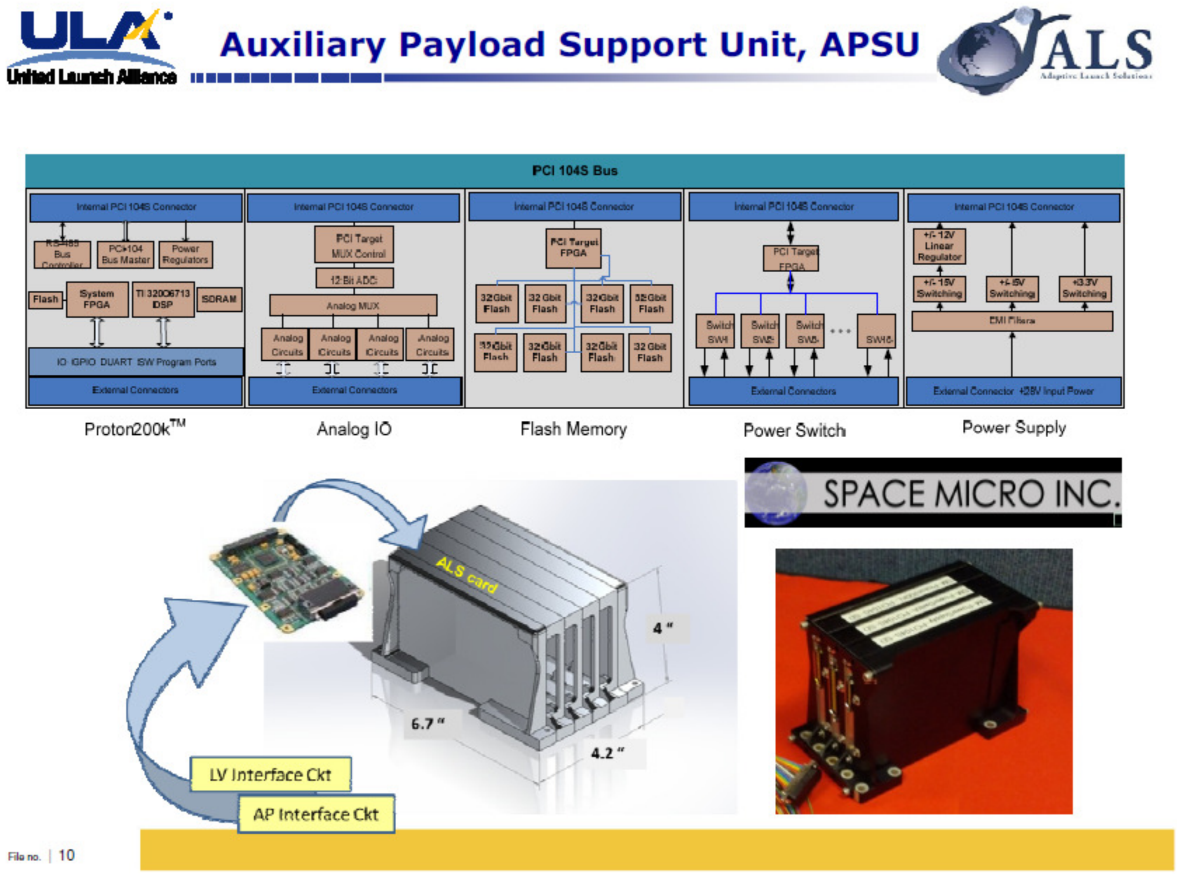

Figure 7, Auxiliary Payload Support Unit (APSU)

S-Band Transmitter

- The high performance µSTDN™ Transponder provides telemetry, tracking and command (TT&C) between STDN and DSN ground systems, and NASA satellites. The receiver/detector section detects and locks to the S-Band uplink signals, demodulates the BPSK (PCM/PSK optional) telecommand signal, outputs command data and bit timing. The transmitter section receives data from the Command & Data Handling (C&DH) unit, encodes and modulates it on an internal subcarrier and/or directly on the S-Band downlink.

- FEATURES
  - S-Band, CCSDS Compliant
  - Software Defined Features
  - STDN / USB compatible
  - Ranging Options
  - Radiation Hardened (TID, SEU, SEL)
  - Part level options from Commercial
  - Space to full Class S/NASA Level 1

Figure 8, Space Micro S-Band Transmitter System

Table 2. Communication Link System Calculation

MISSION & CONFIGURATION DATA		
Distance (600 naut mile)	1111200	meters
Frequency	2.20E+009	Hz
Elevation Angle	30	deg
Gnd Rx Antenna Gain	30	dB
ESPA Tx Antenna Gain	-3	dB
Free Space Loss	166.2266704	dB
Rx Loss (Noise Figure)	2	dB
Polarization Loss	0.1	dB
Ionosphere Loss	1	dB
Pointing Error Losses	0.5	dB
Dual Antenna Losses	3	dB
Desired Margin	3	dB

k (Boltz)	1.38E-023
T (Kelvin)	300
kT (dBW/Hz)	-203.83

RAW DATA		
Total Data	1.20E+010	bits
Time per pass	480	seconds
Number of Passes	90	days
Required BER	1.00E-009	Pe
Required Data Rate	277.8	kbps
Required Eb/No	12.5	dB
Symbol Rate BPSK	277.8	ksps
Symbol Rate QPSK	138.9	ksps

Required EIRP =	8.93	dBW
Tx Power =	15.61	W

DATA + RS(255,223)		
Total Data	1.37E+010	bits
Time per pass	480	seconds
Number of Passes	90	days
Required BER	1.00E-009	Pe
Required Data Rate	317.6	kbps
Required Eb/No	6.5	dB
Symbol Rate BPSK	317.6	ksps
Symbol Rate QPSK	158.8	ksps

Required EIRP =	3.52	dBW
Tx Power =	4.48	W

References

1. Sklar, Bernard Digital Communications Fundamentals and Applications", 2nd Edition, 2001, pg. 263.
2. Figure 5 with permission from Adaptive Launch Solutions Inc., http://www.adaptivelaunch.com/
3. Figure 6 with permission from Adaptive Launch Solutions Inc., http://www.adaptivelaunch.com/
4. Figure 9 with permission from Space Micro Inc., http://www.spacemicro.com/

Biography

Dr. Gerard (Jake) Szatkowski

He earned a BS, two Masters, and a PhD in electro-mechanical control systems, and a Masters in Business from Rensselaer Polytechnic Institute, in Troy, NY.

He has worked 36 years on space vehicles systems in: Ground & airborne launch systems avionics; Hardware/software systems verification for fault-tolerance; and Satellite control & telemetry analysis products. He currently works at United Launch Alliance as the project manager in Advance Programs for secondary payload accommodations and is coordinating development of hosted experiments on the ULA vehicles. He has achieved numerous firsts and patents on EELV vehicle systems in avionics, telemetry and solar power.

David R. Czajkowski

David Czajkowski has over 25 years of experience in space computer design/architecture, RF communication systems, rad hard ASIC design, and space radiation effects mitigation, and has co-founded two rad hard electronics manufacturers. At Space Micro, Mr. Czajkowski led the development of new rad hard technologies and products, such as Proton400k space computer product with > 4,000 MIPS performance level, ProtonX-Box avionics, IPC5000 image processing subsystem, uSTDN S-band transponder and uX-Tx X-band transmitter. Additional space industry experiences include co-inventor of RAD-PAK™ radiation shielding packaging technology and team leader for the development of over 150 different monolithic and multi-chip module microelectronic products. Mr. Czajkowski is currently the President of Space Micro Inc. He received a BSEE and MBA from San Diego University. He is the holder of 12 US patents relating to radiation hardened space technologies and encryption key management.