Upperstage Extensibility for Testbed Applications

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Abstract—By leveraging off the flight experience and capabilities of the Atlas and Delta family of vehicles, the opportunity exist to provide lower cost space based testing of avionics systems.[1 2] The author explores options for extending the capabilities of existing expendable launch vehicles to provide flight based testing of avionics systems for future space flight systems. By providing extended vehicle life, the possibility to evolve and mature proximity and control systems is discussed. The paper describes various options for lifetime extension as well as a number of options for extensible test bed configurations, which could allow more rapid determination of integrated system performance and behaviors.

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1. INTRODUCTION

The Case for Space Based Testing

Operating in space is inherently expensive, if for no other reason than the cost of transporting objects hundreds of miles into space. Historically, the rate of change in the systems operating in space is slow. This can in part be attributed to the low production rates. The need to recoup the development cost provides a disincentive to change the systems quickly.
While it is rare that changes need to be made to space based systems after the initial system deployment, the pace of evolution is slow and it takes time for problems to manifest. As pointed out in July 2004 issue of satellite-evolution in the Satellite manufacturing Special article by "LMCSS" in the six years alone between 1996 and 2002, on-orbit insurance claims were made for 83 percent of the total dollar value for all claims for the last 18 years.

For domestic, earth based systems, other options exist rather than rolling out a product with only lab testing. The use of beta testing allows evaluation in real application environments and provides the opportunity for rapid evolution and refinement of the product. While the space shuttle allowed for experiments to be lifted to orbit and returned, the use was primarily for microgravity, materials and life sciences. However, the Hubble Space Telescope Orbital Systems Test (HOST) platform carried experiments to validate components planned for installation during the third Hubble Space Telescope servicing mission and to evaluate new technologies in an earth-orbiting environment.
As we move into an era with commercial providers of crewed vehicles, the time has come to find other opportunities to test and accelerate the pace of space based technology evolution. By better leveraging existing launch capacity, we can gain flight experience with systems and technologies. With increased rates to flight experience we can improve models and refine the technologies the space-based systems rely on without depending on them for the operation existence of space based assets or crewed vehicles. By increasing the flight rates, we can drive down the time between operational system upgrades, ensure space worthy components and solutions, and drive the operation risk down by field-testing component upgrades before relying on them in operational systems.

2. THE ACKNOWLEDGED NEEDS

Thus far, we have seen increasing awareness of the need to provide low-cost access to space for small technology demonstrations. A few DARPA and USAF initiatives have, or will soon, fly on ULA launches. The premiere example of experimental missions is the flight of STP-1.

As then Major Tim Sumrall pointed out in his 2003 paper [1]
"The goal of the STP since 1965 has been to fly as many DoD R&D payloads as possible. These R&D payloads are picked from the Space Experiments Review Board (SERB) priority list. The most practical way to approach this is to maximize the number of R&D payloads per launch. To put this simple concept into action and faced with limited number of launch opportunities, STP in partnership with the

[1] 978-1-4244-7351-9/11/$26.00 ©2011 IEEE
[2] IEEEAC paper#1510, Version 5, Updated 2011:01:11

Air Force Research Laboratory (AFRL) developed the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA).”
The STP-1 mission flew on the Atlas EELV in 2007 and added a host of capabilities to the EELV fleet, including flight demonstrating the ESPA ring and the generalized guidance algorithm allowing guided retrograde burns.

As a result of the successful flight, AFRL is readying the next secondary mission. As Mark Scherbarth discussed in his 2009 paper [2], thirteen individual payloads were combined into a single platform (DSX) to provide a low-cost opportunity for AFRL. DSX will be co-manifest with an operational DoD satellite on an Evolved Expendable Launch Vehicle (EELV). As a result, a large number of experiments will be run at a fraction of the cost of the dedicated STP-1 flight.

The DSX mission was developed to research and advance the technologies needed for the Air Force to operate spacecraft. In fact, the Air Force has devoted significant resources to enable the flight of as many of these secondary missions as possible to expand their knowledge base.

This issue is not limited to the Air Force. NASA has designed a few of the experiments in DSX. In addition, the NASA technical fellow for G&C observed [3] “the critical need for multiple, low cost and routine flight test opportunities to demonstrate and validate emerging GN&C technologies cannot be overstressed nor overlooked.”

While the anticipated use of ISS for at least another decade will allow opportunities for using ISS as a test bed, the cost of delivering the setup to the ISS cannot be overlooked.

Three of the NASA challenge areas in the GN&C discipline are actually well suited to testing with a stable EELV based platform. Autonomous Rendezvous, Proximity Operations & Docking/Undocking could be accomplished with a small secondary. In space, End-to-End testing of GN&C systems for human exploration could be accomplished as a secondary mission. Integrating GN&C technologies for system-level Integrated Vehicle Health Management (IVHM) functions would be a natural extension of the ascent on any EELV launch.

Clearly, there are many opportunities for leveraging the existing launch systems for enhancing our knowledge and data. Many options exist to further the maturity and evolution of our knowledge and systems.

3. THE EVOLVING CAPABILITIES

ULA has recognized the growing demand for access to space for secondary missions. Over the years, we have developed a number of systems and capabilities to enable this market. Our rideshare capability has evolved from the dual satellite capability first developed in the 1970’s to a virtual cornucopia of offerings on today’s launch vehicles.

The desire by our customer agencies to affordably launch small development, science and operational payloads has resulted in our development of a robust portfolio of rideshare options that span a broad range of payload classes from nano-sats (~10 Kg class) to the Dual Spacecraft System (>2200kg). In addition to the ESPA used for STP-1 and DSX, there are the C-Adapter Platform (CAP), the Aft Bulkhead Carrier (ABC) and the Integrated Payload Carrier (IPC). ESPA and ABC have been discussed at Conferences like the AIAA Small Satellite Conference held at Utah State University last August (2010). These systems provide the basis for various future in-space test-beds.

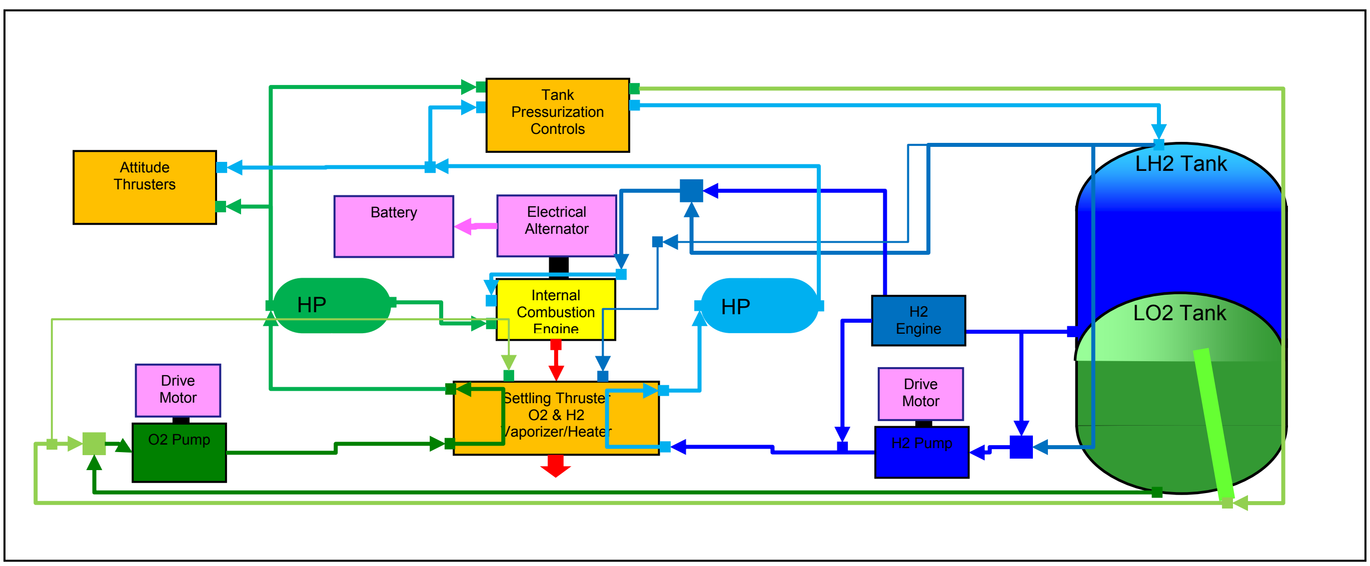

Figure 1: Integrated Vehicle Fluids (IVF) Schematic

4. MAPPING THE EVOLUTIONARY PATH FORWARD

We now propose the next evolutionary step forward in the field. By repackaging existing capabilities in the area between the upper stage and the primary payload, we can provide a space based test-bed for evaluating next generation avionics packages. Upgrading the existing Centaur upper stage avionics and adding a versatile propulsion system will provide a near-term, in-space test bed for Autonomous Rendezvous and Docking (AR&D) technology. The concept is to combine the Integrated Vehicle Fluids (IVF) power system (Figure 1) and an enhanced suite of 1553-based avionics (Figure 2) to extend the Centaur launch vehicle upper stage operational life to several days. The IVF system provides power from an Internal Combustion Engine (ICE) operating on the main Centaur propellants H2 and O2. The alternator and additional gaseous H2/O2 thrusters provide power and lateral thrust capabilities.

The enhanced avionics suite provides a backbone that any AR&D sensor/computer suite can access over the 1553 bus. The avionics would provide both the Fault Tolerant Inertial Navigation Unit (FTINU)-navigated state and the Global Positioning System (GPS)-based state solutions. The suite would also provide access to the Upper-stage Remote Control Unit (URCU) for commanding the various attitude/translation thrusters. The Centaur telemetry system would remain active to provide data to the ground on the performance of each test.

All the launch vehicle systems required for AR&D would be provided by the Centaur, facilitating the testing of various sensor suite and proximity computer combinations. When paired with a mission providing a few thousand pounds of excess margin, the system provides an excellent platform for performing AR&D testing. The EELV Secondary Payload Adapter (ESPA) ring serves as a robust support structure for the system. Integration of the ESPA system as a technology platform on Centaur was demonstrated with the successful flights of the USAF STP-1 mission and the NASA LRO/LCROSS mission. The ESPA is located between the Centaur and the primary payload. The test bed remains inactive until the primary payload separates.

The impact/payoff of this technology demonstration is the rapid development and fielding of an in-space AR&D technology test-bed system for NASA and the aerospace community. The ESPA structure allows testing of a number of different AR&D systems including various sensor suite and proximity computer combinations. Since the system is a test bed, each AR&D suite could be operated in single string

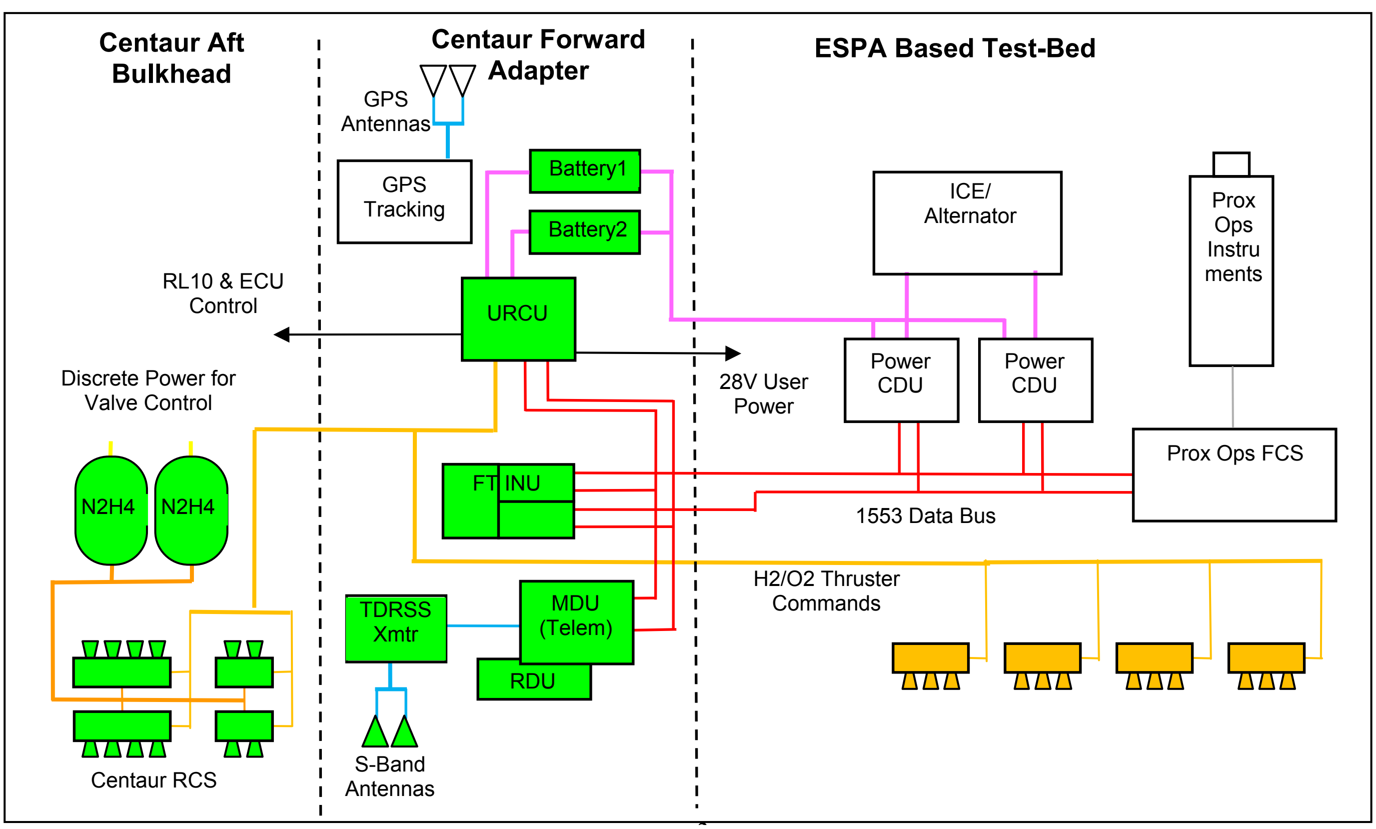

Figure 2: Avionics Overview

reducing the cost of the test while gaining valuable space flight performance testing. The key benefit is that this type of system allows evolutionary, generational expansion of the AR&D capabilities without risk to missions actively using fielded systems.

The development roadmap for the technology demonstration includes new flight software to provide control for the ICE and integration of the H2/O2 thruster commands. It includes minor changes to allow multiple test phases and post-primary mission separation to allow user-defined test/flight sequences. Finally, new interface logic will allow the AR&D to accept thruster commands/requests from 1553 bus messages. Development risk is considered low. The main technologies demonstrated with the first flight of this test bed will be the IVF and avionics.

The primary risk factor is the readiness of the IVF system. The current IVF system is at TRL 3, although many components are in the TRL 4 to 5 range and ULA is heavily investing IRAD to mature the IVF system. Avionics suite enhancement is a low risk effort, and all avionics changes would be thoroughly tested in the ULA System Integration Lab (SIL), which combines hardware in the loop with the expected mission profile.

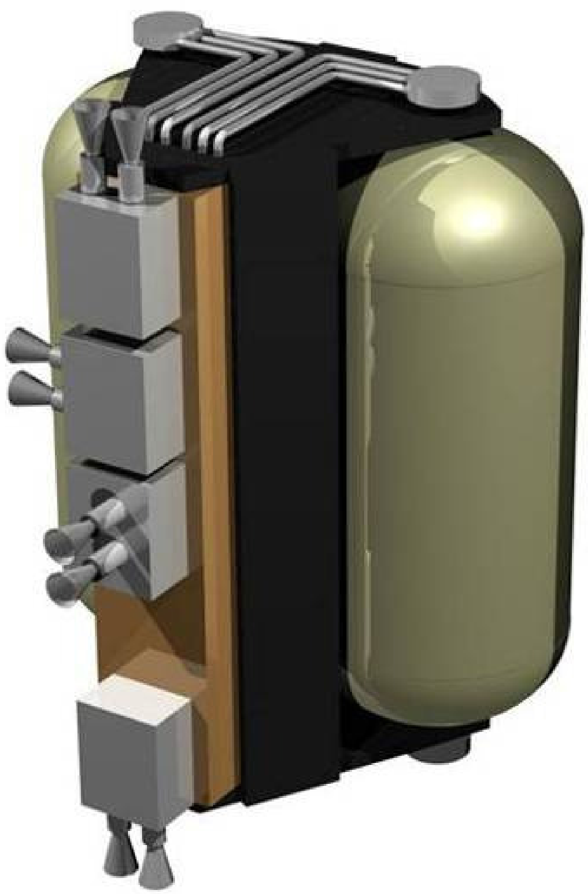

Figure 3: The IVF Thruster Module

Another key aspect of the architecture is the modularity of the design. Based on power requirements the opportunity exists to scale up or down the design. For missions only requiring a short duration (less than a day on orbit) the IVF alternator could be replace with additional batteries, similar to our current GSO kit for 12-hour missions. For missions requiring extended durations, beyond the 3-5 days of IVF power, solar panels could be applied with ~1kW allocated to the upper stage systems.

Likewise, the control system could be scaled. For missions only requiring attitude control there is no need for the weight penalty of the forward thruster system. For missions needing a more expansive translation capability, a set of hydrazine (N2H4) bottles with their associated thruster assemblies could be added in the test-bed region.

5. THE WORK TO GO

Interestingly, the alternative systems are not a large evolutionary step forward from today's flying systems. Support structures, RCS bottles and thrusters, batteries and even solar panels fly in space today and it is a matter of recombining and integrating these systems to expand the mission space to facilitate these test-bed activities.

The creation of IVF is the more challenging and to some the more rewarding endeavor. The IVF system will allow the use of hydrogen and oxygen from the upper stage primary tanks to satisfy the settling, attitude control, pressurization, and power requirements. With the creation of the IVF systems, a number of the limitations in today's systems can be overcome. In addition to simplifying the upper stage systems by eventually removing the RCS systems, the IVF system solves a number of secondary analysis issues with extended flight. The thermal issues with maintaining liquid N2H4 and the thrusters within the necessary temperature ranges is obviated by the use of ullage gases as the attitude control "fluid". The use of the IVF alternator removes the temperature constraint and depth of discharge of the batteries. The use of IVF also has a self-regulating benefit in that using the Ullage gas and producing a steady exhaust stream has a double benefit in keeping the cryogenic fluids in a stable and knowable condition, settling the tanks and reducing excessive boil-off.

ULA continues to fund a variety of R&D efforts to mature the IVF technologies, witnessed by the recent successful firing of the XCOR hydrogen piston pump.

Figure 4: Hydrogen/Oxygen Thruster Testing

Development of the hydrogen/oxygen thruster is progressing well with concept testing under way (Figure 4). Cryogenic composite pressure bottle testing is also progressing well. Development of the small pumps that will enable system operation is in the early stages.

Clearly, for any of these system concepts the final push will be the integration of the various required components in to a mission peculiar kit to modify the standard rocket. Unfortunately, the need will lead the capability by necessity. However, the concept proposed will easily allow incremental changes to evolve the capability of today's upper-stages.

6. THE UPPER STAGE TEST-BED

With the modularity of the discussed systems a wide range of mission models become achievable. Foremost from a secondary market perspective, the extended duration allows a two-burn separation from the primary mission to guarantee that recontact or interference with the primary satellite mission is not possible. Thus, we can provide delta V on both sides of the orbit to ensure the upper stage and the associated secondary payloads are in physically different orbits and will continue to move away from each other.

However, the new capabilities open a wide variety of testing opportunities. Sensor packages can be flown and run through their paces in the space environment. With the proper primary mission pairing, the test environment can very closely match the operating environment, in space radiation, thermal and lighting conditions the end item flight will experience. The flight profile can be tailored to characterize the system response to space environments the primary mission will attempt to avoid. For instance, the response and recovery to earth albedo for varying solar lighting conditions can be assessed and evaluated to better define look angle restrictions for a variety of instruments.

Of course, as we touched on earlier, the use of such a system for testing proximity and rendezvous systems, next generation navigation systems and GN&C systems for future crewed vehicles is an obvious benefit. With the addition of thrusters on the forward end of the upper stage, we have a full 6 degree of freedom control system. Targets could be deployed and systems tested to acquire, track, rendezvous and dock. Obviously, there are a number of restrictions on separating systems, but the benefit of flight-testing these systems, which lives will depend on, cannot be overstated.

For manned systems, there is the additional benefit of being able to space test a wide variety of devices and materials. Seals and actuators, thrusters and manipulators could all be flown and tested in the real operating environment before relying on them in primary commercial crew systems. Competing designs can be flight tested in the operating environment and traded against each other. Evolving technologies can more rapidly and safely be tested and further refined.

Another key benefit is in space electronics. With flying extended mission profiles, electronic systems can be flown through high-energy regions of space. As we saw on the launch of the Solar Dynamics Observatory, the Centaur upper stage electronics can successfully operate in high energy regions of the Van Allen belt. There is clearly benefit to testing a variety of electronic systems which need to function in these regions before relying on them for the next generation of flight systems.

While I have focused on testing aspects, there are also ample opportunities for science missions. With the longer ability to dwell in space and maintain desired orientations for extended, multi-day durations, the opportunity exists to gather new scientific data. The IVF system opens the door for a variety of continuous low thrust environments, either compensating for drag in low-earth orbit, or getting a broader swath of space with a spiraling trajectory. A number of new and fascinating test and scientific profiles open up.

Finally, one additional opportunity comes to mind. As we expand the number and diversity of the manned vehicles flying to low earth orbit, the opportunity exists to gather more data about the upper atmosphere. With a dozen or so flights each year and the increased pressure to mitigate the amount of space debris, a significant number of upper-stages will soon be returning to earth and burning up in the atmosphere. The opportunity to gather data on the decent would allow better characterization of the environment from 45-100 NMI above the earth surface. The data would be of clear benefit to all the returning crewed vehicles. It would allow improved mission design and better more accurate definition of the vehicle margins during reentry.

7. CONCLUSION

The challenge ahead will be to mate secondary missions to primary payloads. The current structure of the industry will require sponsors within the flying organization. NASA secondary missions will need to be mated by NASA, to NASA primary missions, and likewise with the Air Force payloads. Fortunately, the Satellite Test Program office is actively working the issue for the USAF. The key will be for the flying programs to recognize the importance of the missions accomplished by the secondary payloads and for the secondary missions to take the cost burden to ensure that the primary mission is fully successful.

For our part, ULA will continue to develop the capabilities required to effectively support the mission objectives of the secondary mission. We will continue to enhance and evolve our capabilities to delivery low risk solutions to multiple mission models and deliver increase value to our flying customers. We continue to focus with Internal Research and Development dollars to improve our systems and capabilities. We look forward to the challenge of expanding access to space and providing ever-increasing value to our customers.

By expanding the capability of our upper stages to maneuver on orbit for extended periods of time, we look forward to helping increase the pace of development for avionics and other space technologies. The proposed evolution will also facilitate earth observation and better understanding of low earth orbit phenomena. By continuing to develop our knowledge and understanding, we can collectively make access to space safer and more affordable.

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BIOGRAPHY

John Reed is an Associate Technical Fellow at United Launch Alliance. His current focus is external and cross-functional collaboration. He was a lead engineer for the launch of the LRO/LCROSS lunar mission. He was the technical lead for the guidance and navigation team developing the Atlas V vehicle and was instrumental in the development of the Fault Tolerant Inertial Navigation Unit and the divergence mitigation algorithms to minimize the transients associated with a system failure. He has a bachelor's degree in Aerospace Engineering from the University of Missouri Rolla and a Master's degree in Computer Science from the University of Colorado. He started his Aerospace career with McDonnell Douglas Technical Services Company working on the Space Shuttle in 1982.