Highly Operable Propulsion Technologies and Propulsion System Approaches for Operationally Responsive Space Systems

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ABSTRACT

In 2001-2002, the USAF developed an Operationally Responsive Spacelift Mission Needs Statement (ORS MNS) that defined the requirement for responsive, on-demand access to, through, and from space. This requirement not only encompassed the spacelift mission of delivering payloads rapidly to or from orbit, and their operation on orbit; it also states the systems will address operational issues related to launch on-demand, provide mission flexibility, and be cost effective. The ORS MNS indicates that future operational systems are needed that must be able to launch within hours of need, be low cost relative to today's launch architectures, and provide greater on-orbit mission flexibility. Previous Responsive Space workshops have also indicated that operationally responsive space systems must also provide a roadmap toward overcoming the business barriers that inhibit low cost operation. Propulsion technologies and the propulsion system have been shown to be one of the primary enablers of meeting the requirements that formulate Operationally Responsive Spacelift architectures.

Pratt & Whitney has explored several promising individual and integrated propulsion technologies that exist today or are in development that would provide the USAF with the capability to launch with-in hours of a mission determined need. These propulsion technologies include use of modular or integrated air-breathing booster systems, employment of soft-cryogenic fuels and oxidizers, and hybrid motors. Part of the employment of the soft-cryogenic fuels (i.e. liquid methane) could include the use of an Integrated Thermal Management Unit (ITMU) that would provide a stable storage environment during pre-launch and during launch. This unit would also have synergy with the use of methane for on-orbit systems. The air-breathing propulsion would have synergy with current USAF systems and act to provide a capability to launch from CONUS bases to deploy assets on demand to any inclination. These booster systems would be derived from current hardware, thus reducing the cost to develop and operate them as part of a USAF evolutionary responsive launch system.

The expendable, low cost hybrid boosters could be used as alternative booster or strap-on stages, as launch assist systems, much like the "JATO/RATO boosters" of the 1950's or low cost expendable upper stages for in-space systems.

The use of and advanced integrated engine health management system (EHMS) working with the vehicle management system (IVHM) creates a "system of systems". It creates a more responsive system by increasing the overall reliability by integrating propulsion or engines systems health management with the overall vehicle health management system.

Consequently, this paper will discuss the attributes and applicability of specific propulsion technologies and systems that could provide a robust performance capability as well as the capability meet a military aircraft-type operational responsiveness via horizontal take-off boosters.

INTRODUCTION

Responsive space systems have been described as being composed of several elements that include the spacecraft, the space launch vehicle or space access system, and the process of rapidly integrating the spacecraft and space access system. In order for a new generation of responsive space launch systems to be successful at meeting the missions needs specified in AFSPC 001-01 (Mission Need Statement for Operationally Responsive Spacelift, 2002) they will have to deliver on more than low cost and be at least as responsive as the legacy United States Intermediate and Intercontinental Range Ballistic missiles in the 1950's and 1960's.

Launch systems like the Jupiter, Thor, and Titan I were small and ranged in gross weight from 110,000 (Jupiter and Thor) to 222,000 pounds and all could be loaded (oxidizer and fuel) and launched in less than 15 minutes from launch command order. The Jupiter, Thor, and Titan I used integrated ground support assets and oxidizers and fuels (i.e. LOX and Kerosene) that could be ground transported or manufactured near the launch location as well. This important because it indicates that using a cryogenic oxidizer doesn't prevent rapid, responsive launch capability. The same could be inferred for a fuel that can provide more performance than kerosene or JP-8 fuel and has a higher normal boiling point temperature than liquid oxygen (e.g. liquid methane). (Broyhill, 2004)

These missile systems were the closest operationally responsive "rocket-based" vertical launched system we have had that come close to meeting the requirements of "flexible, inexpensive, and available on demand" as called out in the ORS MNS. Those legacy systems can be used to understand how higher performance propellants and support systems can be made to provide highly flexible operationally responsive space launch systems. (ORS MNS, 2002)

Using legacy designs to build up a "lessons learned" approach to operationally responsive spacelift applies directly within the new DoD acquisition process referred to as "Spiral Development" in the DoD 5000 series of regulations. A successful application of this process would start with qualified, proven design knowledge to formulate the concept and then evolve the concept using evolutionary steps to meet the initial operational capability with more useful capabilities. The key is to define early in the development the "evolutionary sustainment strategies" and maintain a "modular open systems approach to facilitate technology insertion". (Lumb, 2004)

The responsive spacelift systems for the 21st Century will need to expand upon the legacy of the propulsion and propellants that made the 15-minute launch alert systems reliable and responsive in terms of serving as weapons of deterrence at the time. Some small spacelift systems that build off the legacy of those design (e.g. the gas generator propulsion system and kerosene fuel) are in the final stages of develop today in 2004. Systems like Space Exploration Technologies' (SpaceX) Falcon vehicle have essentially been derived from proven technology of the historical systems and apply technology to the other vehicle elements to attempt to create a low cost system. The Falcon vehicle and Microcosm's Sprite launch vehicle concepts could serve to test the operationally responsive space lift capabilities of small launchers and demonstrate how the proper evolution of propulsion technologies can facilitate a "Spiral Development" to systems that can respond to call-up within 2 hours with a capability to deliver 3,000 pounds or more to Low Earth Orbit. The Falcon or Sprite may be the first pathfinders for vertical launched responsive small launch vehicles (RSLV). (Anonymous-SpaceX.com, 2004) (Wertz, 2003) (Lumb, 2004)

One possible approach to "Spiral Development" using the Falcon RSLV would involve using demonstrated rapid launch preparation processes with it as the pathfinder and adapting it's first stage with alternative upper stage propulsion and alternative propellants. Follow-on evolutionary development could use alternative strap-on Hybrid boosters. Later "Spiraled-in" elements would possibly be reusable horizontal take-off stages that used the earlier expendable RSLV elements that have demonstrated proven technology. The reusable horizontal take-off element could make use of technology proven by the DARPA Responsive Access, Small Cargo, Affordable Launch (RASCAL) program to arrive at fully "operationally responsive spacelift" system that can be dispersed from vertical take-off launch pads and operated more robustly to support a wider military mission needs or help develop lower cost commercial small spacecraft spacelift. (Carter II, 2001)

This approach can provide the "Spiral" or evolutionary development roadmap that leads to the overall objective of a rapid-response, global reach space system that the United States can employ. The final "Spiral Development" RSLV that provides the means for rapid-responsive space access will ultimately need to be able to be prepared with the spacecraft, fueled for the mission, and possibly stand ready for subsequent tactical deployment on the mission all within less than 24 hours, with the objective to being ready to launch and put a spacecraft into LEO or deliver payloads anywhere globally in less than 2 hours.

BACKGROUND

The concept vehicle study results in this paper are based on investigations performed at Pratt & Whitney to determine if particular propulsion technologies, which are already significantly developed, can provide low cost, high reliability, and higher performance to meet responsive spacelift mission goals.

To examine the benefits of the propulsion technologies under discussion in this paper, a notional orbital mission to 100 nautical miles by 28.5 degrees inclination was used and a generic two-stage vehicle was defined that would use liquid propellants. The two stage vehicle was "sized" and flown-off using the Program to Optimize Simulated Trajectories (POST) trajectory program. Variations in the propulsion systems and propellants of the first stage and second stage were investigated to determine the impact of using a hybrid booster (i.e. HTP/solid fuel), liquid oxygen and methane propulsion system based on an expander engine cycle, and the mission performance when the two-stage vehicle was used with a horizontal take-off launch system. Additionally, the benefits of using an ITMU to eliminate the cryogenic oxidizer and fuel losses during launch preparation and "strip-alert" was examined. A nominal design payload of 1,700 pounds was used to "size" each spacelift system and the lift-off thrust-to-weight was kept at 1.2 or higher. Maximum dynamic pressure was kept below 1,000-psia and maximum axial acceleration was limited to 5g's. The 1,700-pound payload size was selected because it represented the typical LEO payload value for several small spacelift vehicles under development. It also captures many of the small tactical spacecraft systems launched or under study. (Bille, 2002)

Two particular architectures evolved out of this study, a vertical two-stage small launch system and a horizontal take-off system that was a "spiral" development from the vertical take-off spacelift system. Employing evolved or "Spiral Development" to accomplish a wide range of payload performance needs would provide higher performance capability and optimize the two-stage vertical spacelift system to be more responsive to a wider range of military and possible commercial missions. Optimizing the combined use of expendable and reusable systems could provide the economic benefit desired to support USAF affordability needs for responsive spacelift and the low cost market needs to expand commercial spacelift if the spacelift systems are "right-sized" for a given mission payload capability. Starting off with a small affordable expendable spacelift system and coupling it with more efficient, higher performance expendable and/or reusable stages with proven technology may achieve the ultimate objectives and meet all the requirements specified in the ORS MNS. (Dolvin, 2002), (Wertz, 2004)

Several launch systems are in the process of being defined or in final stages of development that are can be test-beds for responsive space launch. The small launch systems such as SpaceX's Falcon and Microcosm's Sprite will help to demonstrate how small spacelift vehicles can be made into responsive spacelift systems. These systems could represent the first step in a progressive "Spiral Development" that will in the final increment be used in conjunction with other propulsion technologies to achieve all the ORS MNS requirements (i.e. launch within hours not days, carry a wide variety of payloads, be secure from a variety of threat environments, be highly responsive and operable).

ALTERNATIVE ROCKET BOOSTER AND UPPER STAGE PROPULSION

The two-stage concepts that were described above were investigated using liquid oxygen (LOX) as the oxidizer with kerosene fuel and liquid methane fuel and solid fuel as a Hybrid propulsion system with 98% Hydrogen Peroxide (HTP) as the oxidizer. Other combinations were also studied, but these enabled use of developing technologies to reduce cost and permitted the evolution of the small spacelift systems under development such as Falcon and Sprite. Two levels of liquid propulsion performance were defined; low-pressure engines, which operated at less than 500-psia chamber pressure and high-pressure engines, which operated above 500-psia chamber pressure. The LOX/methane expander engine performance was based on running at 750-psia. Nozzle area ratios were selected for the booster to maximize sea level performance. The upper stage performance was based on area ratios above 100:1, limited to 150:1 to limit nozzle exit diameters from growing larger than the nominal 5-foot diameter of the two-stage systems. The 5-foot diameter was selected since that corresponded to the Falcon spacelift vehicle's diameter range and it also coincided with the original B-58 Hustler bomber's external payload/fuel pod. The implications of the B-58's external pod size has tremendous synergy with a "Spiral Development" approach that could evolve the expendable two-stage small launchers into a more responsive horizontal take-off system.

The evolution of the two-stage spacelift system from using all LOX/Kerosene propellants to alternative configurations that would use a LOX/methane upper stage or that would substitute a Hybrid stage as the primary boost element and/or as a strap-on to achieve higher performance at low cost. The base LOX/Kerosene system was sized to ~64,000 pounds gross weight for the 1,700 pound payload. A low-pressure two-stage system also was sized to deliver the 1,700 pounds but the lower performance of the pressure-fed system drove the gross lift-off weight to over 144,000 pounds. When a LOX/methane upper stage was combined with the LOX/kerosene booster of the higher-pressure propulsion LOX/Kerosene system, the performance increases over 37% to 2,300 pounds. This system actually sized out to have a gross lift-off weight of 63,800 pounds. The use of higher specific impulse (ISP) of the LOX/methane upper stage propulsion system (over 370 seconds with the 150:1 area ratio nozzle) and the expander cycle engine running at 750 psia pressure permitted an increase in the payload with a lower propellant fraction on the upper stage. This evolutionary upper stage would be one of the elements in a 'Spiral Development" toward a highly capable responsive spacelift system. The same LOX/methane expander cycle propulsion system could be scaled up to meet the booster stage propulsion requirements. The all LOX/methane two-stage RSLV would have a 24% smaller gross lift-off weight than the all

LOX/Kerosene system, but it requires the simultaneous "Spiral Development" of a large (e.g. ~80,000 pounds) LOX/methane expander engine and a smaller (e.g. ~15,000 pounds) LOX/methane expander engine. Although the larger LOX/methane expander could be based upon the LOX/hydrogen RL60 developed components, the lower risk approach would most likely be to use the smaller LOX/methane expander engine as a "Spiral Development" element to improve the all LOX/Kerosene system performance to LEO while keeping the stage size small to prove out the LOX/methane technology insertion. The smaller LOX/methane propulsion stage could serve as the pathfinder for early small payload GTO missions since the liquid LOX/methane expander engine is restartable like the LOX/hydrogen RL10 engines already used on the Atlas and Delta launch systems. The larger LOX/methane propulsion system could be another evolutionary step once the smaller LOX/methane stage is proven to be a "responsive" technology step.

Another evolutionary approach would employ Hybrid propulsion (98% hydrogen peroxide (HTP) oxidizer and solid fuel) as a low cost alternative to the liquid booster stages. The Hybrid booster would use solid fuel canisters manufactured in volume without the oxidizer and then use liquid HTP as the oxidizer. HTP was down selected for two reasons for further study. In the Hybrid the HTP replaces a large quantity of LOX that would need to be stored at the normal boiling point (NBP) conditions and it has promise of supporting higher combustion efficiencies with the solid fuel in the discomposed state versus injection of liquid LOX. It also may be stored more easily for long periods of time in the oxidizer tanks on the Hybrid and can be decomposed using a catalyst "pack" without the need for a gas generator system like the LOX oxidizer based Hybrid. The evolved Hybrid would use the LOX/methane expander upper stage as the "Spiraled-in" alternative responsive launch system to keep the gross lift-off weight competitive with the LOX/Kerosene two-stage spacelift system. The design issue with this two-stage RSLV is that the lower performance Hybrid drives the gross lift-off weight up by 28%. Although this system has a higher gross weight it may still be competitive in terms of affordability with the all-liquid systems at the same mission payload. The storability of the HTP and the reduction of propulsion system components (e.g. no gas generator) may be the design elements to improve the overall system reliability and create a more responsive launch vehicle. The Hybrid also has the potential to serve as a responsive "Spiraled-in" strap-on to keep launch cost low when trying to get to higher LEO payloads. Figure 1.0 shows the comparison of the gross lift-off weights of several small payload two-stage responsive spacelift systems that were studied. (Frolik, 2003)

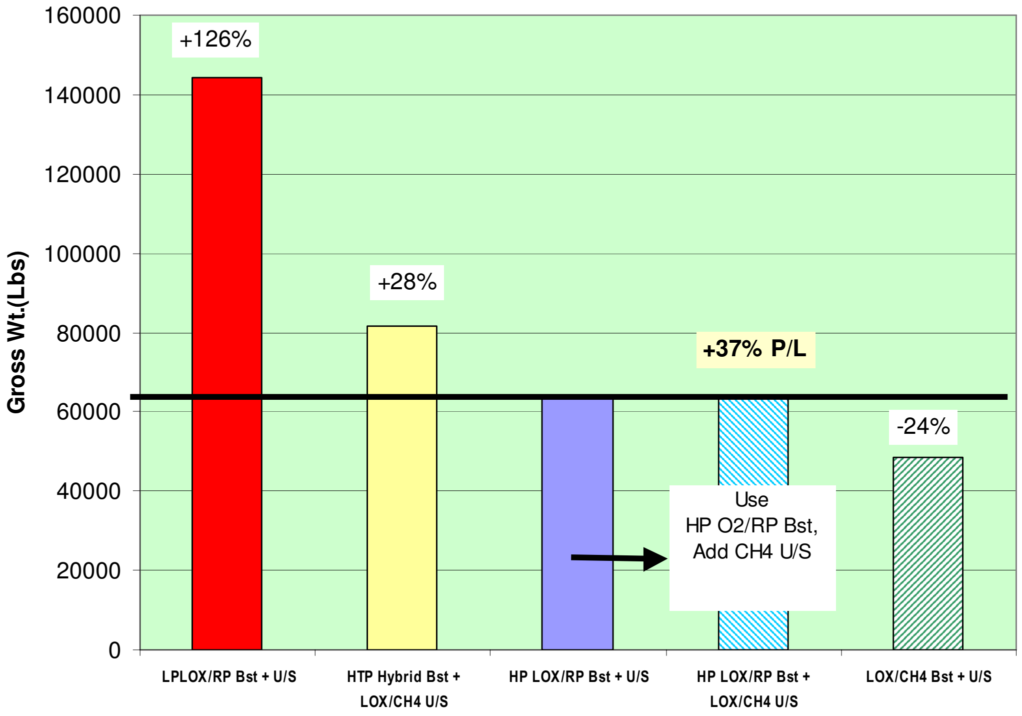

FIGURE 1.0 Comparison of Several Small Launch Vehicle Systems for a Responsive Launch System

Table 1.0 shows the lengths of the four systems discussed above; low-pressure all LOX/Kerosene, high-pressure all LOX/Kerosene, high-pressure LOX/Kerosene booster with LOX/methane upper stage, and the HTP Hybrid with LOX/methane upper stage. The assumption of these expendable RSLV's that sets the stage sizes is the common diameter of five feet, an interstage length of four feet, and a payload fairing length of ten feet.

Table 1.0 Comparison of Responsive Small Launch Vehicle Lengths

(feet)	LP LOX/Kero	HP LOX/Kero	HP LOX/Kero + LOX/methane	HTP Hybrid + LOX/methane
Boost Eng Length	8	8	8	5
Boost Stage Length	67	26	28	40
InterStage Length	4	4	4	4
Upper Stage Length	12.3	10.3	13.6	15.6
PLF Diameter	5	5	5	5
PLF Length	10	10	10	10
TOTAL Est. Length	**101.3**	**58.3**	**63.6**	**74.6**

The lengths shown for these systems are important because it can also influence the degree of engineering challenge associated with the integration of later "Spiral Development" elements like a horizontal take-off boost stage or the change out of higher performance upper stages. Note that the length of the B-58 Hustler supersonic bomber external pod captively carried under the aircraft up to Mach 2 was 75 feet. The length of that aircraft was 95 feet for comparison. The smaller high-pressure LOX/Kerosene and LOX/methane systems would easily fit under the B-58 aircraft for captive carry at Mach 2. The longer HTP/Hybrid two-stage would have to be optimized with the HTO to see how that lower cost approach could be made to have a minimum impact on the HTO "Spiral" element.

If an ITMU is "Spiraled-in" for the original LOX/Kerosene booster stage, then the operational responsiveness and cost advantage of using a Hybrid stage would need to be traded together for a given mission scenario to find the best system. The actual cost per stage (development, acquisition, and operation) of the LOX/kerosene with the ITMU and the Hybrid would need detailed analysis to determine what the absolute life cycle cost differences would be. The implications from historical design efforts and analysis is that hybrid boosters for small launch systems could be lower cost than similar mission sized liquid stages. Thus using Hybrid stages for the primary booster or as a strap-on to cover a broader range of mission payload capability warrants further investigation

AIRBREATHING PROPULSION BASED HORIZONTAL TAKE-OFF RSLV

The DARPA RASCAL technology demonstrator with a focus on low cost and a highly flexible launch capability to any azimuth will help to demonstrate how coupling expendable rockets with reusable booster/accelerator stages can benefit responsive spacelift. That technology work lays the foundation for the proving out horizontal take-off support for spacelift so it can be "spiraled" in as at the 2nd or 3rd element step in the "evolutionary development" process for a responsive spacelift system.

Horizontal take-off support of spacelift is not new. The Orbital Sciences Corporation's (OSC) Pegasus launch system's performance of ~1,000 pounds to LEO is adequate to support launch of small spacecraft, but the processing time and published cost per flight doesn't seem to support responsive spacelift requirements. Today though, per flight cost targets of $5 to $8 million dollars per flight are desirable for small launch systems. In all fairness, the OSC system was designed and became operational before the ORS MNS was defined (note: Pegasus has published values of ~ $15-20 million per flight and processing times nominally of < 15 days, but 48 hours has been discussed as a possibility). (Bille, 2002)

The HTO RSLV "Spiraled-in" element provides a large boost for the expendable RSLV. It takes-off horizontally from a military airbase and accelerates the expendable RSLV up to Mach 3. This is accomplished using derivative F119-type turbofan engines similar to those being developed for the F-35 joint strike fighter. The derivative F119 would use mass-injection technology proven by the DARPA RASCAL program or other technology modifications to boost the maximum Mach number up to 3.0. The Mach 3 staging value appeared to meet with engineering judgement without further optimization for these specific vehicles because the air breathing technology requirements for Mach 3 flight have been demonstrated with the SR-71 Blackbird. The lower Mach 3 staging also puts lower heating rates on the expendable RSLV stages. There is still significant benefit of accelerating the expendable RSLV to Mach 3 using horizontal take-off. This is two-fold; it provides a 70% increase in LEO payload (3,000 versus 1,700 pounds) and it creates a more responsive spacelift system that can deploy from any military base with a 10,000-foot runway. This creates a truly robust, responsive spacelift system when used in conjunction with the VTO expendable RSLV.

Several of the expendable RSLV systems were examined to see how they drove the gross take-off weight of the HTO RSLV system. The best two systems were the LOX/Kerosene high-pressure Falcon RSLV-type system with the LOX/Methane upper stage and the all LOX/methane RSLV system. Using a 40% structure fraction to size the empty weight of the air breather and a sea level take-off thrust-to-weight of 0.5, the gross take-off weights fell at or below the gross take-off weight of the B-58 Hustler strategic supersonic bomber. Although the expendable RSLV's being carried varied in size from 60,000 to 140,000 pounds (higher than the 36,000 pound external pod of the B-58), at least three of the HTO RSLV systems appear to be attractive in terms of total gross take-off weight since they require only two engines in the derivative F119 thrust class. The sea level thrust requirement in this analysis scaled with the gross weight and the sea level thrust-to-weight (T/W) loading with the smaller engine thrust requirement being for the all LOX/methane HTO RSLV. The low-pressure all LOX/kerosene system would require at least four engines to stay in the derivative F119 engine size. Figure 2.0 shows the comparison of the gross lift-off weights for several of the expendable two-stage RSLV's when coupled with the reusable HTO air-breathing stage.

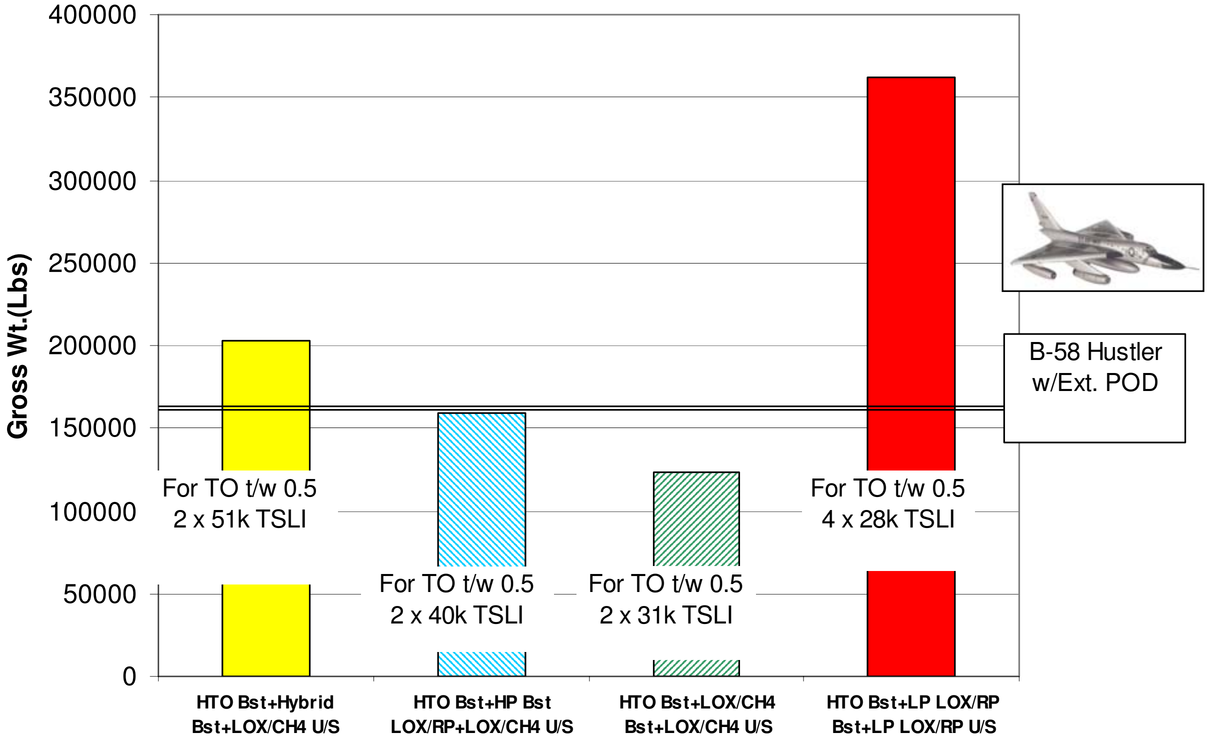

FIGURE 2.0 Comparison of Gross Lift-off Weight for the HTO Spiral Element Using the RSLV Systems.

ITMU APPLICATION FOR OPERATIONALLY RESPONSIVE SPACELIFT

Using cryogenic propellants such as liquid oxygen or fuels like liquid methane or even hydrogen requires that the bulk temperature be maintained at or slightly below the NBP to minimize losses as the fluid tries to equalize to the warmer ambient conditions. To maximize the propellant load, due to the nature of cryogenic propellants, the design of the cryogenic tanks are one of several evolutionary techniques that must be explored further. The fluid in the tank must be protected from exposure to warmer ambient conditions as much as possible and/or be topped off as thermodynamic venting is allowed to maintain pressure equalization, or recirculated within a refrigeration cycle and optimally insulated. Combinations of the above can be used to keep the propellants ready for use in the vehicle propulsion system. Technology has evolved for cryogenic fluid management to where other active propellant management techniques are possible in the design. One such design concept is the ITMU or Integrated Thermal Management Unit. Pratt & Whitney has collaborated with NASA Glenn Research Center on several mission/vehicle designs looking at how to minimize cryogenic propellant loss and build a “self-management” system into the tankage. NASA GRC has worked on cryo-cooler technology for several years and has developed "Stirling cycle" units that would act as a cold-finger in the tank to keep the bulk temperature below the NBP. Figure 3.0 shows how the ITMU system elements are integrated to create a "zero boil-off" approach so that cryogenic propellant elements can support a responsive spacelift system.

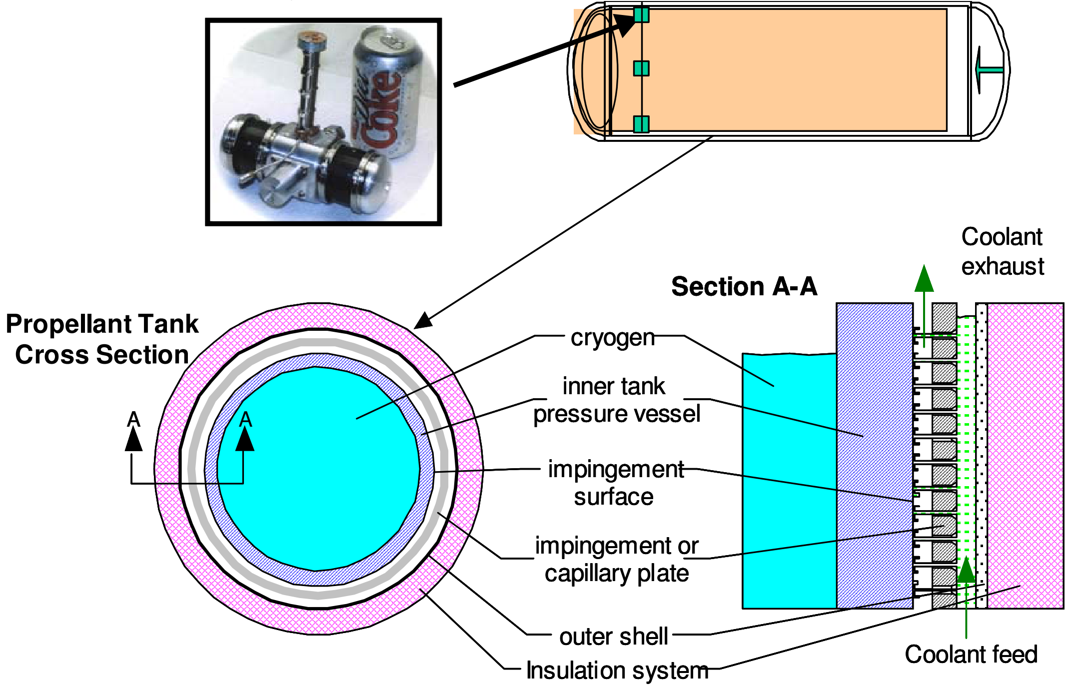

FIGURE 3.0 ITMU Integrates Cryo-cooling & Thermal Management Technologies Into Vehicle Propellant Tanks.

Pratt & Whitney, working with the United Technologies Research Center (UTRC) has been evolving the ITMU approach that could employ either a unit such as the NASA GRC "cryo-cooler" or a similar reverse Brayton machine in conjunction with the insulation design of the tank to create the ITMU. The concept technology is at the point of demonstration and would highly benefit responsive launch vehicle design that carry large propellant loads that must be maintained to keep "launch on demand" or "strip-alert" status without being connected to propellant feed lines for continuous "topping-off". The unit does have an electrical power demand and varies in proportion to the quantity of propellant to maintain at or below NBP and the delta-temperature between NBP and the ambient surroundings. The technology now only would reduce the overall ground support, but would improve the management of propellant loading and ground storage losses. Figure 4.0 shows the difference in the power requirements for several of the small launch vehicles discussed earlier in the paper. The all LOX-kerosene two-stage system that used low-pressure engines has the greatest power demand due to the larger LOX load.

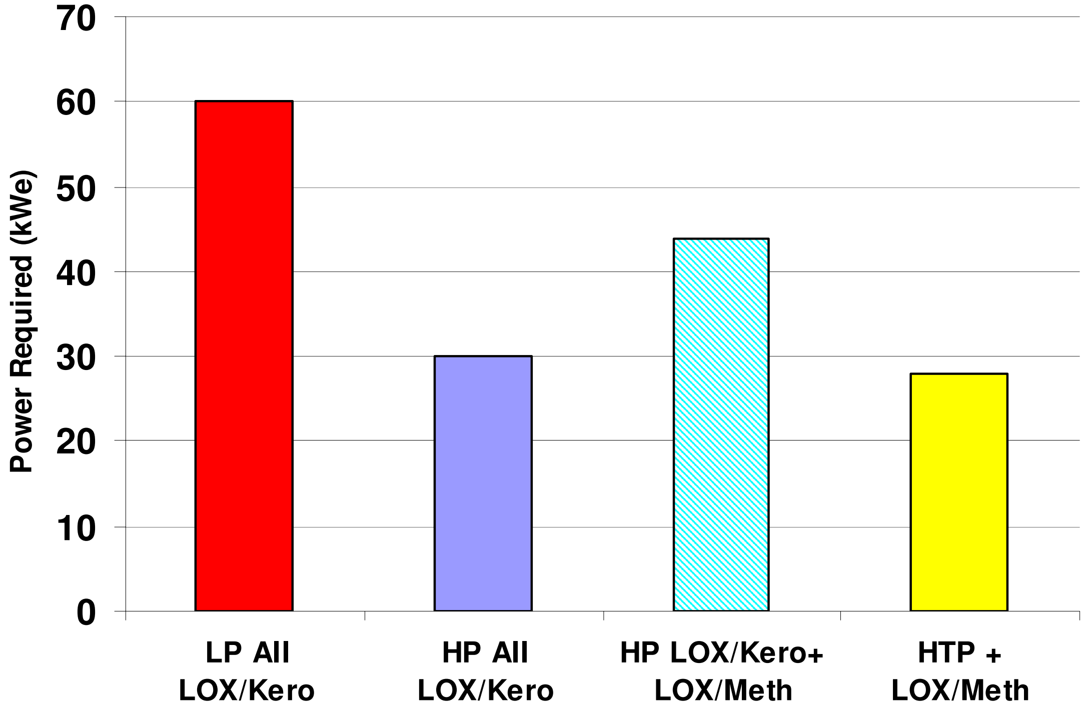

FIGURE 4.0 Variations in ITMU Cryo-cooler Power Demand.

It is envisioned that this technique could be applied to new designs or "evolved" design steps within the "Spiral Development" process once the technology had been proven. It holds great promise as a technology that could improve the management of cryogenic propellants for launch systems and in-space vehicles. Further integrated development and testing would be desired to prove the technology can be integrated with vehicles that use LOX and with vehicles that use LOX and cryogenic fuels since those propellants provide the highest performance in payload and smallest vehicle size.

SUMMARY

Responsive spacelift must be approached with a focus on how to obtain many of the far-reaching objectives over the "Spiral Development" of a responsive launch system. Launching within minutes like military fighters and strategic bombers must be a primary objective, but the system must also keep trading off how the system meets affordable cost criteria, obtains high reliability and low maintenance, and has the performance to deliver a wide range of payload that could go as low as 100 pounds or as high as 12,000 pounds to LEO. This of course would most likely not be done by a single launch vehicle design due to the economics trade-off but some combination of stages that builds off the base design. One approach for this has been described in this paper that uses horizontal take-off with a SpaceX Falcon 1 type launch system. (Wertz, 2004), (DARPA/ITO, 2002)

The global reach and rapid response mission needs will only be satisfied if the system can respond in minutes like current military aircraft. So far the physics has shown (from legacy systems) that the vehicle must be small; thus not needing days to prepare like "launch on schedule systems", focus on the lower range of payloads (e.g. 100-12,000 pounds). The goal would be to "spirally develop" off propulsion technologies that have a history of operability within a military mission environment (e.g. F119, RL10) and evolve them to formulate a reliable, operationally responsive spacelift and on-orbit architecture. Through innovative use of air-breathing propulsion, employment of soft-cryogenic fuels and oxidizers, low cost hybrid motors, and an integrated vehicle-engine health management system, an "operationally responsive propulsion" roadmap can be created to support responsive spacelift for the military forces of the United States of America. (DARPA/ITO, 2002)

REFERENCES

1. Bille, M., "Practical Military Applications of Near-Term Rapid Launch Options", *2002 Core Technologies for Space Systems*, November 19, 2002.

2. Broyhill, Marvin T., Website: "Strategic air-command.com/missiles", Visited March 30th, 2004.

3. Carter II, Preston H.,"DARPA Responsive Access, Small cargo, Affordable Launch (RASCAL)", Introduction Briefing, August 2001.

4. DARPA/ITO,"FALCON-Force Application and Launch from CONUS", Proposer Information Pamphlet Phase I BAA 03-35, DARPA/ITO, Arlington, Virginia, 2002, pp 1-6.

5. Dolvin, Douglas J., "System Concepts and Technology Development for Operationally Responsive Reusable Military Aerospace Vehicle", 11th AIAA/AAAF International Conference, Space Planes and Hypersonic Systems and Technologies, Orleans, France, September 29th-October 4th, 2002.

6. Frolik, Stephen A., "Hybrid Rockets-Propulsion and Energy", Aerospace America, American Institute of Aeronautics and Astronautics, Washington, D.C., December 2003, page 68.

7. Lumb, Mark D., "DoD Business Transformation & The 5000 Series Regulations, Meeting the Security Challenges of the 21st Century", Presented at the 2nd Annual DAU-South Contracting Conference & Expo, February 18 & 19th, 2004.

8. ORS MNS, "Mission Need Statement AFSPC 001-01, for Operationally Responsive Spacelift", HQ AFSPC/DRS, 2002.

9. Anonymous-SpaceX.com, Website: “www.spacex.com”, Visited February 15th, 2004.

10. Wertz, James R., Conger, Robert, Kulpa, Jack, “The Scorpius Expendable Launch Vehicle Family and Status of the Sprite Small Launch Vehicle”, AIAA-LA Section/SSTC 2003-98005, 1st Responsive Space Conference, Redondo Beach, California, April 1-3 2003.

11. Wertz, James R., ”Reusability: The Death Knell of Low Cost, Responsive Access to Space”, SPACE NEWS, March 22, 2004, page 11.