THERMAL-BASED COMPARISON BETWEEN ROCKET BOOST-BACK AND JET FLY-BACK BOOSTER RECOVERY APPROACHES

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ABSTRACT
The Air Force Research Laboratory has been exploring approaches that may be considered for a quick turn-time booster research demonstrator for possible utilization on a full scale such as the Affordable Responsive Space (ARES) system. Part of this effort includes the evaluation and comparison of a wide variety of operating approaches that may yield significant variations in aerodynamic heating, material selection, design-space expansion, and maintenance approaches. One approach that has been under investigation by AFRL since 2001 is Rocket Boost-Back. This approach replaces the fly-back hardware (Thermal Protection System (TPS) and the jet engines) used to fly back to the launch site area (common in the most widely publicized systems) with additional rocket fuel and uses rocket motors to "boost" the system back within gliding range of the launch site. Eliminating the need for TPS opens up the design space and may allow a larger variety of wing and tail configurations than the limited Space Shuttle looking concepts. This paper will compare the relative size, weight, and thermal implications of the rocket boost-back and jet engine fly-back (AFRL baseline system) concepts at a high level in order to identify where additional effort may be desired.

INTRODUCTION
The Air Force is currently in the process of considering the development a low turn-time (measured in hours instead of weeks) reusable first stage to support affordable rapid access to space. In order to achieve this challenging objective, all options must be considered and a thorough understanding of the challenges must be known. Reusable Military Launch System (RMLS) team members have worked closely with NASA Kennedy Space Center (KSC) and NASA Johnson Space Center (JSC) maintenance and flight operations personnel for the last five years in order to increase their understanding of this challenging task. From their work and collaboration with jet aircraft operators and maintainers, a straight forward conclusion appears to be that the greatest difficulty lies in reducing or eliminating flight operations and maintenance actions that make the system vulnerable to catastrophic failure mechanisms. Catastrophic failure mechanisms are undesirable because they can cause a loss of vehicle (and possibly life). This looming possibility forces operators and maintainers to expend significant resources. It also causes the military to expend valuable resources (personnel, money, and hardware) needed to support the US during conflicts. A rough idea of effort involved can be seen in figure 1 that captures NASA KSC's estimate of the man-hours used to maintain the Space Shuttle in the Orbiter Processing Facility (OPF). It can be seen here that TPS maintenance is a very large part of the maintenance effort. Part of this effort can be tied to how NASA fly's or operates the vehicle. For example, when the Space Shuttle lands the gear doors are opened. Opening the gear doors breaks a high temperature seal. When this critical seal is broken maintenance must be performed. Seal maintenance is a time consuming and critical task that demands highly skilled

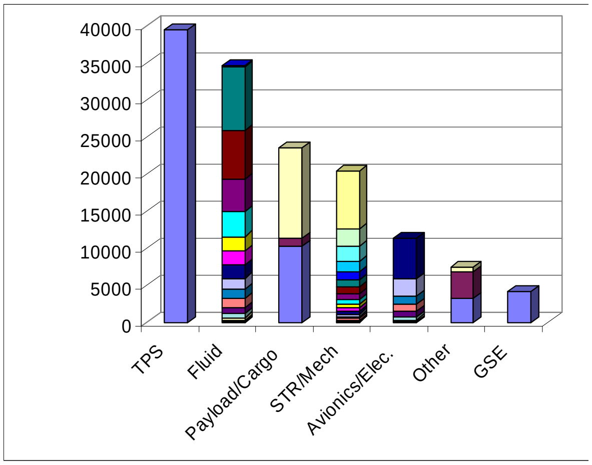


Figure 1. Man Hours in the OPF
Space Shuttle STS-85 Man-hours Courtesy of Edgar Zapata NASA KSC

technicians and a robust verification process, because if the seals are not “perfect”, a catastrophic event like the Columbia may occur. Therefore, the question may not be “how do we make better seals”; it may be “how do we avoid the seals entirely”. These types of questions and considerations pushed the RMLS team to consider options that may enable future Air Force boosters to recover by avoiding the high thermal environment encountered during normal reentry. The rocket boost-back approach is one of these approaches being considered.

The rocket boost-back approach uses the rocket engines (not necessarily the main engines) to decelerate the booster after staging to a velocity where either non-critical TPS or no TPS is required. This trading of thermal energy for fuel can be accomplished in a variety of ways. The approach presented here simply turns the booster around after staging until the vehicle is parallel with the Earth’s surface with the engines burning and pointed in the general flight path direction (figure 2). The design and thermal analysis of this approach will be compared to the baseline system that reenters similar to the Space Shuttle before employing jet engines for the return to launch site flight segment. This paper will describe analysis software, sizing assumptions, and present the results (size, aerodynamic, trajectory, and thermal loading) of the baseline fly-back and rocket boost-back approaches.

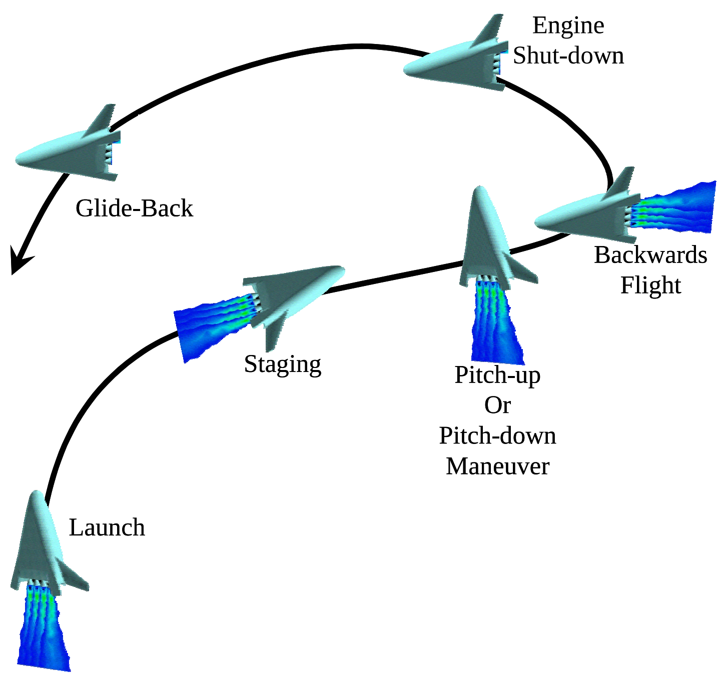


Figure 2. Rocket Boost-Back Concept

ANALYSIS SOFTWARE

System sizing was accomplished using the Integrated Propulsion Analysis Tool (IPAT) developed by the Air Force Research Laboratory (Air Vehicles and Propulsion directorates) which was heavily based upon the RMLS sizing software co-developed with the Air Force Aeronautical Systems Center (ASC). This software utilizes TechnoSoft Inc. Adaptive Modeling Language (AML) as the core software for managing the parametric design process. AML has links into several analysis codes that provide the required sizing information. These include aerodynamics, trajectories, and thermal analysis. Lift and drag coefficients were obtained using Missile Dat Com developed by AFRL. Trajectories were simulated using the Program to Optimize Simulated Trajectories (POST II) developed by NASA Langley Research Center (LaRC). Thermal analysis was accomplished using MINIVER also developed by NASA LaRC. These are the same tools utilized by the Air Force during NASA's Second Generation Launch Initiative (SGLI) and Next Generation Launch Technology (NGLT) study efforts and verified with NASA and industry.

ASSUMPTIONS

In order to level the analysis playing field as much as possible, common assumptions and models were used for both assessments. The rocket boost-back sizing was performed using the baseline jet fly-back model with the TPS and fly-back systems removed. We assume that leading edge heating can be handled by high temperature metallic materials with minimal to no insulation.

Common Conditions

Payload	58,279 lb
Launch Thrust to Weight	1.3
Engine ISP	290 seconds
None throttling of rocket engines	
Staging velocity	7,000 feet per second
Staging flight-path angle	20 degrees
Wing loading	74.7 pounds per square foot
Aspect Ratio	2.4 (approximately)
Maximum dynamic pressure	700 pounds per square foot
Maximum normal wing loading	2.5 g's
Maximum axial loading	6.0 g's
Cruise and glide lift over drag	5 to 6
Return-To-Launch-Site Altitude	Pass over the field at 30,000 feet or more
Standard day conditions	

Fly-Back Specific

Fly's 15 minutes past launch site to account for cruise condition winds

Rocket Boost-Back

After staging keep two out of four engines ignited at full throttle (50% of full-throttle used to boost back)

RESULTS

The results of the comparison follow in figures 3 through 11. The rocket boost-back has a higher fuel fraction and is 31% heaver at launch than the jet fly-back system; however, it has a 27% lower empty weight. Staging altitude was not constrained and both approaches staged at nearly 145,000 ft. Figures 10 and 11 show an estimate of the nose stagnation temperature using MINIVER. This preliminary estimate may not be accurate due to uncertainties in the input file and with the use of a two foot radius nose. Work will be accomplished to improve these estimates as the Air Force activities continue. The trend should be correct because only the trajectories varied between the two analyses.

Description	Fly-Back	Boost-Back
Fuel Fraction	0.6878	0.8122
Launch Weight	423,122 lb	615,726 lb
Landing Weight	70,714 lb	52,940 lb
Empty Weight	69,240 lb	50,841 lb
Fuselage Length	81 ft	97 ft
Fuselage Diameter	14 ft	16 ft
Time Back Over Field	84 minutes	11 minutes
Cross-range	94 nm	0 nm

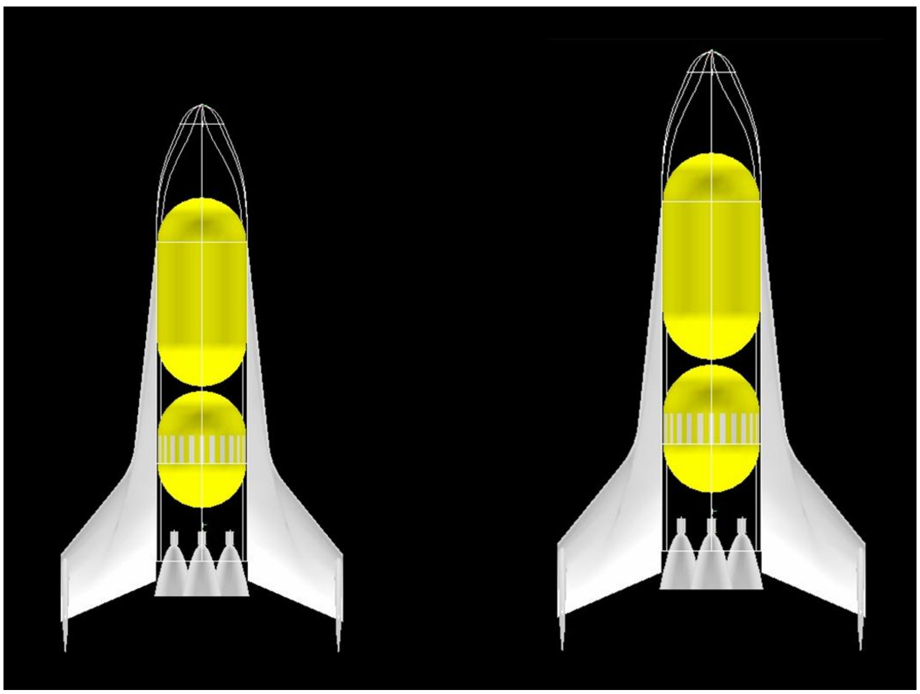


Figure 3. Fly-Back (left) and Boost-Back (right)

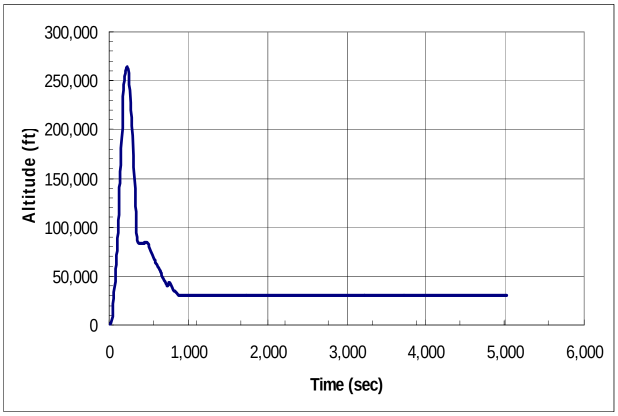


Figure 4. Fly-Back: Time vs altitude

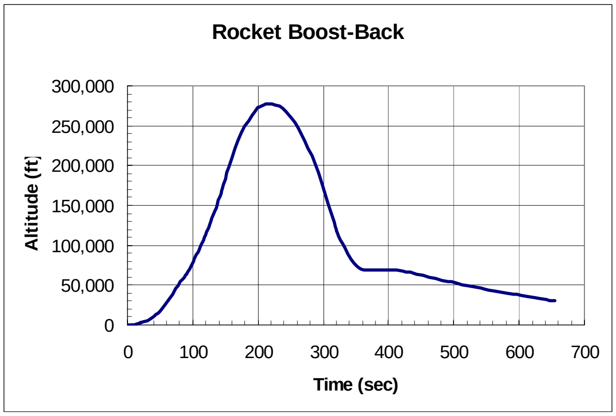


Figure 5. Boost-Back: Time vs altitude

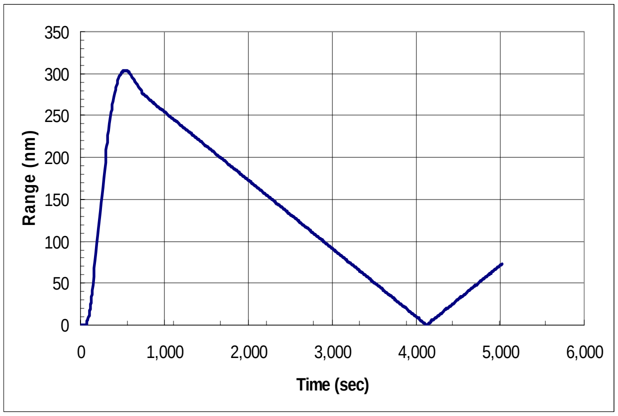


Figure 6. Fly-Back: Time vs range to field

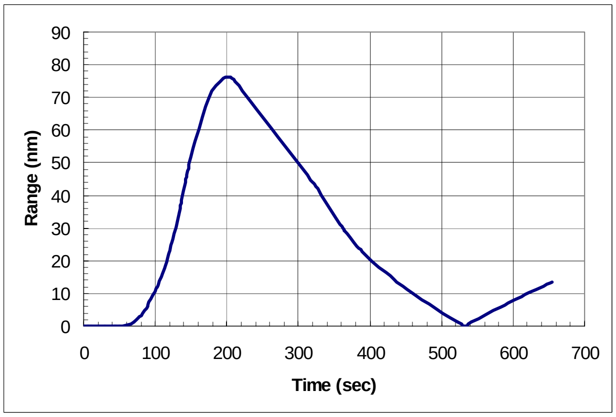


Figure 7. Boost-Back: Time vs range to field

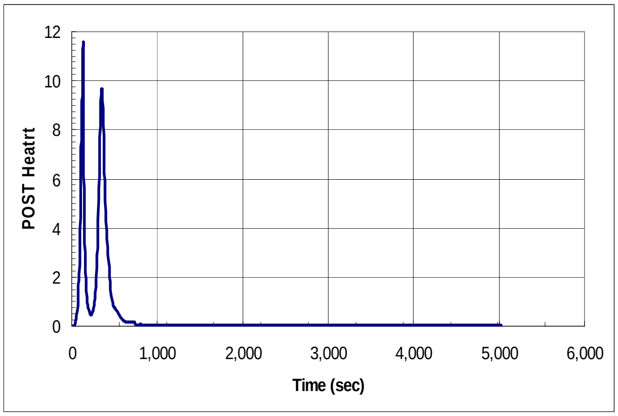


Figure 8. Fly-Back: Time vs heat rate

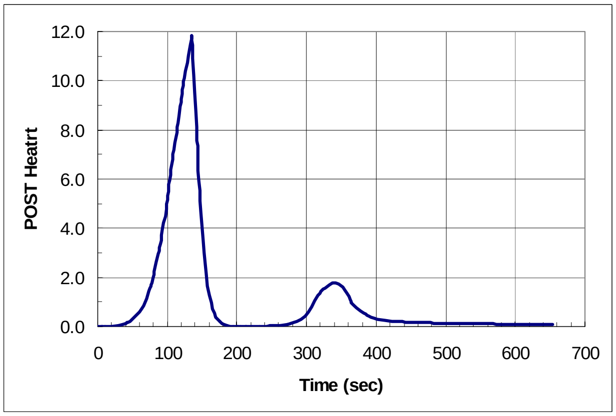
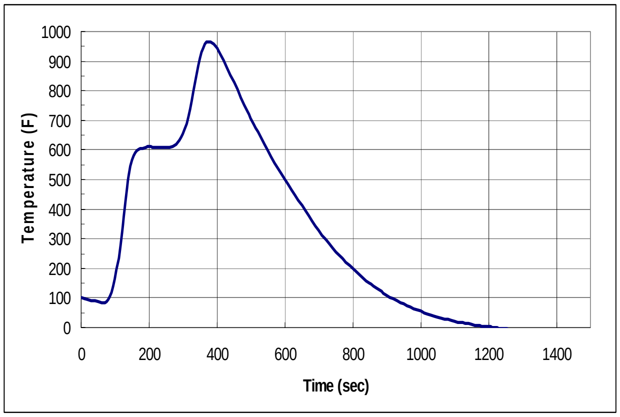


Figure 9. Boost-Back: Times vs heat rate



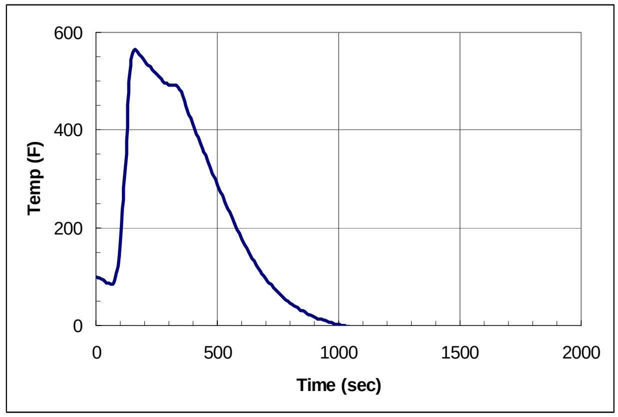


Figure 10. Fly-Back: Time versus nose stag. temp **Figure 11. Boost-Back: Time versus nose stag. temp**

CONCLUSIONS

The jet engine fly-back booster is smaller both in size and launch weight than the rocket engine boost-back booster, but not in empty weight. Typically, empty weight is considered the acquisition cost driver, so the rocket boost-back booster would normally be expected to be cheaper. The cost savings is compounded by the possibilities of using normal aircraft materials without TPS and not requiring jet engines. Eliminating the TPS and jet engines combined with normal aircraft materials may drive the cost of the rocket boost-back system down to half of the fly-back booster and make the option selection straightforward. The simplicity of the larger boost-back may more than make up for it's larger size with operations cost and turn-time reductions too. For example, large and simple airline transports and Air Force refueling aircraft have very short turn-times and are very reliable; however, more complex fighter and bomber aircraft take considerably more time and resources to maintain and return to use. Therefore, the rocket boost-back approach looks extremely promising, but needs further exploration to verify these results and determine how it compares to the typical jet fly-back systems being currently proposed to the Air Force and NASA.

REFERENCES

1. Rooney, Brendan; Hartong, Alicia, "A Discrete-Event Simulation of Turn-Around Time and Manpower of Military RLV's", AIAA 2004-6111, 2004.

ACKNOWLEDGEMENTS

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