

Aerocapture Technology Demonstration Risk Reduction Activity

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Abstract

NASA Langley Research Center (LaRC) has developed and constructed a full-scale mockup of a trim tab mechanism for a steerable entry vehicle forebody to address the risks associated with a Technology Demonstration Mission (TDM) with respect to the mass and volume needed for such a system as compared to existing steering systems. This paper provides an overview of the conceptual design effort and the results of the risk reduction effort.

Introduction

Current state of the art steering of entry bodies includes jettisonable ballast systems, an example of which was used on the Mars Science Laboratory (MSL) which used a ballast system that accounted for 35% of the entry capsule.¹ Alternatively, the proposed Aerocapture TDM implements trim tabs that extend and retract to provide pitch and yaw control during descent through an atmosphere. Trim tabs have previously been discounted due to “large system weight and complexity”², but state of the art batteries and drive systems have decreased in mass such that a four trim tab system becomes feasible in the small entry body format (currently sized at 0.6 m diameter and 100 kg) used in this activity. This risk reduction effort advances the concept to the preliminary design phase with respect to sizing drives and batteries to ensure those components fit within the allowable volume of the entry body and have a net mass no greater than the current state of the art steering systems.

Risk Reduction Overview

Entry Body Volume Constraints, Component Sizing and Preliminary Design

Actuator Selection

Preliminary design used flight-like actuator mechanisms for initial placement. These were sized for the forces and rates required for deploying and retracting the trim tabs for the proposed demonstration. Once selected, the total amp hours required for driving the actuators during the demonstration period drove the size and number of batteries needed.

Actuator size considerations were based on preliminary load calculations and deployment timing requirements. Market research showed no off-the-shelf solutions were available, so several companies were contacted through a Request for Proposal (RFP). Only one company responded with a new design that would fit into the limited space available for the actuators in the overall design, providing the necessary linear force, stroke length and a compact design for flap deployment, and vehicle integration. Considerations for actuator placement within the forward shell included overall actuator stroke length, clearance with the cryogenic full tank and to provide mass as far forward in the forebody as possible. Actuator mounts and restraining elements were designed to nestle within the tight confines of the forebody, while taking assembly integration into consideration.

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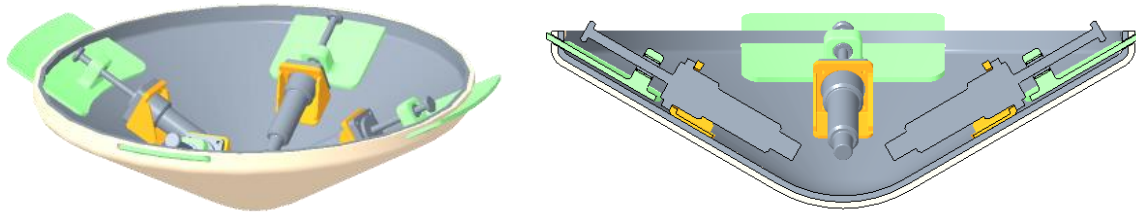


Figure 1. Preliminary Design using Flight-like Linear Actuators

With actuators selected, procurement of Engineering Development Units (EDUs) was solicited for this risk reduction effort. The solicitation requested new EDUs but allowed that existing or used actuators would be acceptable (if shown to be operable) due to the limited timeframe of this effort (about 11 months). Unfortunately, there were no responses from the responding vendor or any other due to the very short delivery period.

Mockup Final Design

To preserve schedule, a decision was made to substitute the flight-like actuators with commercial off-the-shelf (COTS) industrial linear actuators with the same mechanical characteristics. The mounting scheme for the actuators was modified to keep the actuators' lines of action in the same location. Batteries were nested in the forebody and play a dual role, primarily for flap actuators power and secondly, they provide additional mass in the forebody to assist in improving the vehicle's center of gravity.

COTS actuator characteristics included the following key parameters:

Actuator Physical Configuration:

Linear actuators are available in a wide variety of shapes due to the different methods of driving the threaded rod that provides the linear motion. Motors (or gearmotors) can be coaxial with the drive rod, as with the flight actuator originally selected, or parallel to the drive rod connected via spur gears, or at a right angle to the rod driving the rod via worm and worm gear. Market research failed to find a comparable coaxial actuator. Readily available right angle drive linear actuators were fitted to the CAD model successfully, but a source for one that met the speed requirement (discussed below) were not readily available. A parallel configuration actuator was located and successfully fitted to the CAD model, and it had the correct additional characteristics discussed in the following paragraphs.

Actuator Mass:

The COTS actuators selected weighed 3.60 lbm each, with a maximum force at 24 volts of 100 lbf. These are higher in mass than the flight units at 2.64 lbm but are well within the actuator mass allowable value for preliminary design of 4 lbm per actuator.

Actuator Force:

As the flaps move into the gas flowing over the forebody, the force on the flaps increases as the flaps proceed to their deployed limit, causing a rearward force on the rail system that guides the flaps. The force felt by an actuator is the force due to friction in the mechanism. For the flight design, we have identified the need for lubricated needle bearings to overcome the forces due to friction. Pressure differential is not considered as the rail system for flight would include an isolation

cavity for the flap assembly to keep exterior gasses from entering the forebody. The selected actuators are rated for 100 lbf at 24 VDC, well beyond the needs expected.

Actuator Speed:

With a no-load speed of 1.4 inches per second at 24 VDC, and a rate of 1.25 inches per second at full load of 100 lbf, the chosen actuators meet the deployment rate requirement of 1 inch per second for flight.

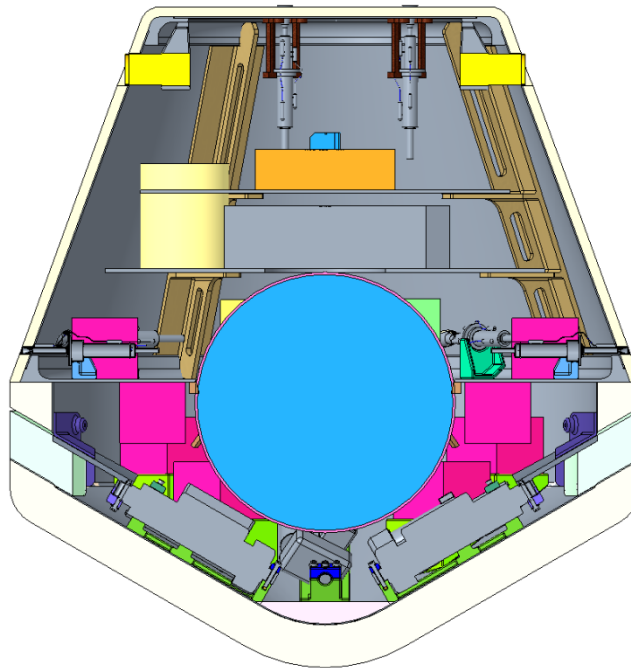


Figure 2. Actuators (gray) and Batteries (red) Clearance to Spherical Tank

Flight Flap Requirements and Preliminary Design

Flap sizing and locations were provided by the Principal Investigator and were used to generate the shape and locations of the flaps. Key characteristics for the preliminary design included:

- Dimensions are determined by aerodynamic considerations, and flight regime criteria, each radially offset 90° from each other with the flap sizes alternating.
 - Two measuring 20.32 cm (8.0 in) wide x 7.62 cm (3 in) long.
 - Two measuring 12.7 cm wide (5.0 in) and 7.62 cm (3 in) long, for a total of 4 flaps.
- Flap range of motion from flush with forebody to maximum deployment of 7.62 cm (3 in).
- Flaps are covered with TPS (Thermal Protection System) using the same thickness and grade as on the forebody.
- Flap deployment travel parallel with the cone angle of the vehicle's forebody.
- Flap movement guided internally by a rail system which keeps the flaps positioned properly during flap extension sequences.

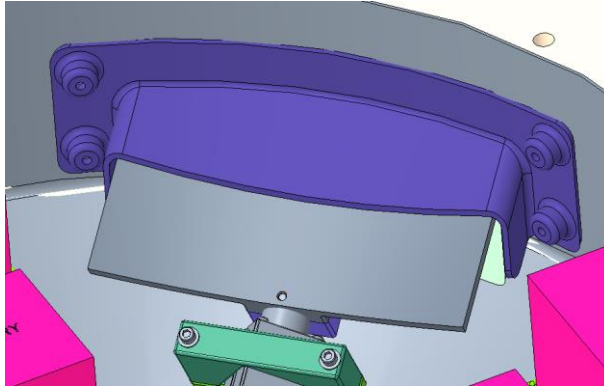


Figure 3. Flap Assembly and Guide Rail (Retracted)

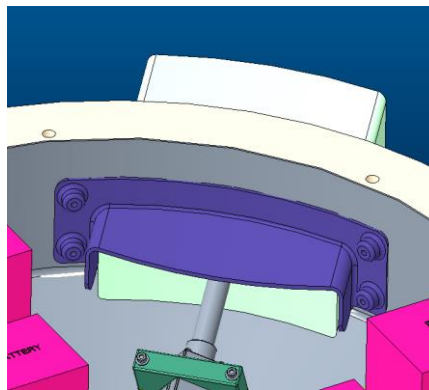


Figure 4. Flap Fully Extended

Preliminary design flap assemblies are comprised of a titanium carrier flap with flap-shaped TPS bonded to it. The carrier rides in a titanium rail system constraining the flap assembly during radial motion. The flap carrier also includes the actuator's flap connection, pinned to the end of the actuator's rod. The rail system is designed to be aligned axially with the actuator.

Actuator Mounting

Considerations for actuator placement within the forward shell included overall actuator stroke length, clearance with the cryogenic full tank and to provide mass as far forward in the forebody as possible. Actuator mounts and restraining elements were designed to nestle within the tight confines of the forebody, while taking assembly integration into consideration. The mounts are contoured to fit the interior mold line (IML) of the forebody's titanium aeroshell liner, to which TPS is bonded.

Battery Placement Selection

Battery sizing and selection was conducted by the Electronic Systems Branch at LaRC. They took into consideration actuator power requirements, battery power output, durability, and reliability. Battery placements were incorporated in both the fore and aft body of the vehicle and were arranged with the intention of powering the electronic devices within their respective quadrant of the vehicle. Batteries within the forebody of the vehicle will power the actuators during the re-entry phase. The forebody battery mounting bracket was not only provide a mounting platform for the batteries but as additional ballast mass in the forebody. A total of 8 batteries and 4 mounts are housed in the forebody.

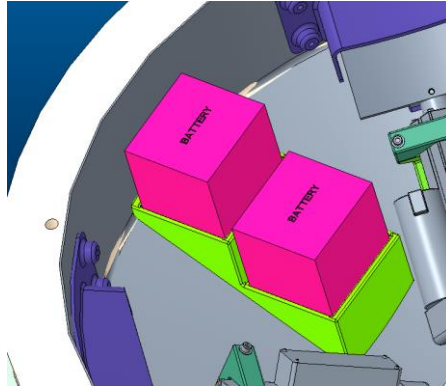


Figure 5. One of four battery installations

Mockup Fabrication and Assembly

With the preliminary design of the flaps and their actuators and batteries established, a mockup of the conceptual forebody with operational trim tabs was commissioned. The mockup was fabricated, assembled, and wired by LaRC technicians. Being a mockup, substitute materials were used including close-celled foam for the Thermal Protection System (TPS) on the forebody and trim tabs, fiberglass composite for the inner aeroshell liner, and printed polycarbonate for all other components. The industrial actuator mechanisms were mounted and test operated demonstrating extension and retraction.



Figure 6. Completed Mockup

Risk Reduction Results

This effort shows that the mass and volume of the flight-like actuator mechanisms and batteries meet the volumetric and mass constraints of the proposed TDM using COTS actuators with comparable physical and performance characteristics. Through this effort, a case can be made to proceed with the rest of the preliminary design for an Earth atmosphere flight demonstrator.

References

¹ Edquist, Karl, et al., “Concepts for a Deployable Trim Tab on a Rigid Mars Aeroshell”, NASA LARC Paper, December 2016

² Dutta, Soumyo, “Aerocapture Technology Demonstration Potential Risk Reduction Tasks”, presented January 2022