Marshall Problem/Project Statement - Senior Design Topic

Problem/Project Title: Innovative Reaction Control System for Small Spacecraft

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Indicate which discipline(s) is/are most appropriate to work on this problem (e.g., aerospace, mechanical, electrical, chemical, industrial, civil, computer, physics, materials, test, nuclear, earth science, other)

Aerospace, Mechanical, Materials, Additive Manufacturing, Propulsion, Compressible Gas Flow, Stress Analysis, Mechanism Design, Robotics

Marshall Problem Statement

Background: The big picture with references to previous work (Why would a senior design student be excited about this work?)

Help revolutionize reaction control systems for small spacecraft through hands-on design and testing of hardware!

In-space maneuvering of spacecraft is accomplished through the use of an array of body-mounted thrusters, collectively known as a Reaction Control System (RCS). In traditional RCS, each thruster in the system is actuated using a dedicated on/off valve. This project introduces an innovative RCS that reduces the total number of on/off valves in the system to a single valve. The reduction in valve count is made possible through the use of a rotary selector positioned after the on/off valve that routes the propellant to different set pairs of thrusters. This Rotary Selector Valve System (RSVS) can be used for diverse applications including small launch vehicle upper stages, cubesats, and other small spacecraft. The volume and mass of multiple valves and associated fittings are removed, allowing for additional payload and/or propellant. The resulting reduction in leak paths also reduces risk. The selector can be scaled for different quantities of thruster combinations, different sized spacecraft, different temperatures and pressures of propellants, and different materials.

Although the drum of the RSVS does not rotate during activation of the on/off valve, the aligned ports and drum need innovative seals to prevent gas from escaping to the other ports of the selector manifold due to the backpressure generated by the nozzles. The objective of this activity is to re-design the RSVS to eliminate leakage through hardware and software troubleshooting and active testing. Drum valves are notoriously difficult to seal and this area of research is highly beneficial to the aerospace industry. For this portion of the task, the team will receive some guidance from one of the world's top propulsion valve experts.

The rotary selector will be tested on the flat floor at Marshall Space Flight Center (MSFC) to demonstrate the technology in a simulated frictionless environment. Any additional innovations to the system are welcome.

Recent/on-going research on the problem (What resources, if any, are available to the senior design team, such as equipment, software, facility utilization)

A working prototype, 3D-printed with Formlab's Tough Resin, was designed and tested in summer 2019. It was tested on MSFC's flat floor, was fully controllable, and successfully demonstrated the theory of the rotary selector. However, further testing is on hold due to excess leakage to inactive ports. The leakage exhibited was exacerbated by improper alignment of the drum inside the manifold due to the drum being turned by a stepper motor with an incremental rather than absolute encoder. Proper alignment is vital. In addition to a redesigned drum seal, proper alignment methods need to be included in the next iteration. One possible alignment solution is the integration of a small hall effect sensor into the manifold with a small magnet in the drum.

Another issue is the minimum impulse bit, which is the fastest rate of activation of the RCS valves (and in this case, rotation of the stepper motor also). The seals should be designed to be low friction to allow rapid rotation with the smallest motor that can provide the appropriate torque and speed. Unfortunately, stepper motors have a torque curve that falls off rapidly with speed.

The team may use NASA databases for materials, ES21 (Spacecraft Design Branch) printers for prototyping (SLA and FDM available), and ES20 designers as resources to review and improve their models and optimize the design. Some funds are available for hardware purchases. Nozzle design is available for various system pressures. The current system prototype is designed for 300 psi at the on/off valve. The team may also have access to our Nvidia Jetson Nano and associated python code for control of the test platform if needed. This system also allows for wireless control of the test platform with a PS2 controller.

Details of the problem; design constraints, requirements (if any), outcome expected. One semester Senior Design course lasts 15 weeks; two-semester course lasts 30 weeks. (What do you expect the senior design team to accomplish?)

Design Constraints and Requirements:

1. Rotary selector shall be designed to provide independent roll, pitch, and yaw activations.
2. All tubing/piping from the selector to the nozzles shall be the same length.
3. Manifold/drum shall be designed to minimize leakage to inactive ports.
4. Selector shall have the capability to reference a home position after power cycles.
5. Motor shall not exceed NEMA17 dimensions.
6. Selector shall be attached directly, or as close as possible, to the on/off valve.
7. Test platform shall be designed to fit on top of an 8 inch diameter air bearing.

Expected Outcome:

1. Update seal design to prevent leaks to non-active ports while minimizing seal friction to allow rapid rotation of drum.
2. Integrate home position capability.
3. Demonstrate proper control and firing of the RSVS.
4. If time allows, design a fully 3D printed enclosure with an integrated rotary selector that matches the volume of VACCO's NEAScout RCS system: https://www.cubesat-propulsion.com/nea-scout-propulsion-system/ This enclosure should have an interface for the stepper and on/off valves (one valve for translation only).

Senior Design Project Rules:

1. Weekly telecons will be scheduled to maintain proper progress and prevent dead-end ventures.

2. Deliverable(s) required (e.g., one semester course – a written final report; two semester course – written final report and a prototype/model (if practical))