From: David Tovani davidt@accion-systems.com
Subject: RE: IRVINE02 FCC - Responses
Date: August 21, 2018 at 4:31 PM
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Alicia and team,

Here are Accion's responses:

- describe the issue, and what Irvine's done to address it

  - Accion Systems Inc. acknowledges that its ionic liquid propellant will not evaporate in vacuum and therefore could be considered "debris" if it leaked from the spacecraft. Accion establishes that the risk of its propellant leaking from the spacecraft is very low, and we thoroughly test this condition under representative mission environmental conditions. Testing is described below.

- how Irvine came up with this "coating" that they're proposing to use

  - Accion applies a barrier (coating) to our thrusters to contain liquid during exposure to humid environments such as during storage and time on the launch pad. This barrier material is designed to sublimate away from the thruster at a predetermined rate when exposed to vacuum – this means that the barrier will fully sublimate once the spacecraft reaches orbit and not prior. Once the barrier has sublimated, the thruster is ready to operate. This barrier was developed by MIT and by Accion in the time since MIT's previous launch. Accion has tested several barrier material options and has run long-duration tests of shelf life in storage, extreme thermal cycling, expected thermal cycling with margin in vacuum, vibration, depressurization, vibration with depressurization, and chemical compatibility testing on this material in flight-like configurations (most of these tests are presented in the attached summary).

- why Irvine thinks the coating is a solution to the problem

  - Our sublimation barrier has been thoroughly tested. We have tested numerous thrusters under 99% humidity for long periods of time, conditions which are more severe than expected prior to launch, and have observed complete containment.

- test results are useful but maybe some additional analysis would be helpful as well

  - Additional humidity tests were added to the test summary previously sent (attached, bottom row). To date, on over 50 test articles that match the IRVINE02 design, we have not identified a leak through this barrier. Sublimation of the barrier material show predictable rates during vacuum tests using the same material used on IRVINE02. The graph below illustrates the predictable nature of two sublimation materials on 4 thruster samples.

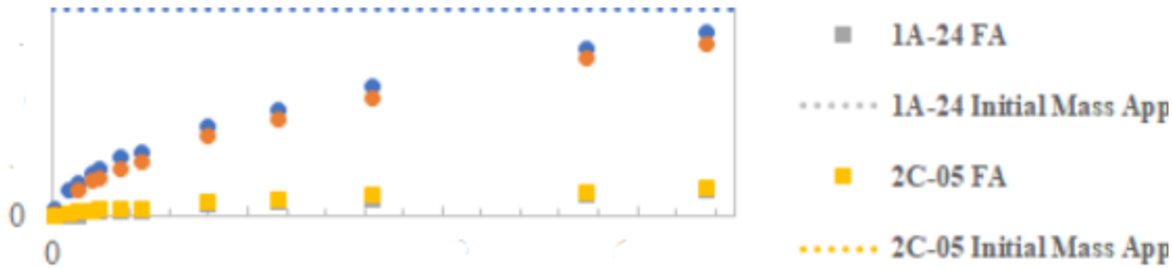

Figure shows sublimation mass over time - X axis is time and Y axis is sublimated mass. Due to sensitive information, units have been removed.

- is Irvine confident it will be durable, not just in the test facility but in real operational conditions

  - Accion Systems is confident that our system is durable during actual flight conditions and it is tested to worst case conditions.

- how is the testing protocol representative of what they'll experience on orbit

  - Accion Systems tests its products under NASA standard GSFC-STD-7000A, GENERAL ENVIRONMENTAL VERIFICATION STANDARD (GEVS) which provides accurate, industry standard environmental testing guidelines with appropriate margins for specific spacecraft configurations and missions.

- what are the consequences if it fails on orbit, partially or completely

  - Accion can envision two main failure modes of low likelihood at the high level: (1) liquid leaks and remains in the confines of the spacecraft and its components and (2) liquid leaks and exits the vehicle. These will be discussed in order of Accion's estimation of likelihood, (1) more likely than (2).

    (1) In the case where liquid leaks and remains in the spacecraft and components, the liquid will most immediately present a risk of malfunction to the propulsion system itself. Either the liquid will bridge a high-voltage electrode and a ground electrode or it will bridge opposite polarity high-voltage electrodes, and this would occur either in the thruster head or on the electronics board. This scenario means that the power processing unit (PPU) would see a reduced load, and would be unable to achieve high voltage or drive thrust. This failure is of the same basic severity regardless of partial or full leakage. The spacecraft operator will then simply need to deny power and/or control input signal to the power processing unit to prevent further operation.

    (2) Should the ionic liquid propellant become a free-orbiting mass in space in the form of droplets or mist, it is not expected to last a significant amount of time in low Earth orbit. Both UV and atomic oxygen degradation of the organic and inorganic chemical components is expected to gasify the material. While a small leak would be of lower consequence than a full leak in this scenario, the low total propellant mass means that the consequence overall is expected to be low.

    Since capillary forces dominate by orders of magnitude in a microgravity environment, and this system is not pressurized, the chance is low that liquid clinging to propulsion system hardware inside the spacecraft will ever detach and float out.

- is this the MIT module with the addition of that model?

  - No, this is a different module, designed and built by Accion Systems.

- how is this different/similar from the MIT module?

  - Because Accion's products are developed for high reliability, long duration missions, we differ greatly from MIT's technology. The two systems are similar in that they both provide thrust from ion electrospray, however the reliability, survivability, performance, test requirements and mission assurance all greatly exceed those of the MIT system.

Regarding design for propellant containment, several differences exist between the design flown on MIT SPL's last launch and what Accion delivered to Irvine. First, Accion has chosen to use a circular, annular seal rather than square for a major sealing interface, removing variations at corners and improving reliability to the point of failure eradication at that seal. Also, liquid and electrical feedthroughs in Accion's tank, as well as their associated assembly procedures, have been updated to improve inherent sealing of mechanical interfaces which are then additionally sealed with a low-outgassing, thermally-stable epoxy. Accion has implemented larger fasteners and a thicker flange to make the main sealing structure more rigid and able to both have and meet industry-standard torque specifications. At the interface between the Propellant Supply System and the Thruster Chip, Accion has again improved on the choice of sealants, the assembly method, and the quality control of the build—quality assurance testing has shown that this interface is no longer of any concern hermetically or structurally. As mentioned previously, both MIT and Accion have developed and implemented the sublimating barrier seal—the seal prevents flow of liquid from the thruster chip prior to extended-duration vacuum exposure.

Regarding other aspects of the product, Accion has developed its electronics fully independently and has made performance improvement changes to the Thruster Chip. A major differentiator in the Thruster Chip is that MIT SPL delivers and flies much more experimental, low-test-heritage designs as part of the several thrusters in their assembly and Accion has only delivered standard, highly-tested designs on the TILE 50 for Irvine.

- was it developed totally separate from the MIT version?

- Accion designs its own hardware, however it is not without heritage from MIT SPL's previous and current hardware - MIT shares best practices based on lessons learned with Accion. Accion operates with much more focus on deliberate and recorded process control, industry standard testing, and inspection during design, build, and test.

Happy to answer anything further.
-David

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