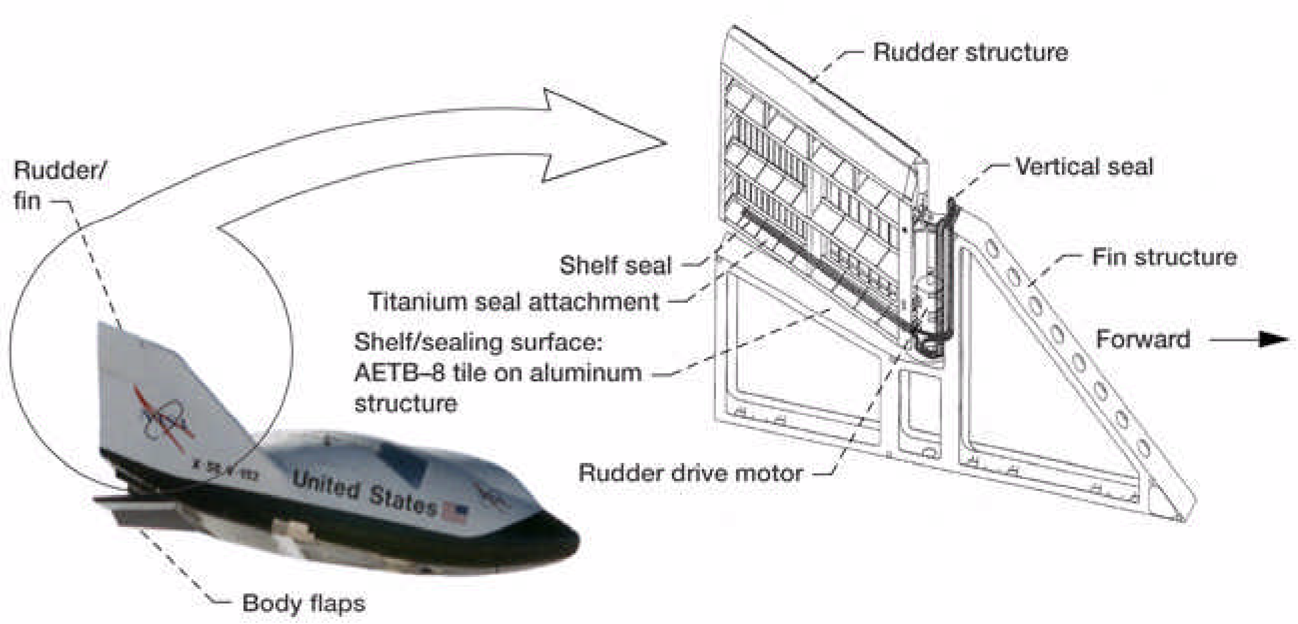
Control Surface Seals Investigated for Re-Entry Vehicles

Re-entry vehicles generally use control surfaces (e.g., rudders, body flaps, and elevons) to steer or guide them as they pass into and through the Earth's atmosphere. High-temperature seals are required around control surfaces both along hinge lines and in areas where control surface edges seal against the vehicle body to limit hot gas ingestion and the transfer of heat to underlying low-temperature structures. Working with the NASA Johnson Space Center, the Seals Team at the NASA Glenn Research Center completed a series of tests on the baseline seal design for the rudder/fin control surface interfaces of the X-38 vehicle. This seal application was chosen as a case study to evaluate a currently available control surface seal design for applications in future re-entry vehicles. The structures of the rudder/fin assembly and its associated seals are shown in the following illustration.



X-38 rudder/fin seal assembly with rudder/fin structure and seal locations. (AETB-8 is the shuttle tile material.)

Long description of figure 1 Illustration of re-entry vehicle and enlarged rudder/fin assembly showing rudder structure, shelf seal, titanium seal attachment, shelf/sealing surface (AETB-8 tile on aluminum structure), vertical seal, rudder drive motor, fin structure, and forward direction

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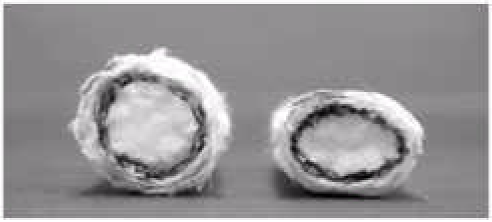
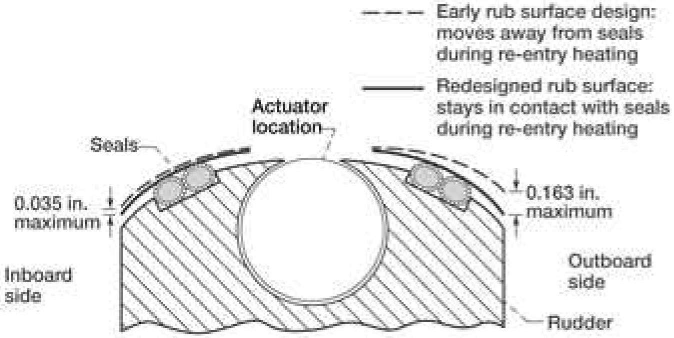
Tests performed at Glenn indicated that exposure of the seals in a compressed state at simulated seal re-entry temperatures (1900 °F) resulted in a large permanent set and loss of seal resiliency (see the photograph). This could be of concern because the seals are required to maintain contact with the sealing surfaces while the vehicle goes through the maximum re-entry heating cycle to prevent hot gases from leaking past the seals and damaging interior low-temperature structures. Because these seals experienced a large permanent set and lost resiliency upon temperature exposure, designers were forced to redesign the X-38 rudder/fin vertical rub surface to ensure that the seals remain in contact with the sealing surface during re-entry (as shown in the schematic).



Seals before (left) and after (right) 1900 °F temperature exposure.



X-38 rudder/fin cross section showing vertical Inconel rub surface redesigned to accommodate lack of seal resiliency. (Note: not drawn to scale.)

Long description of figure 3 Illustration showing actuator location, seals, rub surfaces, rudder, and inboard and outboard sides. Early rub surface design moves away from seals during re-entry heating, whereas redesigned rub surface stays in contact with seals during re-entry heating. Old design deflects up to 0.035-in. on the inboard side and up to 0.163-in. on the outboard side.

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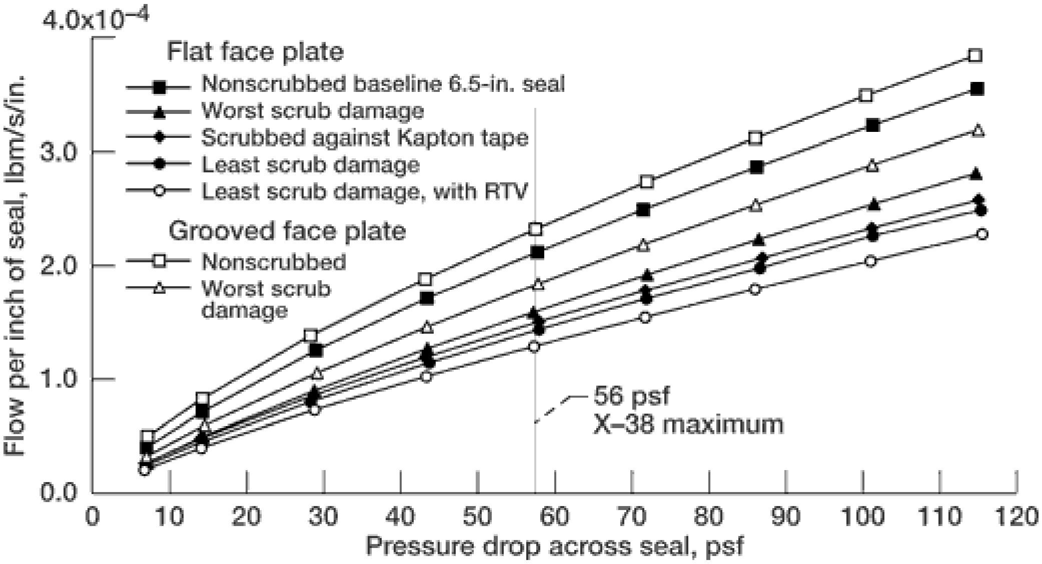
Glenn researchers performed room-temperature compression tests to determine seal loading characteristics. Compression test results showed that seal unit loads and contact pressures were below the limits that Johnson had set as goals for the seals. In the rudder/fin seal location on the vehicle, the seals are in contact with shuttle thermal tiles along the horizontal rub surface and are moved across the tiles as the rudder is rotated during re-entry. Low seal unit loads and contact pressures are required to limit the loads on these tiles and minimize any damage that the seals could cause.

In fiscal year 2002, Glenn researchers performed a series of room-temperature seal flow tests under a variety of test conditions. Seals were tested in an as-received condition and after being scrubbed over shuttle thermal tiles for 1000 cycles. Flow tests were performed on two segments of the scrub-tested seal, the section with the most damage and the section with the least damage. Tests were also performed using either a flat plate in contact with the seals or a plate with a groove in it to simulate a gap between two thermal tiles that the seals might be in contact with. The results of these flow tests are presented in the following graph.



Flow versus pressure data for 6.5-in. double seals at 20-percent compression under different test conditions with a gap of 0.25 in. RTV, room-temperature, vulcanized rubber material.

Long description of figure 4 Graph of flow per inch of seal versus pressure drop across seal from 0 to 120 psf, where 56 psf is the X-38 maximum. Results are shown for the flat face plate in the following conditions: nonscrubbed baseline 6.5-in. seal, worst scrub damage, scrubbed against Kapton tape, least scrub damage, and least scrub damage with RTV. Results are also shown for the grooved face plate in the nonscrubbed and worst scrub damage conditions.

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The tests performed at Glenn verified that the baseline seal design is satisfactory for the X-38 application. However, requirements for higher temperature limits and 100- to 1000-cycle reusability in future reusable launch vehicles necessitate the development of high-temperature seal designs that remain resilient for multiple missions while still exhibiting low flow rates and good wear resistance.

Find out more about this research:
Structural seals and thermal barriers
http://www.grc.nasa.gov/WWW/structuralseal/
High-temperature, flexible, fiber preform seal
http://www.grc.nasa.gov/WWW/structuralseal/InventYr/1996Inv_Yr.htm
Glenn’s Mechanical Components Branch
http://www.grc.nasa.gov/WWW/5900/5950/

Bibliography

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Headquarters program office: OAT
Programs/Projects: X-38, ASTP, 3rd Generation RLV, Advanced Control Surface Seals, Advanced Propulsion System Seals