WHY TEST AT SIMULATED ALTITUDE CONDITIONS?

SUMMARY

Rocket engines and propulsion systems that are designed to operate in space often require testing under simulated altitude (low ambient pressure) conditions for a variety of reasons. White Sands Test Facility (WSTF) maintains five large altitude simulation test cells designed to test typical spacecraft engines and systems.

DISCUSSION

Rocket engines often incorporate high expansion ratio nozzles for increased performance. When these nozzles are operated in an ambient pressure significantly higher than what they were designed for, the flow in the nozzle will separate from the nozzle wall, with a resultant reduction in thrust. Separated flow can also cause nozzle burning due to the shock wave that exists at the separation point, nozzle damage due to unsymmetrical pressure distribution, and excessive vibration as the separation point moves erratically around the nozzle.

Ignition characteristics of both solid and liquid propellants are significantly altered. Solid rocket motors that ignite reliably in a sea level ambient pressure may not obtain sufficient pressure for propellant ignition in a vacuum environment. Liquid engine ignition delay caused by vaporization and cooling of the propellants in a space environment could be masked by testing in an ambient atmosphere. The lack of propellant vaporization in an ambient environment may lead to “zots” as a result of an accumulation of incompatible propellants in the injector cavity. Both zots and ignition delays can cause significant hardware damage.

Combustion instability triggering at engine start may also be masked by ambient pressure ignitions. One engine tested at WSTF indicated combustion instability during 10 percent of the pulses with ambient pressure ignitions and 80 percent of the pulses with vacuum ignitions. Combustion instability can also cause significant hardware damage.

Convective heat transfer that readily exists at ambient pressure is nearly nonexistent in the space environment. Engines and surrounding equipment that have successfully passed ambient ground testing may overheat during operation in a space environment due to the lack of convective cooling.

Thrust vector control by fluid injection into the nozzle flow path causes a controlled separation at the point in injection, resulting in an asymmetric thrust vector. This testing cannot be performed if the nozzle flow field has been altered by an ambient pressure environment. Thrust vector control by gimballing is also affected by the test altitude. Nozzles that have been shortened to allow engine firings at ambient pressure will not load the actuators and bearings to the same level as a full-size nozzle. Conversely, a full nozzle that suffers internal flow separation due to ambient pressure can impart significant, sometimes damaging, loads to the gimbal actuators and bearings.

WSTF EXPERIENCE

WSTF has been testing propulsion engines and systems at simulated altitude conditions since 1965. Test facilities include five altitude simulation test cells supported by one of three altitude simulation systems. Engines from 1 to 25,000 lb thrust can be tested in the WSTF altitude cells.

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