AN IN-SITU MEASUREMENT OF PARTICULATES FROM SOLID ROCKET MOTORS FIRED IN SPACE

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ABSTRACT

INTRODUCTION

The ability of the Space Transportation System to routinely deploy orbital payloads has been remarkably and repeatably demonstrated since the fifth Shuttle mission. Among these deployed payloads have been communications satellites designed to operate in geosynchronous orbit (GEO). The Space Transportation System currently uses solid rocket motors (SRM's) to boost these satellites from the Shuttle's orbit to GEO. However, powdered metals or metallic compounds are added to the fuel of the SRM in order to dampen the motor's burn rate instabilities. These metals, or metallic compounds, are ejected from the SRM in the form of aluminum oxide particles that range in size from 0.1 to 20 microns in diameter. The particles are ejected from the SRM nozzle at speeds from 1.0 to 4.0 km/s and account for approximately 35% of the mass of the SRM plume. Since the second stage burn of a GEO transfer has an out-of-plane component and since some particles leave the SRM at angles as large as 40 degrees from the center line of the nozzle, the majority of the particles are inserted in orbits that do not immediately decay into the Earth's atmosphere. Recent studies have shown that as high as 5% of the particles remain in orbit for over one year. Furthermore, this man-made particulate flux is distributed evenly from low Earth to geosynchronous altitudes. Also, the flux from a single SRM burn can exceed the natural meteroid flux for similar diameter particles. Hence, a permanent manned presence in space will not only have to protect cosmic dust and micrometeroids but also from the aluminum oxide flux from SRM's.

Current models exist that predict the damage caused by the impact of these particles as well as their lifetime in useable space. In both models, two necessary inputs are the size of the aluminum oxide particles and the flux of these particles. An experiment was designed for the Remote Manipulator System of the Space Shuttle Orbiter that could be used to measure in-situ the flux and material effects of a SRM firing in space. The objectives of this paper are to present the results of this experiment, compare these results with ground-based SRM firings, estimate the lifetime and locations of the ejecta, and, finally, compare the experimental results with the predictions of the current plume trajectory/plume damage model.

UPPER STAGE PLUME MODEL, DAMAGE MODEL VERIFICATION EXPERIMENT

The aforementioned experiment was the Upper Stage Plume Model, Damage Model Verification, also called the Plume Witness Plate. The experiment was designed to update the safe separation distance required between an upper stage and the Space Shuttle Orbiter before the SRM ignition. The experiment has been flown on two Space Shuttle missions, STS-41B in February 1984 and STS-41D in August 1984. The experiment is also scheduled to fly on STS-61B in November 1985. The latter flight will expose the experiment to a different

SRM than the previous two. The technique used in the experiment was the exposure of materials representative of the Orbiter structure to the particulates in the SRM plume. To accomplish this goal, the experimental samples were chemically bonded to three sample trays mounted on the Remote Manipulator System (RMS) of the Orbiter. Five different types of samples were used to provide a broad range of substances :

1) Fused Quartz Glass (Representative of Orbiter Windows).
2) Germanium Micrometeroid Capture Cells.
3) Orbiter HRTS Tiles from the Thermal Protection System.
4) Kapton Foil.
5) Metallic Disks of Aluminum, Copper, Titanium, Graphite Epoxy, and Gold.

During the normal operations for deploying an upper stage, the Orbiter is oriented in a protect attitude that exposes the underside of the vehicle toward the SRM prior to its ignition. The RMS is positioned at that time so that the samples are perpendicular to the line-of-sight between the Orbiter and the SRM. The samples are exposed to the full duration of the SRM burn. After return, the samples are analyzed via optical and scanning electron microscopy to determine the flux of the particulates through the total number of impacts, the diameter of the particles from the size of the impact craters, the velocity of the particulates from the crater depths, and the chemical composition of the residue in the impact craters.

CONCLUSIONS

The analyses of the Plume Witness Plate data show excellent agreement with ground-based SRM firings in terms of particle size distribution and mass distribution. The Particle Impact Damage Integrator computer model used to calculate potential damage of Orbiter surfaces by SRM exhaust plumes agrees favorable with the results in terms of particle size and velocity distributions though it may be conservative by as much as 20%. The results of the Plume Witness Plate experiment provide a sound physical basis from which detailed studies of the particulate environment and lifetimes can be pursued for the benefit of future space activities.