Fundamental Understanding of Propellant/Nozzle Interaction for Rocket Nozzle Erosion Minimization Under Very High Pressure Conditions

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Abstract: To substantially increase the operating pressures of future missiles, this MURI project addresses scientific understanding and methods for mitigation of rocket nozzle erosion by solid-propellant combustion products. Several processes can affect the nozzle erosion rate at high pressure and temperature conditions. Three approaches have been used to reduce the thermochemical/mechanical erosion rates of nozzle materials, including improving the thermochemical resistance of the nozzle materials, modifying the solid propellant formulation, and/or introducing boundary-layer control methods. The experimental efforts of the program are guided by state-of-the-art theoretical calculations. During the past year, great progress has been made on the development of both numerical codes and new experimental test facilities. Test rigs have been designed for simulating ultra high-pressure rocket nozzle conditions; with X-ray radiography for erosion rate measurements. A vortex combustor was also designed to simulate propellant product species and to evaluate their effects on nozzle erosion process. A nozzle erosion code has been updated to include comprehensive heterogeneous surface reaction mechanism at high-pressure conditions. The reaction kinetics of nozzle materials has been studied and calculations have been performed using quantum-mechanical and molecular dynamics models. A micro-scale dynamics sub-grid model has been adopted in a parallel LES code to determine the effect of surface shear forces on physical erosion of nozzle throat. Phase diagrams of the W-O-C-H-Cl systems have been obtained to acquire insight into tungsten reaction mechanisms with gaseous mixtures at high-pressure conditions. From equilibrium calculations, tungsten-based nozzles are suitable for aluminized propellants since tungsten **oxide** and tungsten oxychloride formation are significantly reduced due to the strong affinity of oxygen for **aluminum**.

Limitations:	APPROVED FOR PUBLIC RELEASE
Pages:	108
Report Date:	31 AUG 2005
Contract Number:	N000140410683
Report Number:	A328934

Keywords relating to this report:
- GEOLOGY
- LOGISTICS
- MOROCCO
- PORTABLE EQUIPMENT
- SEISMIC ARRAYS
- SEISMIC WAVES
- SEISMOLOGICAL STATIONS
- SEISMOLOGY
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