1. Introduction and Summary

The Environmental Management of the Space & Missile Systems Center (SMC) has set out to evaluate the depletion of stratospheric ozone caused by Air Force space activities. Earlier work supported by SMC included an assessment of the impact of deorbiting debris on stratospheric ozone (Reference 1.1) and the potential for reduction of ozone destruction by use of alternate propellants for launch vehicle rocket engines (Reference 1.2). A more recent effort, supported by SMC, addressed the impact of rocket exhaust on stratospheric ozone (Ref. 1.3). This work was an extension of an earlier study reported in Reference 1.4. The methodology described in Ref. 1.3 and 1.4 allows a quantitative assessment of the destruction of stratospheric ozone by rocket exhaust. The present study describes development and application of upgrades to the methodology by including and multiple engine effects as well as the effects of stratospheric winds.

The primary results of the present study are summarized as follows:

1) Enhancement of HCl dissociation in the plume by Mach disc, barrel shock and multiple engine interaction effects is relatively small: about 10% more than by afterburning alone. The previous assessment of NO_x (used in reference 1.3 & 1.4) has implicitly included Mach disc effects. The present work shows an increase of less than 1% increase in NO_x levels caused by multiple engine interaction effects.

2) Multiple engine interaction effects on stratospheric ozone have been quantified by analysis. The results have been folded into an upgraded model. The effects are relatively small and account for less than a 10% increase in local ozone depletion. This result demonstrates by analysis that single plume assessment (the entire exhaust is considered to be a single plume from a thruster with the total launch thrust and total exhaust flow rate) of stratospheric ozone depletion by rocket exhaust impact is sufficiently accurate for a multiple engine launcher.

3) The effects of wind shear on the diffusion/mixing of the exhaust plume are addressed by analysis (full Navier-Stokes models). This effort leads to a modification of the cold wake diffusion model that is within the range of that suggested by the data and outlined in References 1.3 and 1.4.

4) Local ozone depletion caused by a solid rocket launch vehicle is calculated for several altitudes in the stratosphere. The calculations take into account afterburning, barrel shocks, Mach disks, impingement shock effects resulting from multiple engines and the effects of wind shear. The results compare well with recent fly-through measurements taken in the exhaust plume of a Titan IV launch.