Critical Initial Flaw Size (CIFS) Analyses of Welded Joints for the Upper Stage Simulator for the Ares I-X Flight Test Vehicle

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NASA is developing the Ares I two-stage launch vehicle to transport crew on the Orion spacecraft, in support the Constellation program goal of returning humans to the moon. The primary objectives of the launch vehicle's first test flight, Ares I-X in April of 2009, are to test first-stage flight dynamics, controllability, and separation of the first and upper stages. Mass simulators will be used for the upper stage, spacecraft adapter, service module, crew module, and launch-abort systems in order to replicate the vehicle mass and outer mold line. The Upper stage/Spacecraft adapter/Service module simulator (USS) is being designed and manufactured at Glenn Research Center (GRC). The USS is comprised of vehicle segments that will be joined and assembled at Kennedy Space Center (KSC) by means of bolted flanges. The welds connecting these flanges to the vehicle skin are part of the vehicle's primary load path. Since welding is known to introduce flaws, analyses are being performed to determine a critical initial flaw size (CIFS) that can be tolerated in the welds. Conservative assumptions are used for the analyses whenever possible. The results of the study are being used to determine if the flight hardware weld repair criteria will prevent fracture due to weld defects. It is believed that the CIFS can be detected by non-destructive inspection procedures, although results are still contingent on pending fracture toughness measurements, updated load calculations, and detailed stress analyses of the interstage segments.

NASGRO was used to perform fatigue crack growth calculations and determine final failure from linear elastic fracture mechanics stress intensity factors for the assumed weld defects. Fatigue crack growth was calculated based on estimated load spectra for the cyclic loading events of handling, transportation from GRC to KSC, vehicle assembly, vehicle rollout, winds at the launch pad, liftoff, and ascent. All cycle counts were multiplied by a life factor of 4, per standard NASA practice. The maximum principal applied stress for the bolted joint was determined by MSC/NASTRAN analysis. A separate NASTRAN analysis was performed to determine the stresses due to lifting single segments by flange lugs. In addition to the applied cyclic stress, the effect of a mean residual stress due to welding was incorporated into the NASGRO analyses. The residual stress due to welding was assumed to be at the measured yield stress of the parent material, ASTM A516-70 steel. Room temperature fatigue crack growth data was obtained from the literature and verified by the NASA Engineering and Safety Center (NESC). Results were calculated over a wide range of initial crack aspect ratios for both surface cracks and cracks embedded at varying depths within the skin thickness. It was found that vehicle rollout caused more subcritical crack growth than the other load spectra due to the greater number of cycles. However, the primary factors controlling the CIFS are the liftoff loads, fracture toughness, and residual stresses. This is due to the maximum tensile applied stress occurring at liftoff.