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Failure Analysis of International Low Impact Docking System Latch Hooks

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The international Low Impact Docking System (iLIDS) provides a structural arrangement that allows for visiting vehicles to dock with the International Space Station (ISS) (Fig 1). The iLIDS docking units are mechanically joined together by a series of active and passive latch hooks. In order to preserve docking capability at the existing Russian docking interfaces, the iLIDS latch hooks are required to conform to the existing Russian design. The latch hooks are classified as being fail-safe. Since the latch hooks are fail-safe, the hooks are not fracture critical and a fatigue based service life assessment will satisfy the structural integrity requirements.

Constant amplitude fatigue testing to failure on four sets of active/passive iLIDS latch hooks was performed at load magnitudes of 10, 11, and 12 kips. Failure analysis of the hook fatigue failures identified multi-site fatigue initiation that was effectively centered about the hook mid-plane (consistent with the 3D model results). The fatigue crack initiation distribution implies that the fatigue damage accumulation effectively results in a very low aspect ratio surface crack (which can be simulated as thru-thickness crack). Fatigue damage progression resulted in numerous close proximity fatigue crack initiation sites. It was not possible to determine if fatigue crack coalescence occurs during cyclic loading or as result of the fast fracture response. The presence of multiple fatigue crack initiation sites on different planes will result in the formation of ratchet marks as the cracks coalesce. Once the stable fatigue crack becomes unstable and the fast fracture advances across the remaining ligament and the plane stress condition at a free-surface will result in failure along a 45 deg. shear plane (slant fracture) and the resulting inclined edge is called a shear lip. The hook thickness on the plane of fatigue crack initiation is 0.787". The distance between the shear lips on this plane was on the order of 0.48" and it was effectively centered about the mid-plane of the section. The numerous ratchet marks between the shear lips on the fracture initiation plane are indicative of multiple fatigue initiation sites within this region. The distribution of the fatigue damage about the centerline of the hook is consistent with the analytical results that demonstrate peak stress/strain response at the mid-plane that decreases in the direction of the hook outer surfaces. Scanning electron microscope images of the failed sections detected fatigue crack striations in close proximity to the free surface of the hook radius. These findings were documented at three locations on the fracture surface : 1) adjacent to the left shear lip, 2) adjacent to the right shear lip, and 3) near the centerline of the section. The features of the titanium fracture surface did not allow for a determination of a critical crack size via identification of the region where the fatigue crack propagation became unstable.

The fracture based service life projections where benchmarked with strain-life analyses. The strain-range response in the hook radius was defined via the correlated finite element models and the modified method of universal slopes was incorporated to define the strain-life equation for the titanium alloy. The strain-life assessment confirmed that the fracture based projections were reasonable for the loading range of interest. Based upon the analysis and component level fatigue test data a preliminary service life capability for the iLIDS active and passive hooks of 2 lifetimes is projected (includes a scatter factor of 4).

References:
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[4] Gallagher, Giessler, and Berens, **USAF Damage Tolerant Design Handbook: Guidelines for the Analysis and Design of Damage Tolerant Aircraft Structures**, AFWAL-TR-82-3073, 1984, Section 3.4.

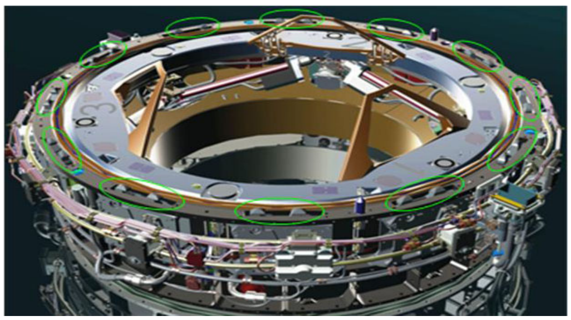

Fig 1. iLIDS solid model image that depicts the active and passive latch hook assemblies.

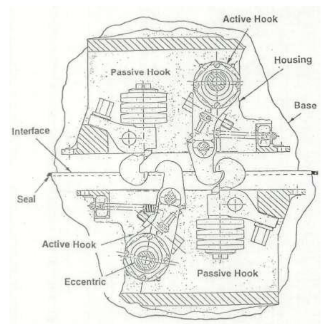

Fig 2. Russian drawings of a hook set with one pair of hooks latched and the other unlatched.

Fig 3. Post test photographs of the active hook test articles.

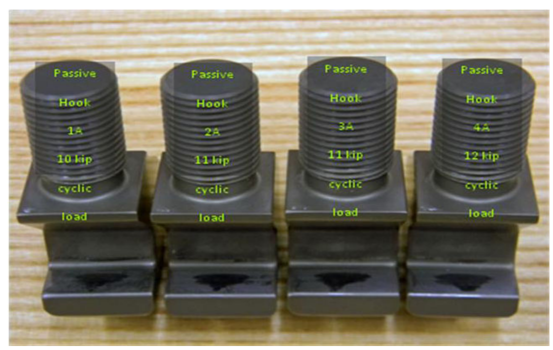

Fig 4. Post test photographs of the passive hook test articles.

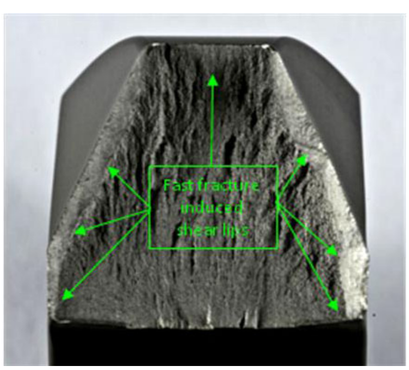

Fig 5. Active hook (10 kip fatigue loading) fracture photograph.

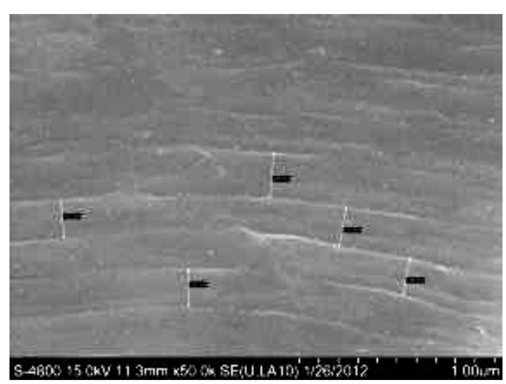

Fig 6. SEM image of fatigue striations adjacent to the shear lip-fatigue transition region.

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