EFFECTS OF LONG-TERM EXPOSURE ON LDEF FASTENER ASSEMBLIES

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Effects of Long Term Exposure on LDEF Fastener Assemblies

This presentation summarizes Systems SIG findings from testing and analysis of fastener assemblies used on the LDEF structure, the tray mounting clamps, and by the various experimenters.

PRIMARY STRUCTURE FASTENERS

- STAINLESS STEEL BOLTS
  - 1/4 to 7/8 inch diameters
  - Silver-plated nuts
- All primary structure fasteners were re-torqued to pre-flight values following experiment deintegration
  - Only 4% (119 of 2,928) assemblies had relaxed
  - Nut rotations required to re-establish pre-flight torque levels ranged from 5 to 20 degrees
  - Small number of relaxed assemblies indicates high reliability of bolted joints in space applications
- Intercostal fastener assembly cross-section

(Original figures unavailable)

Primary Structure Fasteners

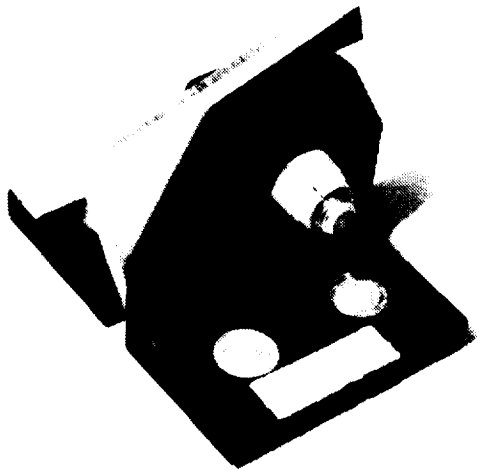
The LDEF structure consisted of a welded center ring and aluminum beams called longerons connecting the center ring frame to the two end frames. Aluminum intercostals were used to connect longeron to longeron. The longerons were bolted to the end frames and center ring. The intercostals were bolted to the longerons. This provided flexibility in adapting the LDEF structure to meet future Shuttle payload manifest requirements (LDEF was designed as a reusable structure). For overall stiffness, eight tubular structural members stretch diagonally through the interior of LDEF from the center ring to the end frames. These components of the LDEF structure were also bolted into place. Stainless steel bolts and silver plated nuts were used to bolt the structural components together.

As one of the last deintegration activities, all LDEF primary structure fastener assemblies were re-torqued to pre-flight values. Only approximately 4% of the 2928 fastener assemblies showed any sign of relaxation. Nut rotations required to re-establish the pre-flight torque values were closely monitored. These values ranged from 5 to 20 degrees.

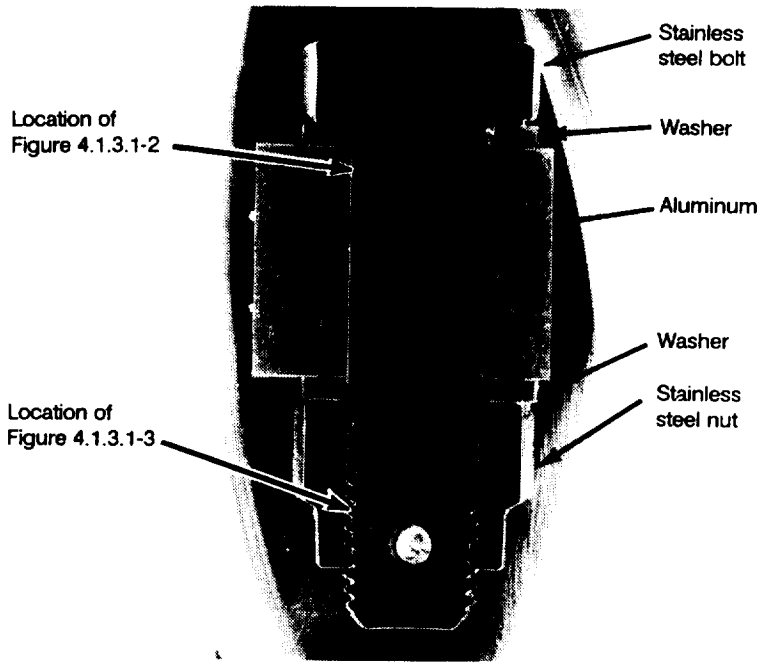
This small number of relaxed assemblies indicates the high reliability of bolted assemblies for spacecraft applications. See figure 1.

Intercostal Fastener Assembly

An undisturbed intercostal fastener assembly (shown in figure 2) was removed from the LDEF structure to investigate its post-flight condition. This fastener was selected because of its availability and not because of any evidence of coldwelding, galling or any other suspect condition.



Fastener Assembly



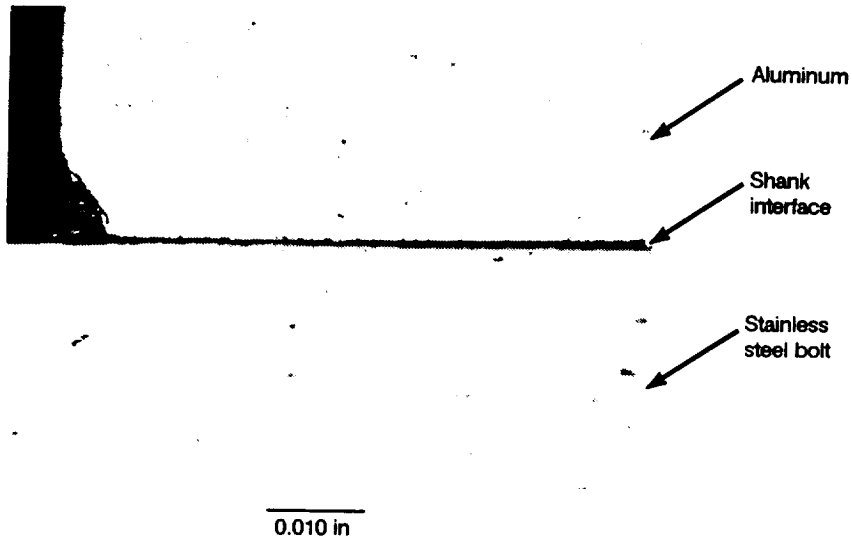
Metallographic Cross-Section

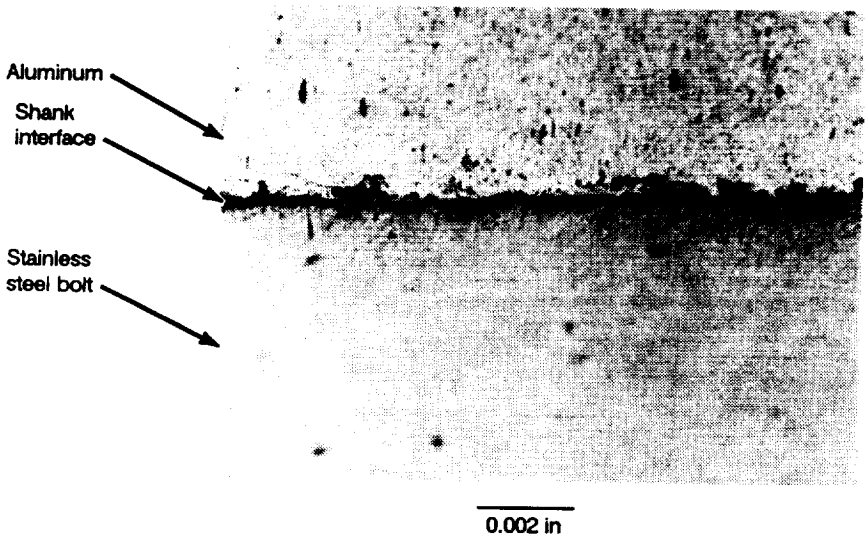
0.040 in

Figure 2 Unassembled Intercostal Fastener Assembly

Intercostal Fastener Assembly Cross-Section

The stainless steel/aluminum interfaces and bolt/nut interfaces were examined for indications of damage. Closeups of these areas are shown in figures 3 and 4. Metallographic examination of the bolt shank interface revealed no evidence of galling or coldwelding.



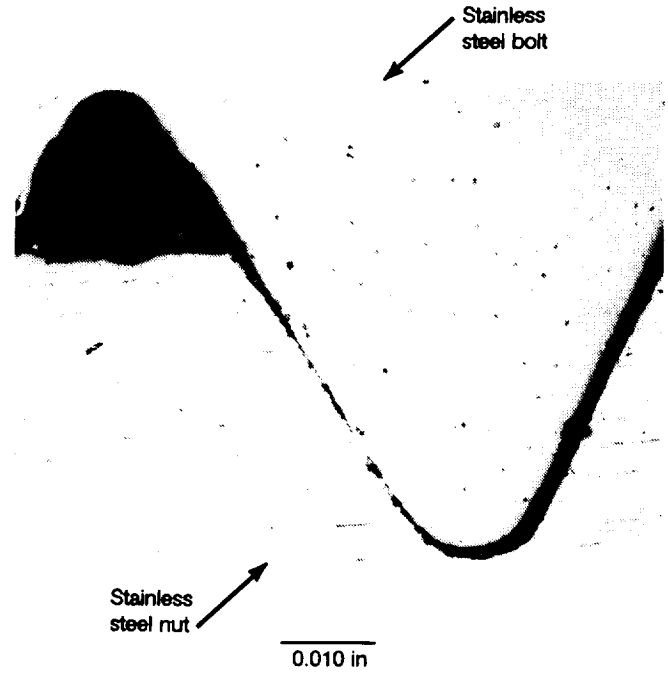


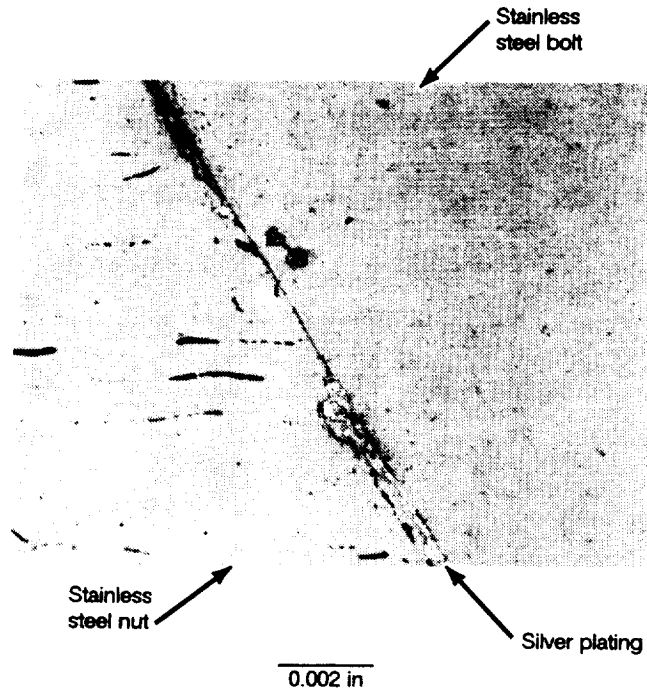
Intercostal Fastener Assembly Cross-Section

Figure 3 Closeup of Shank Interface Area Indicated in Figure 2

Intercostal Fastener Assembly Cross-Section

The thread mating surfaces also show no evidence of coldwelding; however, some minor galling and smearing of the silver plating is evident. The behavior of the plating is normal because it is specified to act as a lubricant during both installation and removal to prevent galling and seizure of the nut to the bolt (fig. 4).





Intercostal Fastener Assembly Cross-Section

Figure 4 Closeup of Nut/Bolt Thread Faying Surfaces as Indicated in Figure 2 (Note Smearing of Ag-Plating Which Acts as a Lubricant Between the Nut and Bolt.)

Experiment Tray Clamp Fasteners

The experiment trays were held to the longerons and intercostals by aluminum clamps. These clamps consisted of flat 0.25" thick rectangular or "L" shaped plates with three mounting holes in them. They were attached to the structure with NAS1004-4 hexagon head 0.25-28 bolts. The bolts, with alodined aluminum washers under the head, were installed into self-locking threaded inserts mounted in the primary structure. Installation torque was 75 in-lb, plus or minus 5 in-lb. See figure 5.

INSTALLATION DETAILS

- Trays held in structure by 1/4" aluminum clamps
- Clamps mounted to structure with three A286 heat-resistant steel bolts
  - 0.25-28 UNF-3A
  - Heat-treated to 140 KSI and passivated
  - Alodined aluminum washers
  - Self-locking threaded inserts installed on structure
  - Bolts cleaned with alcohol prior to installation
  - Pre-flight installation torque 75$\pm$ 5 in-lb
  - Bolts installed into inserts 2 or 3 times

Experiment Tray Clamp Fasteners Cont.

During the experiment tray removal portion of deintegration, unseating (breakaway) torque values were recorded for 2,159 of the 2,232 tray clamp fasteners. Prevailing (running) torque values were obtained for every third bolt (the middle of the three bolts in each tray clamp). A database was created that contained all unseating and prevailing torques as a function of the bolt and its location on LDEF.

The results in figure 6 show that the unseating torques averaged 72 in-lbs and ranged between 10 and 205 in-lbs. The averages of the 20 lowest and 20 highest values were 31 and 175 in-lbs. The average unseating torques were similar throughout LDEF, indicating no pronounced effect of the different LEO exposures on bolt behavior. The prevailing torques averaged 17 in-lbs and ranged between 2 and 132 in-lbs. The average of the 20 highest prevailing torques was 58 in-lbs. There was little correlation between high unseating torques and high prevailing torques. Only one bolt possessed both one of the 20 highest prevailing torques and one of the 20 highest unseating torques.

The threaded insert vendor stated that they were not surprised by the wide variation and range of unseating torques. These values are very unpredictable due to fatigue, bolt stretching, corrosion, particle contamination, etc. The prevailing torque specification for these self locking inserts is a maximum of 30 in-lbs. Approximately 10% of the prevailing torques exceeded this maximum value. Further testing and analysis was performed in an attempt to understand why.

LDEF DEINTEGRATION BOLT TORQUE DATA BASE

- Data base contains all 2,232 tray clamp bolts
- Unseating (breakaway) torques measured for all fasteners
  - Average 72 in-lb
  - Range 10 to 205 in-lb
  - No location effects
- Prevailing (running) torques measured for one third of the fasteners
  - Average 17 in-lb
  - Range 2 to 132 in-lb
  - No correlation between high running and high breakaway torques

Tray Clamp Fastener Rating System

A tray clamp bolt and washer rating system was developed to further characterize the tray clamp fasteners. The various codes used for this rating system are shown in figure 7. Eighty-nine fasteners were examined using 8x magnification and then coded. These codes, along with the associated bolt torque data and associated parameters were entered into another database.

Bolts B1 = No galling, very little scoring on threads.
B2 = Light galling or thread wear, no metal deposits, threads crests may be sharpened or rounded.
B3 = Medium galling, threads may be sharpened or rounded, a few deposits and smears, a few areas of metal removal.
B4 = Heavy galling, threads sharpened or rounded, several metal deposits, smears of areas of metal removal, slivers.
B5 = Threads mostly removed, much smearing, deposits, metal removal.

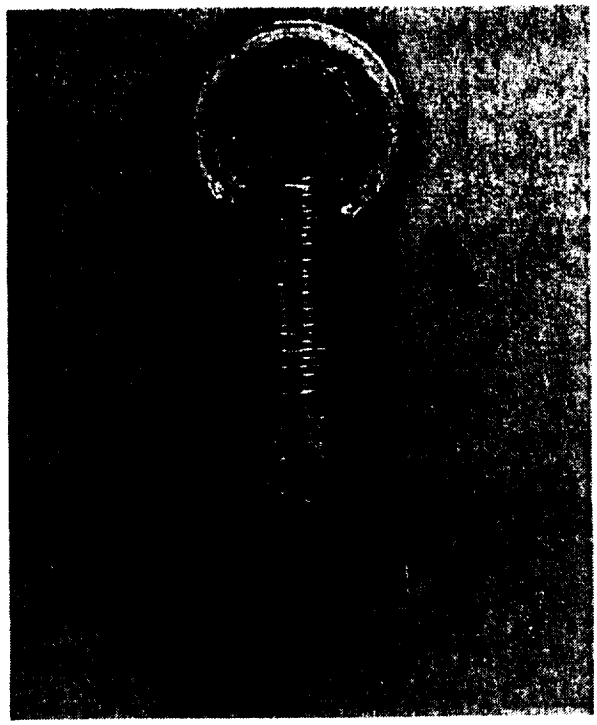
Note: Some bolts were given mixed codes i.e. B2/B3, to better describe them.

Washers W1 = Very little smearing or scoring.
W2 = Moderate smearing or scoring.
W3 = Heavy smearing or scoring.

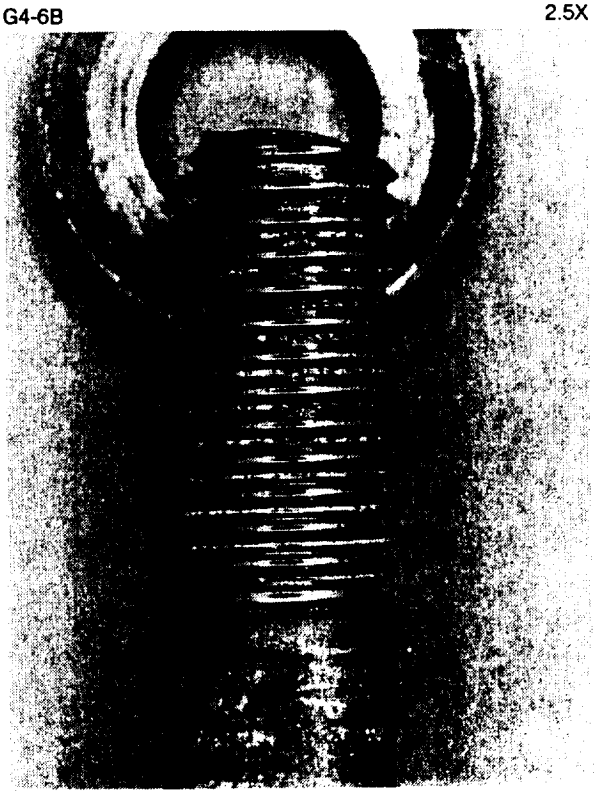
C-3

Tray Clamp Fastener with a "B1" Rating

These two photos (fig. 8) show a typical "B1" tray clamp bolt. Both the unseating and prevailing torques were close to the average values. The condition of the bolt threads is nominal.



G4-6B 2.5X



G4-6B 4.5X

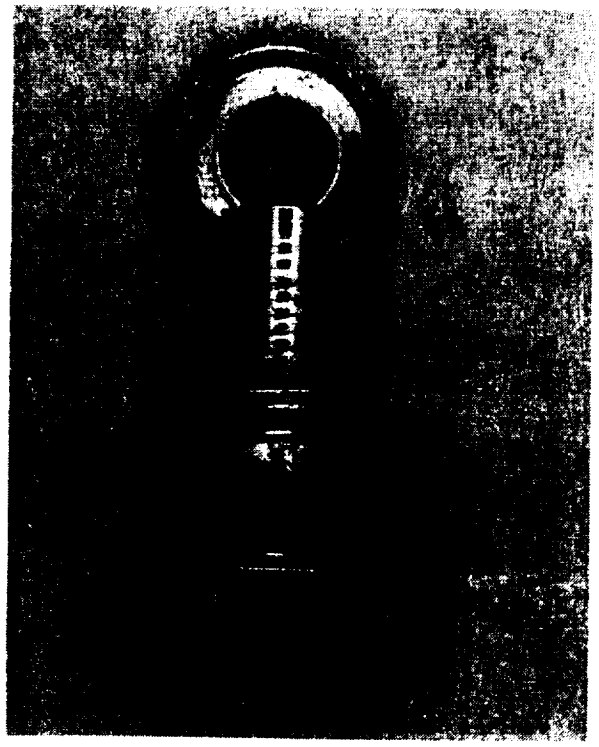
Unseating torque = 70 in-lb

Prevailing torque = 15 in-lb

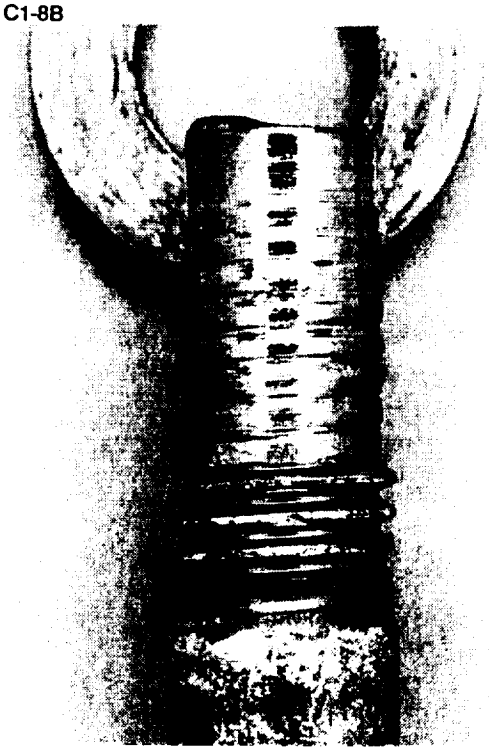
Tray Clamp Fastener With a "B1" Rating

Tray Clamp Fastener with a "B5" Rating

These two photos (fig. 9) show a typical "B5" tray clamp bolt. While the unseating torque was actually below average, the prevailing torque was almost twice the maximum specification value. Note the severely damaged (stripped) threads.



C1-8B 2.5X



C1-8B 4.5X

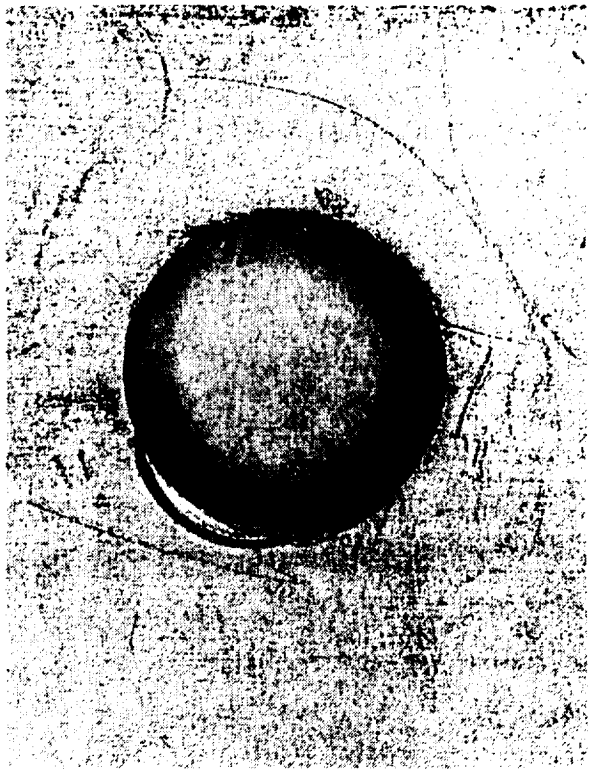
Unseating torque = 190 in-lb

Prevailing torque = 35 in-lb

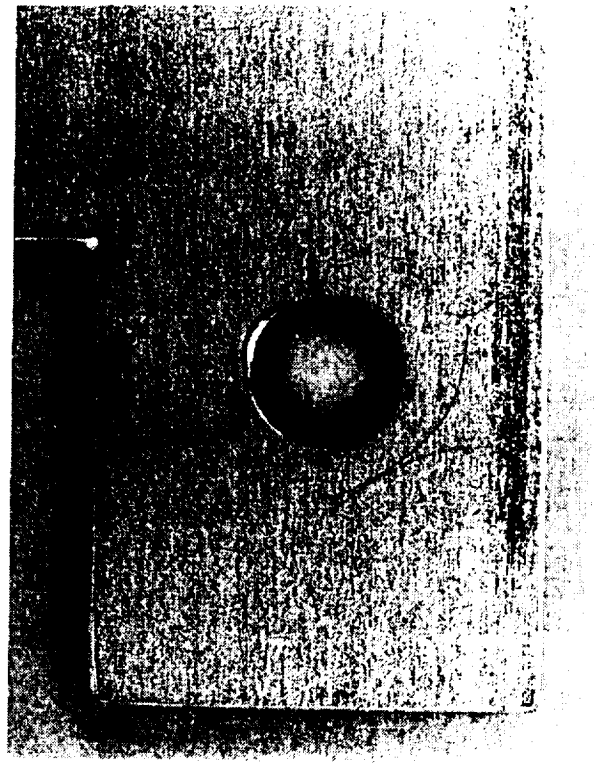
Tray Clamp Fastener With a "B5" Rating

Tray Clamp Shim

As would be expected, the threads of the bolts with the higher prevailing torques generally exhibited greater thread damage. Most of the bolts examined have varying amounts of smears or deposits of aluminum on the grip (unthreaded) portion of the bolt shank, suggesting that there was a hole misalignment between the clamp and structure. Visual examination of a few clamps revealed varying amounts of burnishing in most of the holes. A visual examination of 21 shims (used between the tray clamp and structure) revealed varying degrees of bolt thread contact in the holes. It is thought that this apparent misalignment may have contributed to the high prevailing torques noted for some of the bolts. See figure 10.



E1-3 2.5X



E1-3 5.5X

Unseating torque of bolt = 62 in-lb
Prevailing torque = Unknown

Tray Clamp Shim

Tray Clamp Fastener Conclusions

It is believed that an unusually high percentage of bolts exhibited prevailing torques above the 30 in-lb maximum required for the self-locking inserts, especially for only two or possibly three installation/removal cycles. It is unknown how much bolt contact with the clamp and shim holes and the relative softness of these bolts (140,000 psi versus the more commonly used 160,000 psi ultimate tensile strength) may have contributed to this result.

No clear correlation has been made between thread condition, washer damage, and unseating torques. No evidence of coldwelding was observed. All thread damage was consistent with galling damage generated during installation and removal. See figure 11.

- **Threads of high prevailing torque bolts generally exhibited greater galling damage**
- **Most bolts examined have varying amounts of smears or deposits of aluminum on shanks**
  - **Suggests hole misalignment between clamp holes and structure inserts**
  - **Apparent clamp misalignment may have contributed to high unseating and high prevailing torques upon removal of some bolts**
- **Unusually high percentage of bolts exhibited prevailing torques greater than 30-in lb max permitted for self-locking inserts**
- **No clear correlation thus far between thread condition, washer condition and unseating torques**
- **No evidence of cold-welding. All damage consistent with galling damage**

Experimenter Fasteners

The LDEF Project Office suggested that experimenters use type 303 stainless steel bolts combined with self-locking fasteners. In fact, a wide variety of fastener assemblies and lubrication schemes were used. (fig. 12).

Dr. Richard Vyhnal (Experiment A0175) reported severe difficulties with seizure and thread stripping during fastener removal. Typical fastener damage is shown in figure 13.

Further investigation determined that the nut plates had the original MoS_2 dry-film lubricant removed by acid stripping prior to installation. This was done because of possible concerns about volatilization and contamination while on-orbit. The MoS_2 was replaced with cetyl alcohol. Initial speculation was that the fasteners may have coldwelded on-orbit because of insufficient lubrication provided by the cetyl alcohol.

Unseating and prevailing torques were obtained for the majority of the fasteners by Dr. Vyhnal. Several fasteners were left undisturbed for analysis by the System SIG. Examination of one of the two trays at Boeing revealed that some of the nutplates had not been stripped of their dry-film lubricant. Correlation of the torque data with the nutplate lubrication conditions (with or without MoS_2) showed that the average prevailing torques associated with the MoS_2 nut plates was15 in-lbs as opposed to 64 in-lbs for the bare nutplates. The specification for these types of nut plates (with MoS_2) requires a prevailing torque range of 2 to 18 in-lbs. The average unseating torques were the same for both the MoS_2 and cetyl alcohol nutplates at 31 in-lbs. If coldwelding had occurred in the cetyl alcohol lubricated nutplates (as was initially speculated), the unseating torques would have been substantially higher and there would have been a difference in unseating torque values between the MoS_2 and cetyl alcohol nutplates. The excessively high cetyl alcohol nutplate prevailing torques were a result of severe galling. The removal difficulties were a direct result of lack of adequate lubrication during removal that caused additional galling. This resulted in seizure, thread stripping, and sheared bolts.

Fasteners and clamps located graphite-reinforced composite panels

- A286 bolts, no finish
- A286 self-locking nut plates
  - Majority had $MoSo_2$ dri-lube removed by acid-stripping
  - Cetyl alcohol used as lubricant during installation

Experienced severe seizure/thread stripping during post flight removal

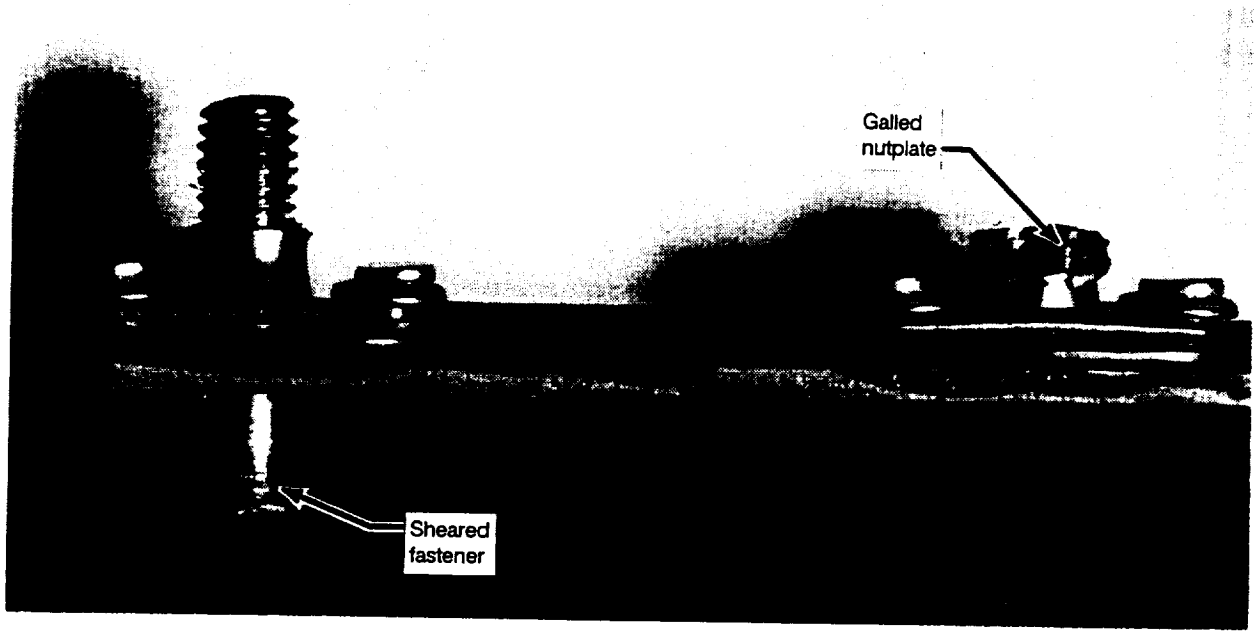
- Average breaking torques:
  w/MoS_2: 31 in-lb, w/o MoS_2 : 31 in-lb.
- Average running torques:
  w/MoS_2: 15 in-lb, w/o MoS_2: 65 in-lb.

Post flight examination

- Correlated seizure with galling during installation caused by lack of MoS_2
- No evidence of coldwelding

Severely Damaged Experimenter Fastener Assemblies

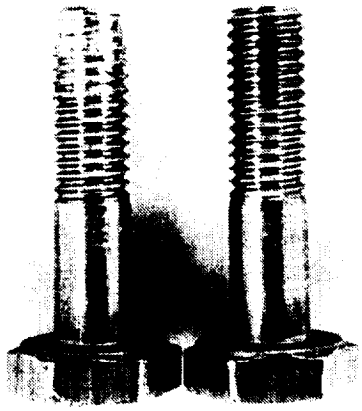
This photo (fig. 13) shows two of the severely damaged fastener assemblies from Experiment A0175. Note the severely damaged nut plate and sheared fastener. One of the Boeing fastener experts stated that this was the worst galling he had seen in his 30 years of working with fasteners.



A0175 Sheared Fastener and Galled Nutplate

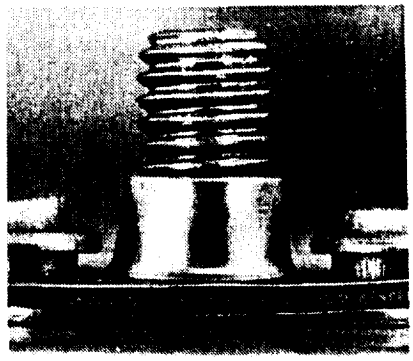
Experiment A0175 Tray Fasteners

Figure 14 shows typical bolts removed from nutplates that had the MoS2 removed prior to bolt installation and removed from nutplates that had the MoS2 intact. Fourier transform infrared spectroscopy (FTIR) found no traces of the cetyl alcohol remaining in either the nutplates or bolts.

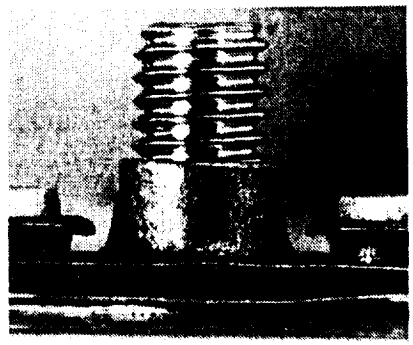


No MoS2 MoS2

(Top) – Comparison of Thread Conditions of AO175 Tray Bolts Removed from Nut Plates. Undisturbed Assemblies Were Cross-Sectioned. Note Thread Galling Damage on Fastener That Had MoS2 Removed (Center).



No MoS2



Fastener Conclusions

The LDEF deintegration team and several experimenters noted severe fastener damage and hardware removal difficulties during post-flight activities. The System SIG has investigated all reported instances, and in all cases examined to date, the difficulties were attributed to galling during installation or post-flight removal. To date, no evidence of coldwelding has been found. Correct selection of materials and lubricants as well as proper mechanical procedures is essential to ensure successful on-orbit or post-flight installation and removal of hardware (fig. 15). For additional details on the investigation of fasteners flown on LDEF, the reader is referred to the February, 1992, Systems SIG Interim Report.

- **Fastener removal difficulties in all cases have been related to galling damage on installation or during removal**
- **No evidence of cold-welding**
- **Stainless steel fasteners are very susceptible to galling**
  - **Success application on orbital replacement units (ORU 's)**
    - **High thread quality and, most importantly,**
    - **Effective lubrication schemes or surface modifications**
- **Simulated space effects testing, in conjunction with tribology studies, is required to determine optimal lubrication schemes for long-term space exposure for high-reliability fasteners to be employed on ORU's**