NASA
Engineering Directorate
Materials Science Division
Kennedy Space Center, Florida

March 25, 2011

KSC-MSL-2011-0045

SUBJECT: Failure Analysis of an EckAdams Office Chair from the Maintenance and Operations (M&O) Building

CUSTOMER: John Llibre / URS Federal Technical Services, Inc. / ISC-8400

1. ABSTRACT

A 17 year old EckAdams model number 5353 chair was submitted for failure analysis when the cylinder of the chair failed during use. Both macroscopic and microscopic indications of fatigue were observed on the cylinder fracture surface, indicating that the cylinder progressively failed due to the bending stresses imparted on the cylinder during a reclining motion. The stress on the cylinder was likely exacerbated by failed welds that were observed between the chair back mounting plate and the base plate, which would reduce the stiffness in this location and allow for more flexure. The failed welds did not have proper fusion during manufacture of the chair, as indicated by metallographic examination of a cross-section of a failed tack weld. A tack weld is not a robust design choice in this location and a fillet weld would be more appropriate for the loading conditions.

2. FOREWORD

Institutional Services Contract (ISC) safety personnel submitted a chair that had been used at the M&O Building, M6-0486, after the cylinder of the chair failed while in use. The customer reported that the chair was used by an employee weighing less than 300 pounds when the failure occurred. The chair was submitted for failure analysis in order to determine if the failure was due to a manufacturing flaw that could be present in other chairs or if the failure was due to abuse.

3. PROCEDURES AND RESULTS

3.1. The chair was photographed, as received (Figure 1), and inspection of the underside of the seat base revealed a manufacturer's tag that dated the chair to January 1994 (Figure 2). The chair was an EckAdams Company model number 5353 ergonomic office chair, order number 131165002. The cylinder fracture was observed to occur at the location where the shaft narrowed down to a smaller cross-sectional area, which would impart a stress concentration in this location

(Figure 3). The chair mechanism on the underside of the seat was disassembled in order to remove the shaft for fractographic inspection. During disassembly, two additional parts were revealed to have failed: an internal-external tooth lock washer under the knob that holds the back of the chair in place (Figure 1, yellow circle and Figure 4) and two tack welds that secured the chair back mounting plate to the base plate (Figure 1, blue arrows and Figure 5). The fractured washer probably did not contribute to the cylinder failure, but may be an indication of the amount of force that was exerted on the tightening knob or the chair back. The separated welds could have allowed more stress to be imparted to the cylinder of the chair during reclining due to reduced stiffness in the mounting plate.

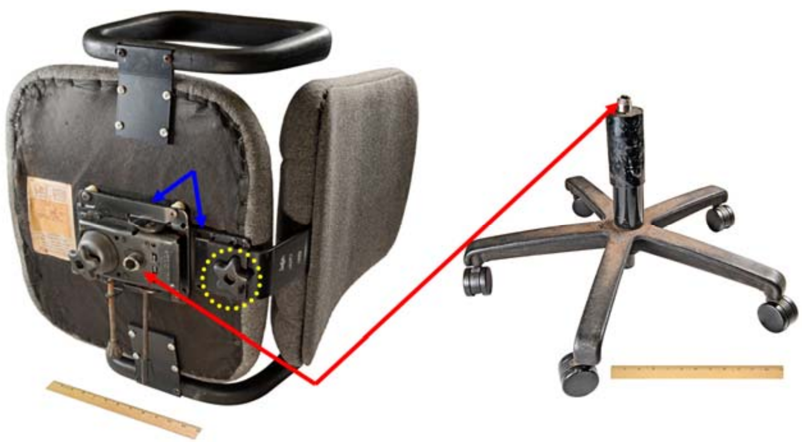

Figure 1. EckAdams office chair, as received. The red arrows indicate the location of the cylinder failure, the yellow circle indicates the location of the chair back adjustment knob, and the blue arrows indicate the locations of the chair back mounting plate and the base plate. Scale is 1 foot.

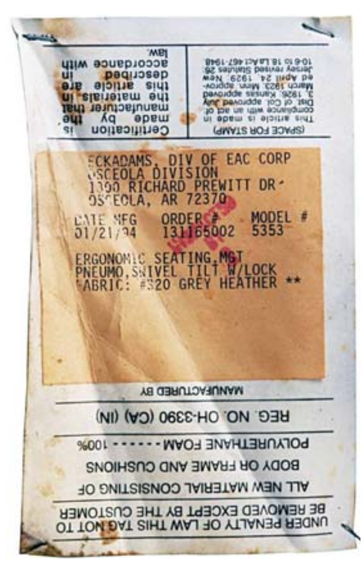

Figure 2. Identification tag from the bottom of the chair.

Figure 3. Photograph of the cylinder failure, showing the narrowing of the cylinder in this location. Scale is one inch.

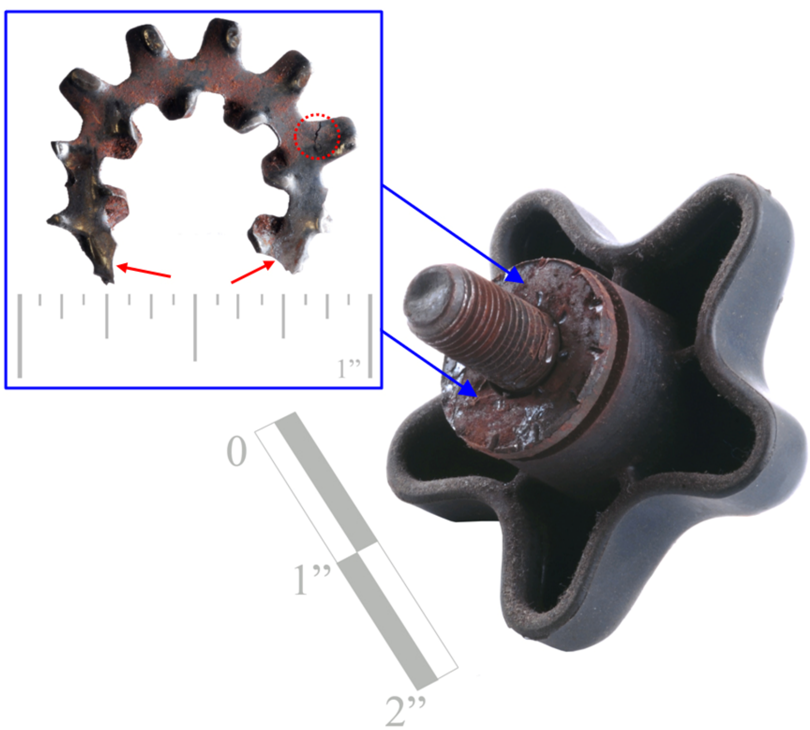

Figure 4. Photograph of the internal-external tooth lock washer that was observed to be fractured (arrows and circle) after removal of the chair back tightening knob (right). Scales are in inches.

Figure 5. Photographs of the two locations where tack welds had liberated on the chair base plate and a fracture that was observed near one of the welds (right image). Scale is six inches.

3.2. Stereomicroscope observation of the fractured shaft revealed different regions on the fracture surface. The crack appeared to initiate towards the front of the chair and propagate towards the back (Figure 6, blue arrows). Ratchet markings were observed towards this side of the cylinder (Figure 6, blue circles), which are indications of multiple crack origins and are one macroscopic indication of fatigue. The initial region of the fracture surface was relatively flat and displayed faint beach marks (Figure 6, yellow line), which are marks left behind by the crack front when the applied stress is removed for a period of time; this is another macroscopic indication of fatigue. The fracture surface then had a distinct change in appearance approximately one-third of the distance through the cylinder (Figure 6, red line). The final region of the fracture surface displayed a shear lip as the final portion of the cylinder failed and smeared the metal on the fracture surface (Figure 6, red oval).

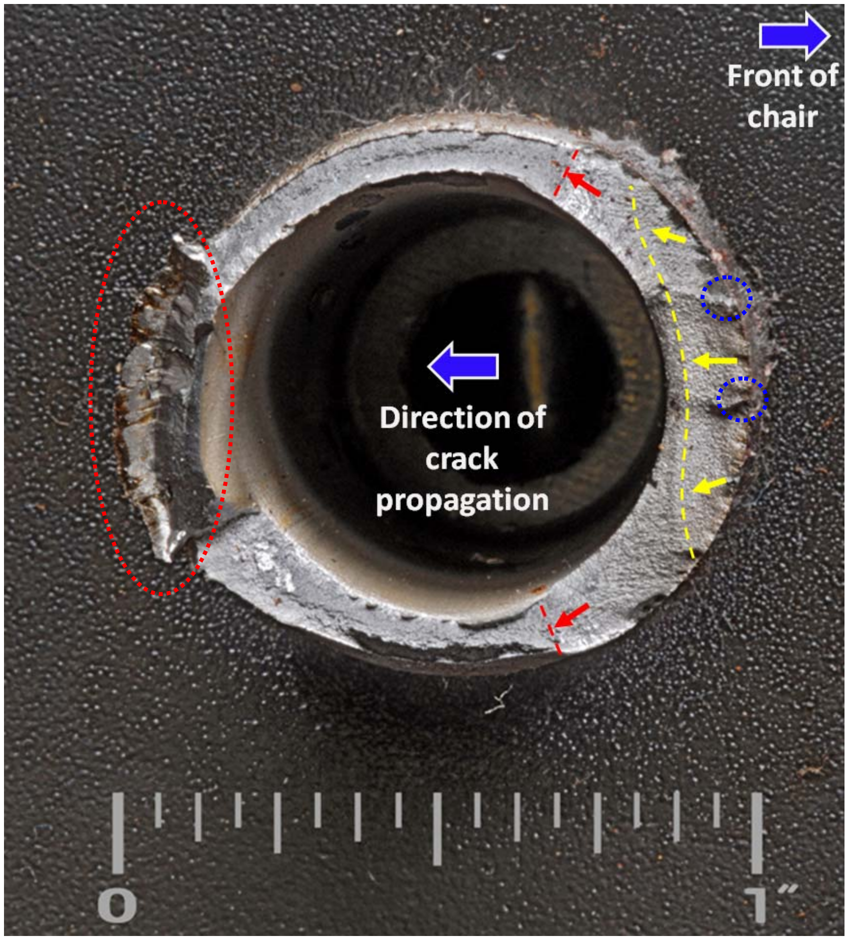

Figure 6. Stereomicroscope image of the cylinder fracture surface showing ratchet markings at the side of the cylinder where crack initiation occurred (blue circles); a beach mark observed on the fracture surface (yellow line); and the distinct area on the fracture surface where the crack path was no longer flat and relatively smooth (red lines). The yellow and red arrows show the direction of crack propagation through the cylinder. Scale is one inch.

3.3. Scanning electron microscope (SEM) evaluation of the flat region of the fracture surface observed via stereomicroscope revealed striations, which are microscopic indications of the fatigue crack front progression through the material with a cycle of applied stress (Figure 7). Areas of smeared metal were also observed, which is typical during a fatigue fracture due to the mechanical contact of the two mating halves of the fracture surface as stress is applied and removed. SEM observation of the distinct transition line on the fracture surface observed via stereomicroscope revealed the onset of stress overload, as indicated by the observation of dimpled rupture formed by microvoid coalescence (Figure 8, red box). Just prior to the transition line (Figure 8, yellow arrow), faint fatigue striations were observed along with secondary cracking of the fracture surface (Figure 8, blue box), which occurred just before the final stress overload of the cylinder.

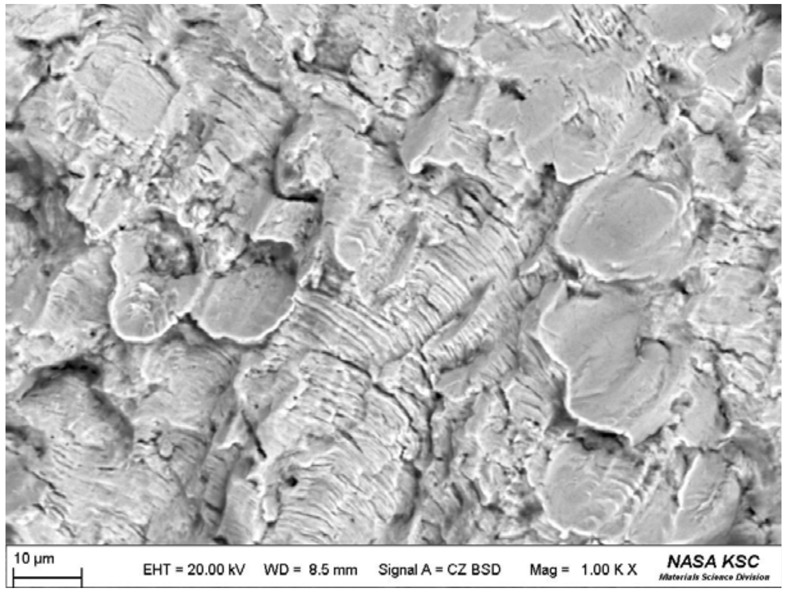

Figure 7. SEM image of the fracture surface showing fatigue striations and small areas of smeared metal. Original magnification: 1,000X.

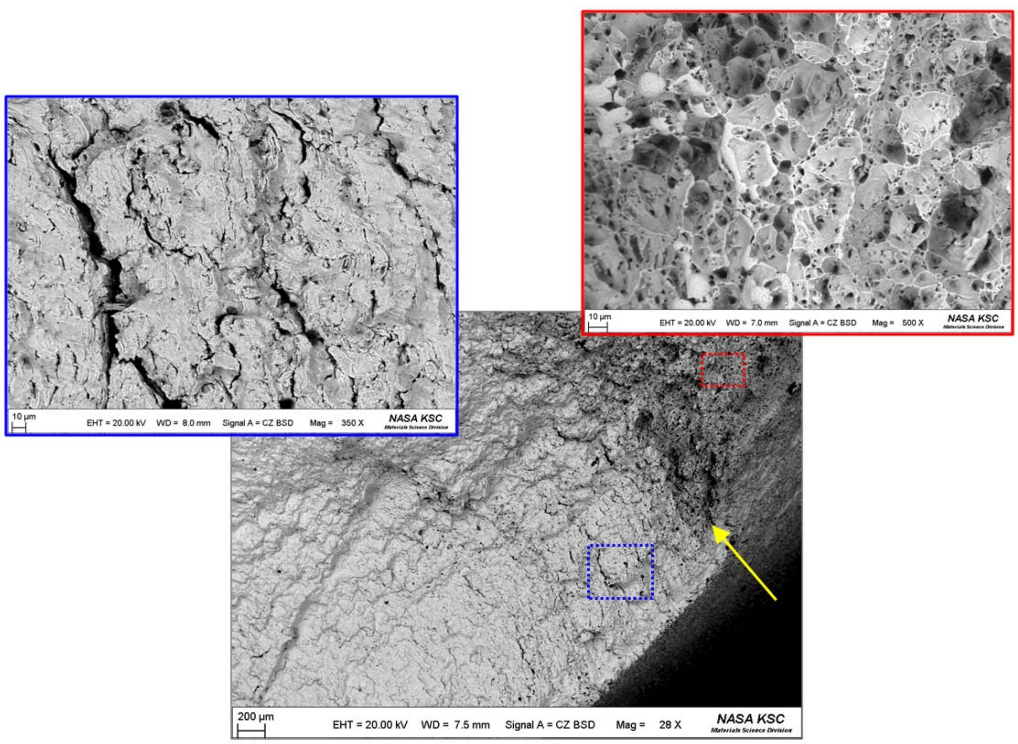

Figure 8. SEM images of the transition line observed on the fracture surface (yellow line). The fatigue fracture started to form secondary cracks (blue box) just prior to the onset of the final stress overload region, characterized by dimpled rupture (red box). Original magnifications: 28X (center), 350X (blue box), 500X (red box).

3.4. Energy dispersive spectroscopy (EDS) evaluation of the cylinder material via the SEM indicated that the composition was consistent with chromium-plated plain carbon steel. EDS evaluation of the base plate material indicated that the composition was consistent with plain carbon steel. No drawings or specifications were provided for reference.

3.5. A cross-section of the cylinder through the fracture surface and a cross-section of the base plate at the location of a failed tack weld were metallographically prepared for microstructural examination. An additional transgranular crack was observed to be propagating roughly parallel to the primary fracture surface in the cylinder, which is typical for fatigue (Figure 9, arrows). The microstructure of the cylinder was primarily ferrite with small regions of pearlite, which is typical for normalized plain carbon steel. No indications of any deficiencies were observed in the cylinder material. Examination of the cross-section of the base plate where the tack weld had failed showed a heat-affected zone in the material that was between 200 and 300 microns deep (Figure 10, boxed area). No dendritic structure was observed in this area, which would be present if fusion had occurred. The microstructure of the base metal was ferrite, which is typical for plain carbon steel.

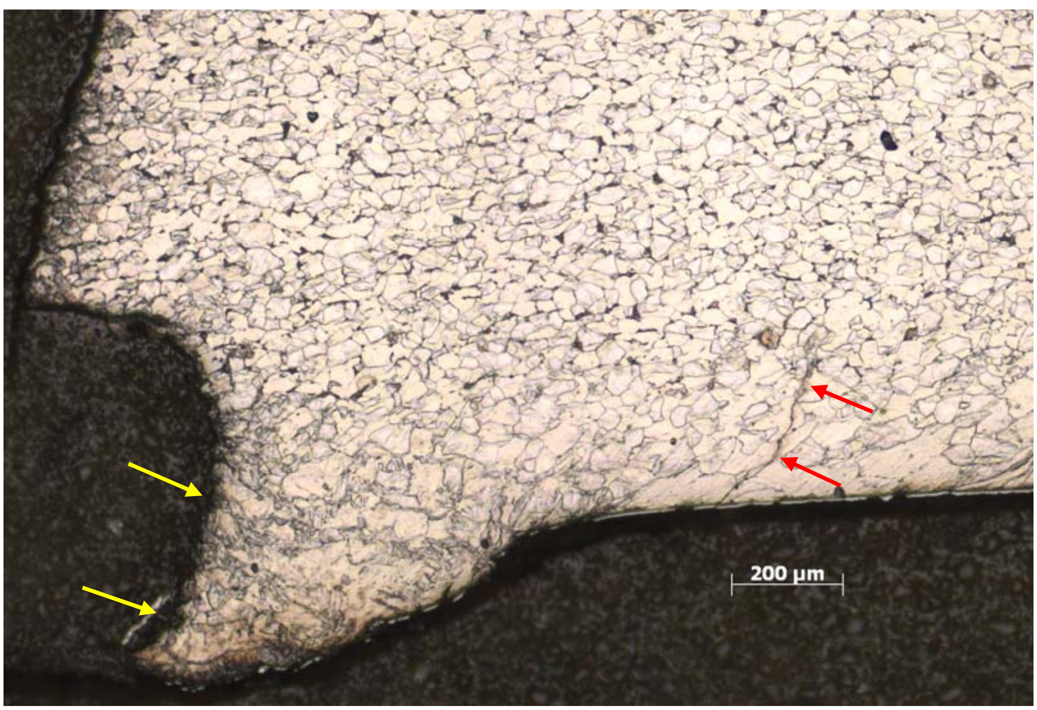

Figure 9. Micrograph of a cross-section of the cylinder near the primary fracture surface showing a microstructure typical for plain carbon steel and a transgranular crack (red arrows) propagating roughly parallel to the primary fracture surface (yellow arrows). Etchant: 2% nital. Original magnification: 100X

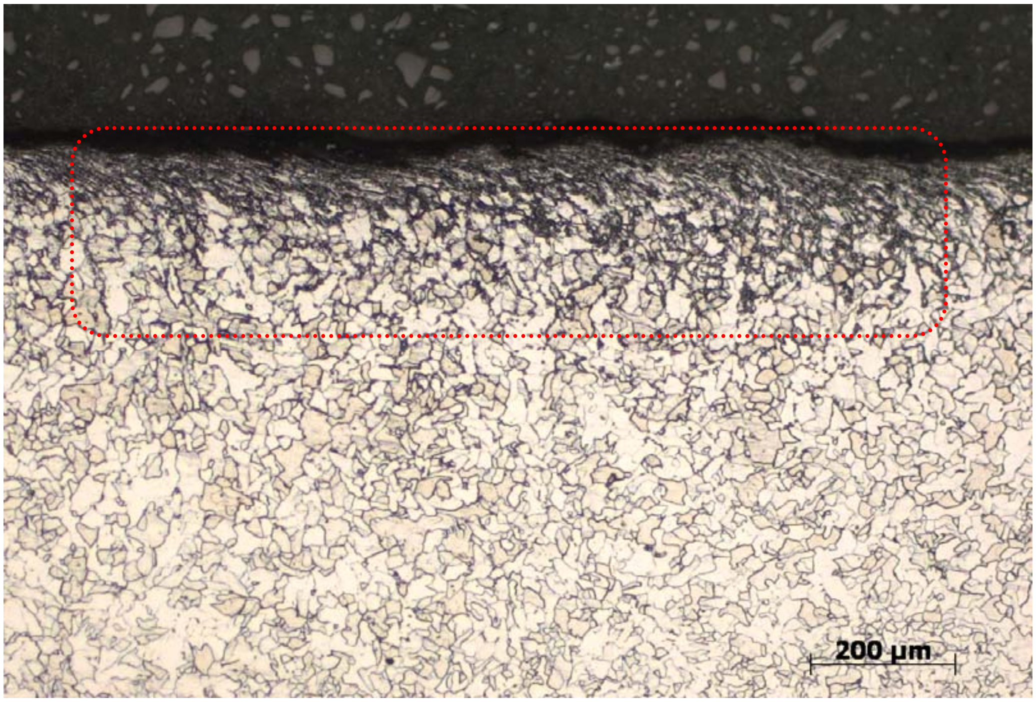

Figure 10. Micrograph of a cross-section of the base plate showing the lack of penetration achieved during tack welding of the chair back plate. No dendritic structure was observed to indicate that fusion had occurred. Etchant: 2% nital. Original magnification: 100X.

4. DISCUSSION

During this investigation, an EckAdams chair with the same model number as the subject chair was observed in the Materials Failure Analysis Laboratory located in the Operations and Checkout (O&C) Building, M7-0355, Room 2217. Examination of the chair revealed one failed tack weld in the bracket that holds the back of the chair in place (Figure 11, circled) and a crack in the bracket opposite this weld (Figure 11, arrow). The tack weld likely failed first due to the stress imparted by the chair back, leading to subsequent cracking of the bracket. Although this failure was not in the same location, the observation of failed tack welds in more than one EckAdams model number 5353 chair is an indication that the failure in the subject analysis may not be an isolated case.

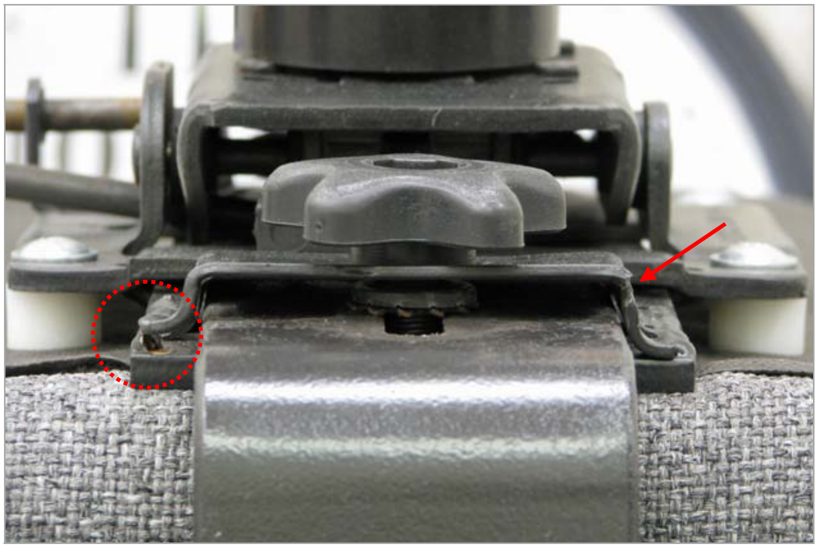

Figure 11. Photograph of a failed weld (circle) and a crack (arrow) in the chair back mounting bracket on an EckAdams chair observed in the Materials Failure Analysis Laboratory. Oblique view.

5. CONCLUSION

The EckAdams chair cylinder failed in fatigue due to repetitive loading. The macroscopic appearance indicated that the loading was unidirectional bending with high nominal stress and a mild stress concentration, due to the narrowing cross-section of the shaft at the location of failure. The fatigue fracture initiated at the front side of the cylinder and progressed approximately one-third of the way through the cylinder before failing due to stress overload. The stress on the cylinder was likely exacerbated by the failure of the two tack welds that were used to hold the chair back mounting plate to the base plate, which led to a decrease in the stiffness during a reclining motion of the chair. Metallographic examination of one of the failed tack welds indicated that proper fusion was not achieved during manufacture; a fillet weld would have been a more robust design choice for this joint. The failed internal-external tooth lock washer probably did not contribute to the cylinder failure, but is noted as additional piece of the chair hardware that failed.

EQUIPMENT: Zeiss EVO 60 SEM S/N 0465 with Oxford INCA EDS S/N 34080
Zeiss Z1m Metallograph, S/N 3837000175

CONTRIBUTORS: P. Marciniak/NE-L1-M

PRIMARY INVESTIGATOR: ________________________________
V. Long/NE-L1-M