**NATIONAL TRANSPORTATION SAFETY BOARD**
Office of Aviation Safety
Washington, D.C. 20594

May 20, 2016

**Systems Group Chairman's Factual Report**

DCA-15-IA-089

## A. INCIDENT

| | |
|---|---|
| Operator: | Gojet Airlines |
| Location: | Chicago O'Hare International Airport (ORD), Chicago, Illinois |
| Date: | March 14, 2015 |
| Time: | 1521 central daylight time |
| Airplane: | CRJ 700, registration N157GJ |

## B. SYSTEMS GROUP

Chairman: Scott Warren
National Transportation Safety Board
Washington, D.C.

Member: Fabio Buttitta
Federal Aviation Administration
Westbury, NY

Member: Jacques Desmarais
Bombardier Aircraft
Mirabel, Quebec

Member: Simon Lucas
UTC Aerospace Systems
Oakville, Ontario

Member: Ivona Szczerbowicz
UTC Aerospace Systems
Oakville, Ontario

Member: Wesley Perkins
GoJet Airlines, Inc.
St. Louis, MO

## C. SUMMARY

On March 14, 2015, about 1521 central daylight time, a Gojet Airlines CRJ 700, registration N157GJ operating as United Express flight 3645, landed with the nose gear retracted on runway 32R at Chicago O'Hare International Airport (ORD), Chicago, Illinois. There were no injuries to the 37 passengers and 4 crewmembers onboard and the airplane received minor damage. The flight was operating under the provisions of 14 *Code of Federal Regulations* (CFR) Part 121 as a regularly scheduled passenger flight from Gerald R. Ford International Airport (GRR), Grand Rapids, Michigan.

The incident aircraft was recovered from the runway under the supervision of the operator and the local airport emergency service authorities. Selected nose landing gear components were removed from the aircraft by the operator for further examination. The systems group convened on April 14-17, 2015, at the United Technologies Corporation Aerospace Systems (UTAS) facilities in both Burlington and Oakville, Ontario, Canada, to examine and document the selected nose landing gear components.

## D. DETAILS OF THE INVESTIGATION

1.0 Aircraft Recovery

Aircraft recovery operations were conducted by the operator in coordination with the local airport emergency service authorities. According to reports received from the operator;

a. When the aircraft was lifted during the recovery efforts, it appeared that the nose gear was not on the uplocks. It appeared as if the doors would not open, and the nose gear was not extending because of the doors;

b. The door brackets were cut to release the door restrictions, and the nose gear then extended;

c. The nose gear was then pinned and the aircraft was towed to a hangar;

d. The nose gear doors were a total loss;

e. A bolt and bracket on the drag brace was found broken – it appeared as if the bolt had broken and allowed the brace to rotate and obstruct/prevent the full opening of the doors;

f. The nose gear strut itself was not damaged – it remained inside the nose gear well, and it did not drag on the ground;

## 1.1 Nose gear description

The nose landing gear (NLG) is a double wheel, forward retracting type with two spin down assemblies. The nose gear consists of a twin wheel shock strut and a folding drag brace that incorporates a mechanical downlock / uplock.

The nose landing gear drag brace assembly folds and positions the shock strut relative to the nose of the fuselage in both extend and retract positions. It consists of an upper drag brace, lower drag brace, over center lock link assembly (jury strut) and two tension springs.

The upper drag brace assembly connects the lower drag brace assembly and the jury strut assembly to the airframe attachment point.

The lower drag brace assembly connects the upper drag brace and the jury strut assembly to a lug integral to the forward side of the outer cylinder.

The jury strut assembly (comprised of lower and upper lock link assemblies), connects the upper and lower drag brace assemblies to the aircraft attachment point, over−center springs and the lock actuator. Dual acting springs assist the lock link assembly arms and are designed to insure over center and mechanical locking of the jury strut.

The nose landing gear doors are slave driven by the nose landing gear and are open when the nose landing gear is down and closed when the gear is up. The nose landing gear doors open and close with landing gear motion through mechanical means.

The forward door mechanism assembly is comprised of two door rods, a driven link assembly, upper and lower locks link assemblies, a drive link assembly and a drive arm assembly.

The door rods, each with rod ends and spherical bearings at each end, attach to lugs integral to their respective door assembly. Both door rods then connect to lugs integral to the driven link assembly which has a clevis at the opposite end for pinning to a lug integral to gear bay structure.

The driven link assembly is acted upon by an upper link assembly, which in turn connects to a lower link assembly. The lower link assembly is pinned to the upper drag brace and acted upon by the drive link assembly. The drive link assembly is pinned to the drive arm assembly, which is rigidly attached to the lower lock link of the jury strut. (See figure 1)

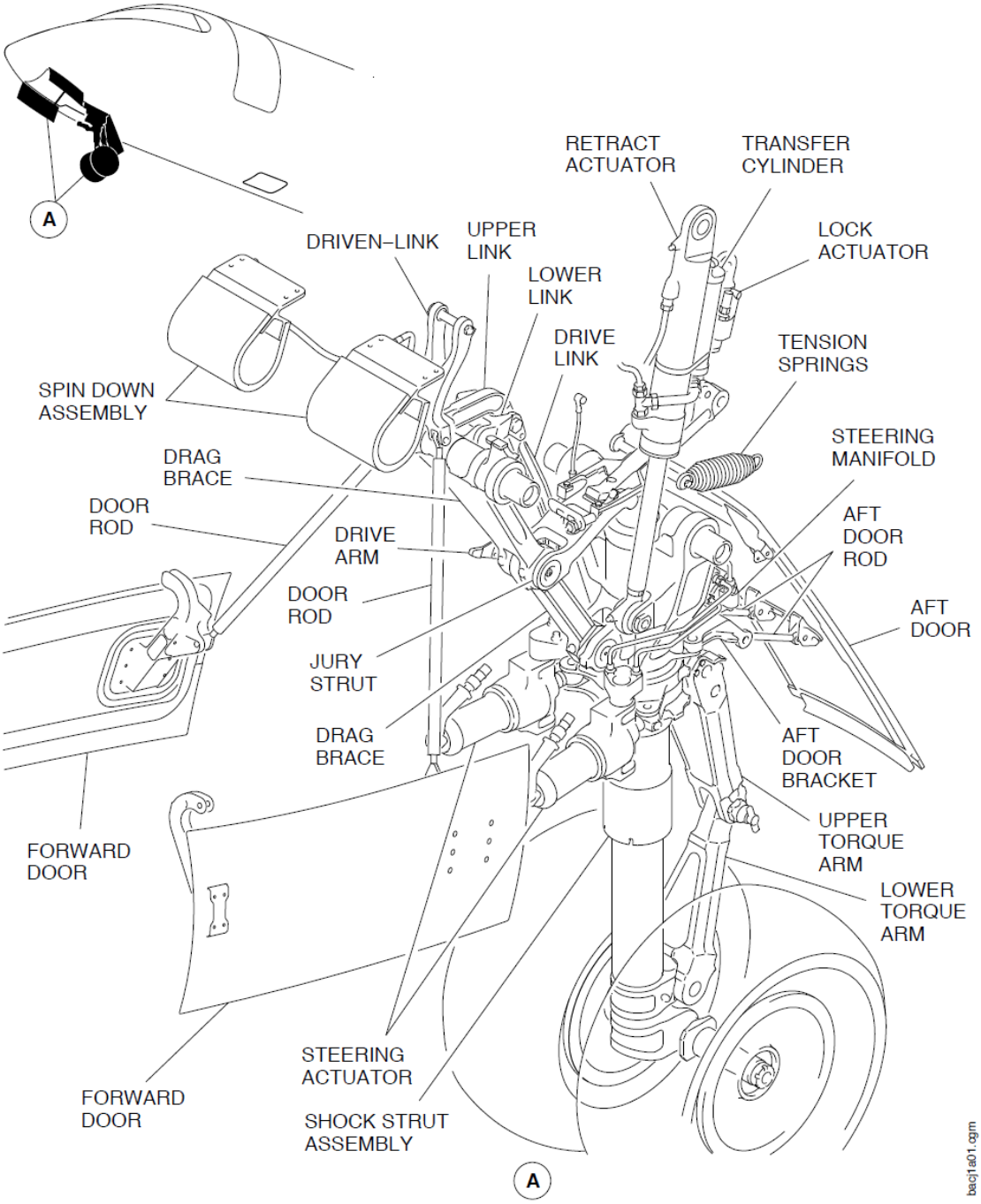


Figure 1
Nose landing gear component locations

When the extension of the NLG begins, hydraulic pressure is directed to the lock actuators, which break the over−center lock of the lock link assembly. The NLG is brought down and locked in the extended position by the retract actuator and two tension springs. The lock actuator and the tension springs complete a solid over−center lock of the lock link assembly. To retract the

NLG, the hydraulic pressure is directed to the lock actuator to break the downlock and to the retract actuator to raise the NLG. The NLG retracts into the wheel well and is locked into position by the two tension springs.

## 1.2 Component Examinations

Nose landing gear components from the incident aircraft were shipped by Gojet to the UTAS facilities. The shipping boxes were opened in the presence of the systems group, and the components were examined. The received components are listed in table 1. Some of the bolt components were located within other assemblies and were not removed during the examination, so they were not photographed or discussed in detail within this document.

After the systems group examinations were completed, the UTAS Materials and Processes (M&P) laboratory was tasked with an in-depth examination of several components. The UTAS report on that work is included as appendix A[1, 2].

[1] The UTAS report contains analysis and comments that should not be confused with the official NTSB analysis. Any analytical statements contained in the UTAS report represent only the opinion of that organization.

[2] According to the UTAS failure report notes, "To maintain consistency with the legal identity of the products manufactured and sold by UTAS Landing Systems (Landing Gear), the name Goodrich continues to remain as the product identification." The report carries a "Goodrich" logo and nomenclature, but was produced by UTAS.

Table 1
Nose landing gear components examined

| Number | Part Name | Part Number | Serial Number |
|---|---|---|---|
| 1 | Driven Link | 52604-105 | WAI0167 |
| 2 | Upper Link | 52603-101 | N/A |
| 3 | Lower Link | 52602-103 | N/A |
| 4 | Lower Lock Link Assembly | 52207-103 | CPS050218 |
| 5 | Upper Drag Brace | 52201-107 | MK030307 |
| 6 | Drive Link Assembly | 52601-103 | WAI0182 |
| 7 | Drive Arm Assembly | 52620-103 | CII0143 |
| 8 | Upper Lock Link Assembly | 52205-1 | ACR110272 |
| 9 | Pin | 52621-1 | N/A |
| 10 | Bolt pin | 52065-101 | CH040225 |
| 11 | Upper drag brace pin assembly | 52052-3 | SPP0656 |
| 12 | Upper drag brace pin assembly | 52052-3 | SPP0655 |
| 13 | Door rod | 52606-1 | N/A |
| 14 | Door rod | 52606-1 | N/A |
| 15 | Pin | 52210-7 | CH040299 |
| 16 | Drag strut cap | 52211-3 | N/A |
| 17 | Lock link apex pin | 52212-1 | SD060027 |
| 18 | Pin | 52610-7 | N/A |
| 19 | Pin | 52610-7 | N/A |
| 20 | Bolt | 52061 | N/A |
| 21 | Bracket | 52230-3 | N/A |
| 22 | Bracket | 52230-4 | N/A |
| 23 | Bolt | 52615-1 | 2053 |
| 24 | Bolt | 52615-1 | 2051 |
| 25 | Bolt | 52615-1 | 2048 |
| 26 | Bolt | 52610-5 | N/A |
| 27 | Bracket Assembly | 52224-3 | N/A |
| 28 | Bolt | 52610-3 | N/A |
| 29 | Bolt | 52610-1 | N/A |

N/A: Not applicable

1.2.1 Driven Link (see figure 2)


Figure 2
Driven Link

The nomenclature for the driven link was determined to be:
P/N: 52604-105
S/N: WAI0167

The door rod holes did not visually appear to be deformed. There was a grease like substance in the part cavity. A sample of this substance was collected for further analysis. A small piece of wire, consistent with part identification tag wiring, was removed from the grease in the area of the driven link to upper link joint.

There was a sticker on the part that read, “C805091907”. According to Bombardier, this sticker notes the disposition of an assembly discrepancy found during manufacture. The discrepancy was that a pin would not fit through one of the holes, and the corrective action was to remove excess chrome plating from the pin and to lightly sand the inside of the hole.

1.2.2 Upper Link (see figure 3)


Figure 3
Upper Link

The nomenclature for the upper link was determined to be:
P/N: 52603-101
S/N: N/A

A contact area was noted between the grease nipple area of the upper link and the lower link (see figure 4). This area was identified for further investigation in the UTAS M&P laboratory.

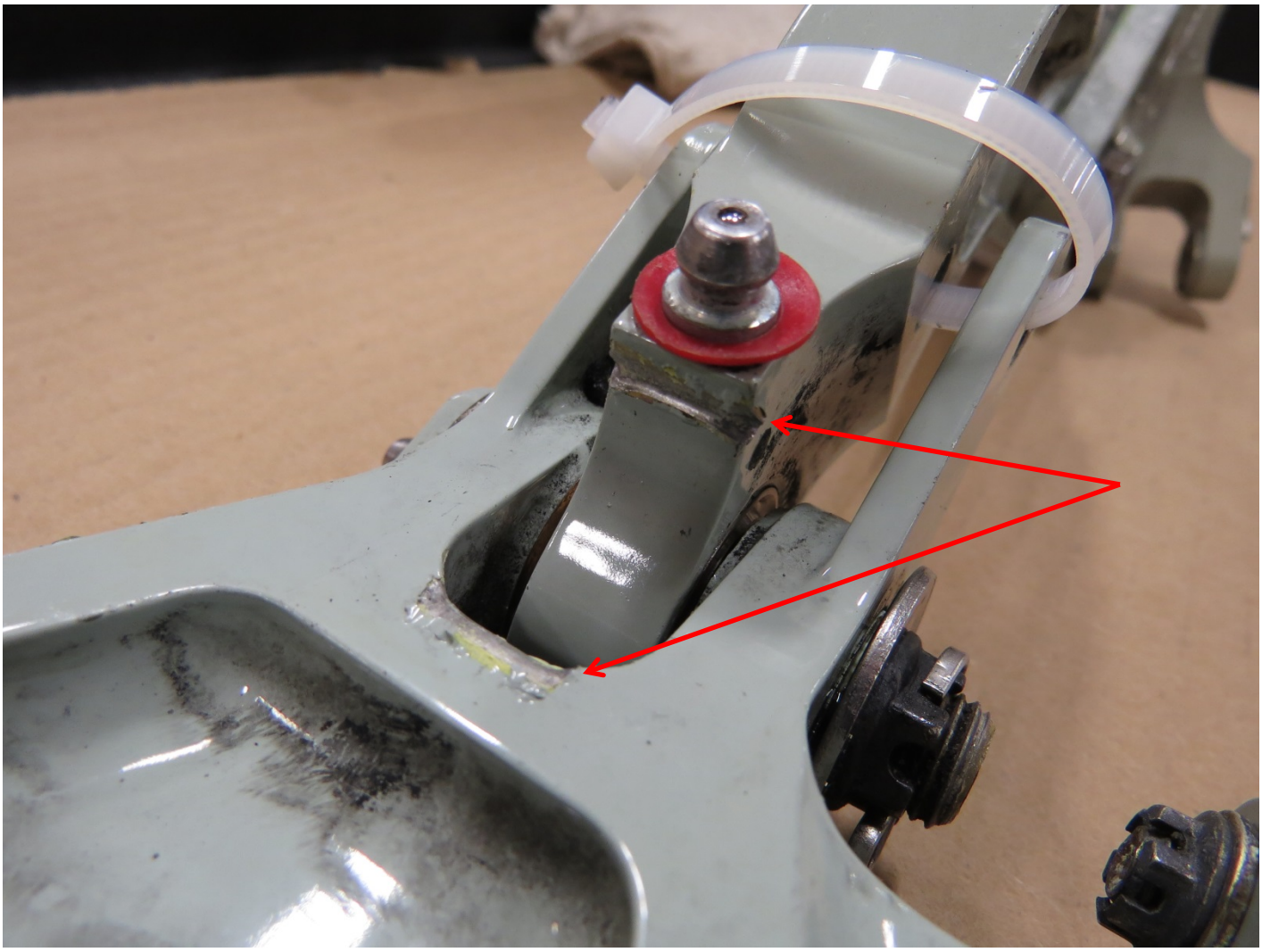

Figure 4
Contact area between upper link and lower link (after cleaning of the parts)

The spherical bearing between the upper link and lower link was noted to potentially have excessive movement (play), and was identified for further investigation in the UTAS M&P laboratory.

1.2.3 Lower Link (see figure 5)


Figure 5
Lower Link

The nomenclature for the lower link was determined to be:
P/N: 52602-103
S/N: N/A

There was a contact area noted between the lower link and the grease nipple area of the upper link. There was an area of missing paint noted in the area of the drive link rod end attachment to the lower link (see figure 6).

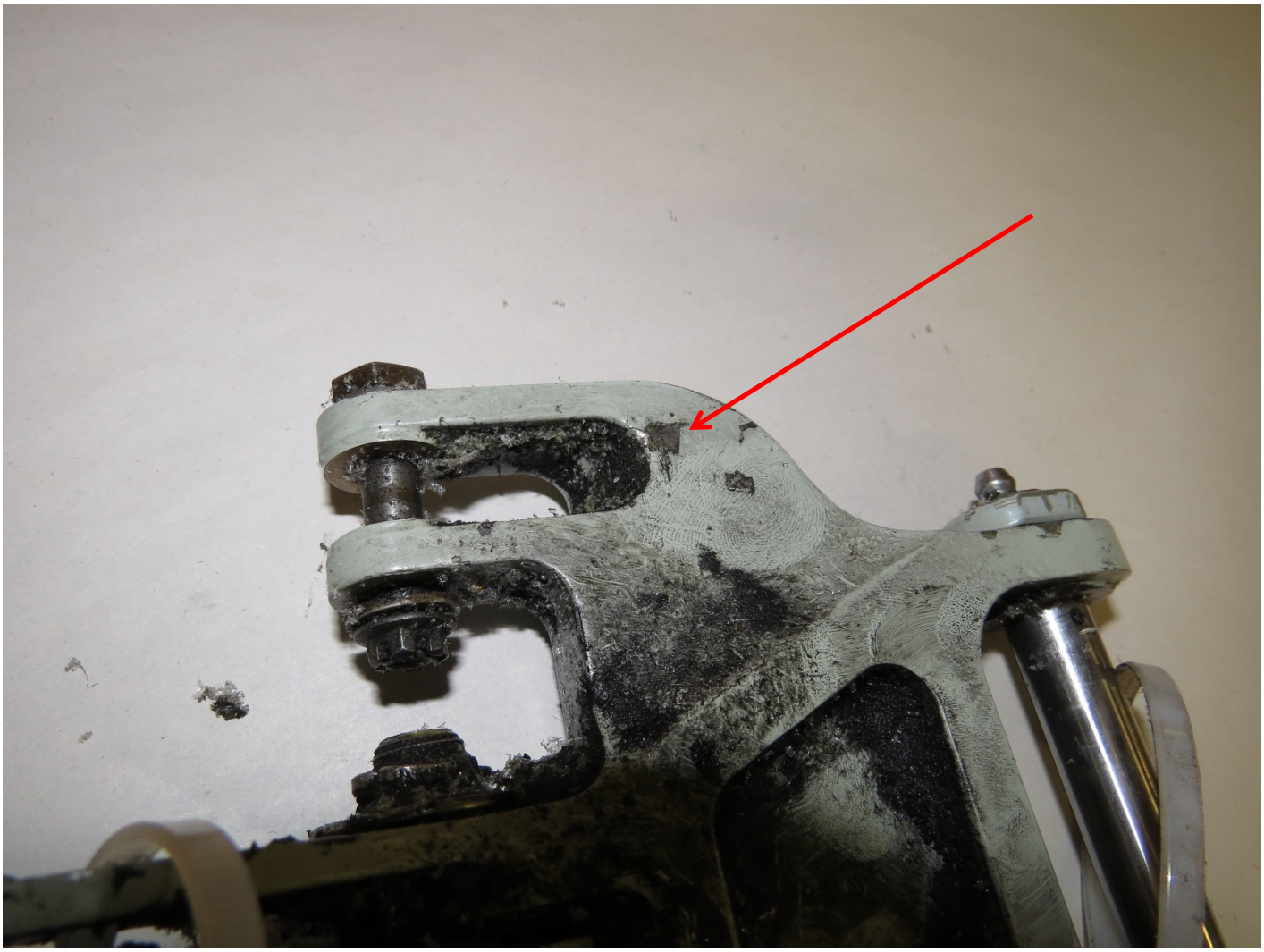

Figure 6
Area of missing paint on lower link

The missing paint area was identified for further identification by the UTAS M&P laboratory to determine if the dimensions of the missing paint area were consistent with the dimensions of the drive link.

1.2.4 Lower Lock Link Assembly (see figure 7)

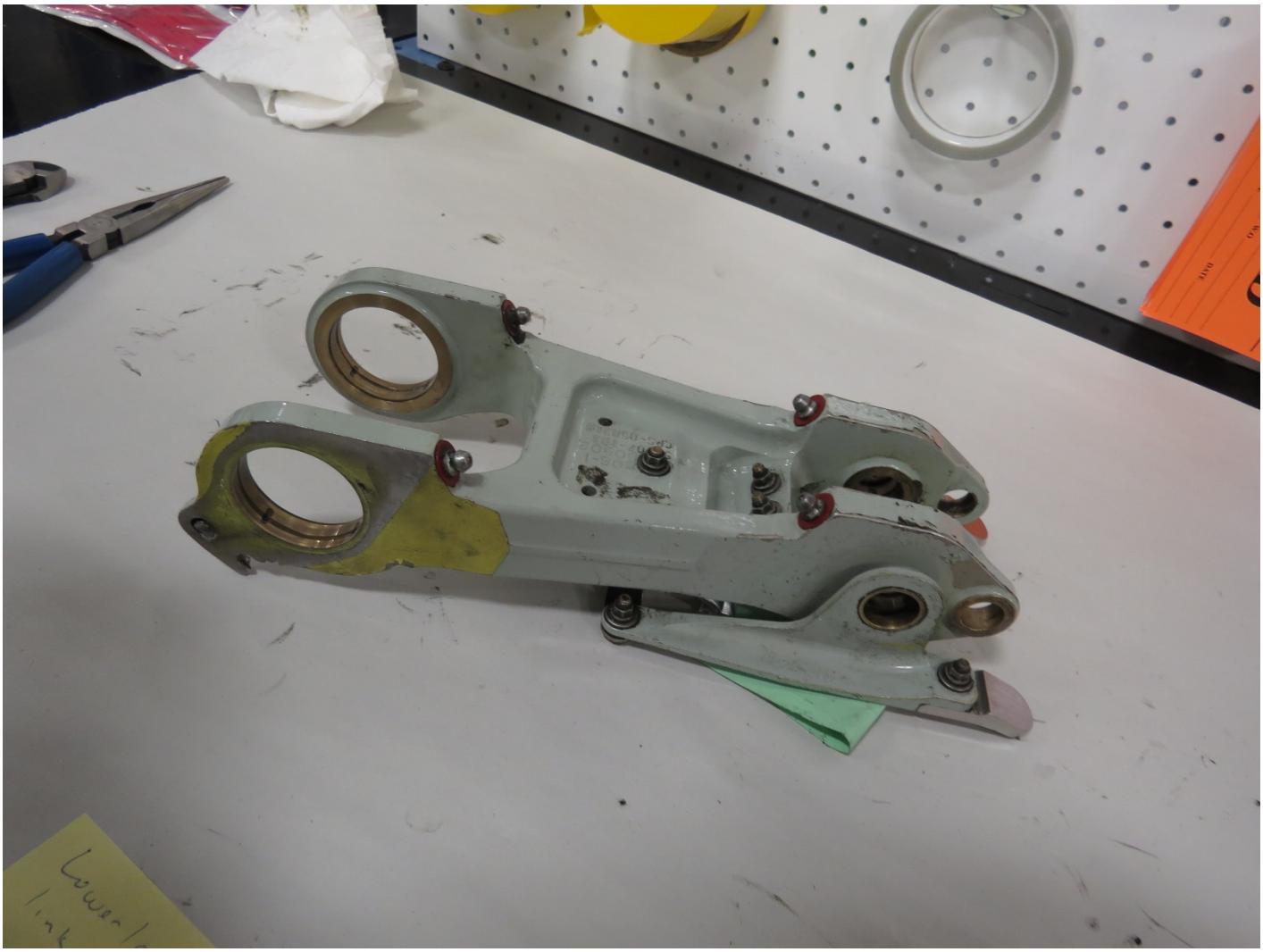

Figure 7
Lower Lock Link Assembly

The nomenclature for the lower lock link assembly was determined to be:
P/N: 52207-103
S/N: CPS-050218

The upper bolt hole on the attachment lug between the lower lock link and the drive arm was noted to have a broken out area where the material from the bolt hole extending to the edge of the lug was missing. The anti-rotation bolt from this hole was found to be deformed and was still present in the drive arm assembly (see figures 8 and 9).

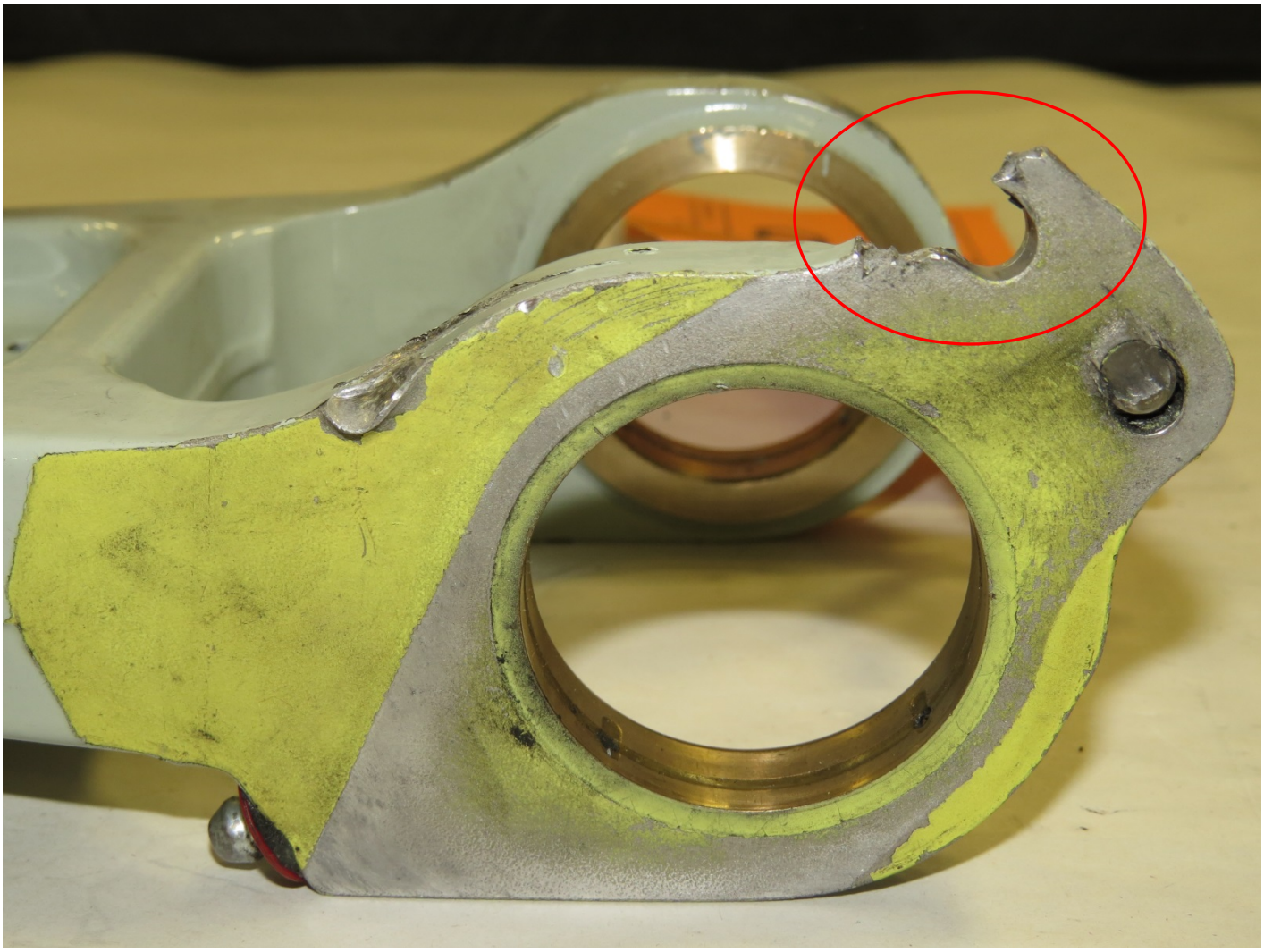

Figure 8
Lower lock link assembly showing upper bolt hole with missing edge material

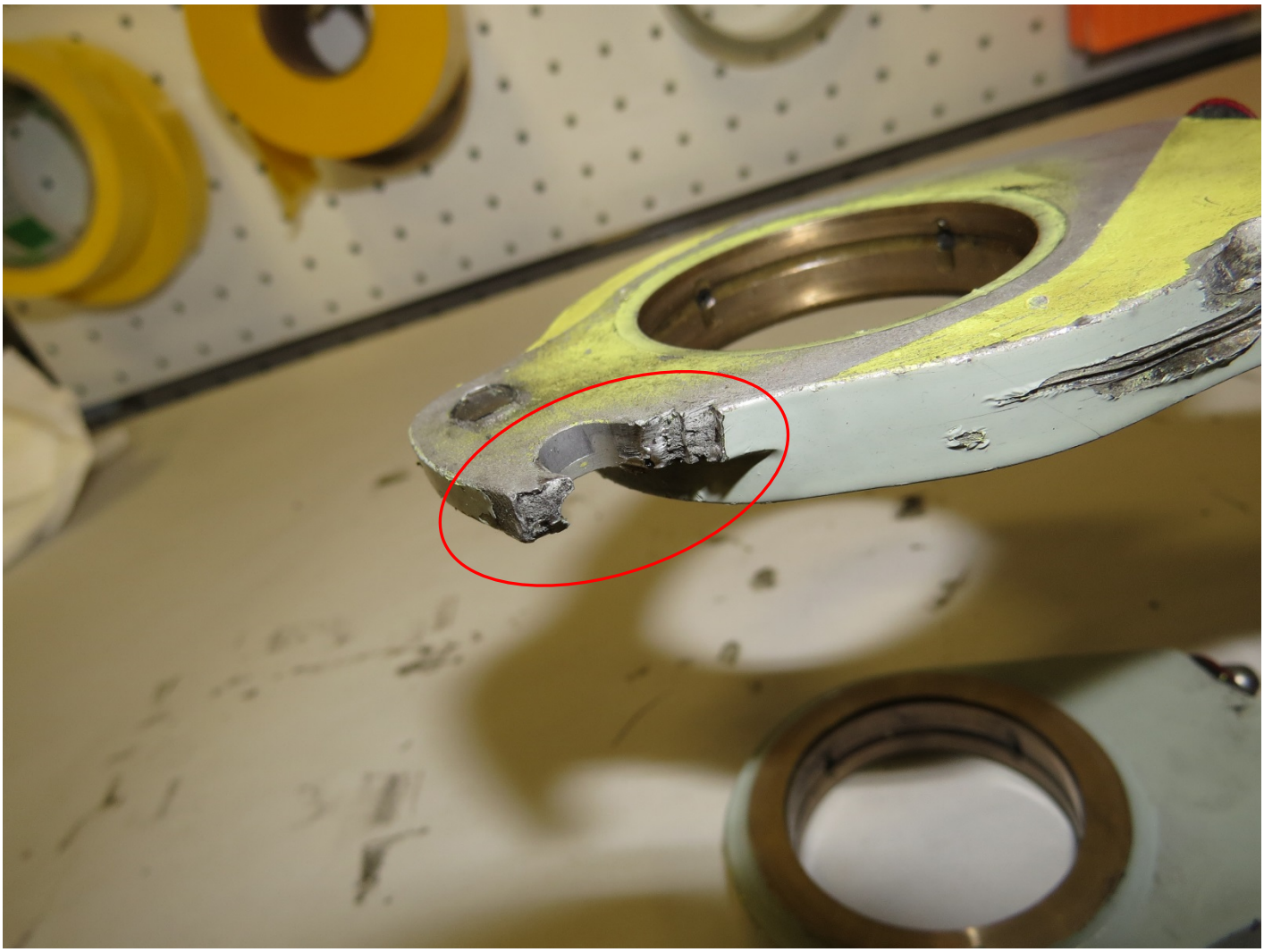

Figure 9
Close up view of the lower lock link assembly showing upper bolt hole with missing edge material

The anti-rotation bolt in the lower bolt hole was found to be sheared off at the level of the flange surface, and material consistent with the bolt was found to be smeared across the flange surface in the direction of the upper bolt hole. The “D” shaped head portion of this bolt was shipped separately in a bag. The end of the bolt, which remained in the lower lock link, did not have a nut attached. The nut from this bolt has not been located. According to UTAS, the nut used in this location was a self-locking nut (see figures 10-12).

Figure 10
Sheared off anti-rotation bolt in lower bolt hole

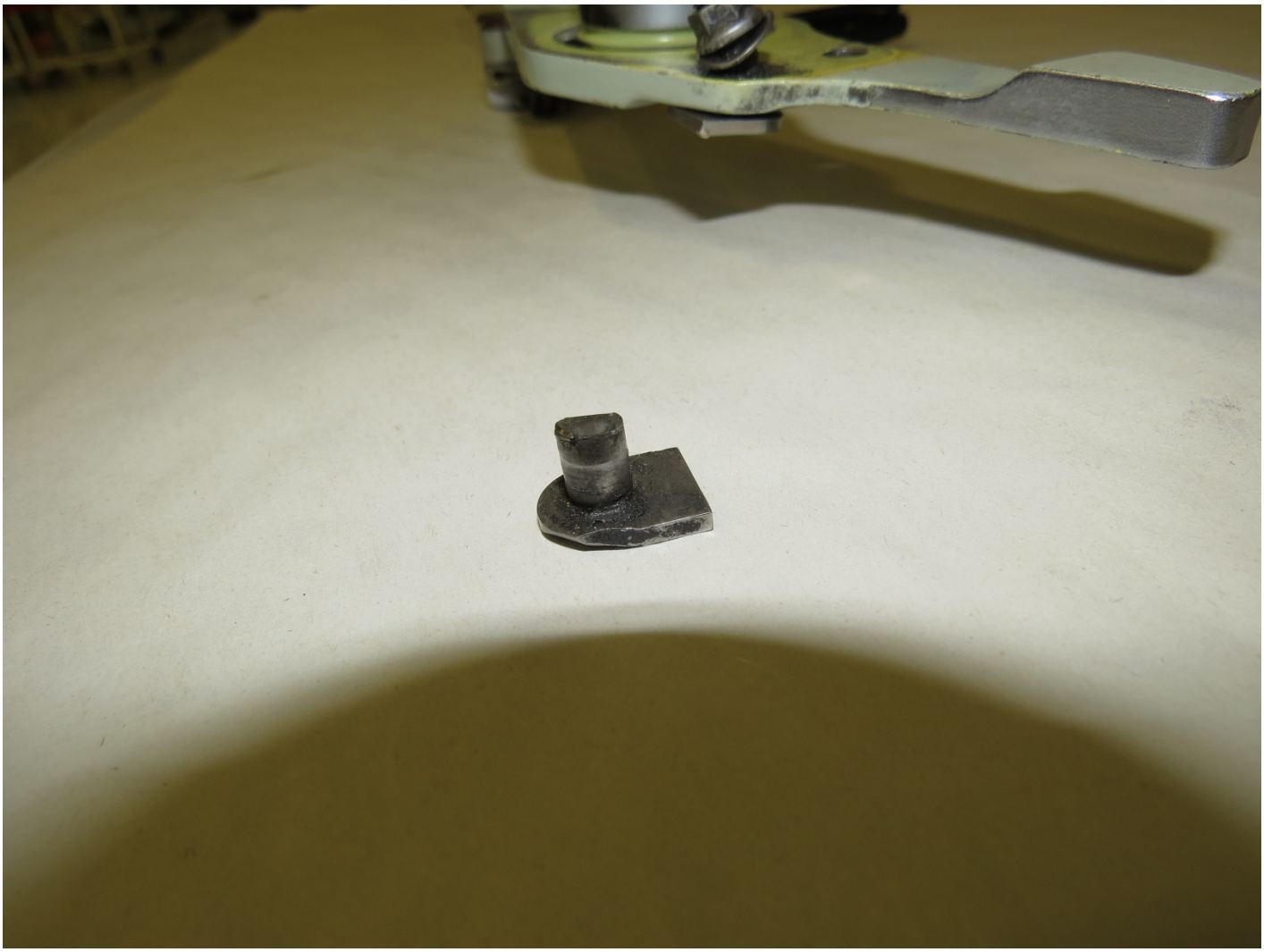

Figure 11
D-shaped portion of sheared off bolt from lower bolt hole

Figure 12
Nut end of anti-rotation bolt in lower bolt hole

There was a linear shaped depression and round divot noted in the same arm as the attachment lug with the broken and missing material. The depression started approximately 1.5 inches away from the broken materials and extended for approximately 1 inch.

Variations in primer paint density were noted throughout the portion of the lower lock link assembly that was not painted with top coat paint. These variations ranged from areas where the primer paint was completely absent to areas where the primer paint appeared to be scuffed. The areas of missing/scuffed primer paint matched those areas of

missing/scuffed primer paint on the mating drive arm assembly surface (see figure 13).

Figure 13
Lower lock link assembly and drive arm assembly with mating surfaces roughly aligned showing primer wear on both surfaces

The lower lock link assembly was identified for further examination in the UTAS M&P laboratory to characterize the fracture surfaces, examine the bolt holes, and to characterize the linear depression and divot.

1.2.5 Upper Drag Brace (see figure 14)


Figure 14
Upper Drag Brace

The nomenclature for the upper drag brace was determined to be:
P/N: 52201-107
S/N: MK030307

There were minor paint nicks in several locations around the part. There were nicks noted at the base of each attach lug where the upper drag brace mates with the lower link.

1.2.6 Drive Link Assembly (see figure 15)


Figure 15
Drive Link Assembly

The nomenclature for the drive link assembly was determined to be:
P/N: 52601-103
S/N: WAI0182

The drive link assembly was noted to be still attached to the drive arm assembly. The rod end was noted to be broken off of the drive link assembly. The rod end was identified for further investigation in the UTAS M&P laboratory.

After the initial examination was complete, the joint between the drive link and the drive arm was disassembled. The

components recovered during that disassembly matched the components specified in the Illustrated Parts Catalog (IPC).

### 1.2.7 Drive Arm Assembly (see figure 16)

Figure 16
Drive Arm Assembly

The nomenclature for the drive arm assembly was determined to be:
P/N: 52620-103
S/N: CII0143

One of the anti-rotation bolts used in the joint with the lower lock link assembly was noted to be in the upper bolt hole, but it was deformed. The other anti-rotation bolt from the lower bolt

hole was noted to be in two pieces – the head of the bolt was bagged separately, and the nut end of the bolt was located in the lower lock link assembly (sheared off with material smeared across the lug) with no nut attached.

Variations in primer paint density were noted throughout the portion of the drive arm assembly that was not painted with top coat paint. These variations ranged from areas where the primer paint was completely absent to areas where the primer paint appeared to be scuffed. The areas of missing/scuffed primer paint matched those areas of missing/scuffed primer paint on the mating lower lock link assembly surface.

The surface of the chrome plated outer diameter was noted to have burnished areas that had a different surface finish from the original surface finish. These areas were at the base of this area and approximately 180 deg apart.

The drive arm assembly was identified for further investigation by the UTAS M&P laboratory.

1.2.8 Upper Lock Link Assembly (see figure 17)


Figure 17
Upper Lock Link Assembly

The nomenclature for the upper lock link assembly was determined to be:
P/N: 52205-1
S/N: ACR-110272

A nut was noted to be missing from the right hand tension spring attachment spool. The right hand tension spring attachment spool had a broken guide surface. There were several areas of scuffed paint (down to bare metal) noted on the right hand side of the assembly in the area of the ground lock pin hole.

The broken guide surface was identified for further investigation at the UTAS M&P laboratory.

1.2.9 Bolt Pin (see figure 18)

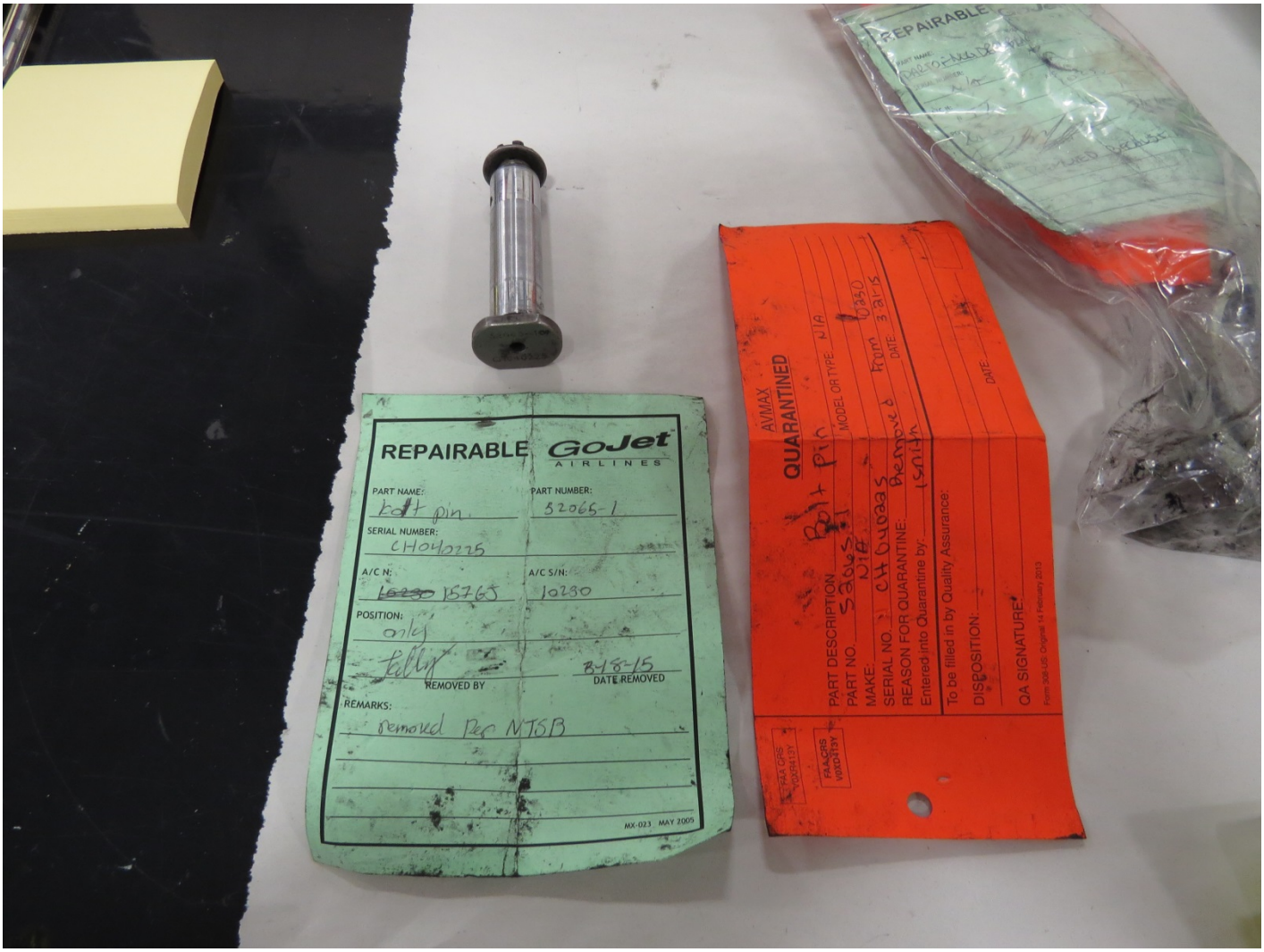


Figure 18
Bolt Pin

The nomenclature for the bolt pin was determined to be:
P/N: 52065-101
S/N: CH040225

1.2.10 Upper Drag Brace Pin Assembly (see figure 19)


Figure 19
Upper Drag Brace Pin Assembly

The nomenclature for the upper drag brace pin assembly was determined to be:
P/N: 52052-3
S/N: SPP0656 and S/N: SPP0655

1.2.11 Door Rod (with yellow tag) (see figure 20)

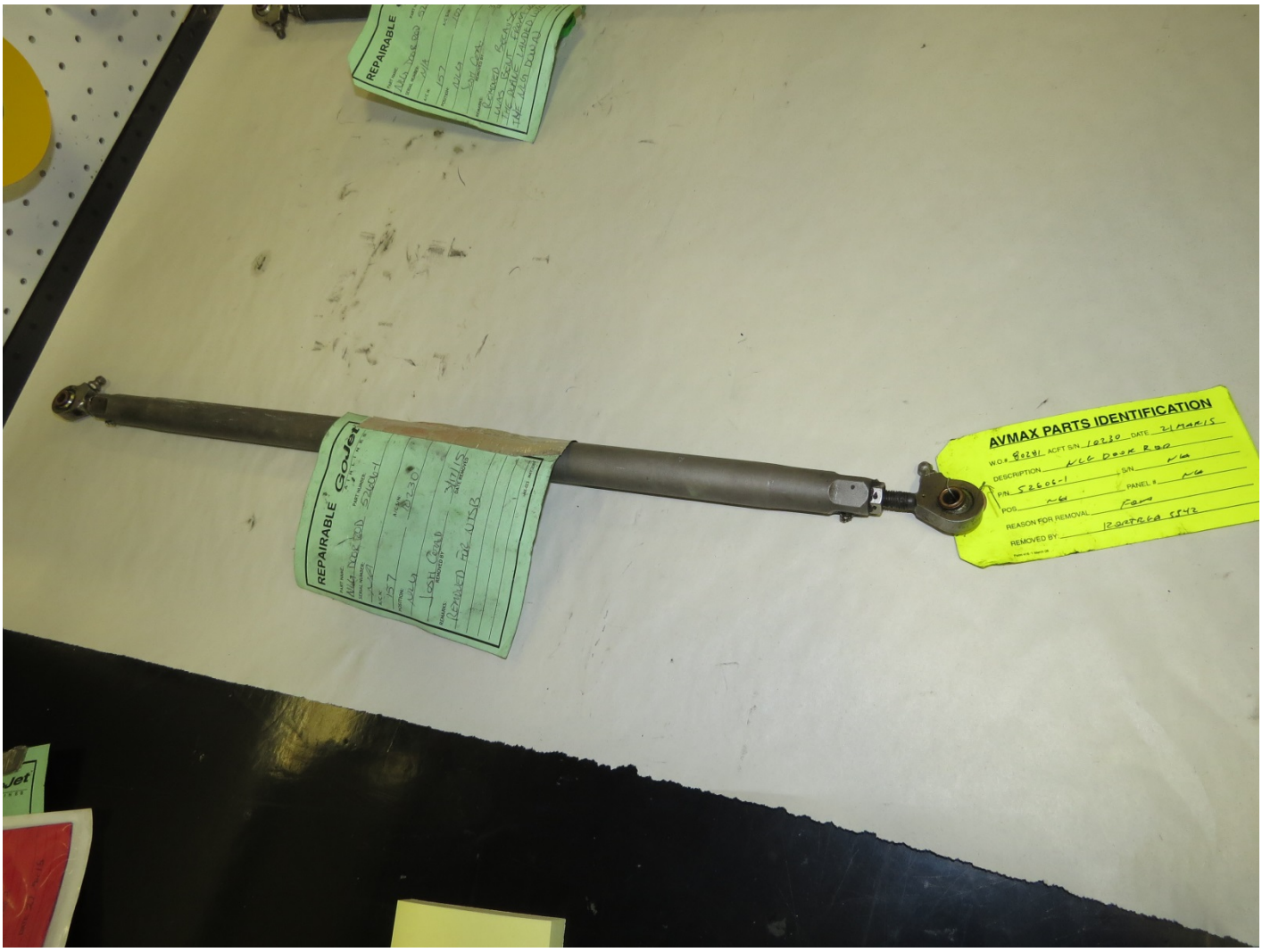


Figure 20
Door Rod (with yellow tag)

The nomenclature for the door rod was determined to be:
P/N: 52606-1
S/N: N/A

The rod was received with a yellow tag attached to one rod end. This rod end was able to rotate freely using hand pressure. The lock nut safety wire was noted to be intact.

The rod end was identified for further investigation at the UTAS M&P laboratory.

1.2.12 Door Rod (with red tag) (see figure 21)


Figure 21
Door Rod (with red tag)

The nomenclature for the door rod was determined to be:
P/N: 52606-1
S/N: N/A

The rod was received with a red tag attached to one rod end. This rod end was able to rotate freely using hand pressure. The lock nut safety wire was noted to be intact. The opposite rod end was noted to be bent.

The rod end was identified for further investigation at the UTAS M&P laboratory.

1.2.13 Pin (see figure 22)


Figure 22
Pin

The nomenclature for the pin was determined to be:
P/N: 52210-7
S/N: CH040299

Wear was noted on the pin surface adjacent to the drive arm. There was also wear noted on the inner pin surface that would be in contact with the drive arm chromed surface outer diameter.

The documentation of the extent of the inner surface wear was identified for further investigation by the UTAS M&P laboratory.

1.2.14 Drag Strut Cap (see figure 23)


Figure 23
Drag Strut Cap

The nomenclature for the drag strut cap was determined to be:
P/N: 52211-3
S/N: N/A

The cap was shipped with the bolt and one washer in the assembly. The nose gear illustrated parts catalog (IPC) shows

that there should be two washers on the nut side of the cap when assembled.

1.2.15 Lock Link Apex Pin (see figure 24)


Figure 24
Lock Link Apex Pin

The nomenclature for the lock link apex pin was determined to be:
P/N: 52212-1
S/N: SD060027

1.2.16 Pin (see figure 25)

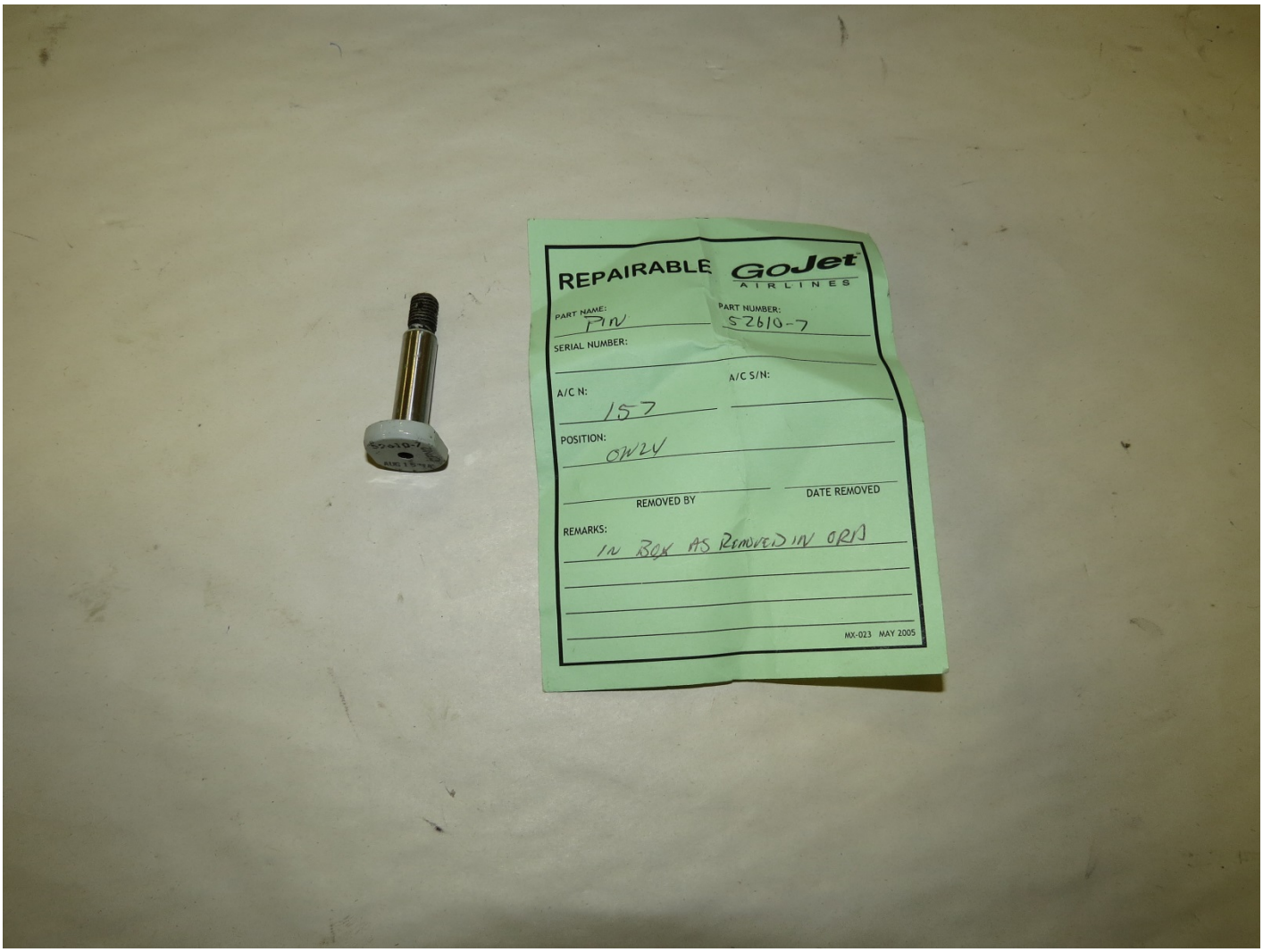


Figure 25
Pin

The nomenclature for the pin was determined to be:
P/N: 52610-7
S/N: N/A

The head of the pin contained the notations of, “CFN2” and “Aug 15 ‘14”. No nut was included with this pin.

1.2.17 Bolt (see figure 26)


Figure 26
Bolt

The nomenclature for the bolt was determined to be:
P/N: 52061-101
S/N: N/A

The bolt face had areas of chipped paint, and there was a nut included with the bolt.

1.2.18 Bracket (see figure 27)


Figure 27
Bracket

The nomenclature for the bracket was determined to be:
P/N: 52230-3
S/N: N/A

1.2.19 Bracket (see figure 28)


Figure 28
Bracket

The nomenclature for the bracket was determined to be:
P/N: 52230-4
S/N: N/A

1.2.20 Bolts (quantity of 3) (see figure 29)


Figure 29
Bolts

The nomenclature for each of the three bolts was determined to be:
P/N: 52615-1
S/N: N/A

1.3 Manufacturer Publications

The nose landing gear manufacturer (Goodrich) published service bulletin 52200-32-88 on September 11, 2015. This service bulletin directed operators to remove and replace the drive arm pin nuts and replace them with nuts with

a new part number and install them with Loctite at a higher torque value. The reason given for the service bulletin was that, "Operators have reported loose drive arm pins PN 52621-1. Loose drive arm pin nuts could lead to damage of the drag brace jury strut attachment flange."

The aircraft manufacturer (Bombardier) published service bulletin 670BA-32-055 on October 2, 2015. This service bulletin provided operators with the instructions to do Goodrich service bulletin 52200-32-88. The reason given for the service bulletin was that, "It is possible for the drive arm of the NLG drag brace to be disconnected from the lower lock-link assembly, if one or both nuts for the attachment pins come off. This can cause the NLG to not extend." Bombardier recommended that the operator accomplish the service bulletin within no more than 1,320 flight hours from the service bulletin release date, unless otherwise directed by the airworthiness authority of the operator.

Scott A. Warren
Lead Aerospace Engineer

Appendix A

UTAS (Goodrich) Failure Analysis Report
Dated: 11 April 2016

GOODRICH

**LANDING GEAR**

| | |
|---|---|
| TITLE | **FAILURE ANALYSIS REPORT<br>GOJET AIRLINES CRJ 700 NLG SHOCK STRUT<br>P/N 52000-21, S/N MA1085** |
| DOCUMENT NO. | **MPTR31020** |
| REVISION | **B** |
| DATE | **April 11, 2016** |

## APPROVALS

SEE UTAS LANDING SYSTEMS (LANDING GEAR) PLM SYSTEM FOR SIGNATURE AUTHORITY AND RELEASE STATUS.
THIS COPY IS UNCONTROLLED UNLESS RELEASE STATUS AND DATE ARE STAMPED BY PDM SYSTEM.

## EXPORT CLASSIFICATION

U.S. Export Classification: NSR

Designed and Engineered by CAGE Code: 13002

†NOTE: *To maintain consistency with the legal identity of the products manufactured and sold by UTAS Landing Systems (Landing Gear), the name Goodrich continues to remain as the product identification*

## Revisions Record

| REV | DESCRIPTION | PREPARED |
|---|---|---|
| NC | Initial Release | Jack FitzGerald |
| A | Removed scales from figure 7, 16-18 & 33 per ITC request | Jack FitzGerald |
| B | Remove proprietary information marking | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

# TABLE OF CONTENTS



## LIST OF FIGURES

## 1.0 INTRODUCTION

On March 14, 2015, a CRJ 700 aircraft (AC N157GJ) operated by GoJet Airlines for United Express landed at Chicago O'Hare Airport, Chicago, Illinois with the nose landing gear in the retracted position. It was reported that flight 3645 was a scheduled flight that originated from Gerald R. Ford Airport, Grand Rapids, Michigan. There were no injuries to the 37 passengers and 4 crew members aboard the aircraft.

It was reported that the aircraft was delivered to the customer on 12/9/2005 accumulating 26,124 TSN and 17,691 CSN. The nose landing gear and drag brace was due for overhaul in early 2016.

## 2.0 CONCLUSION

- The NLG gear failed to fully extend when the lower link, upper link and driven link assemblies articulated over center, mechanically immobilizing these components and the attached door rods to thus preventing them to fully extend.
- The over centering of the linkage occurred by the over travel of the drive link assembly that was a result of missing and damaged fastening hardware on the drive arm assembly.
- Hardness, dimensional, and microstructure testing of the components submitted to UTAS M&PT - Oakville were within the requirements of the engineering drawing.

## 3.0 TEST AND DISCUSSION

After removing the gear from the aircraft, the following components were submitted to UTAS Landing Gear in Burlington and Oakville, Ontario for further analysis

| Number | Part Name | Part Number | Serial Number |
|---|---|---|---|
| 1 | Driven Link | 52604-105 | WAI0167 |
| 2 | Upper Link | 52603-101 | N/A |
| 3 | Lower Link | 52602-103 | N/A |
| 4 | Lower Lock Link Assembly | 52207-103 | CPS050218 |
| 5 | Upper Drag Brace | 52201-107 | MK030307 |
| 6 | Drive Link Assembly | 52601-103 | WAI0182 |
| 7 | Drive Arm Assembly | 52620-103 | CII0143 |
| 8 | Upper Lock Link Assembly | 52205-1 | ACR110272 |
| 9 | Pin | 52621-1 | N/A |
| 10 | Bolt pin | 52065-101 | CH040225 |
| 11 | Upper drag brace pin assembly | 52052-3 | SPP0656 |
| 12 | Upper drag brace pin assembly | 52052-3 | SPP0655 |
| 13 | Door rod | 52606-1 | N/A |
| 14 | Door rod | 52606-1 | N/A |
| 15 | Pin | 52210-7 | CH040299 |
| 16 | Drag strut cap | 52211-3 | N/A |
| 17 | Lock link apex pin | 52212-1 | SD060027 |
| 18 | Pin | 52610-7 | N/A |
| 19 | Pin | 52610-7 | N/A |
| 20 | Bolt | 52061 | N/A |
| 21 | Bracket | 52230-3 | N/A |
| 22 | Bracket | 52230-4 | N/A |
| 23 | Bolt | 52615-1 | 2053 |
| 24 | Bolt | 52615-1 | 2051 |
| 25 | Bolt | 52615-1 | 2048 |
| 26 | Bolt | 52610-5 | N/A |
| 27 | Bracket Assembly | 52224-3 | N/A |
| 28 | Bolt | 52610-3 | N/A |
| 29 | Bolt | 52610-1 | N/A |

N/A: Not applicable

Figure 1 is a two dimensional image of the CATIA model highlighting the locations of the linkage assemblies of the CRJ 700 NLG submitted for examination.

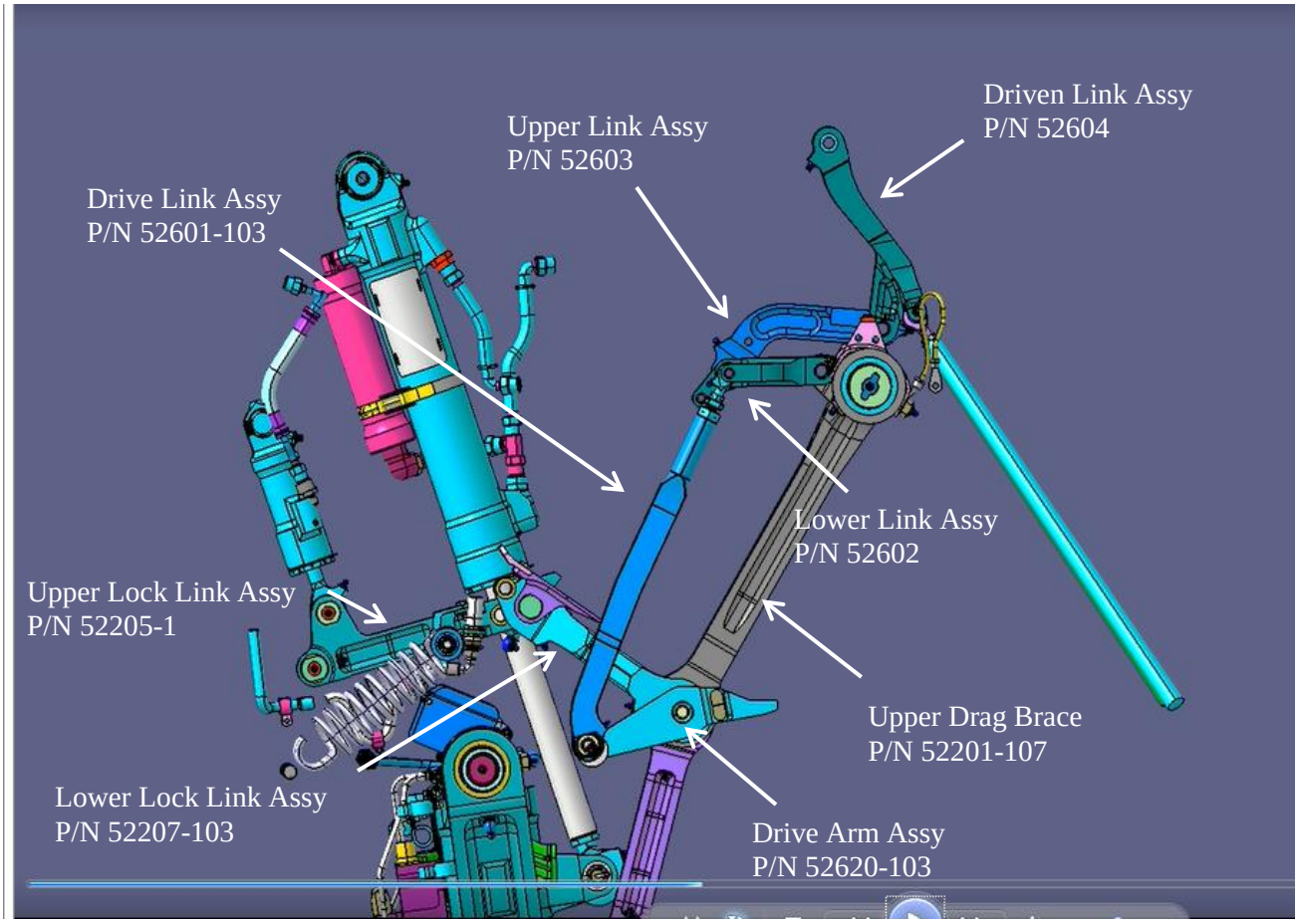


Figure 1: Arrangement of affected components and nomenclature.

The following is the analysis of the components submitted to UTAS M&PT Department:

Part: Driven Link Assembly
P/N: 52604-105
S/N: WAI0167
Material: 7075-T73 or 7075-T7351 Aluminum per QQ-A-225/9 or AMS4124

The upper lugs on the Driven Link Assembly are pinned to the fuselage of the aircraft using a chrome plated pin. The opposite end of the part has three pairs of lugs that facilitate the attachment of the Upper Link Assembly and two rods that attach to the doors.

Visual inspection of the part displayed in figures 2 and 3 did not reveal any outward mechanical damage, distortion, or discoloration. Examination of the attachment lug holes displayed ample black grease with no obvious elongation or mechanical damage.

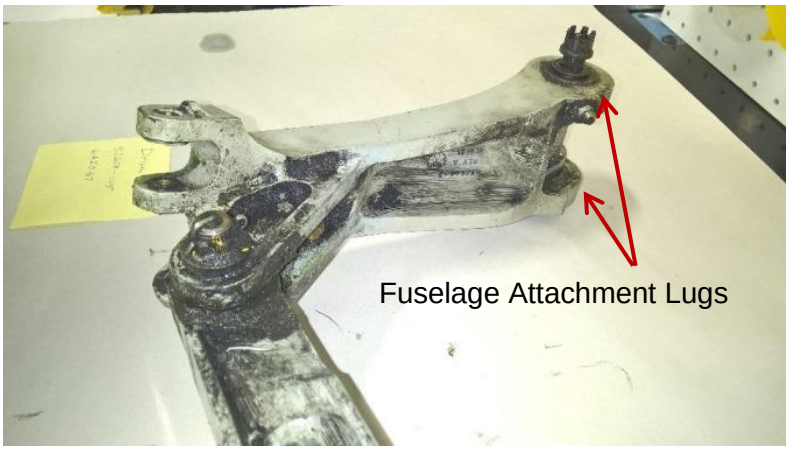


Figure 2
"As Received" Assembly

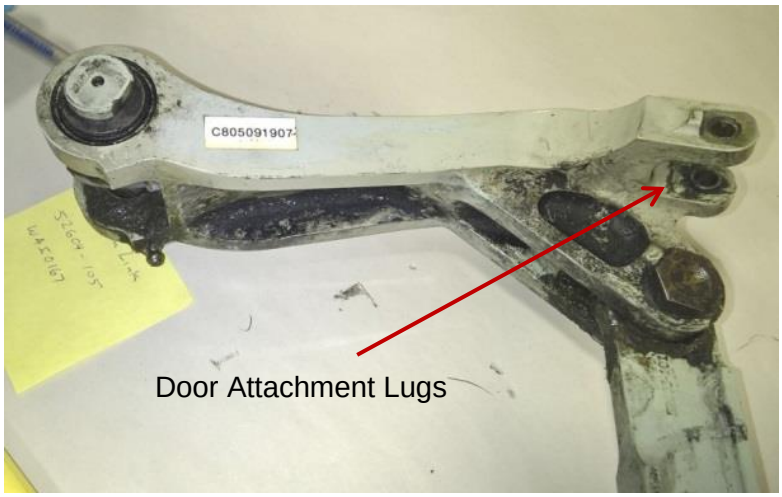


Figure 3
Opposite Side of Assembly

Part: Upper Link Assembly

P/N: 52603-101
S/N: N/A
Material: 4340 Steel per AMS6414, Heat Treat to 180-200 KSI per AMS2759/1

The Upper Link Assembly, displayed in figure 4, is attached to the Driven Link Assembly (P/N 52604) and the Lower Link Assembly (P/N 52602) through chrome plated pins on each end of the part. The attachment points displayed ample grime and black colored grease with no binding exhibited between the joined components.

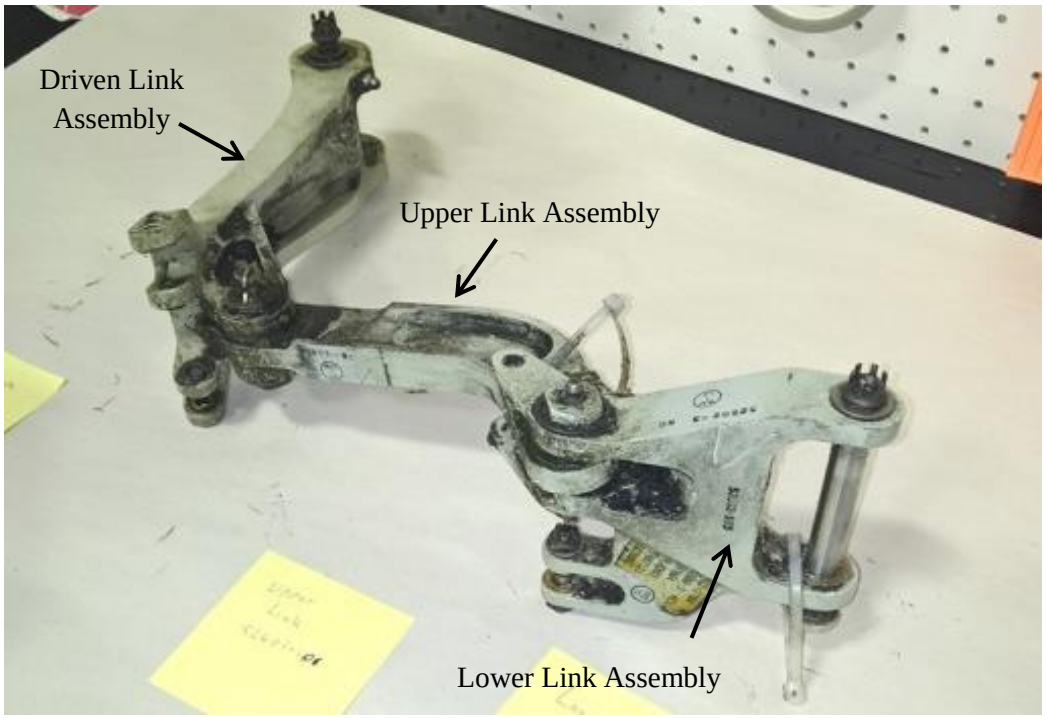


Figure 4
"As Received" Upper Link Assembly
Attached to Mating Assemblies

After cleaning the surfaces using a vapor degreaser, the Upper Link Assembly was re-examined. Inspection revealed impact damage across a flat surface adjacent to the grease nipple on the upper link assembly, as highlighted on figures 5 and 6. Although the damage resulted in the primer and paint to be scraped away to the base metal, no discoloration or corrosion was found on the exposed surface indicating that the damage occurred recently. Inspection of the adjacent corner on the lower link assembly revealed matching contact damage.

To characterize the depth of the damage, a replica of the impression at the contact damage on the upper link was obtained using RepliSet F5™ and is displayed in figure 7. This method of obtaining a replica is considered to render high level of accuracy (better than 1 µm accuracy). The obtained replica was analyzed using a digital microscope using a line-profile, see figure 7. The depth of the impression at the center was determined to be approximately 0.021 inches (547 microns).

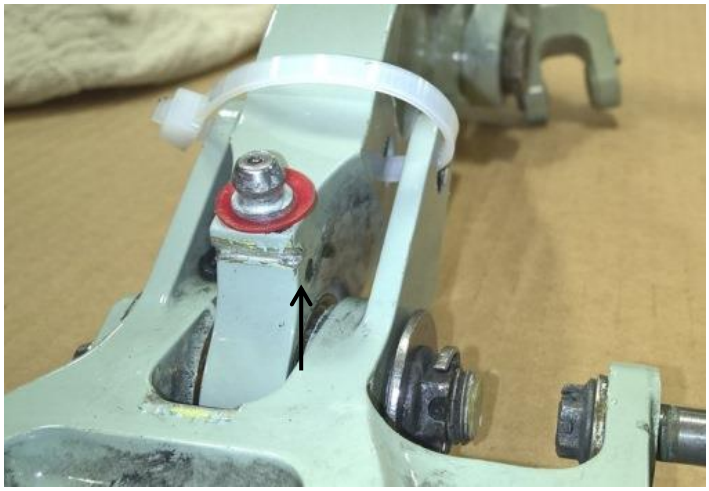

Figure 5
Impact Damage at End
Of Upper Link

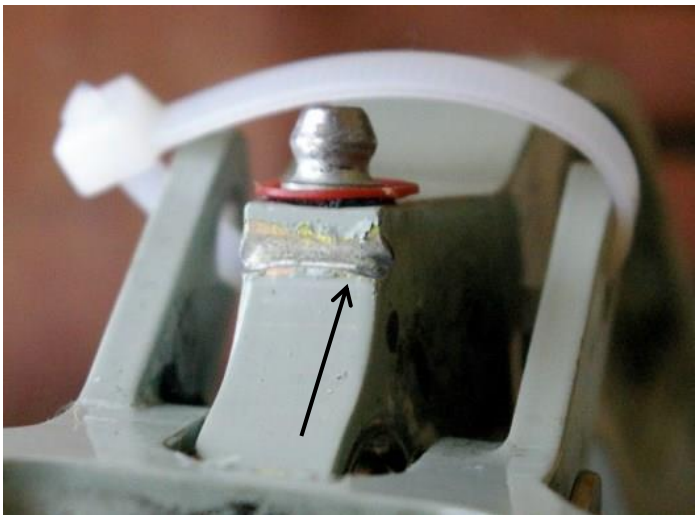

Figure 6
Higher Magnification of
Impact Damage

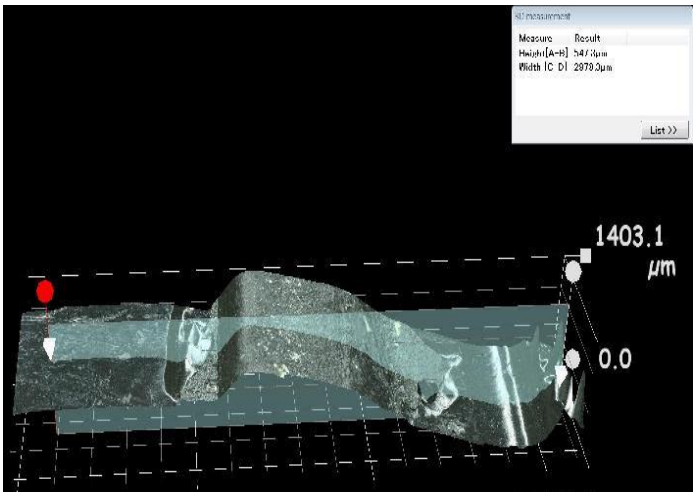


Figure 7
Impression of Impact Area
on the Link, Line Scan with
Depths is shown at Bottom.

Part: Lower Link Assembly
P/N: 52602-103
S/N: N/A
Material: 4340 Steel per AMS6414, Heat Treat to 180-200 KSI per AMS2759/1

The Lower Link Assembly has three sets of attachment lugs. One set of lugs is attached to the Upper Drag Brace using a chrome plated bolt, as depicted on figure 8. The other two sets of lugs, also highlighted on figure 8, are attached to the Upper Link and Drive Link Assemblies using chrome plated bolts.

Figure 8 displays the "as received" surface of the Lower Link Assembly. The chrome plated bolts and mating lug hole surfaces were covered with black colored grease, with unrestricted movement to the attached assemblies.

After cleaning the part, the surfaces were visually re-examined. Inspection of the corner at the base of the upper link assembly attachment lugs revealed contact damage from impacting the flat surface adjacent to the grease nipple on the upper link assembly (figure 9). The damaged area displayed parallel scrapes that removed the paint and primer, exposing the surface of the base metal. The exposed 4340 steel did not reveal any discoloration or corrosion, indicating that the contact damage had occurred recently.

Two other contact damage areas, highlighted in figure 10, were found on the flat surface adjacent to the base of the lugs that connects to the drive link assembly. The damaged areas coincide with the location the end of the rod end nuts on the end of the drive link assembly indicating that the upper linkage had traversed over center during retraction. The contact damage found on the two regions suggests that the upper and lower link assemblies would have had to articulate beyond the expected retract design path.

Since the exposed base metal regions were free of discoloration and corrosion, it's likely that this occurred within the same timeframe as the damage to the adjacent links.

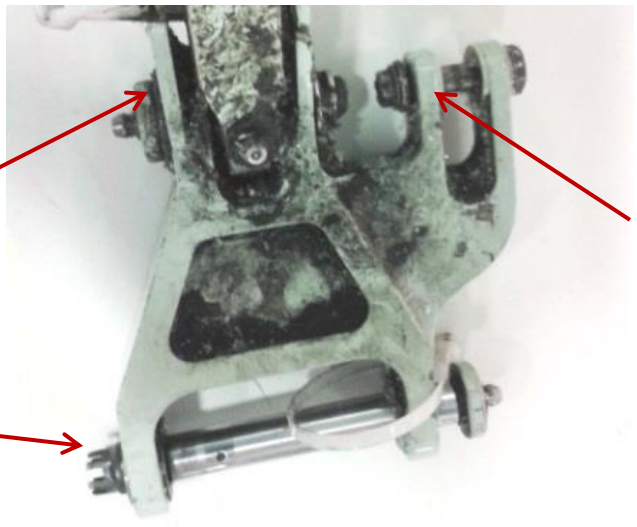


Figure 8
"As Received" Lower Link Assembly

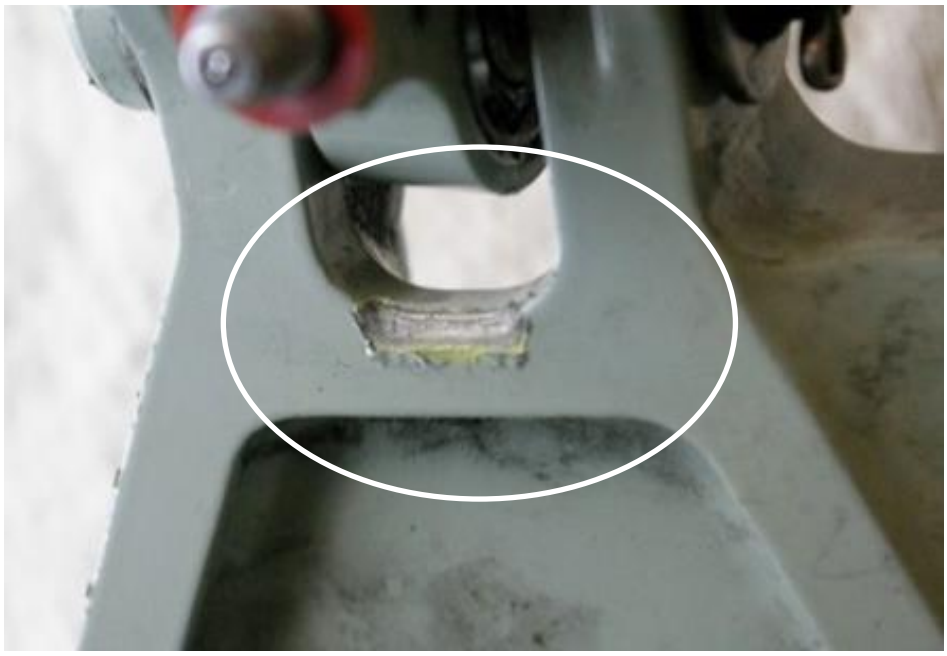

Figure 9
Impact Damage from Contact with the Upper Link Assembly

Figure 10
Contact Damage from Contact with the end of the Drive Arm Assembly

Part: Drive Link Assembly

P/N 52601-103
S/N WAI0182
Material 300M Steel per AMS 6419, Heat Treat to 280-300 KSI per AMS 2759/2

The Drive Link Assembly attached to the Drive Arm Assembly, facilitates the articulation of the Upper Link, Lower Link, and Driven Link Assemblies when the gear is retracted or extended.

The Drive Link Assembly was received with the threaded spherical bearing rod end fractured away as showed in figure 11. Examination of the corners of the adjustment associated with the fractured spherical bearing end, displayed recent contact damage as presented in figure 12. The location of the damage coincides with the scraped paint and primer found on the lower link assembly (ref figure 10), when the attached linkage traversed over center.

Inspection of the painted surface on the end attached to the drive arm revealed circumferential scratches as shown on figure 13. Since this portion of the link does not articulate near another component it is likely the scratches occurred during or after the subject incident.

Hardness inspection was performed on the part with the following results:

- HRC 54.3
- HRC 54.1
- HRC 54.4
- HRC 54.4

The engineering drawing requires the hardness to be HRC 53-55

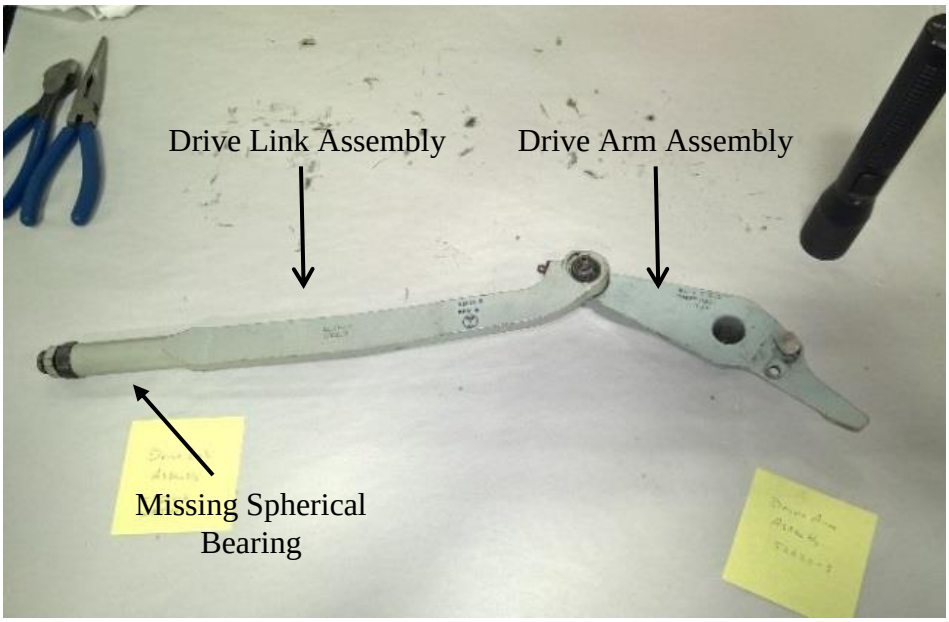


Figure 11
Drive Link Assembly Attached to the Drive Arm Assembly

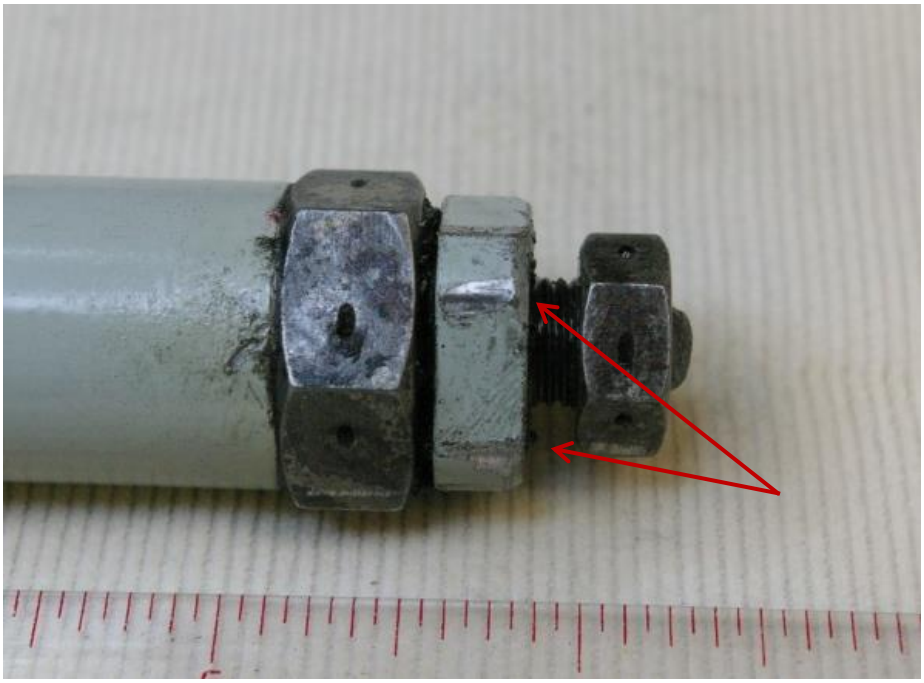

Figure 12
Damage to the Corner of the Spherical Bearing Adjustment Nuts

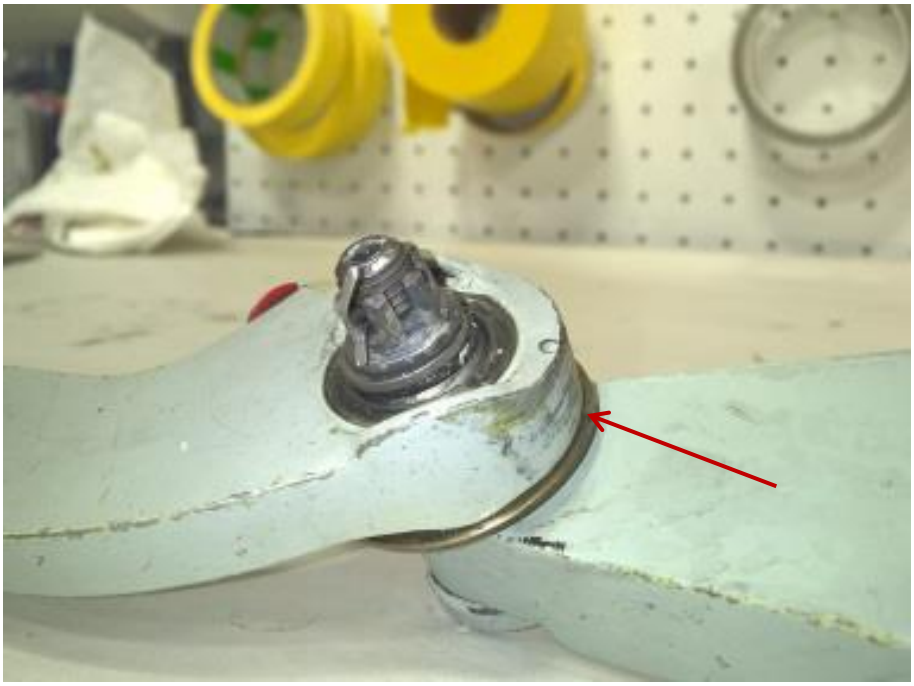

Figure 13
Circumferential Paint and Primer Scrapes on end of Drive Arm Link

Part: Spherical Bearing – Drive Link Assembly
P/N: 52606-1
S/N: N/A
Material: 15-5 PH CRES Bar per AMS 5659, Heat Treated to the H1025 condition. Hardness to be HRC 34-39

The spherical bearing attached to the Drive Link Assembly was discovered fractured across the bearings thread as shown on figure 14. As it can be seen in Figure 14, the thread pitch was compressed on one side and slightly elongated on the opposite side. The surface morphology of the fracture face displayed a cup cone feature across the majority of the outside edge as highlighted on figure 15. This fracture morphology is consistent with components subjected to tensile overload conditions.

Figure 14
Fractured Spherical Bearing


Figure 15
Spherical Bearing Fracture Face

HARDNESS INSPECTION

The bearing was hardness tested with the following results:

HRC 37.5
HRC 37.9
HRC 37.4

The engineering drawing requires the hardness to be HRC 34-39

**SEM INSPECTION**

After ultrasonic cleaning of the bearing using isopropyl alcohol, the fracture face was inspected using the scanning electron microscope. The fracture face exhibited two flat surface features surrounded by shear lips as highlighted in figure 16. The flat surfaces represented in Figure 17 at 950X magnification photo displaying ductile dimple fracture morphology. These two flat features suggest that the fracture occurred in two cycles. One cycle created a large crack with its accompanying shear lip but arrested, the second crack was created after a second high load event which lead to the final fracture.

The surfaces of the shear lip displayed on figure 18 at 1000X magnification was also examined, exhibited elongated dimple ductile shear morphology. These images confirmed that the spherical bearing fractured by tensile overload in bending.

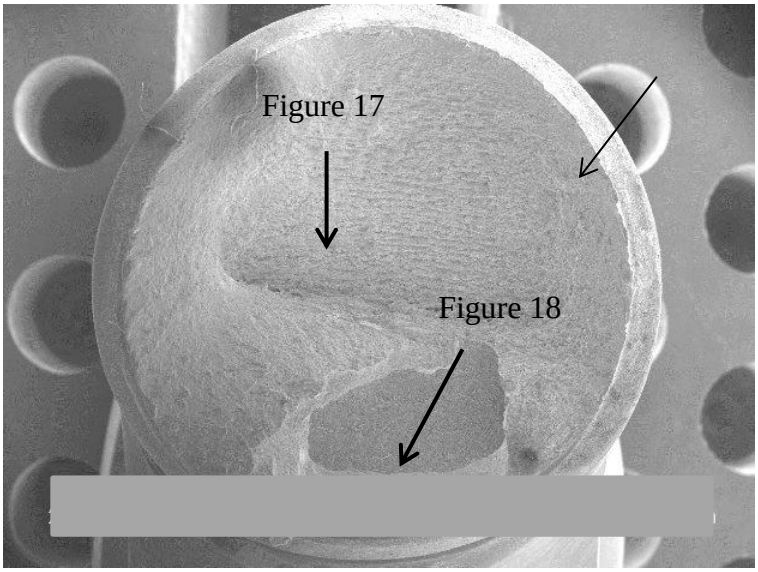


Figure 16
Spherical Bearing Fracture Face

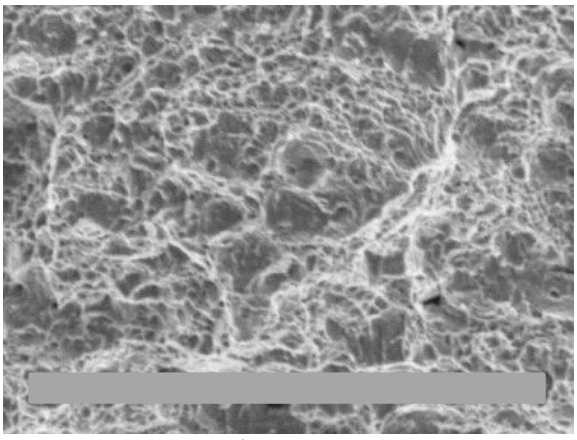

Figure 17
Dimple Ductile Morphology

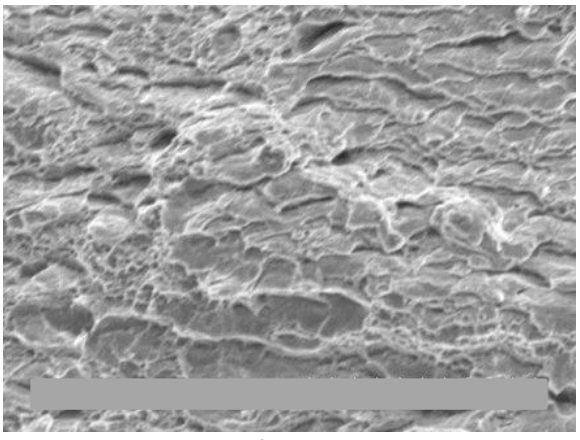

Figure 18
Elongated Dimple Ductile/Shear Surface

Part: Drive Arm Assembly
P/N: 52620-103
S/N: CII0143

Material: 300M Steel per AMS 6419, Heat Treat to 280-300 KSI per AMS 2759/2

The function of the Drive Arm Assembly is to articulate the Drive Link Assembly that facilitates the opening and closing of the NLG doors through the door rods attached to the Driven Link Assembly. The Drive Arm Assembly is attached to the Lower Lock Link Assembly using two “D” headed pins (P/N 52621), nuts (P/N MS21042L4), and washers (P/N NAS620C416L). The Drive Link Assembly in turn, is attached to a chrome plated pin bolted to the end of the drive arm. The drive arm is also used to unlock the jury strut during alternate extension by providing a chrome plated lug which is mechanically driven by the alternate release actuator highlighted in figure 19 and 20.

Figures 19 and 20 are photos of the as-received drive arm assembly. One of the two “D” headed pin used to secure the Drive Arm was found completely bent, as displayed in figure 21. The primed surface adjacent to the lower pin hole displayed scrapes to the base metal indicating relative motion between the two components prior to separation as highlighted on figure 22.


Figure 19
“As-Received” Drive Arm

Figure 20
Opposite Face of Drive Arm

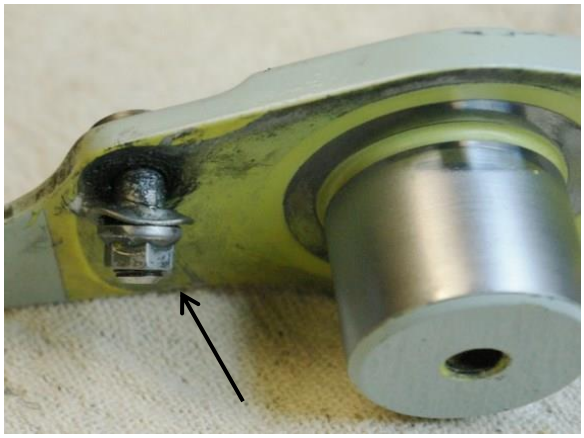

Figure 21
Distorted “D” headed Pin and Nut

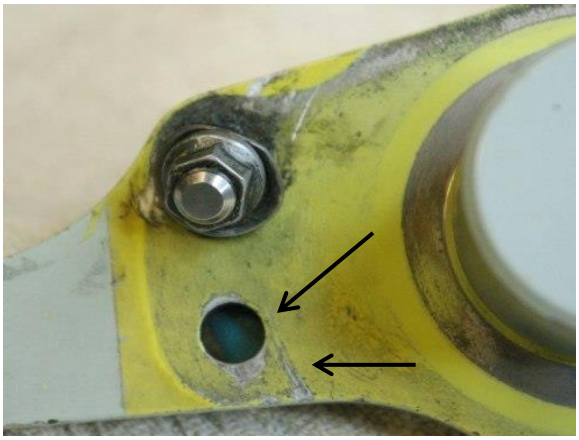

Figure 22
Scratches Adjacent to Pin Hole

The “as chrome plated” OD feature of the drive arm were worn preferentially 180 degrees apart, adjacent to the chamfer as highlighted in figures 23 and 24, indicating non-uniform wear pattern and asymmetric loading of the joint.

Figure 23
Wear on Upper Face of OD Feature

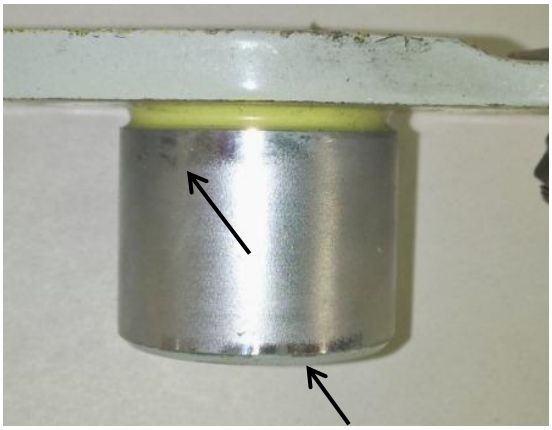

Figure 24
Wear on Upper Face of OD Feature

Hardness inspection was performed on the part with the following results:

- HRC 54.3
- HRC 54.1
- HRC 54.4
- HRC 54.4

The engineering drawing requires the hardness to be HRC 53-55

To examine the microstructure of the Drive Arm material, a specimen was excised from the part, mounted, polished, and etched using 3% Nital Etch Reagent. Metallographic inspection showed the expected tempered martensite as shown in figure 25 at 200X.

Figure 25
Tempered Martensite Microstructure

Part: Lower Lock Link Assembly
P/N: 52207-103
S/N: CPS050218
Material: Make from P/N 52208-1 Forging, 7075-T73 Aluminum per MIL-A-22771

The lower lock link assembly is attached to the apex of upper and lower drag brace assembly and is connected to the upper lock link assembly. The over-centering action of the jury strut mechanically locks the upper and lower drag brace assemblies. This action of the jury strut is used to lock the gear in the retracted or extended position. The second function of the assembly is to facilitate the opening and closing of the NLG doors by transferring the motion of the lower lock link to the attached drive link assembly. The drive link pinned to the drive arm articulates the door rods attached to the drive link assembly.

The Lower Lock Link was received as shown in figures 26 and 27. The outside surface of lug displayed 'V' shaped indentations, a circumferential gouge, and an impact impression as highlighted in figures 28 and 29. The lug hole and impressions of the surface damage are consistent with impact from the nut head and washer after shearing the lug hole. The "D" headed pin and nut that occupied the sheared lug hole was found deformed and still present on the mating drive arm assembly.


Figure 26
Lower Lock Link Assembly

Figure 27
Side View

Figure 28
Fractured Lug Hole and Adjacent Damage

Figure 29
Gouging and Impact Damage

Inspection of the lower “D” headed pin highlighted in figures 30 and 31 revealed that the pin had sheared at the interface of the two assemblies. Viewed from the opposite side, (Figure 31), the sheared “D” headed pin was seen to protrude exposing 4 threads. Aside from the obvious bend, the surface of the exposed threads and lug hole surface did not reveal any mechanical damage. This could suggest that the nut may have failed or backed off and escape the pin during the cycling of the gear.

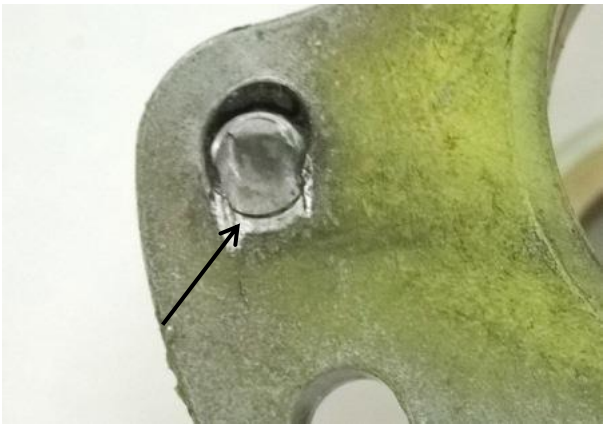

Figure 30
Pin Sheared at Drive Arm/
Lower Lock Link Interface

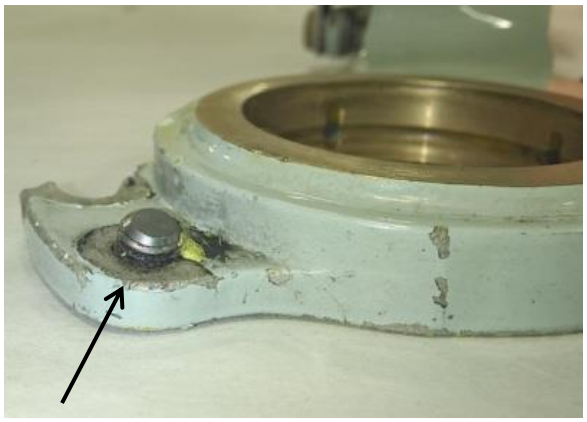

Figure 31
Exposed Threads from Sheared Pin

Conductivity/Hardness

Conductivity of the material was shown to be 39.9 I.A.C.S.
Hardness was found to be HRB 78.

SEM Examination

Inspection of the fracture face and adjacent edges of the lug revealed a dimple ductile rupture morphology, typical of tensile overload, as well as mechanical impact damage as displayed in figures 32 and 33. This damage is consistent with the bolt shearing across the lug.

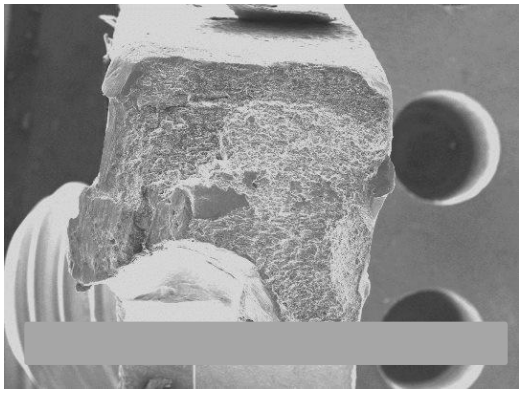

Figure 32
Fracture Face

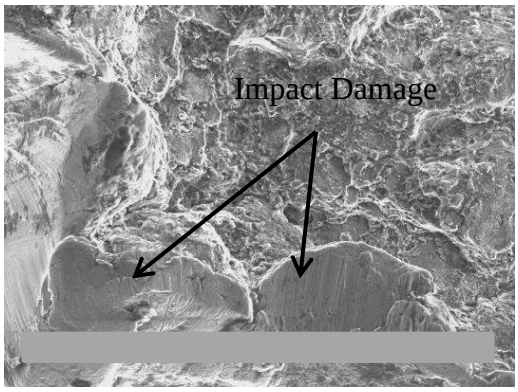


Figure 33
Fracture Face/Edge Interface

Microstructure

A portion of the Lower Lock Link Assembly was sectioned away, polished, and etched using Marbles Etch Reagent. Figure 34 is a 200X magnification photo displaying the expected 7075 aluminum solution treated and aged to the T73 condition microstructure.

Figure 34

Microstructure of the 7075 T73
Lower Lock Link
200X

Part: Nut
P/N: MS21042L4

The Drive Arm is fastened to the Lower Lock Link using two nuts/washers and 'D' headed pins. The engineering drawing calls out that the torque values to be applied to the MS21042L4 nuts are to be 10-12 inch pounds. Due to the extensive damage to the 'D' headed pin and washer the torque value could not be verified. Since the evidence indicates that one of the two pins did not have a nut attached, a design review of the nut and anti-rotational features would be recommended.

Self-locking capability is provided by two indentations placed across two opposite faces of the nut, these indentations were found to be approximately 0.0090 inches deep. Another nut was taken from stock and found to have 0.0095 inch indentation.

Part: Drive Arm/Lock Link Pin
P/N: 52621-1
Material: 15-5 PH CRES per AMS 5659, Heat Treat to HRC 34-39

Hardness inspection of the "D" headed pin still attached to the Drive Arm were tested and found to be:

- HRC 35.8
- HRC 36.7
- HRC 36.3

Threads

The dimensions of the major and pitch diameter on the distorted pin as well as a virgin pin removed from stock were measured and conforms to the engineering drawing.

Part: Upper Drag Brace

P/N 52201-107
S/N MK030307
Material: Make from forging P/N 52202-1 or -3, 300M Steel per AMS 6419
Heat Treat to 280-300 KSI UTS per AMS 2759/2

The upper drag brace was received in a cleaned condition as displayed in figure 35. With the exception of the expected minor chips to the paint of a service component, no outward mechanical damage, discoloration, or distortion was found on the part.

Figure 35
As-Received Upper Drag Brace

## OVERVIEW

The operation of the nose landing gear requires multiple components to articulate in concert with each other to facilitate the opening and closing of the door, locking and unlocking the braces, and extending and retraction of the gear. A review of the events reported by the operator and the examination of the submitted components are summarized as follows:

SUMMARY OF DAMAGED COMPONENTS

- Two areas on the Lower Link Assembly displayed damage from contacting the Upper Link Assembly and the Drive Link Assembly.
- The spherical bearing attached to the Drive Link Assembly was found to have fractured away from the Lower Link Assembly.
- The Drive Arm Assembly that attaches to the Lower Lock Link Assembly using two 'D' pin/MS21042L4 nut combinations was recovered with only one pin/nut still attached. The bolt and washer were shown to be heavily distorted.
- The portion of the hole in the Lower Lock Link Assembly that facilitates one of the two bolts/nuts to fasten the Drive Arm Assembly was found sheared from the lug.
- Inspection of the primed mating surfaces of the Drive Arm Assembly and Lower Lock Link Assembly revealed missing paint 180 degrees from each other adjacent to the bolt holes indicating back and forth movement between the two components.

To facilitate the collective damage listed above and the resulting inability to extend the landing gear, it is likely that the following scenario took place:-

- One of the two MS21042L4 nuts on the lower 'D' headed pins securing and providing anti-rotation between the Drive Arm Assembly to the Lower Lock Link Assembly had lost pre-load and backed off. This conclusion is based on the evidence that the end of the protruding threads on the sheared pin did not show any physical damage from the threads interacting with the nut.
- Accepting the absence of the nut on the 'D' headed pin, the Drive Arm Assembly is provided a side to side rotational movement as well as creating a gap with the Lower Lock Link Assembly during the extension and retraction of the gear as displayed in figure 36. Evidence of the side to side movement between the components was found by way of rub marks in the primed surfaces adjacent to the sheared bolt hole and other surfaces between the two parts.





Gap

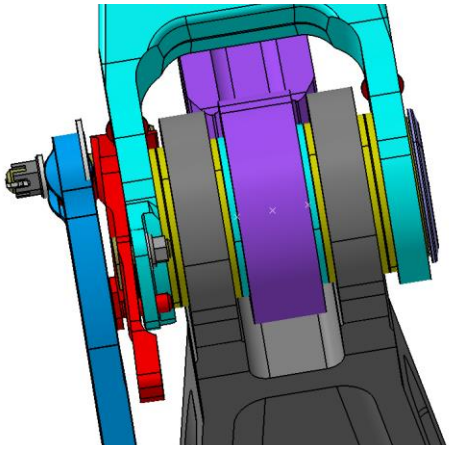

Figure 36

The opening and closing of the landing gear doors is choreographed through the Driven Link, Lower Link, and Upper Link Assemblies, articulated by the Drive Link Assembly attached to the Drive Arm Assembly. The absence of the nut and the gap between the adjacent components causes the loads to be transferred to the upper 'D' headed bolt, in turn causing the aluminum lug to fail in tensile overload, as highlighted on figure 37.

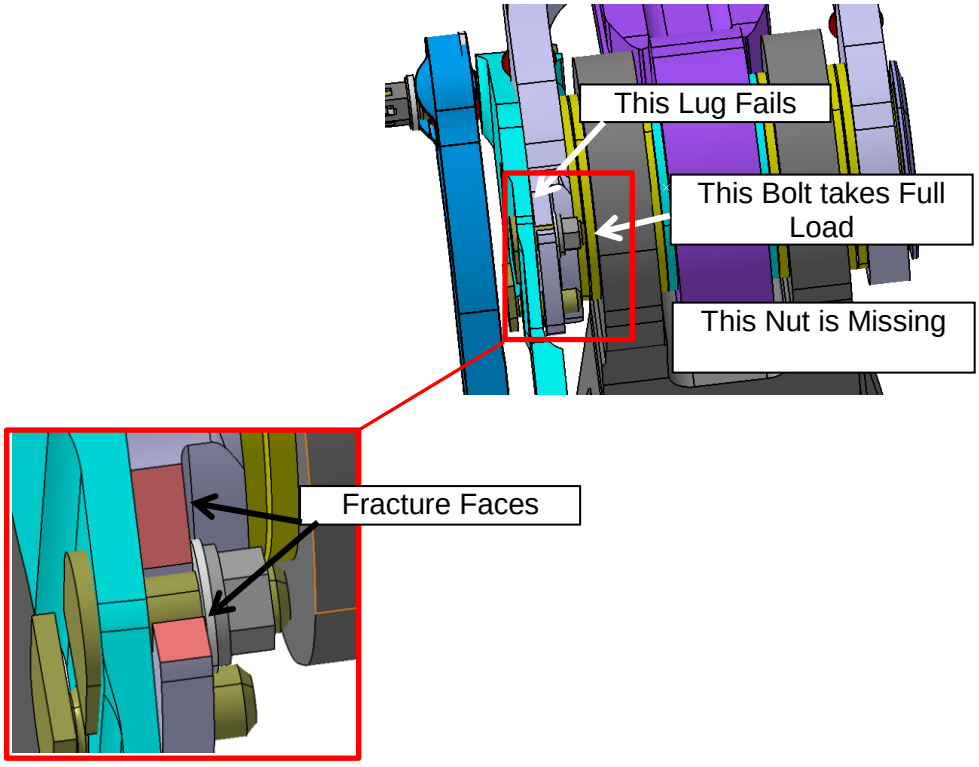


Figure 37

- With the upper D head pin no longer attached, the entire load is transferred through the lower D head pin. The subsequent loads applied during the articulation path circumscribed by the link assemblies resulted in fracture of the lower pin in shear, as displayed in figure 38. Since the drive arm is no longer tethered to the lock link, the drive arm is free to rotate about the apex joint.

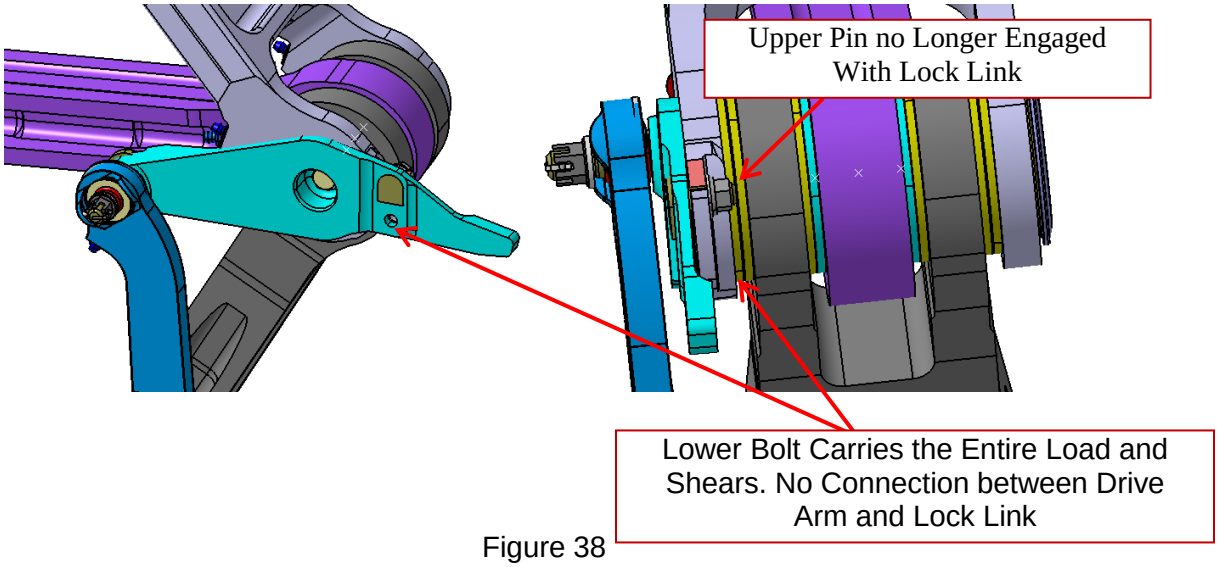


Figure 38
Unrestricted Drive Arm

- With the drive arm free to rotate about the apex joint, the door links were able to go overcenter, further than designed, allowing the drive rod to contact the lower link, as shown in figure 39.

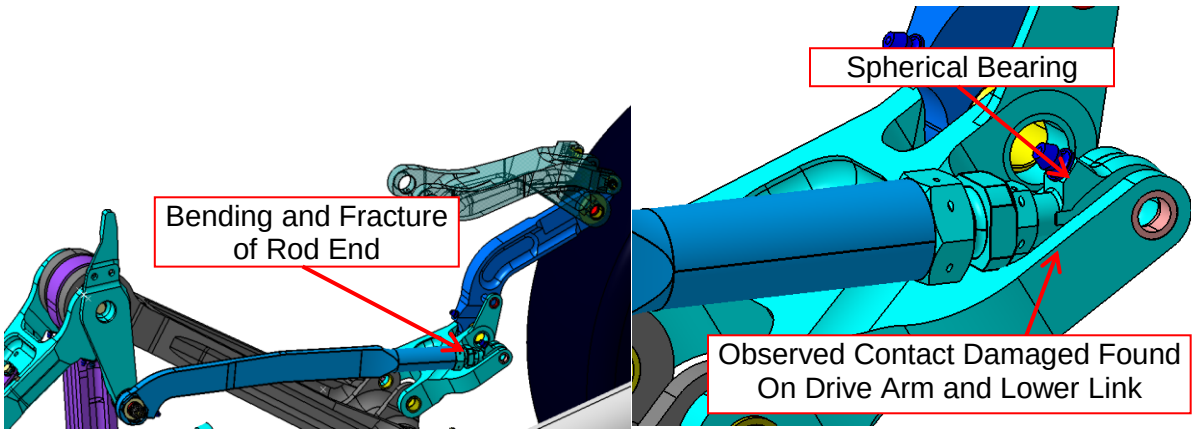


Figure 39

- Since the overcenter between the upper and lower link was deeper than designed, when the NLG was next commanded to extend the geometry would not allow for the drive link to pull the upper/lower link out of lock and thus as the NLG continued to traverse the rod end of the driven link contacted to lower link and subsequently failed in bending.

- As a result of the rod end failure the door linkage is no longer connected to the kinematics of the landing gear and thus the airloads on the fwd doors held the upper and lower linkage in the overcenter condition. The NLG subsequently rested on the forward doors.