INVESTIGATION REPORT RELATING TO

NTSB/GULFSTREAM/GOODRICH/PDI

JOINT INVESTIGATION ON

PN 7438-4, SWIVEL ASSEMBLY, NOSE GEAR

SERIAL NUMBER 0748

AS USED ON GULFSTREAM G550 AIRCRAFT N535GA

REVISION

LTR	DESCRIPTION	DATE	APPROVAL
-	Initial Release	4/15/2011	G. Burns
A	Corrected NTSB agency name in section 1.0 (“Transportation”, not “Traffic”).	4/20/2011	G. Burns
B	Incorporated comments from David Hsu (ANM-120L) e-mail of 4/20/2011: • Added 4.4 and renumbered subsequent sections. • Added Appendix A. • Added second and third paragraphs to section 5.0.	4/28/2011	G. Burns

1.0 SCOPE

This document contains information relating to the investigation activities conducted at PneuDraulics on Thursday, April 7, 2011 involving the National Transportation Safety Board (NTSB), Gulfstream, Goodrich, and PneuDraulics, relating to the PN 7438-4, SN 0748 swivel that was installed on the Gulfstream G550 aircraft, tail number N535GA, which was involved in a runway overshoot at Outagamie County Regional Airport, Appleton, Wisconsin, on February 14, 2011 (NTSB incident identification CEN11IA193). The activities involved visual and dimensional evaluation of the as-received article as well as in its disassembled state, and the scope of this report ends prior to the (now pending) metallurgical evaluation yet to be conducted by NTSB/Gulfstream.

2.0 BACKGROUND

The swivel is an aluminum assembly that allows for hydraulic system continuity and integrity while being attached to the moving nose landing gear structure. It is mounted between the landing gear main load bearing member in the front and the drag brace in the rear.

Photo 1, Swivel Location

After the noted incident (see scope statement) it was observed that the swivel exhibited a crack in one of the short tubes connecting the center and aft swivels.

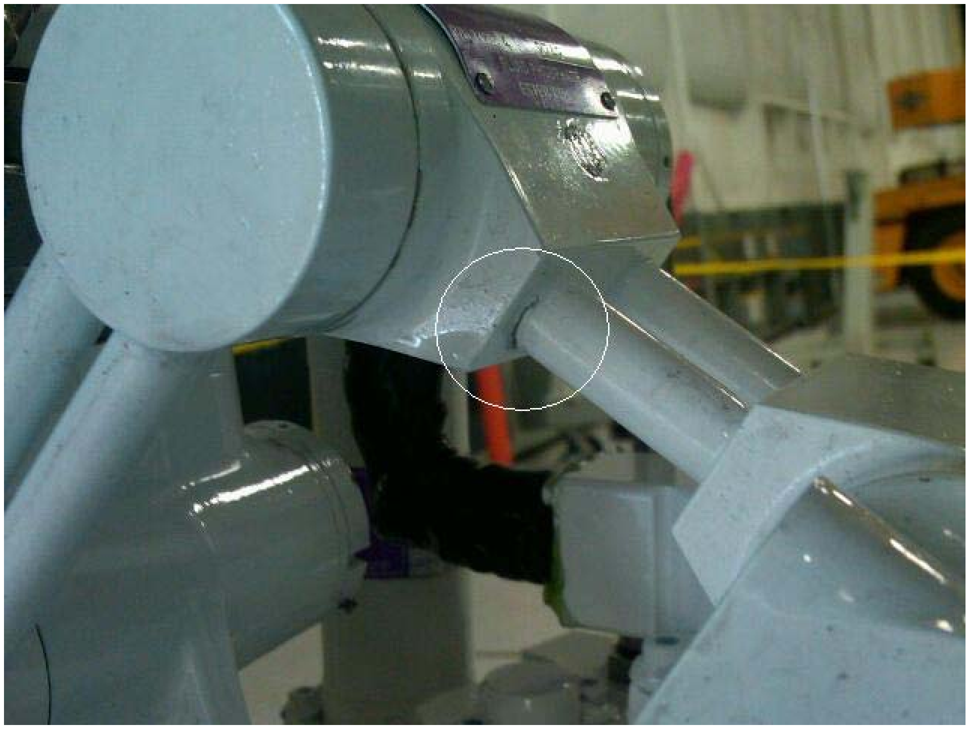

Photo 2, View of Cracked Tube

The swivel was removed from the aircraft and sent to PneuDraulics for the purpose of investigation and teardown. Participating in the investigation at various times throughout the one-day event were:

Name	Title	Organization
Ed Malinowski	Representative	NTSB
Louise Wu	Representative	FAA
David Y. J. Hsu	Representativere	FAA, LAACO
Ben Evans	Materials and Process Technician	Goodrich
Carol Blaine	West Coast SQA	Goodrich
Danny Smith	IP Procurement	Gulfstream
Jay Bias	Quality	Gulfstream
Branko Stropnik	Principal Engr., Service Engineering	Gulfstream
Walter Young II	System Engr. (Mechanical)	Gulfstream
Dain Miller	President	PneuDraulics
Mike Schober	VP/Director of Engineering	PneuDraulics
Greg Burns	Director of Quality	PneuDraulics
Richard Wurtz	Director of Manufacturing	PneuDraulics
Gerry Loftis	Engineering Manager	PneuDraulics
Megan Meehan	Quality Engineer	PneuDraulics
John Palacat	Technician	PneuDraulics

3.0 SERVICE HISTORY

Prior to product return, a review was made of the service history for the 7438-4 configuration. As implied by the serial number, there have been almost 800 of these swivels manufactured and put into service over the course of the ten years since its introduction in 2001. There were also 7438, 7438-1, 7438-2, and 7438-3 configurations dating back to 1994 that were forerunners of the current design.

Serial number 0414 had been reported with broken tubes and was received at PneuDraulics in April of 2011, but was attributed to an installation error of the landing gear assembly during field maintenance activity, where the center swivel segment was installed downwards while being attached to the drag brace (instead of the proper upwards orientation) and was catastrophically damaged upon gear actuation; the unit showing obvious signs of crushing/impact (photos available).

Serial number 0540 had been returned in June of 2010 with a report of “received on gear wrapped towards the right” (RPO55345, Goodrich PO 9919629) – the inference being it had been damaged during transit from Goodrich (which installs the swivel upon the landing gear, bundles to a closed position with plastic ties, and ships to Gulfstream for incorporation on the aircraft and coupling to hydraulic lines and physically to the drag brace at the aft end of the swivel).

Serial number 0689 had also been returned in May of 2010 with broken tubes, but this too was attributed to an installation error of the landing gear assembly at Gulfstream on the line (photos available; reference RPO55835).

4.0 INVESTIGATION RESULTS

The general sequence of investigation was:
a. Visual/photo.
b. Filter patch.
c. Fit check.
d. Disassembly.
f. Dimensional.
Each of these steps will be treated in greater detail in the following sections.

4.1 Visual/Photo

The inbound condition of the swivel was visually confirmed and photographically recorded. Aside from the previously mentioned crack at one of the short tubes, there was also visible associated deformation of the housing subassembly (specifically the orientation of the two housing segments joined by the short tubes) and the paint on the second short tube also displayed evidence of stress cracks. The swivel was actuated by hand: both end segments were able to be rotated, the center segment being frozen. There were no other significant anomalies.

Photographs were taken throughout the investigation process. Note that references in this document to photos or other data being available means that they are located on the PneuDraulics public server in the quality subdirectory (P:\Quality Control\Regulatory and Industry Entities\NTSB\20110415, 7438-4, SN 0748) or are otherwise part of the PneuDraulics data retention system.

4.2 Filter Patch

A standard filter patch was taken and various contaminates noted, metallic, fibrous, etc. – none of which were judged to be relevant to the frozen condition of the center swivel segment. Note that later filter patches taken during/after disassembly showed gross contamination from metallics, the consensus being that they came from the galling apparent on the interior working surfaces of the swivel components described later in this report.

Photo 3, Inbound Filter Patch

4.3 Fit Check

A fit check was done to the tool that is used during the outbound Acceptance Test Procedure (ref: ATP 7438-4). The tool showed an approximate .03" mismatch between the various mounting surfaces. This was also confirmed by checking the parallelism between the mounting faces which confirmed a .030" misalignment. Note that there is no specific drawing requirement for this characteristic, but measurements made on two other new units under construction showed .005/.020". David Hsu comments: "Please note that the 0.03 inches permanent deformation definitely created a secondary bending that would add stresses to the normal design stresses at the location of the Transfer Tube failure, due to the hydraulic proof pressure loading as well as the hydraulic operating pressure along with the normal swivel joint frictional loading during landing and take-off NLG retractions."

4.4 Force Check

Note that no measurement was made to determine the force required to overcome the jamming of the failed part swivel joint. [It is because whatever the amount of the force required to overcome this jamming of the failed part swivel joint, along with other loads, such as the hydraulic operating pressure, etc. etc. may have resulted in a 0.03 inches of distortion (which became apparent in the ATP test fixture [see 4.3]).

4.5 Disassembly

Disassembly could only be accomplished by forcefully extracting (careful hammering) the center shaft segment from out of the center housing. Once removed it was apparent that the frozen state was due to galling that had developed on the shaft outside diameter and the housing inner diameter. Representative photos of the galled areas of both the shaft OD and the housing ID are included here (additional photos and views are available).

Photo 4, Galled Areas – Center Shaft OD – Upper End

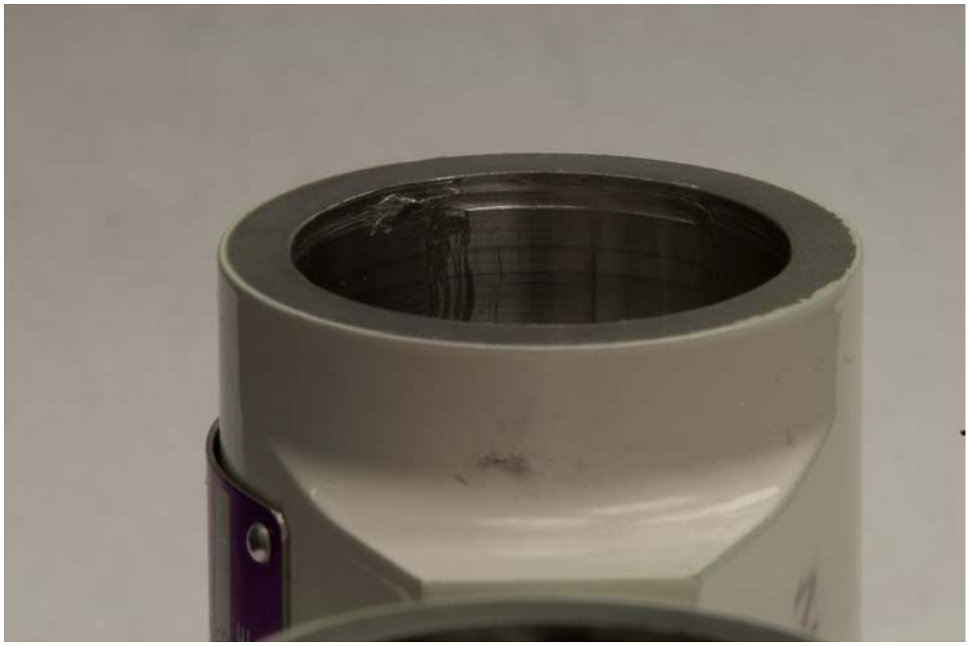

Photo 5, Galled Areas – Center Housing ID – Upper End

4.6 Dimensional

The housing and shaft segments were measured with calibrated gages and confirmed to meet the original engineering defined size requirements:

Center Housing Bore (measured three places): requirement 1.178/1.180” diameter
Inboard 1.1798/1.1795”
Midboard 1.1797/1.1799”
Outboard 1.1800”/1.1800”

Center Shaft Lands (measured at each of six land segments): requirement 1.176/1.175”
1 - 1.1756”
2 – 1.1753”
3 – 1.1756”
4 – 1.1754”
5 – 1.1753”
6 – 1.1757”
All were within .0002” from high to low at each land segment (values above are averaged.)
Note: the galled area showed galling buildup measuring up to 1.1779”

Center Shaft Packing Grooves (measured at each of three grooves): requirement .935/.933”
Inboard .9342”
Midboard .9340”
Outboard .9339”

5.0 DISCUSSION AND CONCLUSION

The consensus of the group was that the findings were consistent with a cause chain that appeared to be constructed thusly (working backwards from the aircraft loss of hydraulic fluid):

a. Loss of fluid – caused by tube cracks.
b. Tube cracks – caused by bending moment[1].
c. Bending moment – caused by development of high friction in the center shaft/housing interface.
d. High friction – caused by galling/spalling of the housing/shaft surfaces.
e. Galling/spalling – caused by unknown factors. Possibilities include the introduction of some type of twist or distortion that may have been the next link in the cause chain. More discussion or investigation steps are likely needed, but since the next actions relate to a metallurgical analysis (to be conducted outside the scope of this document), this report ends with inconclusive results.

Remaining questions that were unanswered include:

- What are the load conditions the existing design is capable of satisfying and what is the margin of safety under various other load conditions (i.e. the jamming influence of increased friction)?
- Were there any issues associated with the means of substantiating compliance with the CFRs relative to the certification basis in the Type Certificate Data Sheet?
- Were there possible design conditions missing that may be relevant? (Such as handling loads/directions which may have distorted the part before it was placed into service which lead to the eventual overloading of the part during actuation on the aircraft.)
- Could this type of component failure cause a more severe incident/accident (perhaps with a less experienced pilot) during different flight phases?
- Is this part considered a “critical part” and is this an appropriate categorization?

Mitigating actions:
No mitigating actions were discussed during the course of the meeting at PneuDraulics, either at the component, system, or aircraft level.

[1] See Appendix A for David Hsu’s comments disagreeing with this term.

APPENDIX A

E-mail from David Y. J. Hsu with his comments dated 4/20/2011:

Ladies and gentlemen:

I like to offer my comments for the two aspects of the proposed reporting on the tear down activities of Thursday, the April 7, 2011, at the PneuDraulics in the City of Cucamonga, CA.

1. *The factual portion of the tear down findings*
2. *The portion involving the review/discussion of those findings during the tear down*

1. *The factual portion of the tear down findings*

   A. The documentation of the factual portion of the tear down appears basically to be accurate. However respectfully, I disagree with the 5.0 b) in the draft investigative report [[which is 7.b) in the summary below[2]]] that "Tube cracks – caused by bending moment." {{Please refer to my comments in 2. below for my reasons for this disagreement of mine, from a stress engineering perspective}}

   B. I believe it is very important to mention that no measurement was made to determine the force required to overcome this jamming of the failed part swivel joint. [It is because whatever the amount of the force required to overcome this jamming of the failed part swivel joint, along with other loads, such as the hydraulic operating pressure, etc. etc. may have resulted in a 0.03 inches of distortion (which became apparent in the ATP test fixture].

2. *The portion involving the review/discussion of those findings during the tear down*

   In any of our reviews of the findings from the investigation, we have to be careful with speculations, because potentially everything may be possible, but may not be probable. Everything we speculate on, need validation and verification with further investigation/simulations with the proper instrumentation, such as the use of strain gages and deflection/displacement measurements. If we are to analyze to determine why the failure occur, and how to correct it so that it does not happen again in the fleet with similar type design, we need to start with the original design of the part that failed and what are the load conditions the failed part was designed to and how it was substantiated to show compliance with the applicable CFRs in the type design certification basis in the Type Certificate Data Sheet (TCDS). We need to question if there was any non-compliances with the applicable CFRs in the type design certification basis in the TCDS. Was there any important missing design condition that may have caused the failure? (Such as the handling load of some sort in certain way and direction which may have distorted the part before it was placed into the service, and led to the overloading of the part during the landing or take-off phases and caused it to fail in the air at certain altitude, which may prevent continued safe flight and safe landing). Even with the warnings annunciations and the available back up hydraulic systems, the pilot is now left with additional work load issues to deal with.

[2] Referring to G. Burns' e-mail of 4/8/2011 outlining similar material to section 5 of this report.

To start off, we did not review during the tear down, what was the margin of safety (MS), when there is no jamming (which the part passed the 25 Lb. ATP test load). It is important to know that what was the reduced MS, when there is some jamming. Finally It is important to know that what was the reduced MS, when the swivel joint is completely jammed for whatever reasons, in the field.

Please note that the 0.03 inches permanent deformation definitely created a secondary bending that would add stresses to the normal design stresses at the location of the Transfer Tube failure, due to the hydraulic proof pressure loading as well as the hydraulic operating pressure along with the normal swivel joint frictional loading during landing and take-off NLG retractions.

The fact that one of the two 6061-T6 Transfer Tubes failed at the tube joint immediate next to the hot-braced socket in the swivel housing and the other one of the two 6061-T6 Transfer Tubes show definite signs of highly distressed painted surface at the tube joint immediate next to its hot-braced socket in the same swivel housing.

In all cases, we need to understand the state of principal stresses at the failure location.

Furthermore, according to the service history mentioned in the draft report, the Transfer Tubes are the weakest link of the failed part and this time, this failure may have caused this experienced test pilot to run-off the runway. Can this type of transfer tube failures cause more severe incident/accident, with less experienced pilot, during a different flight phases? Is this part considered a "critical part", if not, why not?

Again, thanks for the opportunity to comment.

Regards,
David Y. J. Hsu
Aerospace Engineer
Airframe Branch
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(R)