ATTACHMENT 1

Boeing Stabilizer Trim Mechanism Examination Report

TO: Air Safety Investigations (ASI)

EQA NUMBER: AS12067

DATE: July 14, 2014

MODEL NUMBER: 747-400BCF

AIRPLANE NUMBER: RT075

SUBJECT: ***Examination of Stabilizer Trim Drive Mechanism Assembly***

IDENTIFICATION:

Part name:	Stabilizer Trim Drive Mechanism Assembly
Boeing part number:	65B80562
Serial number:	9019
Supplier:	Boeing
Part name:	Stabilizer Trim Control Module
Part number:	160210-10 (stamped on casting)
Serial number:	097 (stamped on casting)
Supplier:	Moog Aircraft Group

REFERENCES:

(a) National Transportation Safety Board (NTSB) accident number DCA13RA081
(b) Component Maintenance Manual (CMM) 27-41-11, dated November 1, 2010

BACKGROUND:

Per reference (a), on April 29, 2013, a 747-400BCF (RT075), operated by National Air Cargo Group (MUA) crashed shortly after takeoff at Bagram Air Base (OAIX), Afghanistan. This resulted in a total loss of the crew and airplane. The Ministry of Tourism and Civil Aviation (MoTCA) of Afghanistan is investigating the event with the assistance of the National Transportation Safety Board (NTSB).

In support of the MoTCA, the NTSB, with the assistance of Boeing Air Safety Investigations, conducted an examination of the stabilizer trim drive mechanism assembly, P/N 65B80562, with associated attachment hardware, and the stabilizer trim control module in Seattle, WA, on January 15, 2014.

SUMMARY:

The stabilizer trim drive mechanism assembly, P/N 65B80562, along with associated attachment hardware and components, were visually examined and photographed at the Boeing Equipment Quality Analysis (EQA) facility on January 15, 2014.

Following the EQA examination, items of interest requiring material and fracture analysis were then examined by Boeing Research and Technology (BR&T) for detailed analysis; see Enclosure A for the full BR&T report.

In summary, the materials that BR&T identified were verified to be correct, as specified on the engineering drawings. BR&T identified the fracture that separated the ballscrew into two pieces as being consistent with a single overload event.

EXAMINATION AND TEST RESULTS:

The stabilizer trim drive mechanism assembly, along with associated attachment hardware and components, were received by EQA in a shipping container. The container was photographed as received; see Figure 1 and Figure 2. The container was opened in the presence of the NTSB representative.

Figure 1: Container as received

Figure 2: Container as received

Two labels attached to the container were photographed; see Figure 3 and Figure 4.

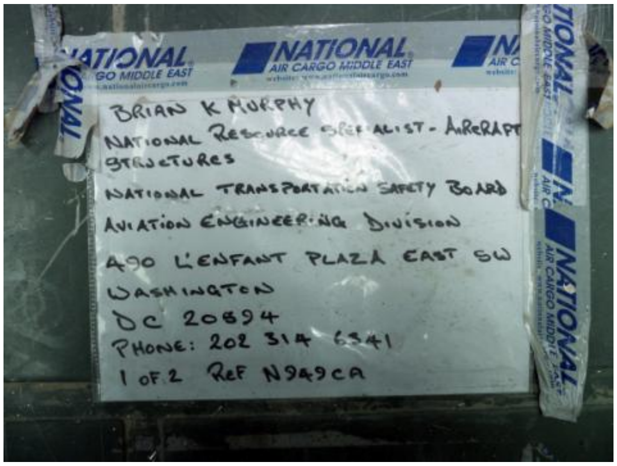

Figure 3: Label on container

Figure 4: Label on container

The straps holding the shipping container cover to the container base were removed. The cover was then removed from the base; see Figure 5 through Figure 7. Figure 6 is a view of the container contents from the opposite end as shown in Figure 5.

Figure 5: Container cover removed, end view

Figure 6: Container cover removed, opposite end view

After removing the container cover, it was observed that there were no bolts attaching the forward yoke assembly, P/N 65880708-2, to the upper gimble assembly; see red arrow in Figure 7.

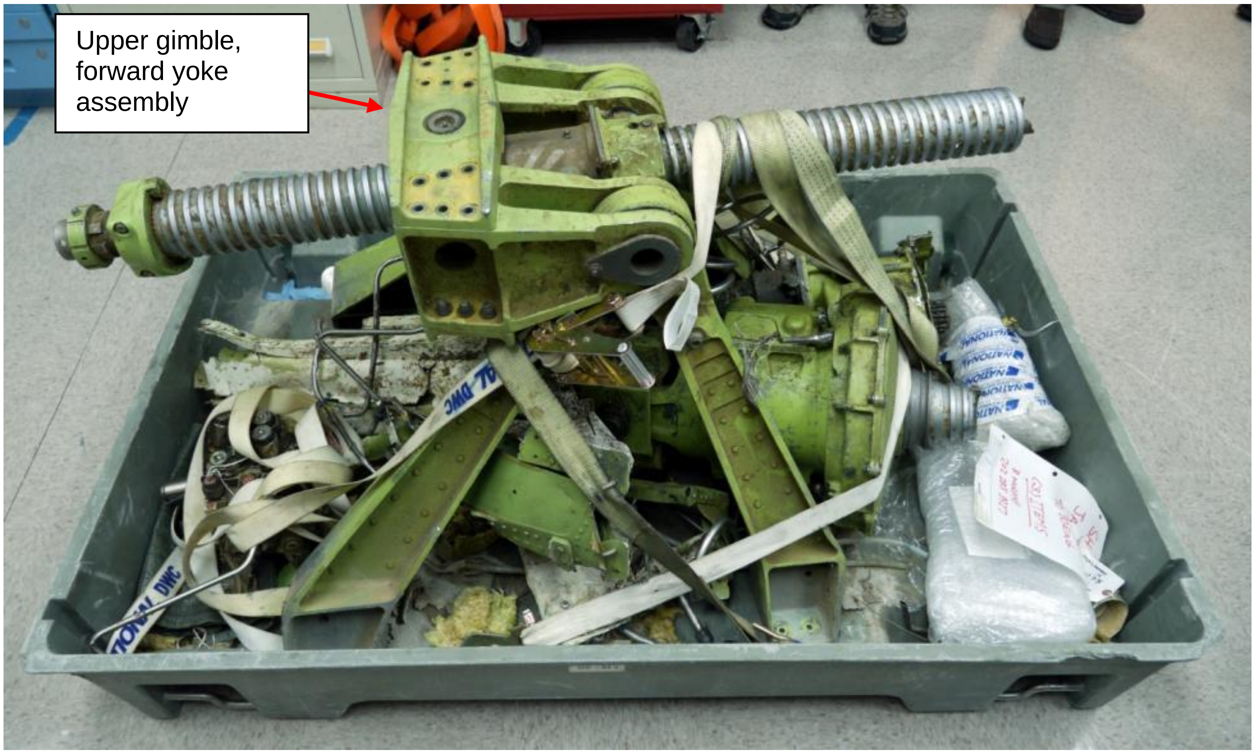

Figure 7: Container cover removed, side view

In addition to the jackscrew assembly and mounting structure received in the container, three other items were also included in the container. They included the following:

- Circuit board wrapped in plastic (Figure 8). The circuit board was retained by the NTSB representative on the day of the examination, January 15, 2014.
- Control unit (Figure 9).
- Skin material (Figure 10).
- Bubble wrap cover (Figure 11). The bubble wrap cover contained no parts.

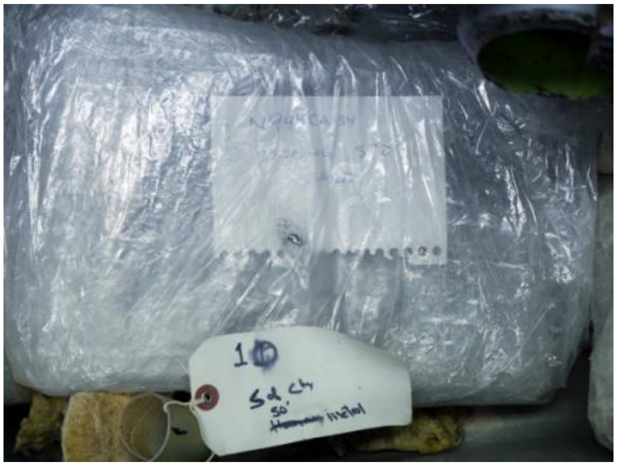

Figure 8: Circuit board wrapped in plastic

Figure 9: Control unit

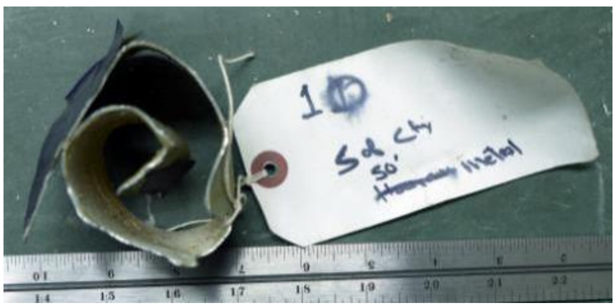

Figure 10: Skin material

Figure 11: Bubble wrap, empty

When un-strapping the forward upper gimble assembly it was noticed that the ball screw rotated freely within the ballnut.

The forward yoke assembly, P/N 65880708-2, was removed from the upper gimble assembly; see Figure 12.

Figure 12: Upper gimble, forward yoke assembly

An overhead view of the container was captured following the removal of the forward yoke, circuit board, control unit and skin material; see Figure 13. Figure 14 shows the actuator assembly and attachment structure remaining in the container following the removal of the ballscrew and upper gimbal assembly.

Figure 14 shows the shipping container after removal of the ballscrew assembly, upper gimble assembly and support structure. The actuator assembly remained in the container and was attached to pieces of attachment structure.

Figure 13: Overhead view of container

Figure 14: Actuator assembly in container

The differential assembly, P/N 65B80552, had broken free of the actuator assembly and was received separately in the shipping container. It was removed from under the actuator assembly and photographed; see Figure 15 and Figure 16. Note that both hydraulic motor assemblies, P/N 342381, were still attached to the differential assembly. The hydraulic brake assemblies were not received.

Figure 15: Differential assembly, aft surface

Figure 16: Differential assembly

The differential assembly had extensive damage on the forward side; see Figure 17 through Figure 19.

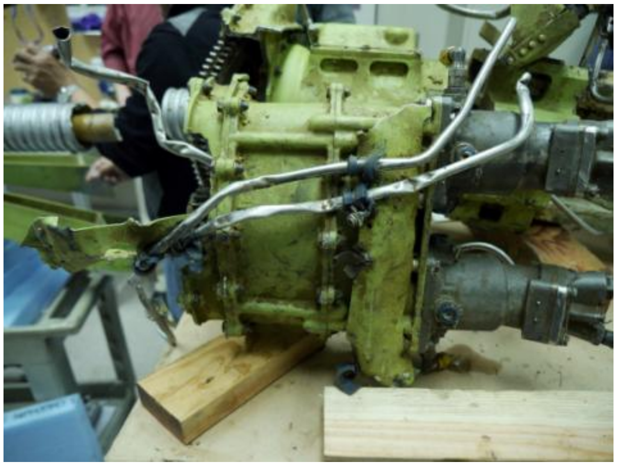

Figure 17: Differential assembly, forward surface

Figure 18: Differential assembly, forward surface

Figure 19: Differential assembly, forward surface

The actuator assembly and attachment structure were hoisted out of the shipping container with lifting straps; see Figure 20.

Figure 20: Actuator assembly removed from the shipping container

A side view of the actuator assembly is shown in Figure 21. Figure 22 shows a view of the upper end of the actuator assembly, as installed on the airplane, and an end view of the fractured ballscrew that remained in the actuator assembly.

Figure 21: Actuator assembly, side view

Figure 22: Actuator assembly, top view

Figure 23 shows a magnified view of a portion of the fractured ballscrew surface. A witness mark on the ballscrew, one thread from the fracture surface, is shown in Figure 24. The area within the red box in Figure 24 is shown magnified in Figure 25.

Figure 23: Fracture surface

Figure 24: Witness mark near fracture surface

Figure 26 is a rotated and magnified view of the mark shown in Figure 25.

Figure 25: Witness mark

Figure 26: Witness mark

An end view of the fractured ballscrew that remained in the actuator assembly is shown in Figure 27. Figure 28 shows the end of the fractured safety rod, within the ballscrew.

Figure 27: End view of fractured ballscrew

Figure 28: End view of fractured safety rod

One of the legs of the upper gimble support structure was distorted and fractured; see Figure 29, Figure 31 and Figure 32. The majority of the ballscrew remained in the upper gimble and ballnut assembly. A longitudinal fracture extended approximately eight threads beyond the primary ballscrew fracture; see Figure 30.

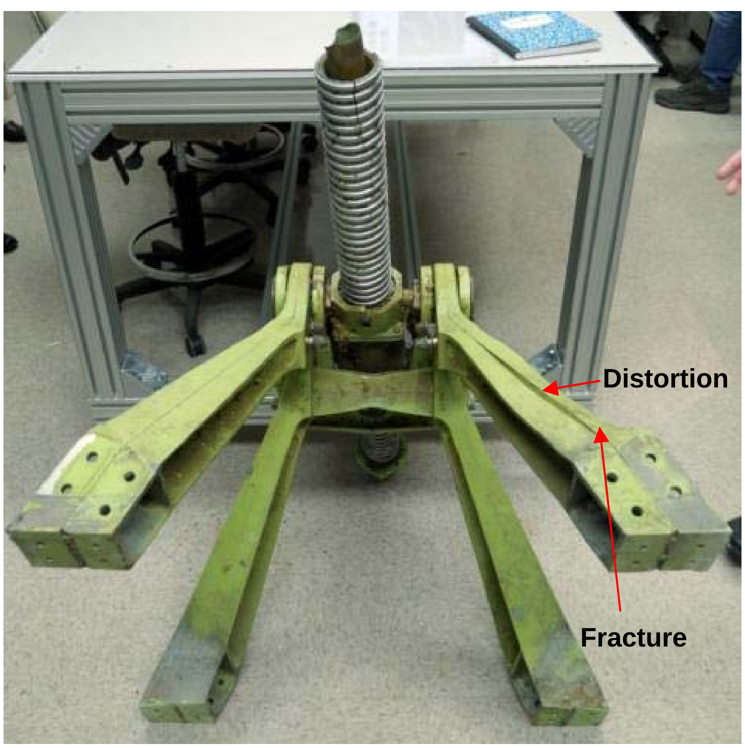

Figure 29: Upper gimble support structure

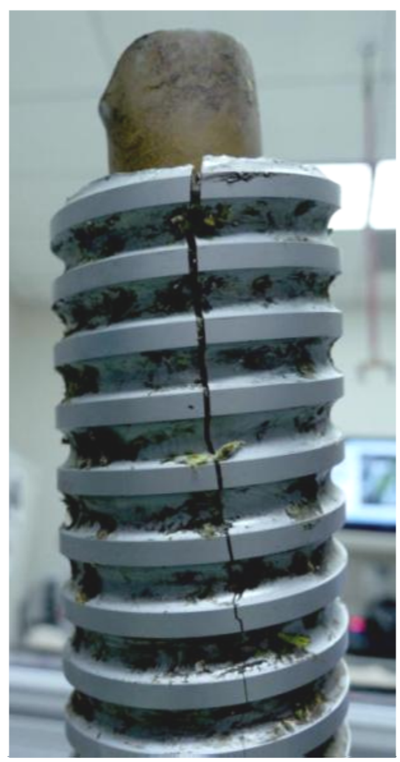

Figure 30: Longitudinal fracture

Figure 31: Upper gimble support structure, distorted and fractured leg

Figure 32: Upper gimble support structure, fractured leg

The safety rod remained within the ballscrew and was fractured; see Figure 33 and Figure 34.

Figure 33: Fractured safety rod

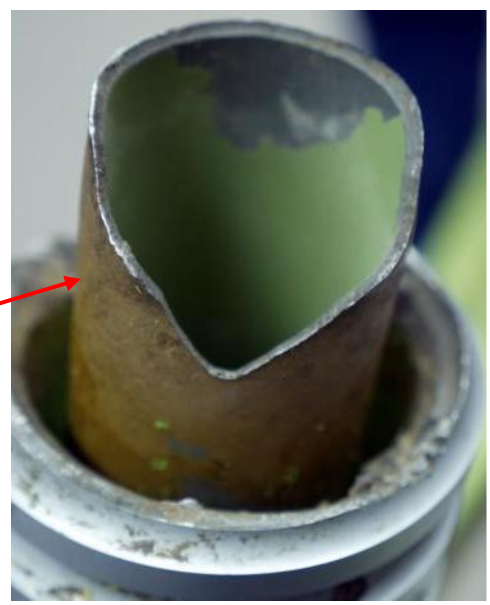

Figure 34: Fractured safety rod

Several views of the fractured ballscrew are shown in Figure 35 through Figure 38.

Figure 35: Fractured ballscrew

Figure 36: Fractured ballscrew

Figure 37: Fractured ballscrew

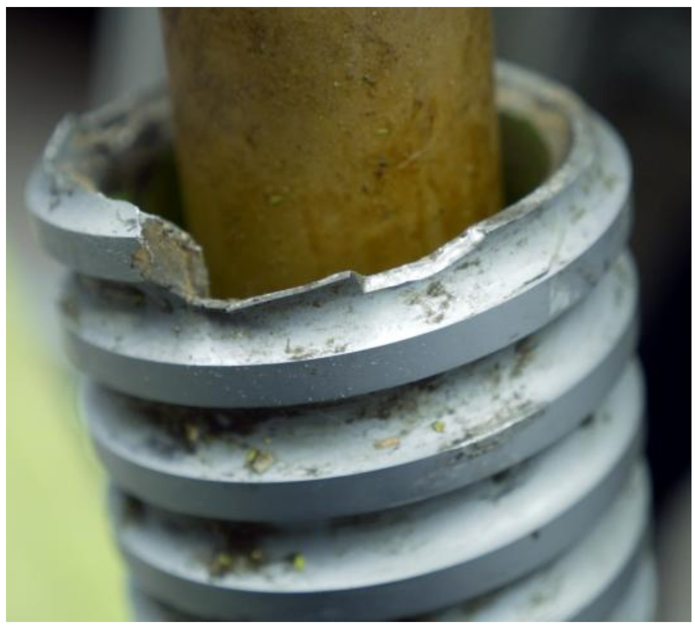

Figure 38: Fractured ballscrew

The actuator's differential assembly was positioned in its approximate installation location, as it would have been prior to being separated. An overview is shown in Figure 39. The differential is on the forward facing side of the actuator assembly, when installed on the airplane.

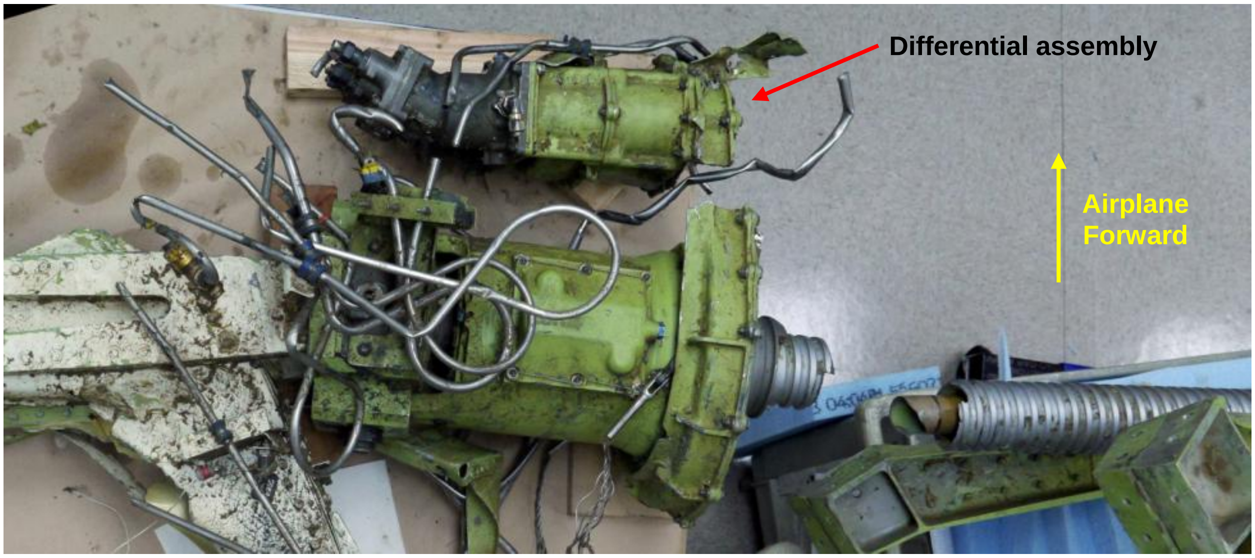

Figure 39: Actuator assembly with differential assembly

The upper gimble support structure and ballscrew were suspended with a hoist and aligned with the actuator assembly containing the remainder of the fractured ballscrew; see Figure 40 and Figure 41. The longitudinal crack shown earlier in the report is on the opposite side of the screw, as shown in Figure 40. The horizontal stabilizer trim mechanism assembly is oriented vertically when installed in the airplane.

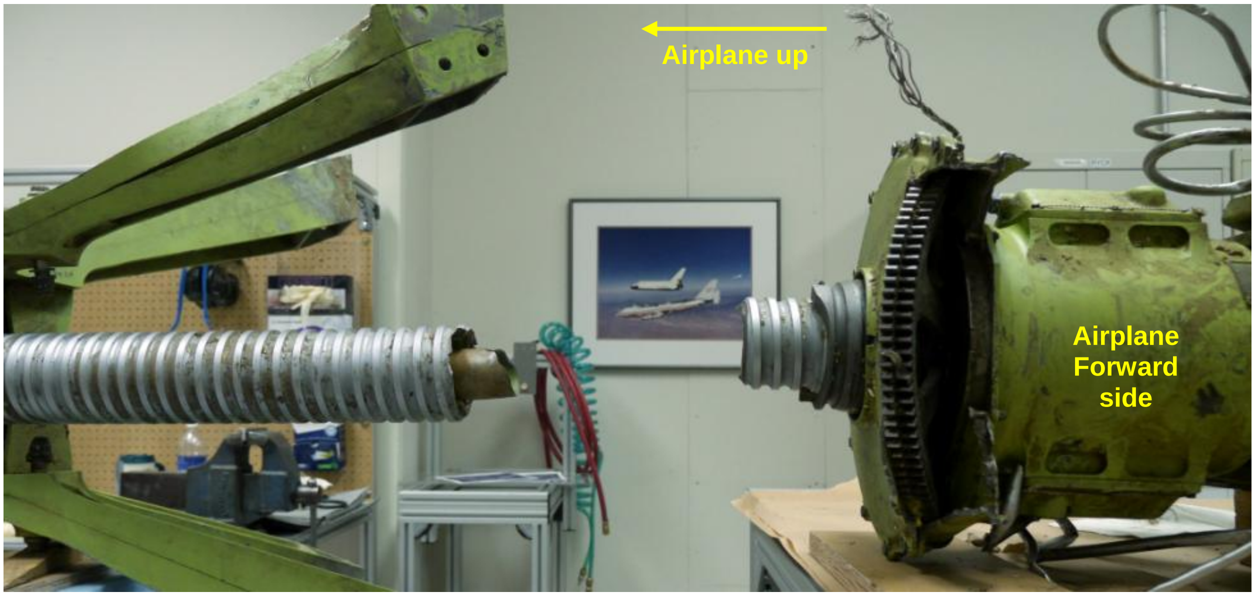

Figure 40: Ballscrew sections aligned

Figure 41 is a closer view of the fracture surfaces of the ballscrew shown in Figure 40. The longitudinal crack in the ballscrew is on the opposite side of the screw shown in Figure 41.

Figure 41: Ballscrew sections aligned

The ballscrew was deformed, exhibiting a slight bend. A straight-edged ruler was laid against the ballscrew to show the extent of the deformation; see Figure 42. The greatest gap between the ballscrew and the ruler occurred approximately fifteen threads from the fractured end of the ballscrew. The distance between the ruler and the ballscrew was approximately 0.04 inch at the fifteenth thread.

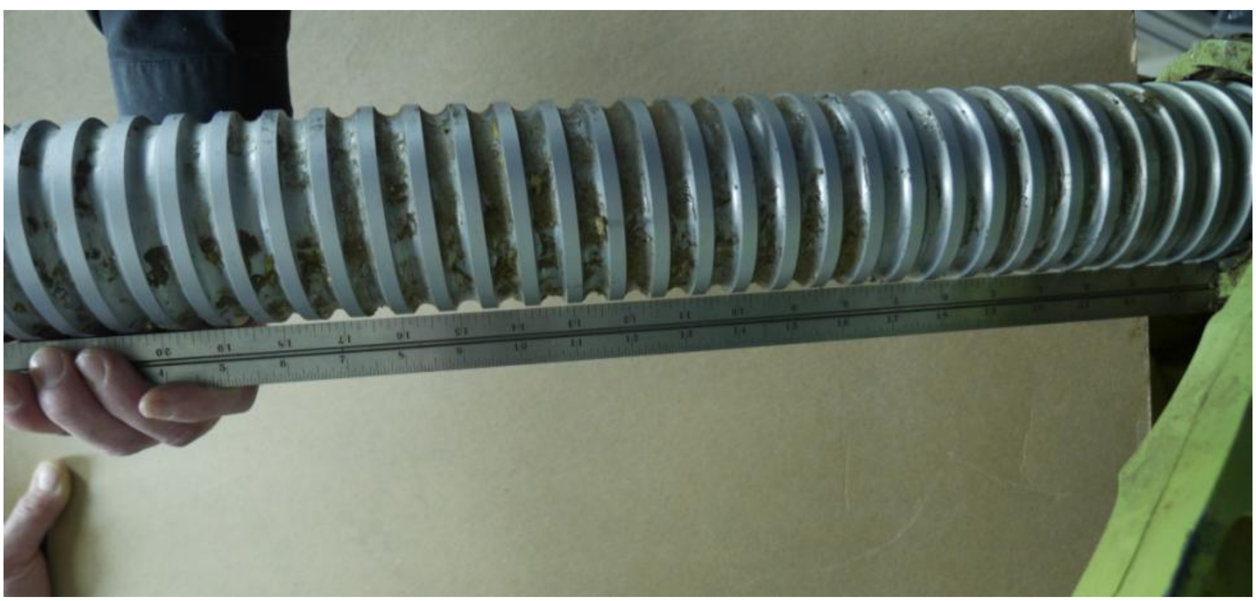

Figure 42: The ballscrew exhibited bending

Witness marks were noted on the longer portion of the ballscrew near the fractured end. Figure 43, Figure 45 and Figure 47 show a witness mark adjacent to the longitudinal fracture. Figure 44, Figure 46 and Figure 48 show a witness mark approximately 180 degrees from the longitudinal fracture.

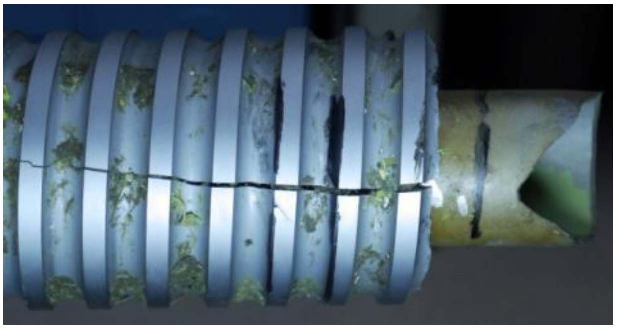

Figure 43: Witness marks on ballscrew

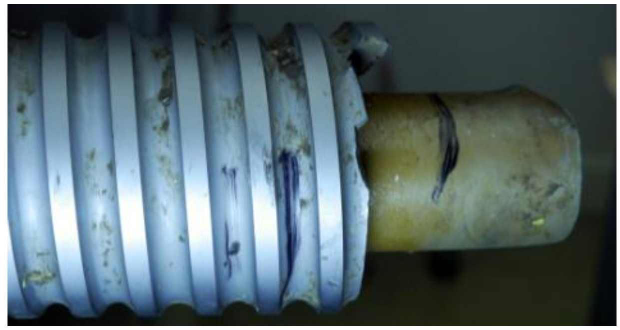

Figure 44: Witness marks on ballscrew, 180 degrees from longitudinal fracture

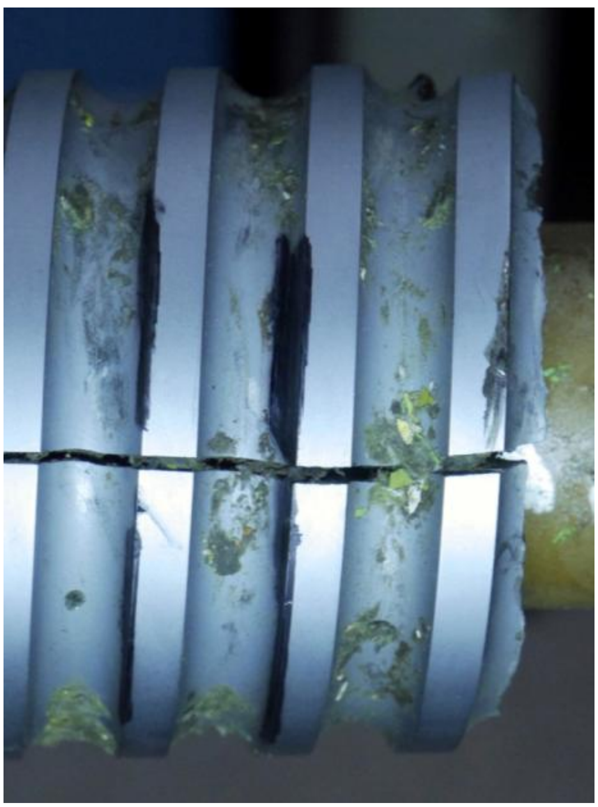

Figure 45: Witness marks on ballscrew

Figure 46: Witness marks on ballscrew, 180 degrees from longitudinal fracture


Figure 47: Witness mark on ballscrew


Figure 48: Witness mark on ballscrew, 180 degrees from longitudinal fracture

Green paint, from an unknown origin, was found adhered to a thread root 26 threads from the fractured end of the ballscrew and was on the same side of the ballscrew as the longitudinal fracture; see Figure 49 and Figure 50. The thread containing the paint was five threads from the lower ballnut stop, once the ballscrew was positioned as it had been reported to have been found at the accident site. The onsite measurement between the upper ballnut stop and the ballscrew end stop was nine and 9/16 inches.


Figure 49: Paint mark on ballscrew

Figure 50: Paint mark on ballscrew

Figure 52 is included to show the location of the paint mark relative to the ballnut's lower stop after the ballscrew was oriented to match its position as found on site. There were approximately 31 threads between the ballnut lower stop and the fractured end of the ballscrew.

Figure 51: Location of paint mark on ballscrew

The ballscrew and safety rod were removed from the assembly; see Figure 52.

Figure 52: Ballscrew and safety rod removed

The left hand hydraulic drive motor and the forward surface of the lower gimble had impact marks that appeared to coincide with each other; see Figure 53 through Figure 55. Green paint was evident within the impact mark on the motor. The right hand hydraulic motor had several fractures in the area of the mounting flange; see Figure 56.

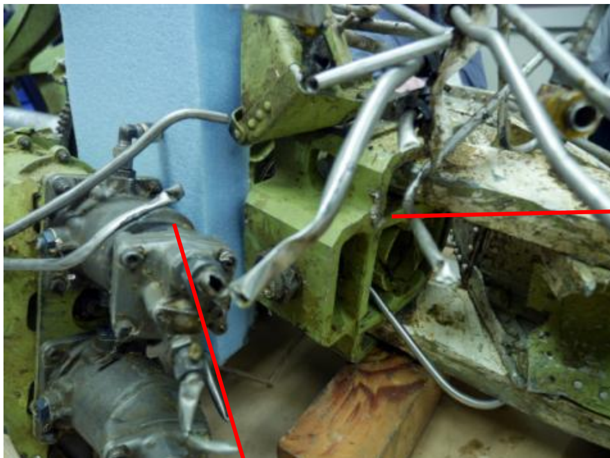

Figure 53: Hydraulic motors and lower gimble

Figure 54: Lower gimble damage

Figure 55: Left hand hydraulic motor damage

Figure 56: Right hand hydraulic motor flange crack

A piece of mettalic material remained trapped by an attachment bolt on one of the legs of the gimble support structure; see red arrow in Figure 57. The structural member of the gimble support that the small piece had fractured from was missing. Figure 58 shows a close-up image of the piece of structure material, prior to removal.

Figure 57: Location of trapped piece of structure material

Figure 58: Piece of structure material

Figure 59 and Figure 60 show magnified views of the piece of material after removal.

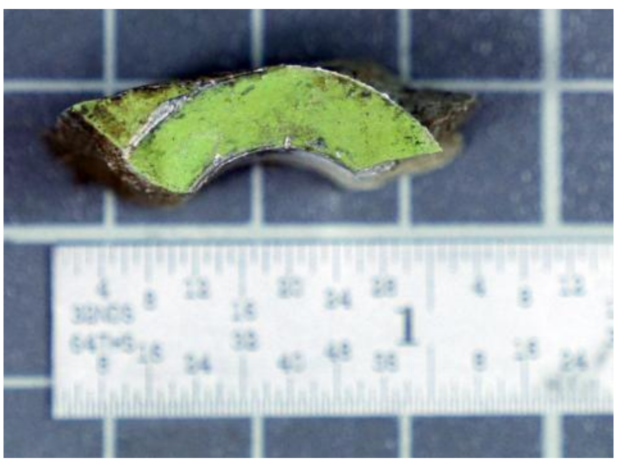

Figure 59: Piece of material

Figure 60: Piece of material, rotated

The red arrow in Figure 61 points to the location the piece of material was removed from. The red dashed oval shows where the missing piece of structure would have been located. The yellow arrow points to an intact structural member similar to the missing member, to show how the missing piece would have been installed. Both structural members are held to the upper gimble support structure by four attachment bolts.

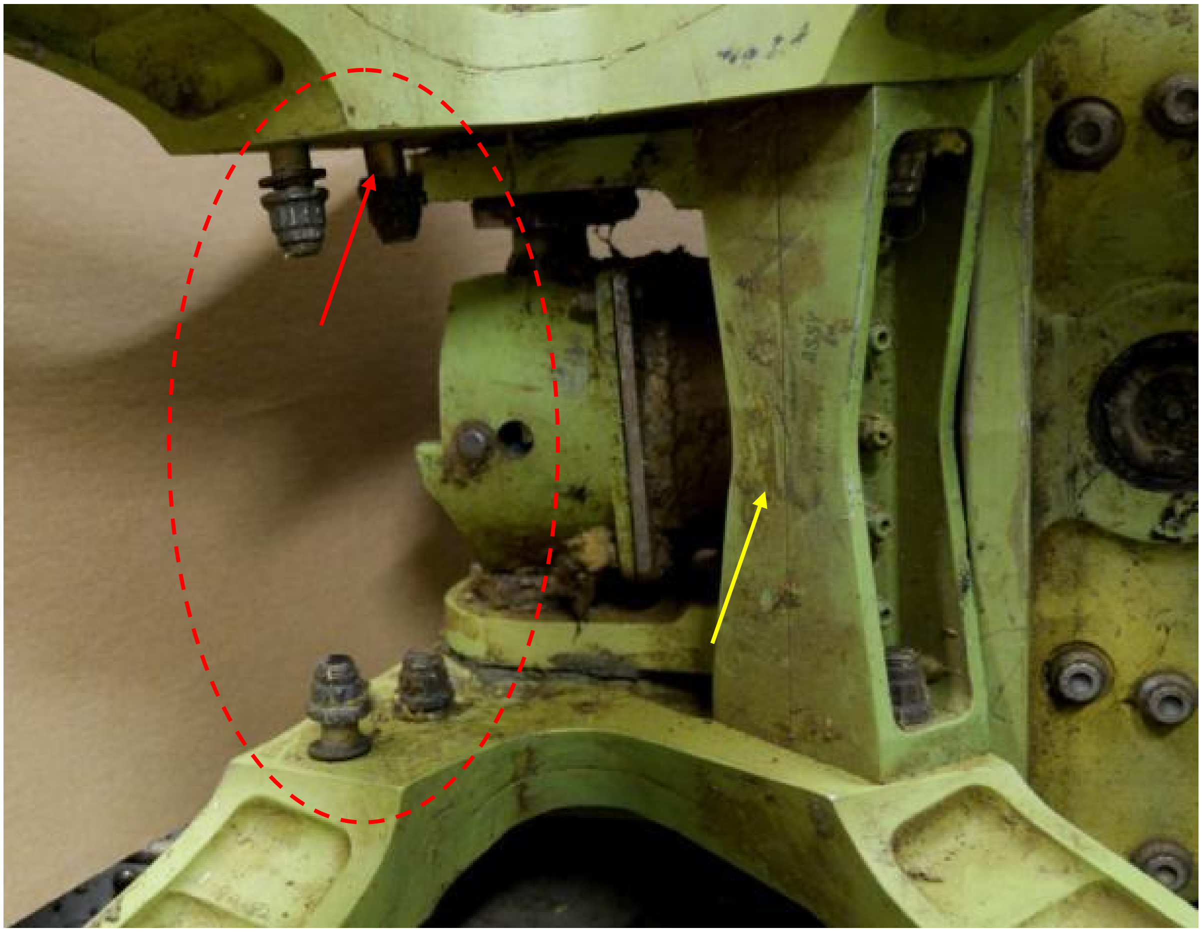

Figure 61: Location of the piece of structure that the material was removed from

The forward yoke was examined and several witness marks were identified; see Figure 62 through Figure 66.

Figure 62: Forward yoke witness marks

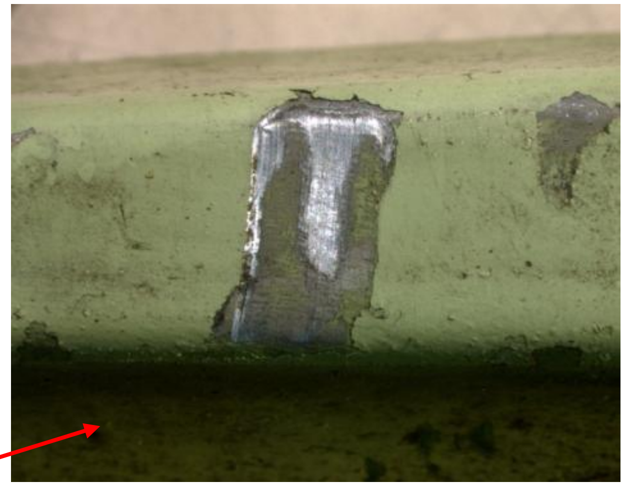

Figure 63: Forward yoke witness mark

Figure 64: Upper gimble, forward yoke

Figure 65: Forward yoke witness marks

Figure 66: Forward yoke witness mark

The piece of skin received was included in this examination. It was reported to have been found near the area of takeoff rotation with other airplane parts, some distance from the crash site. The piece of skin material shown in Figure 10 had blue colored paint adhered to one surface in a few places; see Figure 67 and Figure 68. Much of the blue paint had flaked off prior to receiving it.

Figure 67: Skin material

Figure 68: Skin material

The paint on the side of the skin material opposite the blue colored paint was tan in color. The tan paint was not flaking. A fairly thin, even coating of dirt had collected on the tan colored surface; see Figure 69.

Figure 69: Skin material

The skin material was cleaned with acetone in preparation to measure its thickness, prior to stripping the surface primer. A digital micrometer was used to measure the thickness of the skin where the blue paint was not present; it measured 0.047 inch thick. After stripping the paint, the bare skin material measured 0.044 inch thick.

ANALYSIS:

Portions of the horizontal stabilizer trim mechanism were sent to BR&T Central Fracture Analysis for investigation. A list of what was supplied to BR&T for analysis is as follows:

- End of the ballscrew sectioned from the actuator drive assembly containing the fracture surface.
- Ballscrew removed from the ballnut assembly.
- Piece of attachment structure that had remained with the upper gimble assembly attachment structure.
- Safety rod removed from the longer portion of the ballscrew assembly.
- Grease sample from inside the ballnut assembly.
- Grease sample from the ballscrew.

The end of the ballscrew, provided to BR&T, that had remained in the actuator drive assembly, and that contained the fracture surface was photographed prior to sectioning it from the ballscrew; see Figure 70.

Figure 70: End of ballscrew provided to BR&T

Grease samples were collected from the interior of the ballnut assembly with a cotton swab; see Figure 71. A grease sample was collected from the threads of the ballscrew, near the ballnut; see Figure 72. Both samples were placed in separate glass jars in preparation for providing them to BR&T. BR&T identified both to be BMS 3-33, as specified in the engineering drawing.

Figure 71: Grease collected from ballnut

Figure 72: Grease collected from ballscrew

The parts and samples provided to BR&T were photographed prior to being delivered; see Figure 73.

Figure 73: Parts and samples provided to BR&T

For the complete BR&T report, see Enclosure A. The parts provided to BR&T were returned to EQA following their analysis.

DISCUSSION:

The purpose of this discussion section is to help understand the relative locations of the items of interest found during the EQA examination and the BR&T analysis. Figure 74 was rotated so that the stabilizer trim drive mechanism assembly would appear in a vertical orientation to more closely represent its installation in the airplane. In Figure 74, the ballscrew had been positioned within the ballnut with the same dimension between the upper stops (nine and 9/16 inches), as it was recorded to be at the accident site. The two ballscrew fracture surfaces were then aligned with each other. The image of the reconstruction was captured as if looking aft, as installed on the airplane and with the forward surfaces in view. This reconstruction is solely based upon the condition and position of the components as reportedly found on the ground at the accident site. The noteworthy items associated with Figure 74 are listed below:

1. The longitudinal crack is on the aft side of the ballscrew.
2. The paint mark is on the same side as the longitudinal crack, but beyond view.
3. The approximate fracture origin (forward side).
4. The bending is ninety degrees to the fracture origin; the yellow arc in Figure 74 is exaggerated arc to show the direction of the bending.
5. The witness mark near the fracture surface on the longer section of the ballscrew is located on the side with the fracture origin.
6. Another witness mark near the fracture surface on the longer section of the ballscrew is located on the side with the longitudinal crack (180 degrees to the fracture origin).
7. The third witness mark near the fracture surface on the shorter section of the ballscrew is located on the side of the ballscrew (90 degrees to the fracture origin).

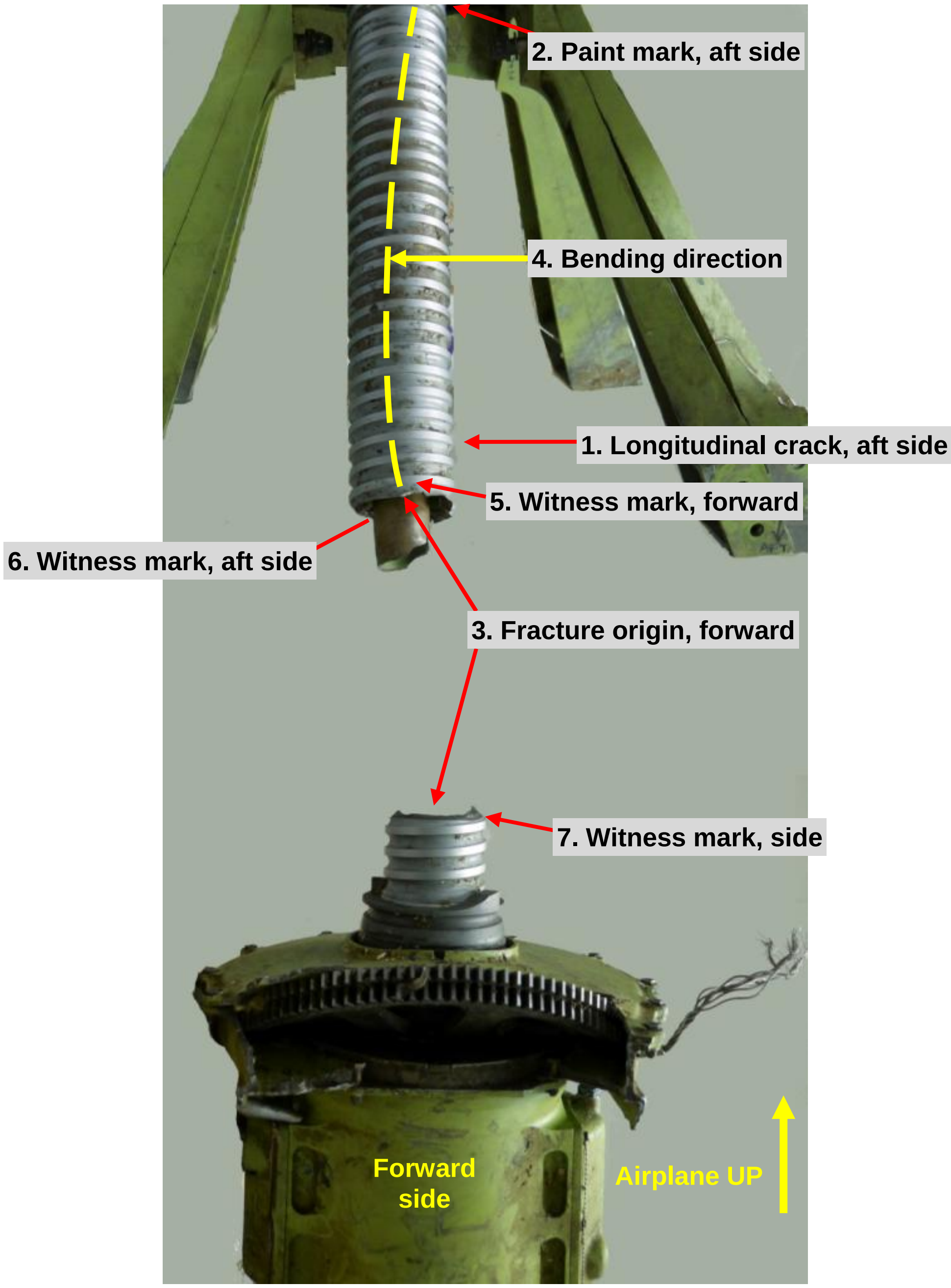

Figure 74: Reconstruction with ballscrew repositioned and aligned. This image is oriented as if looking aft, as installed on the airplane.

DISPOSITION:

The subject component will be routed per instruction from ASI after the completion of this analysis.

The preceding information is being submitted for information purposes.

Signatures on file

ENCLOSURE:

A. BR&T report MS 22997, dated March 21, 2014

BOEING

Engineering, Operations & Technology
Boeing Research & Technology

FRACTURE ANALYSIS REPORT

Engineering Report No: MS 22997 **Date: 3/21/2014**

Lab WR Number: 031-2014-01-20-00034

Part Information:

Design Drawing Part Name: Ball Nut and Screw Assembly – Stabilizer Trim
Part Number: SCD 60B80026 Sup PN: 07387P000-1
ATA Index: Chapter 27 – Flight Controls
Responsible Design Group: BE334 Primary Mechanical Controls and Actuation

Airplane Information:

A/P Customer:	National Airlines (NAL)	A/P Model:	747-400F
Registry No:	N949CA	Line Position No:	960
Flight Hours:	74,155	Number of Landings:	10,003

Material Information: Ballscrew

Material: 9310 Alloy Steel
Heat Treat: Core Hardened 160-200 ksi, Case Hardened
Material Specification: AMS 6265

GROUP INDEX: 9M-MP-EYBC Fracture Analysis

SUBJECT: 747-400F Bagram Airfield Crash Investigation - Stabilizer

BACKGROUND:

During climb from takeoff at Bagram Airfield a Nation Airlines 747-400F experienced a stall and crashed, resulting in a total loss of the crew and aircraft. Portions of the horizontal stabilizer trim mechanism were sent to Boeing Research and Technology (BR&T) Central Fracture Analysis for investigation.

EXPERIMENTATION AND RESULTS:

Upon receipt at the BR&T Fracture Analysis group, the part was subjected to the following analyses:

- Visual examination of part physical condition.
- Measuring the magnitude and direction of plastic deformation in the ballscrew.
- Optical and scanning electron microscopic (SEM) of the fracture surfaces of the tube.
- Cross sectioning of the jackscrew near the fracture for metallurgical analysis.
- Energy Dispersive Spectroscopy (EDS) of the ballscrew to verify alloy composition.
- Analyzing grease samples for drawing compliance.

Figure 1 shows the as received fractured ballscrew, with the fractured region at the right side of the image. Figure 2 shows an end on view of the fracture surface. Secondary cracking is observed running lengthwise on the shaft from the main fracture surface and significant amounts of post-fracture damage and contamination obscure the fracture surface. The mating half of the fracture surface was excised from the components and is shown after cleaning in Figure 3. A region of origin is apparent on the OD of the screw at the base of a thread and is in a relatively flat region of the fracture surface

Plastic deformation was observed along the length of the screw. The screw was laid on a precision table and rotated and measured with feeler gages to find the magnitude and direction of the maximum direction (Figure 4). A deflection of 0.0455 inch was measured at an angle approximately 90 degrees to the origin of the fracture (Figure 5).

The fracture surface was examined in the SEM for further analysis. The surface showed significant corrosion and had to be chemically cleaned to evaluate the features. Dimple rupture morphologies were seen on all surfaces of the fracture, consistent with single event, ductile failure (Figure 6).

A metallurgical cross section of the ballscrew through the fracture is shown in Figure 7. Additional metallographic cross sections are shown in Figure 8. After etching, it was apparent that the threads of the screw were not uniformly case hardened. Hardness values at the surface did not meet the drawing requirement of HRC 58 – 62 in these regions, confirming the lack of case hardening. Figure 8 illustrates the variable case hardening. Despite failing to meet the drawing requirements, the fracture occurred at a hardened location and this did not appear to contribute to the fracture. The surface of the ballscrew threads showed normal burnishing from contact with the ball nut but no indications of significant thread wear. The core hardness of all ball screw sections evaluated met the drawing requirement of 160 – 200 ksi.

Energy dispersive spectroscopy was used to verify the alloy's chemical composition and the results are shown in Table I, meeting the requirements for SAE 9310 alloy steel per AMS 6265, as specified on the engineering drawing.

Two grease samples were provided with the parts and both were confirmed to be BMS 3-33, as specified on the engineering drawing. The other parts examined showed significant post fracture damage and no anomalies that contributed to the fracture.

CONCLUSIONS:

1. All fracture surfaces showed dimple rupture morphology, consistent with single event, ductile fracture.
2. Plastic deformation of 0.0455 inch was measured in the shaft of the ballscrew. The deformation was not aligned with the origin of the fracture.
3. The microstructure, core hardness, and chemical composition of the ballscrew were found consistent with SAE 9310 alloy steel as specified on the engineering drawing.
4. The case hardness on several threads near the fracture on the ballscrew was found to not meet the drawing requirements, but did not appear to contribute to the failure.
5. Grease samples were confirmed to be BMS 3-33, as specified on the engineering drawing.
6. No other anomalies associated related to the failure were observed on the screw or other components.

Figure 1. As received photograph of the fractured ballscrew. The fracture location is the right side of the screw and the distortion is exaggerated by the camera..

Figure 2. End on view of the fracture of the largest piece of the ballscrew.

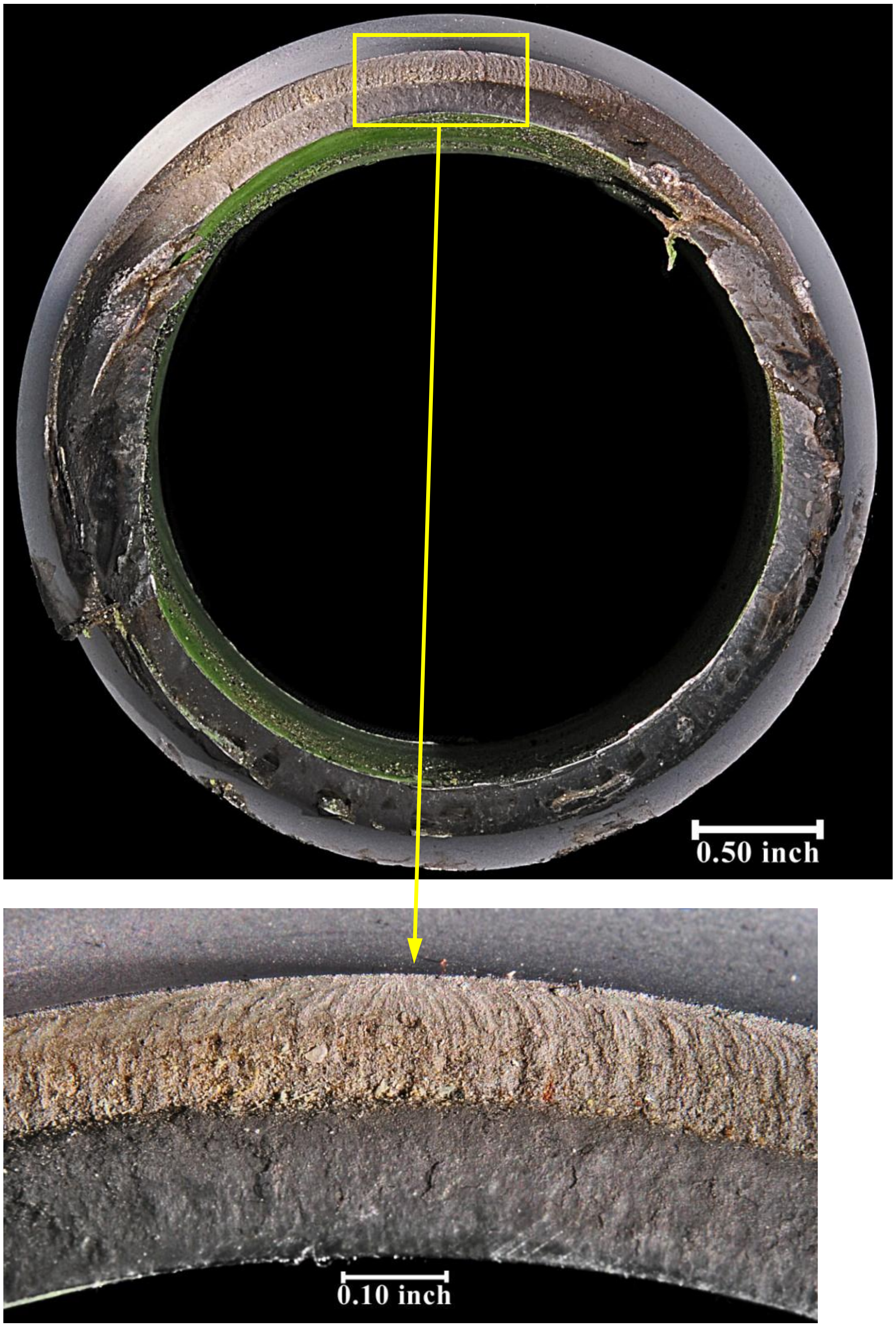

Figure 3. Images of the fracture surface of the mating half after cleaning. An origin can been seen on the OD at the root of a thread in the top of the images.

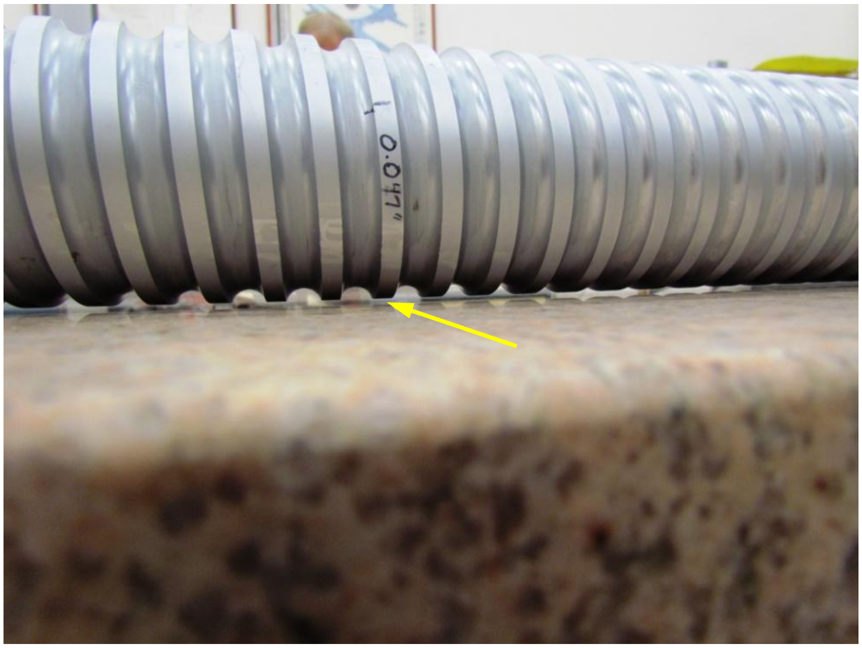

Figure 4. The ballscrew was laid on a precision table and 0.0455 inch of plastic deformation was measured with feeler gages.

Figure 5. Optical image of the direction of the plastic deformation of the ballscrew (red arrow) relative to the origin of the fracture (yellow arrow).

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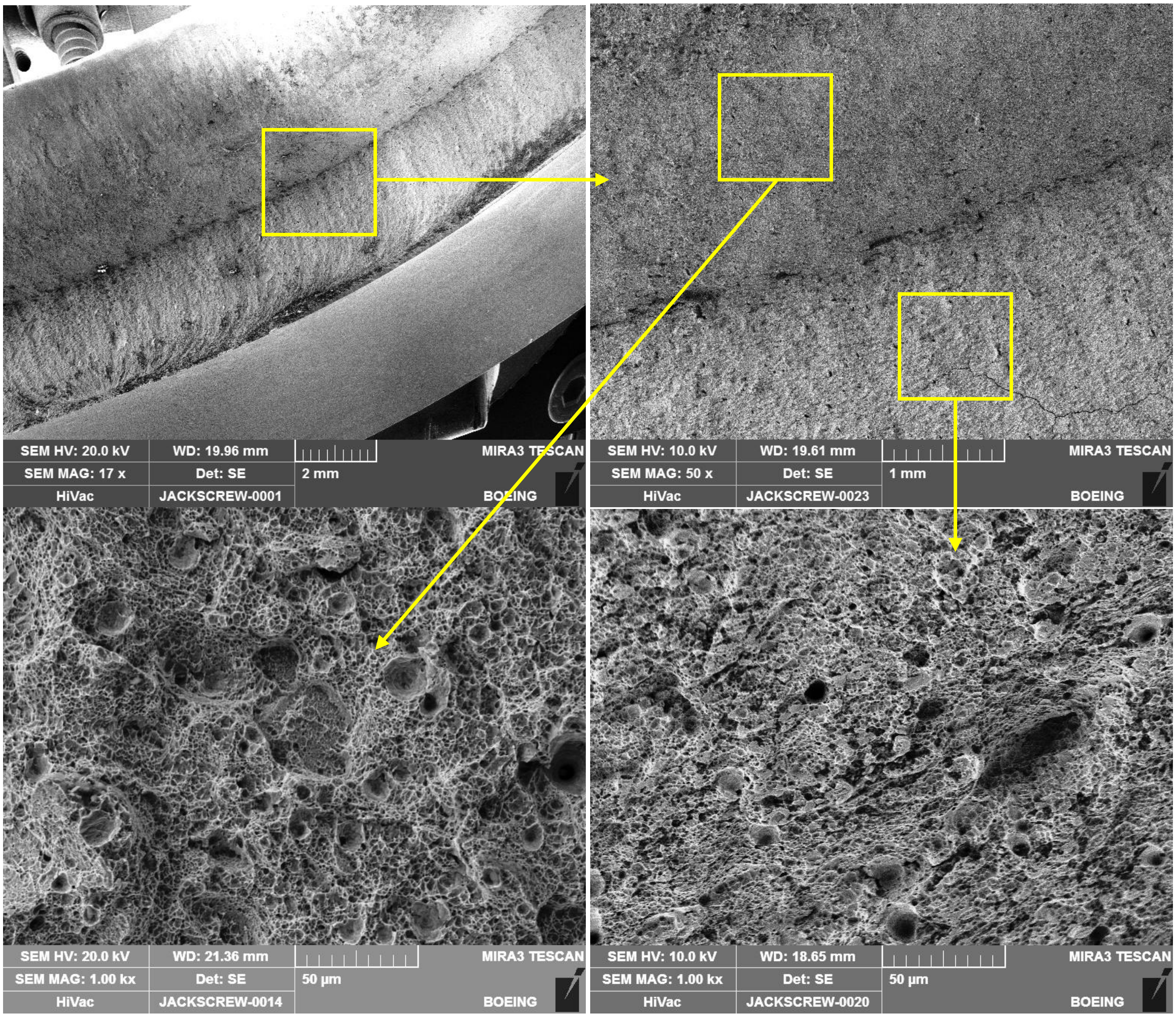

Figure 6. SEM images of increasing magnification showing the fracture surface near the region of origin. The bottom images show dimpled rupture morphology.

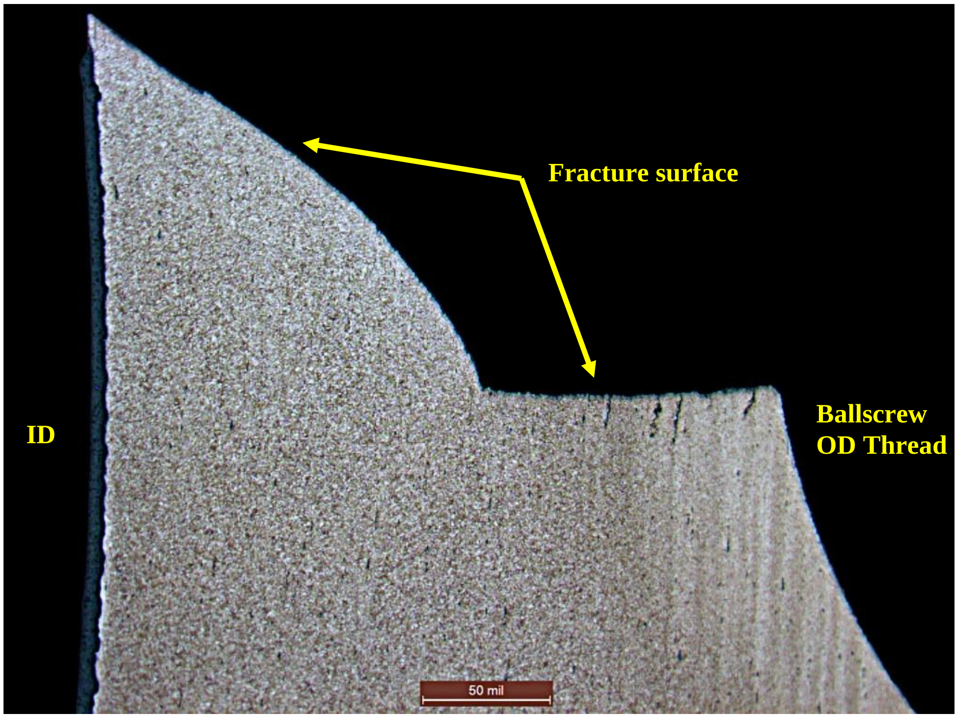

Figure 7. Micrograph of a cross section of the screw near the fracture, showing a microstructure typical of alloy steel.

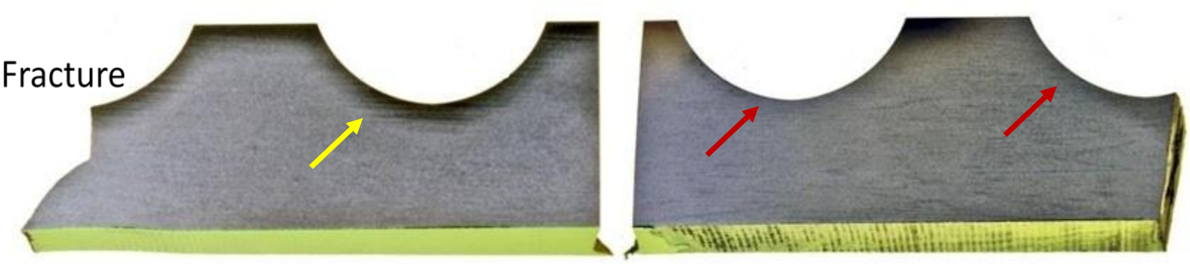

Figure 8. Metallurgical cross sections of several threads near and including the fracture. A case hardened region is shown with the yellow arrow and regions that are not case hardened are indicated with red arrows.

Table I: EDS compositional data for the ballscrew, consistent with AMS 6265.

Element		Fe	Mn	Si	Cr	Ni	Mo	Cu
Weight Percent		94.42	0.55	0.28	1.18	3.27	0.11	0.19
AMS 6265 Spec	Min	Balance	0.40	0.15	1.00	3.00	0.08	--
	Max		0.70	0.35	1.40	3.50	0.15	0.35