

NATIONAL TRANSPORTATION SAFETY BOARD

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Attachment 8 –Airbus No. 2 Engine/Pylon Fuel Connection Materials

Laboratory Analysis Report

POWERPLANTS

DCA18LA163

A330 MSN 578 DAL fire event- RH Engine/Pylon Fuel Connection

Technical Report

REFERENCE	LR71RP2111122
A/C APPLICABILITY	A330
ATA APPLICABILITY	71

SUMMARY:

On 18th of April 2018 shortly after take-off from Atlanta (flight DL-30 to London Heathrow) the A330 MSN0578 powered by Pratt & Whitney PW4168 engines and operated by DAL has experienced fire at the RH engine. An in-flight turn back and overweight single engine landing at Atlanta airport was performed successfully in flight. An accident investigation was initiated. The engine/pylon fuel connection unit was identified as a possible driver of the event. The unit was disassembled from the engine and provided to the Airbus Failure Analysis Lab in Bremen for detailed examination. Hereby all investigation steps were agreed by all involved parties in advance under the lead of the NTSB.

Hereby all investigation steps were agreed by all involved parties in advance under the lead of the NTSB. The results of the laboratory examination of the engine/pylon fuel connection can be summarized as follow:

- All parts needed for the connection are present and found in assembled conditions; the specified securing wires were in place.
→ Insufficient connection due to missing parts can be excluded.
- Flanges and sleeve were found in plane conditions. → Insufficient connection due to tilt or wedged parts can be excluded.
- Clear indications for the presence of a rubber seal were found. → Insufficient connection due to complete missing rubber seal can be excluded.
- All bolts of the connection of the pipes flanges showed torque in the expected range. → Torque was sufficient for all assembled parts.
- No crack findings on all metal parts of the connections. → Insufficient or invalid connection due to cracks in the parts can be excluded.
- Although the surrounding geometry of the flanges show non-flat surfaces, the matting surfaces show flat characteristic
→ The quantitative flatness of the flanges matting surfaces cannot be concluded from the outer geometry of the flanges.
- The pylon fuel rigid pipe flange was installed not as per drawing on the fuel/hydraulic disconnect panel. Installation not as per drawing of the flange resulted in an offset of 6.27 mm, which had to be bridged by the flex line.
- There were indications found showing that the flange was installed as per drawing at one point of assembly life and twice installed not as per drawing.

Conclusively the laboratory examination of the engine/pylon connection unit and its single components revealed no obvious finding which could have driven a failure and caused the event.

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1 Scope

This technical report covers the support to the accident investigation of fire occurrence at right hand engine on A330 MSN0578.

On 18th of April 2018 shortly after take-off from Atlanta, during flight DL-30 to London Heathrow, the A330 MSN0578 (registration N806NW) powered by Pratt & Whitney PW4168 engines and operated by DAL has experienced fire at the right hand engine.

The affected engine was shut down by the flight crew, who initiated an air turn back to Atlanta airport where the aircraft performed an overweight single engine landing.

The subject event is being traced Airbus internally through an Occurrence.

On 1st of May, due to the substantial damage experienced by the pylon, the event was upgraded by the NTSB from serious incident to accident.

An inspection of the engine was done by NTSB, P&W and DELTA shortly after the event (onsite inspection, cf. chapter 3). In frame of this inspection the engine/pylon fuel connection was identified as a possible driver of the event due to deviations in the assembly and reported previous maintenance tasks. Therefore a cut out was taken and sent to the Airbus failure analysis laboratory in Bremen for further examination.



Figure 1: Overview of pylon area after removal of the affected engine

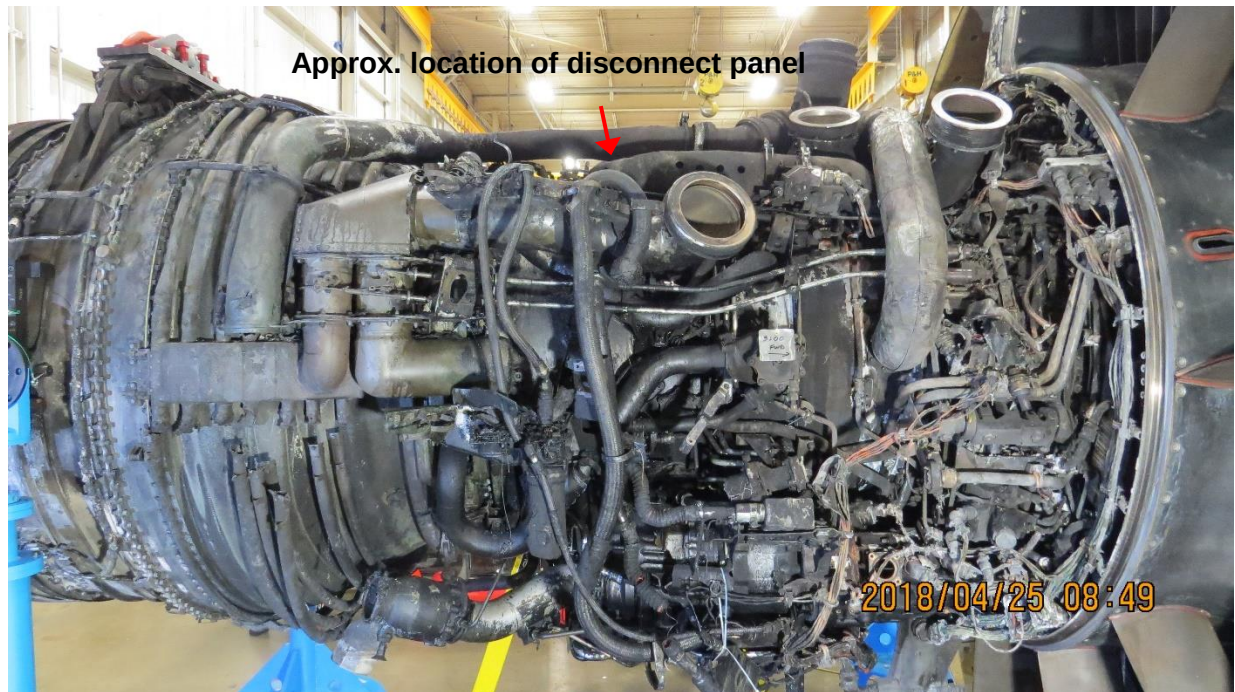


Figure 2: Overview of engine after dismounting, Engine #2 – Outboard side

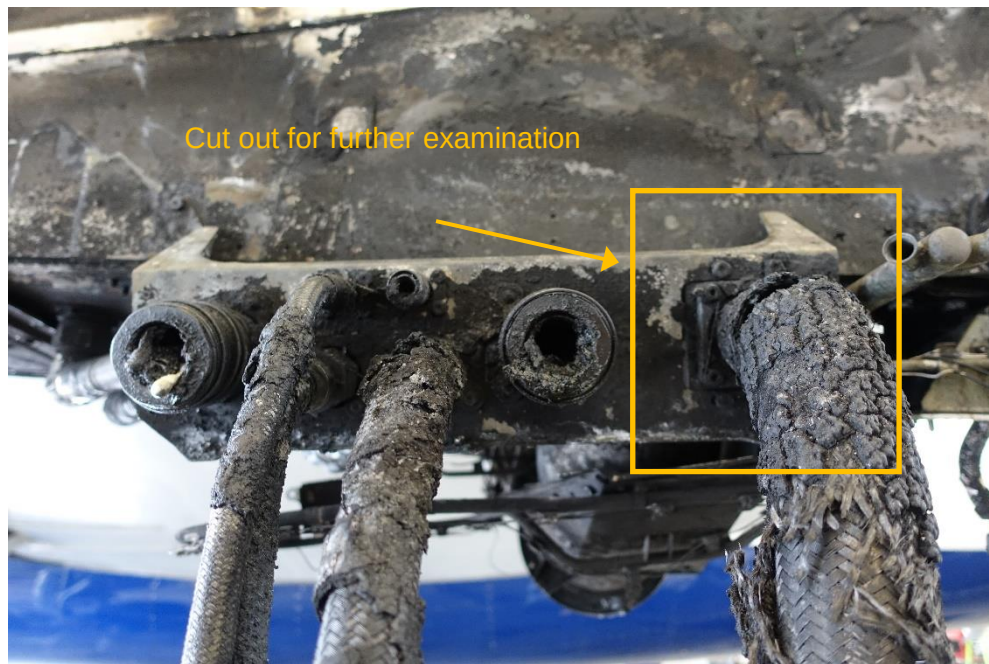


Figure 3: Overview of cut-out brought for examination

The examination in the Bremen laboratory was started in the presence of representatives from involved parties; NTSB, BEA, DELTA, Pratt & Whitney and Air Line Pilots Association under the lead of the NTSB.

Hereby all investigation steps were agreed by all involved parties in advance under the lead of the NTSB.

2 Factual Information

2.1 Aircraft and Part Identification

Related aircraft data and part data is given in **Table 1**.

Table 1: Aircraft and part data

Aircraft Data			
MSN:	00578	Operator:	Delta Airlines (DAL)
A/C Type	A330	A/C Flight Cycles:	8317
Registration:	N806NW	A/C Flight Hours:	63750
Part Data			
ATA chapter:	71		
Part Designation:	Fuel interface connection between the Pylon and the engine		

2.2 Examination Time Line

Table 2: Examination Time Line

Date	Action / Event	Remark
18 th of May 2018	Cut out arrived at Airbus Material, Processes and Test Lab	Airbus, Bremen plant
30 th of May 2018	1 st 3D scan	Airbus, Hamburg plant
11 th of June 2018	X-ray scan	GE Sensing & Inspection Technologies GmbH, Wunstorf
26 th to 28 th of June 2018	Investigation committee meeting	Airbus, Bremen plant
5 th of July 2018	2 nd 3D scan	Airbus, Hamburg plant
29 th of June until 22 nd of July	Detailed documentation and further lab examination (flatness, geometry, hardness,...)	Airbus, Bremen plant
23 rd of July 2018	Pylon fuel rigid pipe and pylon fuel rigid pipe + flange and sleeve send for testing	Shipped to Parker Hannifin Corporation (TX – USA)

2.3 Used Terms

The object of examination was a cut-out of the engine/pylon fuel connection with the following sub-items

- Cut-out of the fuel/hydraulic disconnect panel in the area of engine / pylon fuel connection
- Main supply line – labeled as flex line (item 4)
 - Flex line flange
 - Flex line sleeve
- Pylon Fuel rigid pipe (including welded-on flange)—also labeled as fixed line in Figure 6(item 2)
- Gasket (item 3)
- Four bolts with self-locking nuts connecting the Pylon fuel rigid pipe flange to the fuel/hydraulic disconnect panel (item 5)
- Four bolts and nut plates connecting the pylon fuel rigid pipe with the flex line(item 6)

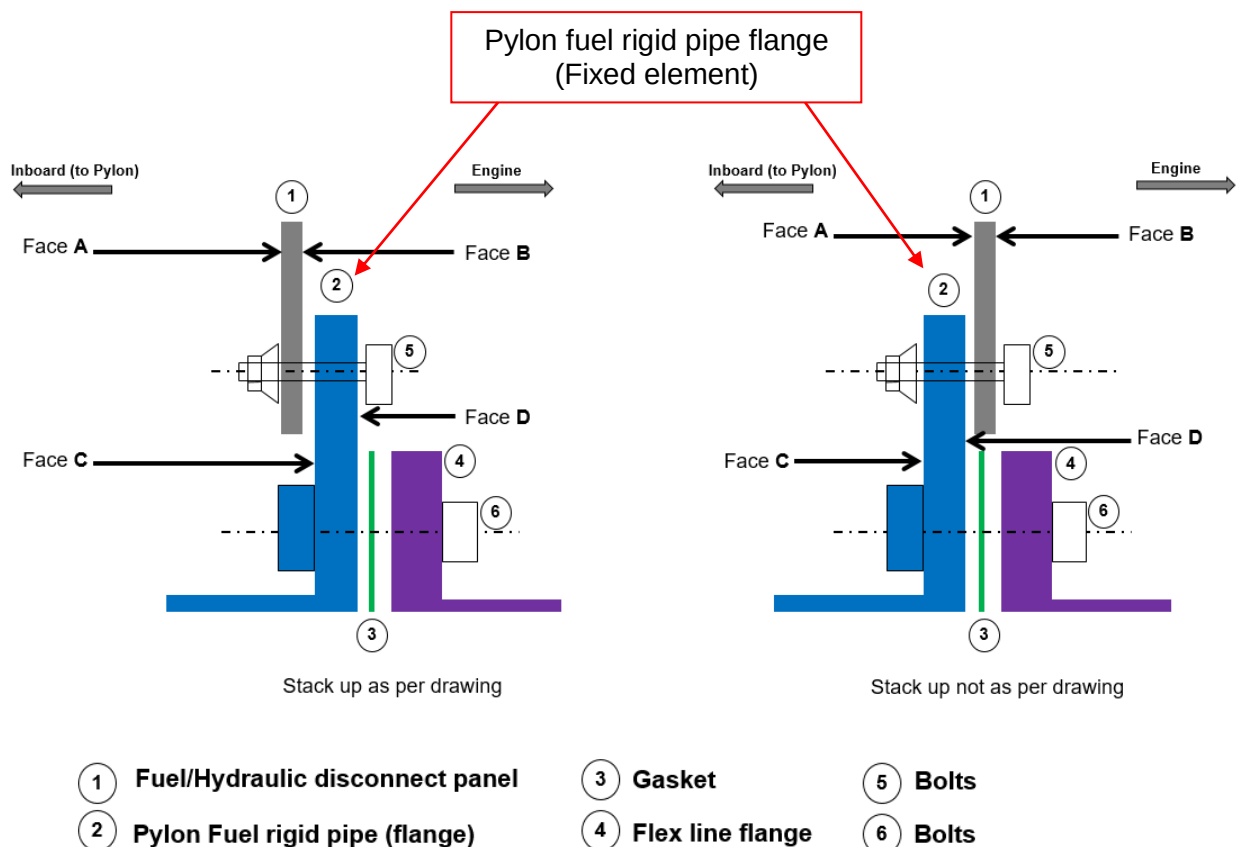


Figure 4: Installation of pylon fuel rigid pipe flange as per drawing and incorrect

3 Assembly Condition after the Event – Onsite Inspection

The onsite inspection revealed that the installation of the flex line to the pylon fuel rigid pipe was performed correctly. However the pylon fuel rigid pipe flange was not connected as per drawing to the Fuel/Hydraulic disconnect panel (Figure 5). During this initial inspection there was no clear indication that the flange has been assembled on the correct location at one point in time. The as per drawing vs not as per drawing installation of the pylon fuel rigid pipe flange can be seen in Figure 4 to Figure 6.

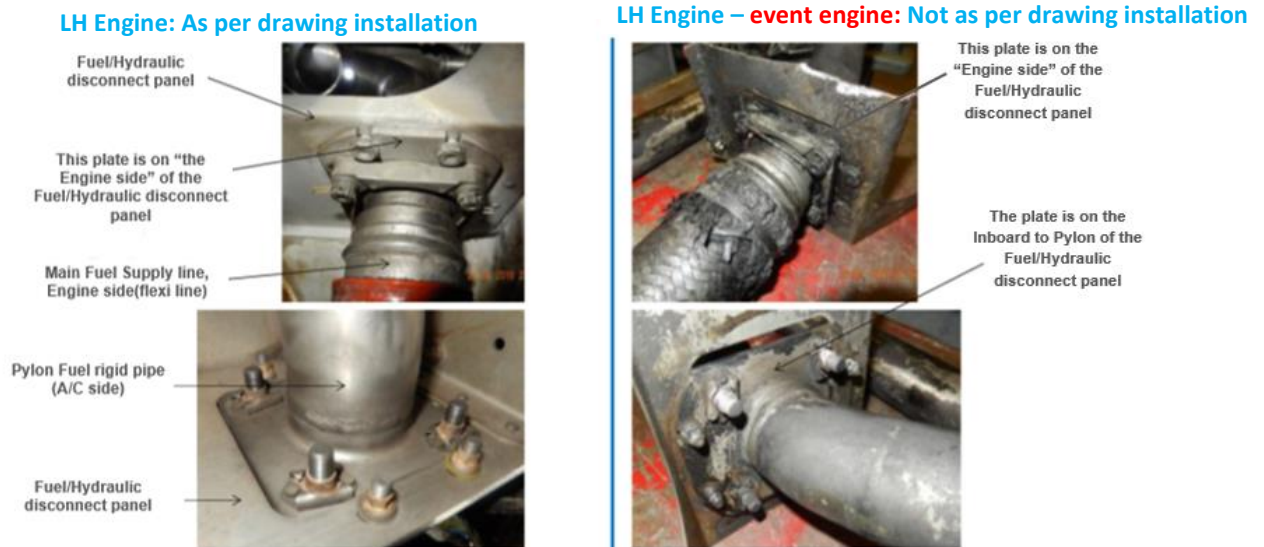


Figure 5: As per drawing vs not as per drawing installation of the Pylon fuel rigid pipe flange on event engine

According to the installation stack-up the installation not as per drawing of the pylon fuel rigid pipe flange caused an offset. The flex line connection plane has been moved inboard by 4.77 mm representing the pylon fuel rigid pipe flange thickness plus 1.50 mm representing the fuel/hydraulic disconnect panel thickness which results in a total offset of 6.27 mm (Figure 6).

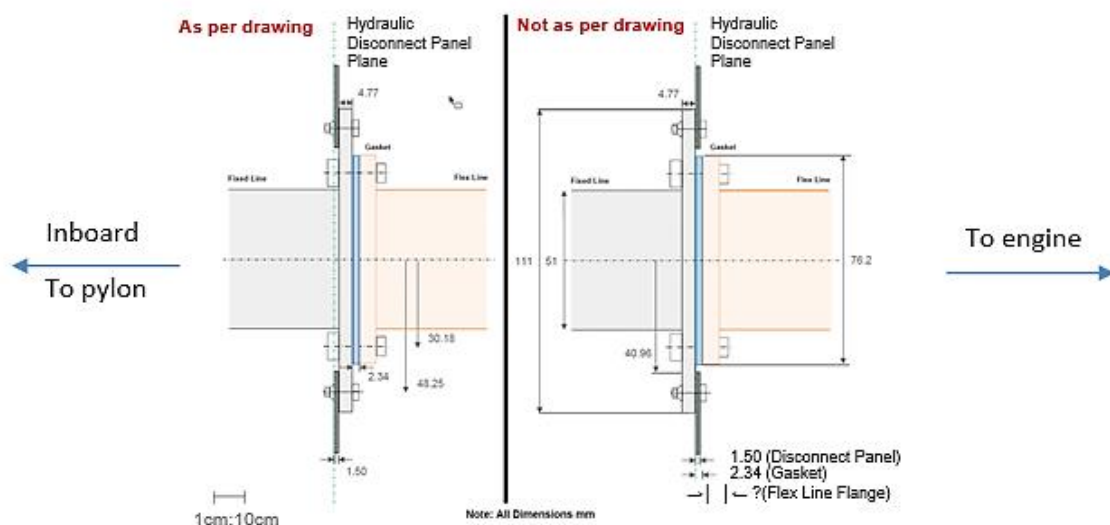


Figure 6: Design of the junction of pylon fuel pipe and flexible fuel line as per design and the observed not as per drawing assembly

The on-site inspection shortly after the event showed that fuel sprays out of the flexible line as well fuel escapes at the flange-gasket connection. Figure 7 shows a snapshot taken from the on-site video documentation and the related location on the connection of the cut-out taken after the onsite inspection.

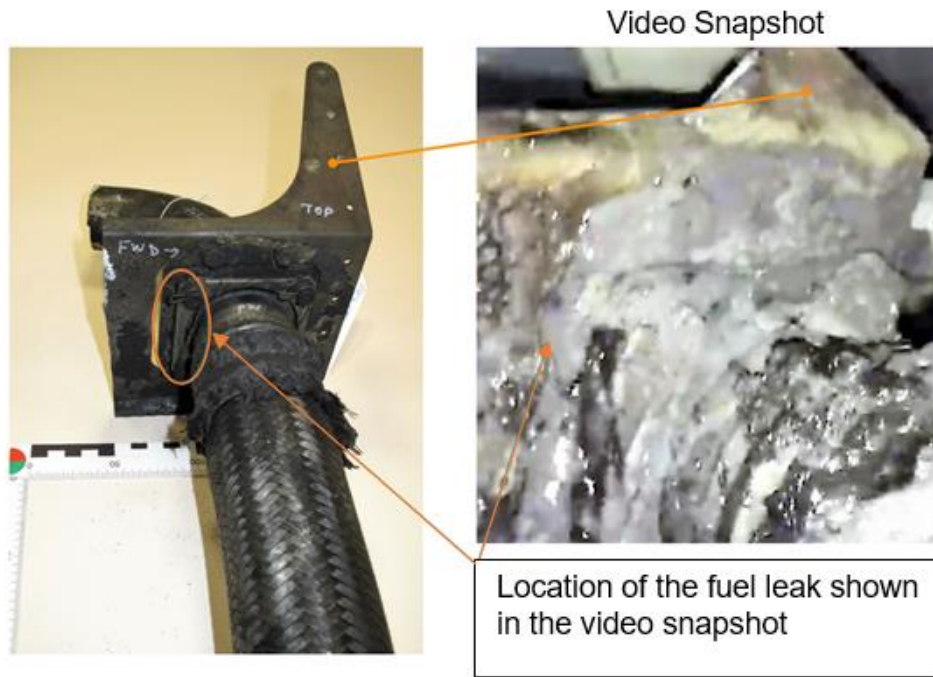


Figure 7: Location of fuel leakage at the flex line and the gasket location

4 Laboratory Examination

4.1 Incoming Inspection of the Fuel Connection Cut Out

The engine/pylon fuel connection consists of the pylon fuel rigid pipe (from pylon to fuel/hydraulic disconnect panel), the flex line (from fuel/hydraulic disconnect panel to engine fuel pump), the gasket and the fuel/hydraulic disconnect panel. The assembly (cut out) has been received by the Airbus Failure Analysis Lab in Bremen for examination (Figure 8 and Figure 9).

The incoming documentation showed beside the indication of the fire:

- The pylon fuel rigid pipe flange is assembled at the inboard side of the fuel/hydraulic disconnect panel (Figure 10 and Figure 11) which is not in accordance with the drawing.
- Clearance was found between the flex line sleeve and the fuel/hydraulic disconnect panel cut-out (see Figure 12 and Figure 13 and 3D measurement (chapter 4.2)) which is in accordance with the drawing.
- All bolts and the lock-wires are in the correct place (Figure 13).
- By a qualitative visual flatness check it can be seen that the flex line sleeve and the pylon fuel rigid pipe flange present a slight non-flatness of the outer surface (Figure 14).
- The flex line showed after disassembly from the sleeve, melted material residue close to the flex line cut location (Figure 15).

All bolts were labeled for examination purpose as shown in (Figure 16).

For the detailed analysis and check, a 3D scan of the assembly has been performed in as-received conditions (chapter 4.2) and for single parts after disassemble and cleaning (chapter 4.13). Furthermore an X-ray CT was done prior to disassembly (chapter 4.3).

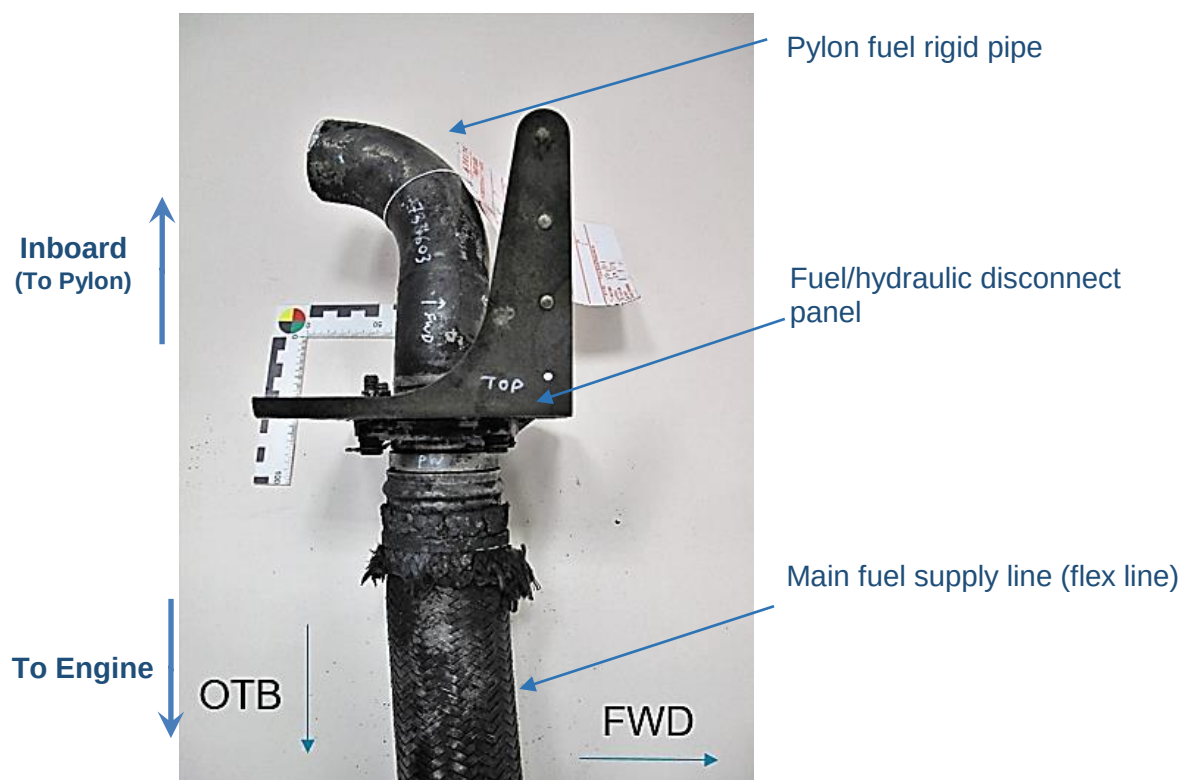


Figure 8: Engine / pylon fuel connection, view from top

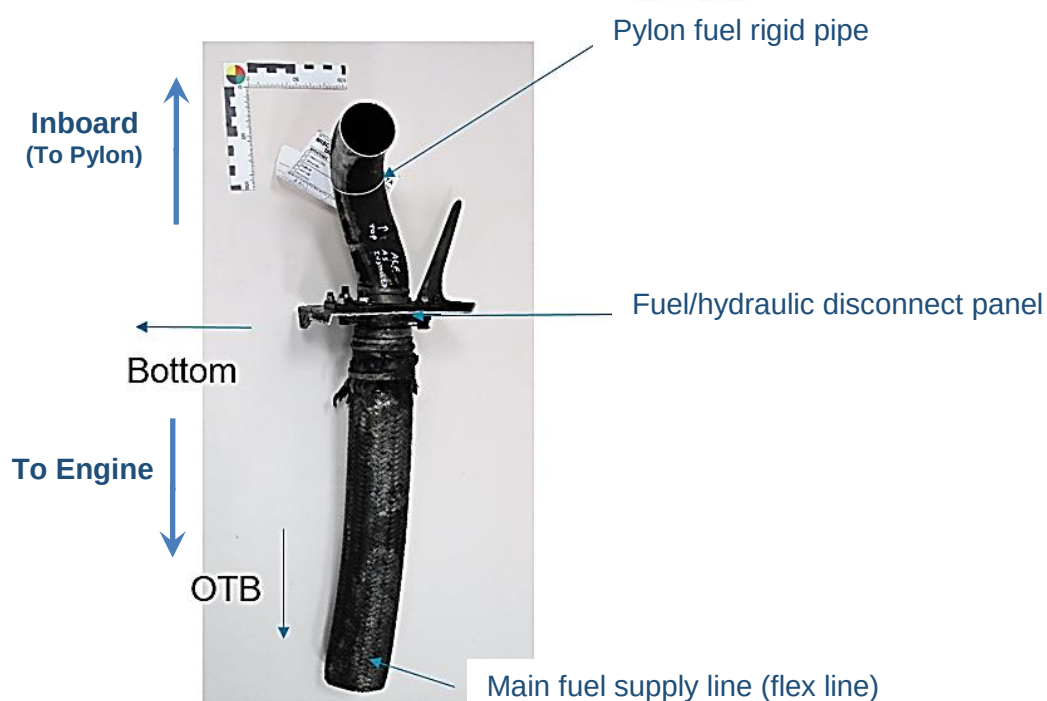


Figure 9: Engine / pylon fuel connection, FWD view

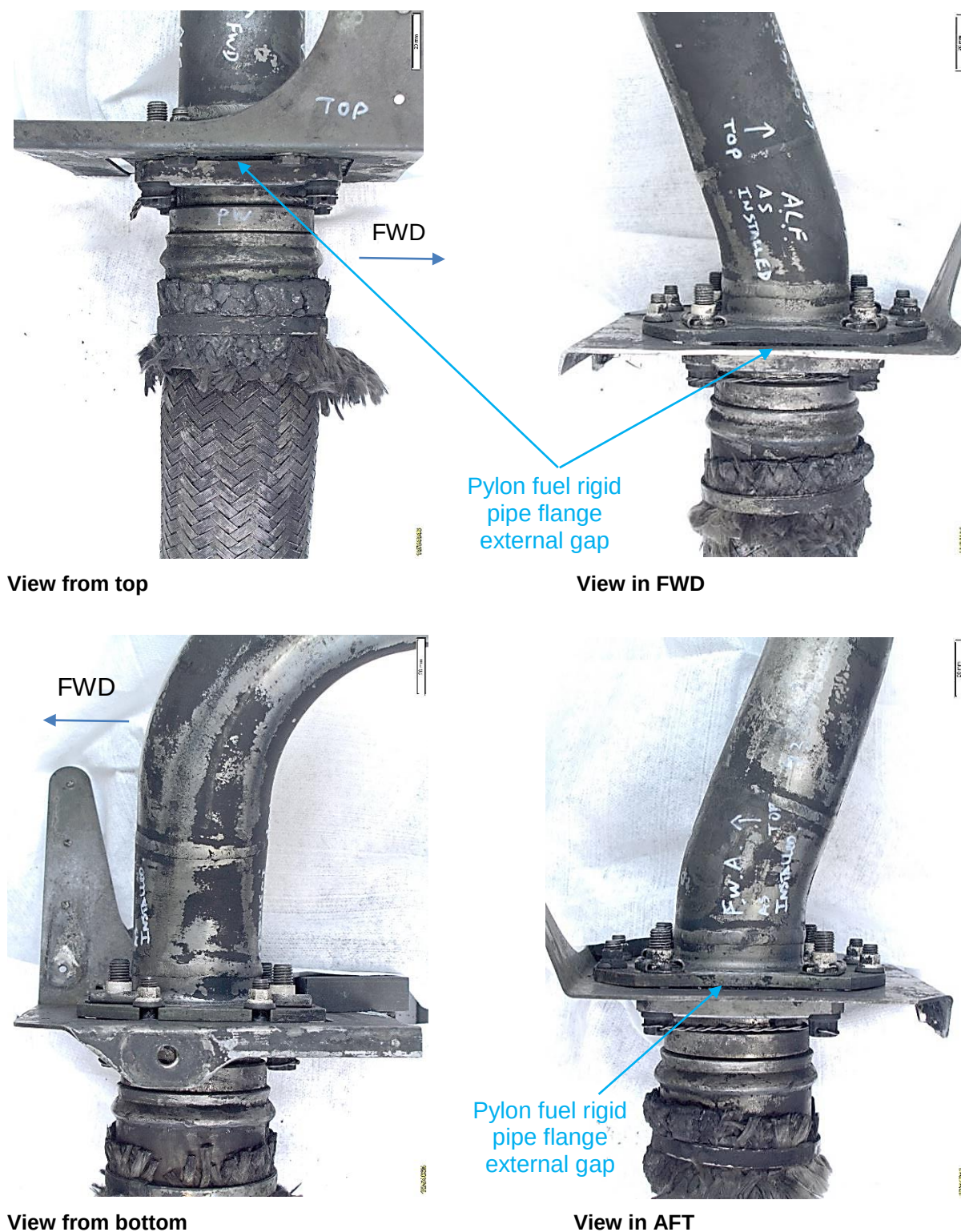


Figure 10: Engine / pylon fuel connection each view is rotated by 90°;
Observation: Pylon fuel rigid pipe flange connection is gapping externally

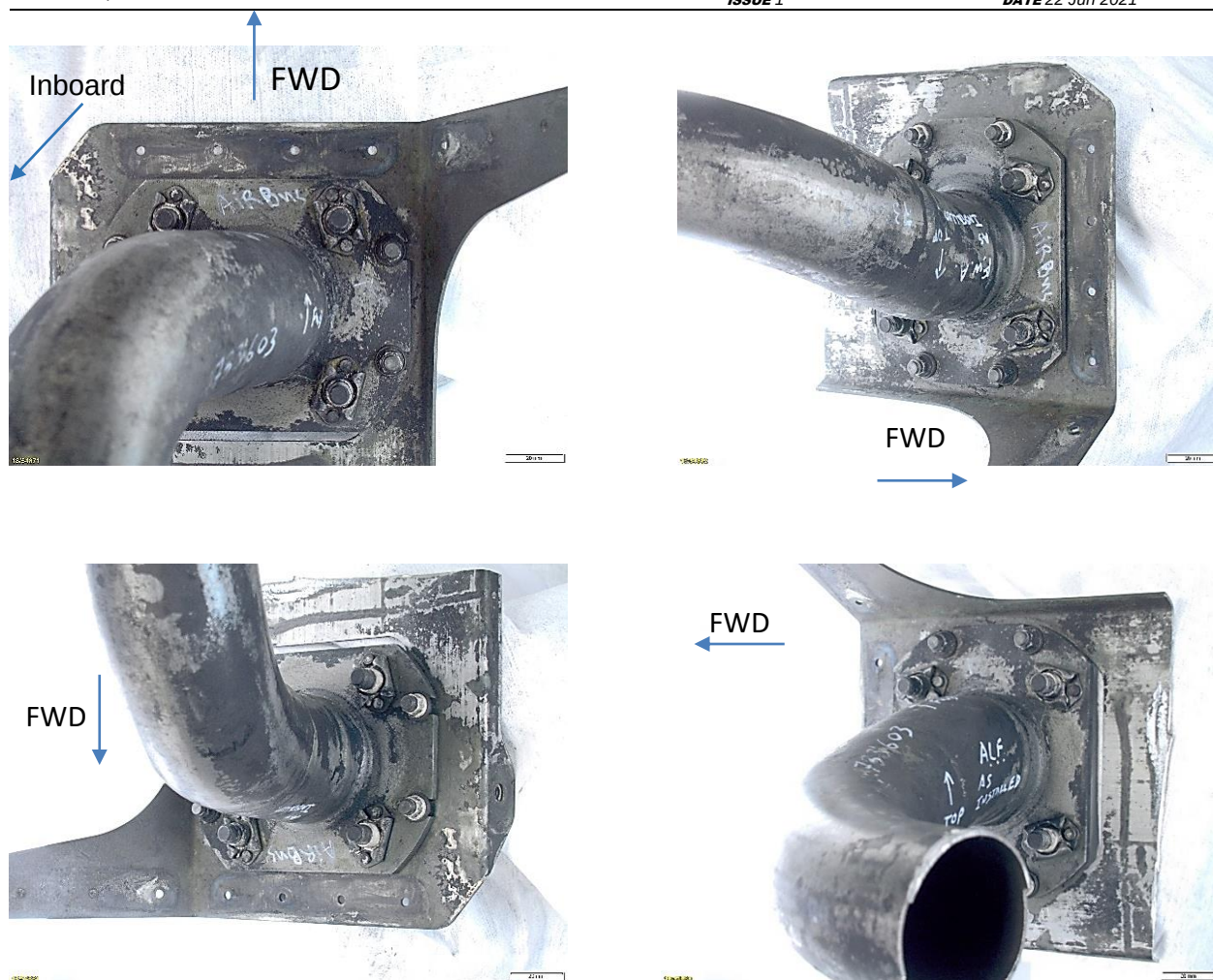


Figure 11: Engine / pylon fuel connection views of the pylon fuel rigid pipe flange from In-side



Figure 12: View from OTB (outboard) side - flex line sleeve and flange position to the fuel/hydraulic disconnect panel – no contact between sleeve and fuel/hydraulic disconnect panel

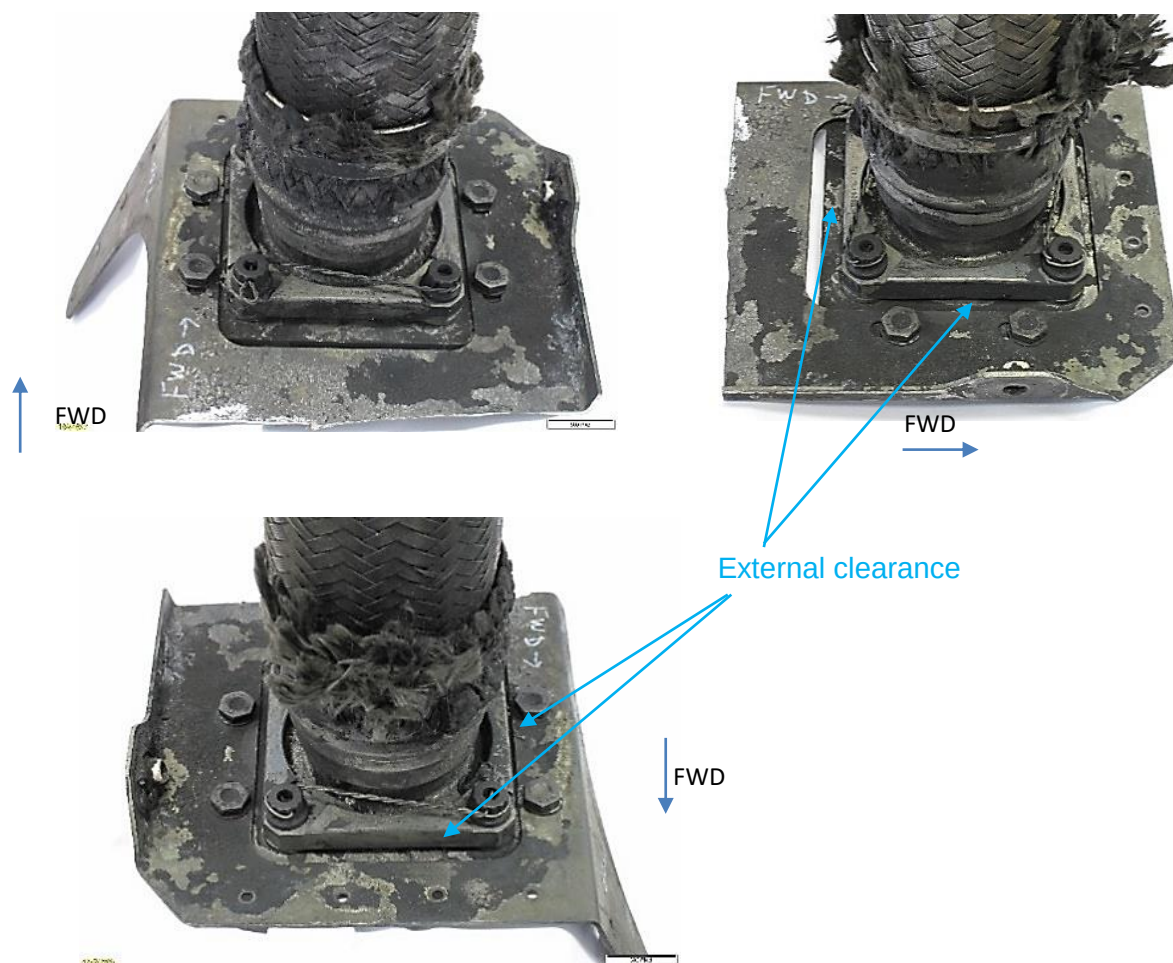


Figure 13: View from OTB - no contact of flex line sleeve to the fuel/hydraulic disconnect panel, cf. also 3D scan

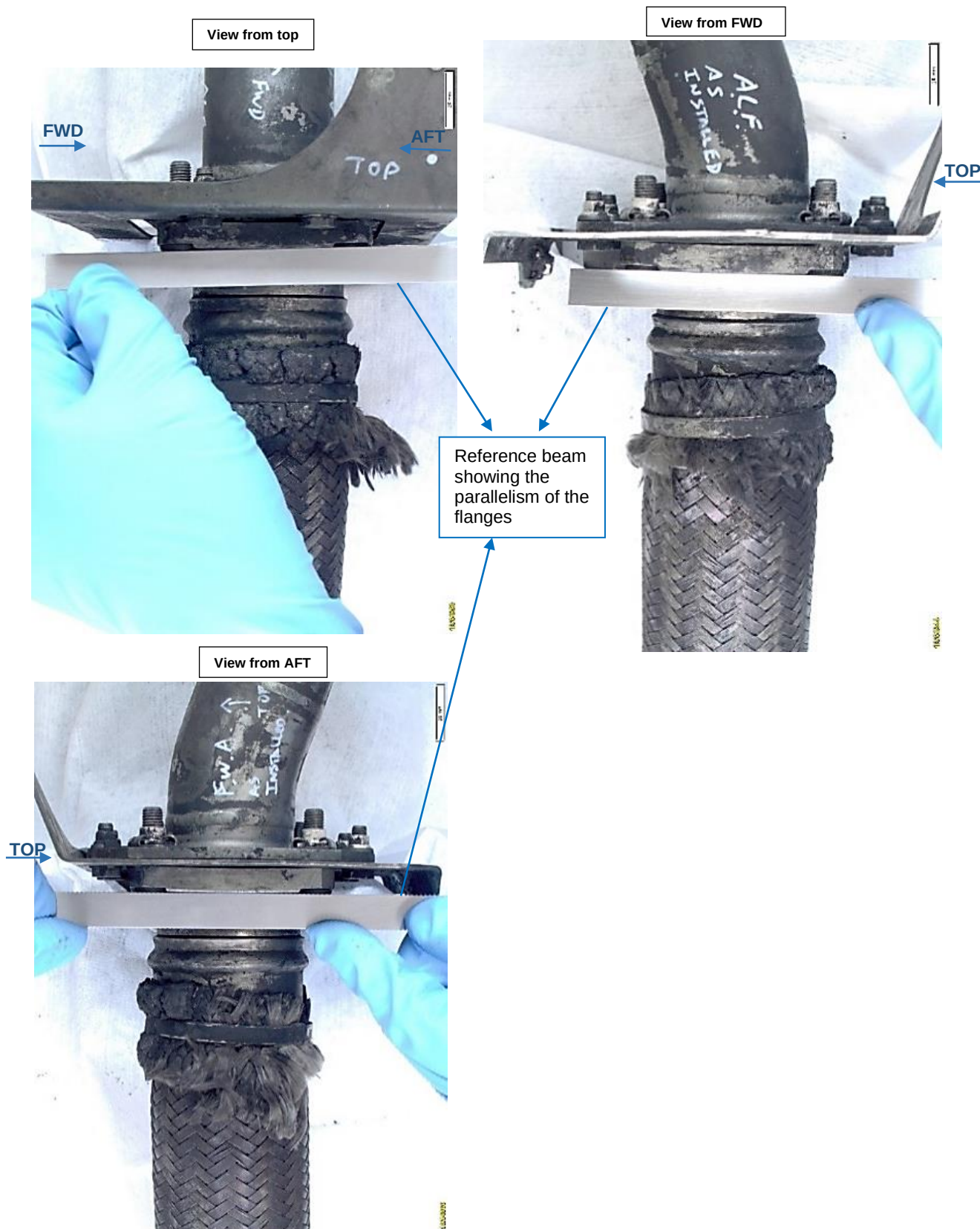


Figure 14: Flex line sleeve - qualitative sleeve flatness check on the outer surfaces



Figure 15: Flex line view in inboard direction presenting melted material on bottom side, at cut location

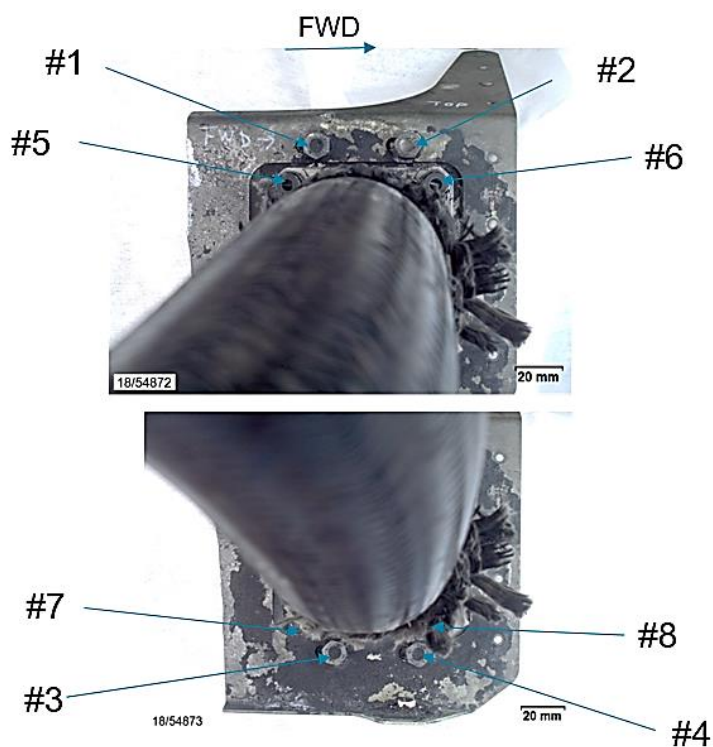


Figure 16: View from outboard side onto the fuel/hydraulic disconnect panel – labeling of bolts

4.2 3D Scan of the Fuel Connection in as-received Condition

3D scan has been performed for the as-received assembly to highlight the deformations and possible deviations from the standard drawings. This is performed without cleaning. For measurement after cleaning see Chapter 4.13.

3D scan conditions:

- Used equipment: Handy Scan 3D – Ametek (Figure 17, calibrated before each measurement and certified each year)
- Room condition: 20°C
- The Resolution during the scan is 0.3mm (viz. measurement point each 0.3 mm on the surface of the part) → triangle mesh
- The accuracy of the scan is 0.1mm.
- Software for data collection during Scan: VX Elements
- Software for Model views and measurements: Polyworks
- Data format: STL
- Limitations: shiny surfaces can lead to difficulties for contours

The following points need to be considered for the 3D views:

- CAD reference model was only integrated for Airbus parts (pylon fuel rigid pipe & flanges), as it was only available for this parts of the assembly
- Color range shows deviation from the CAD model [mm]
- Failure tolerance of the model per view was chosen in a manner that makes deviations from CAD visible on all areas of the part. Chosen tolerance is stated in Appendix 2 – 3D Scan as received.
- The drawings of the parts specify tolerances dependent from the specific dimensions and requirement, i.e. on one part not only one single tolerance value is applicable for all dimensions → this varying tolerances where not taken into account in the chosen failure tolerance.
- Available drawings are added to 3D view for information in Appendix 2 – 3D Scan as received.

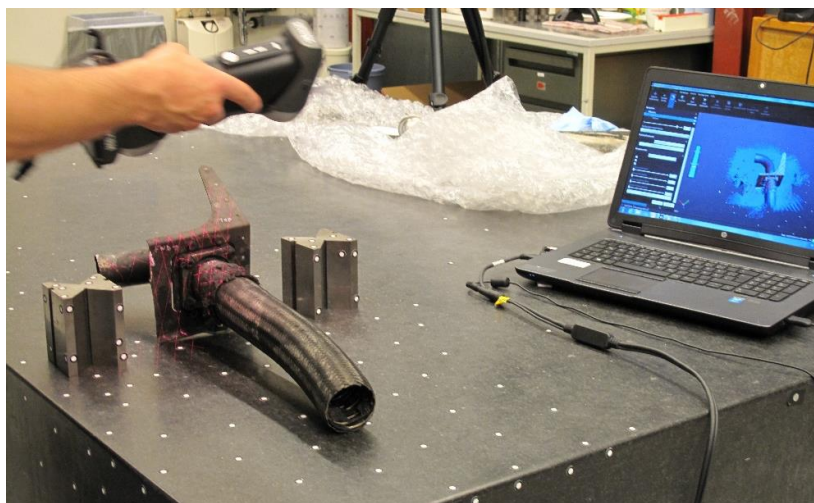


Figure 17: 3D scan setup

The inboard side of the pylon fuel rigid pipe flange is not flat, mainly on the “long sides” of the flange. The maximum deviation can be observed at FWD side (Figure 18).

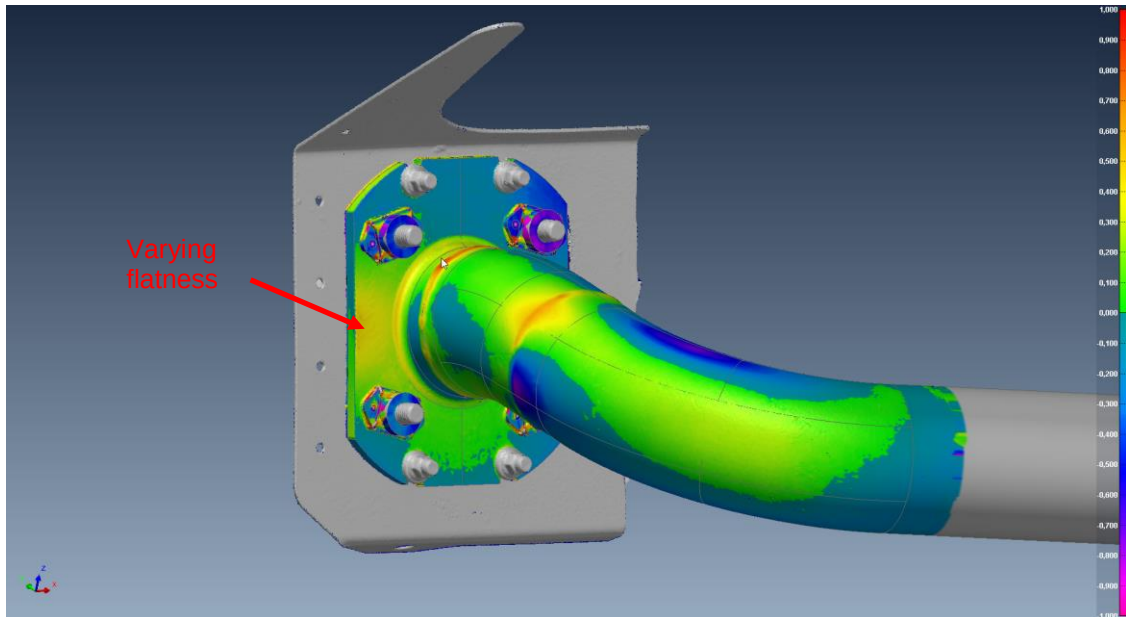


Figure 18: Varying flatness of pylon fuel rigid pipe flange at FWD side

The 3D scan shows the flex line sleeve in view parallel to the pylon fuel rigid pipe flange and the fuel/hydraulic disconnect panel. This means the flex line sleeve is assembled in plane condition (Figure 19 and Figure 20). This observation was confirmed after disassembling (Figure 35).

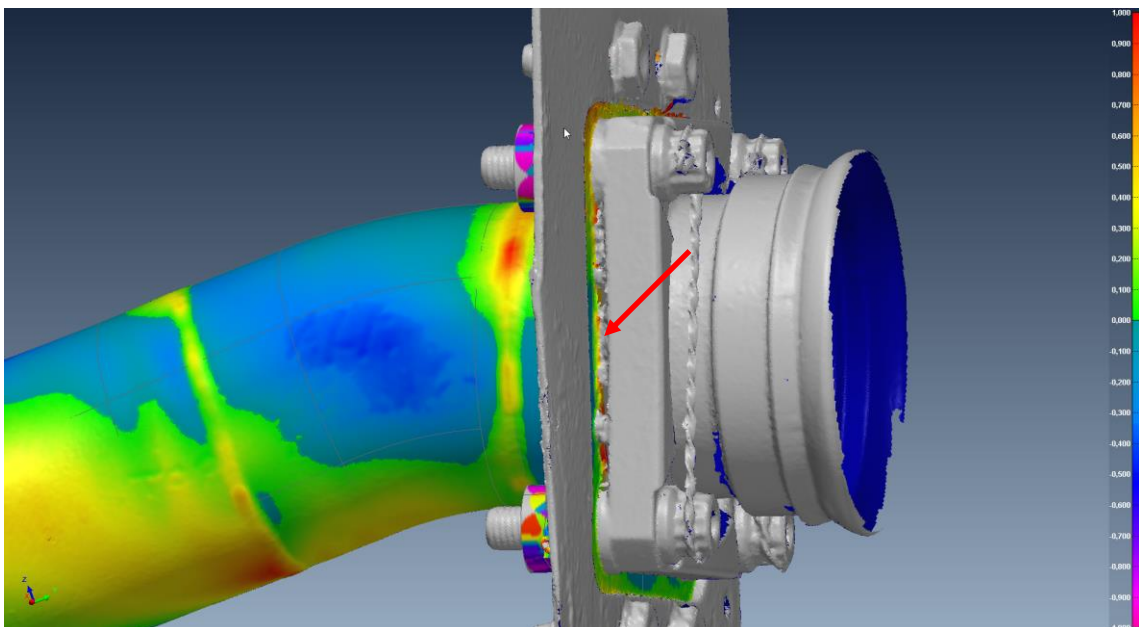


Figure 19: Position of the flex line flange towards the pylon fuel rigid pipe flange and fuel/hydraulic disconnect panel – view 1

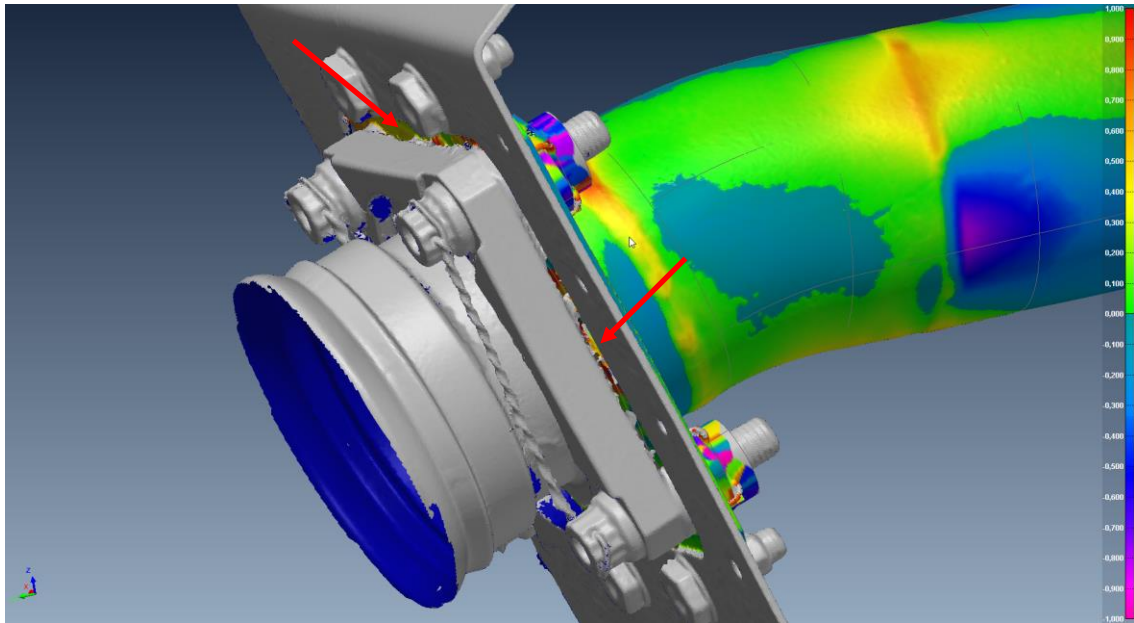


Figure 20: Position of the flex line flange towards the pylon fuel rigid pipe flange and fuel/hydraulic disconnect panel – view 2

Further views of the as-received 3D scan can be found in Appendix 2 – 3D Scan as received.

As not all relevant CAD models of the assembly are available for comparison to the specification and as the assembly was contaminated by dirt and residues from the fire event, a detailed evaluation of the 3D results is not done, except for the pylon fuel rigid pipe and the related flange.

If a detailed evaluation of the 3D data is needed for further analysis the missing CAD models are needed and the responsible design departments shall be consulted.

4.3 X-ray CT of the Fuel Connection in as-received Condition

To enable a detailed inspection of the components conditions the fuel connection assembly was examined by X-ray computer tomography by GE Sensing & Inspection Technologies GmbH prior to disassembly in the lab (chapter 4.4).



Figure 21: X-ray CT setup

The following CT source data files are made available as volume data in vgl-format, ready to be used e.g. in Volume Graphics VGSTUDIO max 3.1.

- X-ray CT part 1 - Pylon fuel rigid pipe / Flex line connection
 - Overview Scan, Voxel Size 150µm (file name: Full Pipe Part 1 450KV_1.vgl)
 - Detailed Scan, Voxel Size 78µm (file name: Full Pipe Part 1 300KV detail.vgl)
- X-ray CT Pylon fuel rigid pipe –Part 2 - transition Pylon
 - Overview Scan, Voxel Size 144µm (file name: Full Pipe Part 2 300KV scan 1.vgl)

The available X-ray data were analyzed during the investigation team meeting in Bremen. Due to X-ray artefacts the data were preliminary assessed to be detailed enough in the area of concern to support the examination further. However the X-ray data could proof that the gasket was installed (see Figure 23).

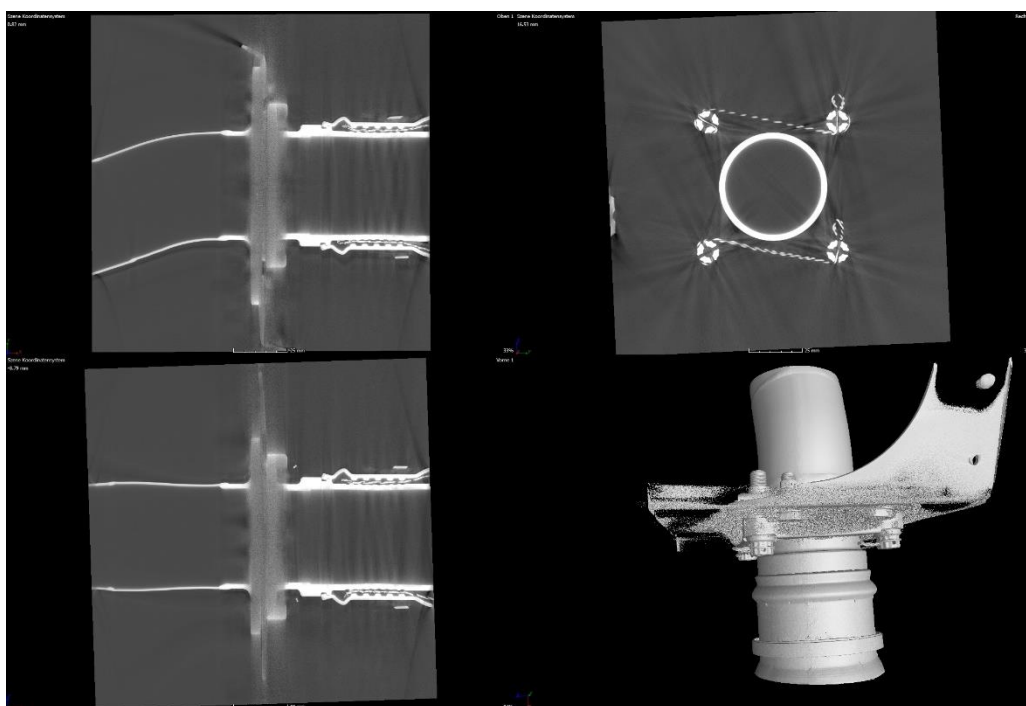


Figure 22: X-ray CT volume data

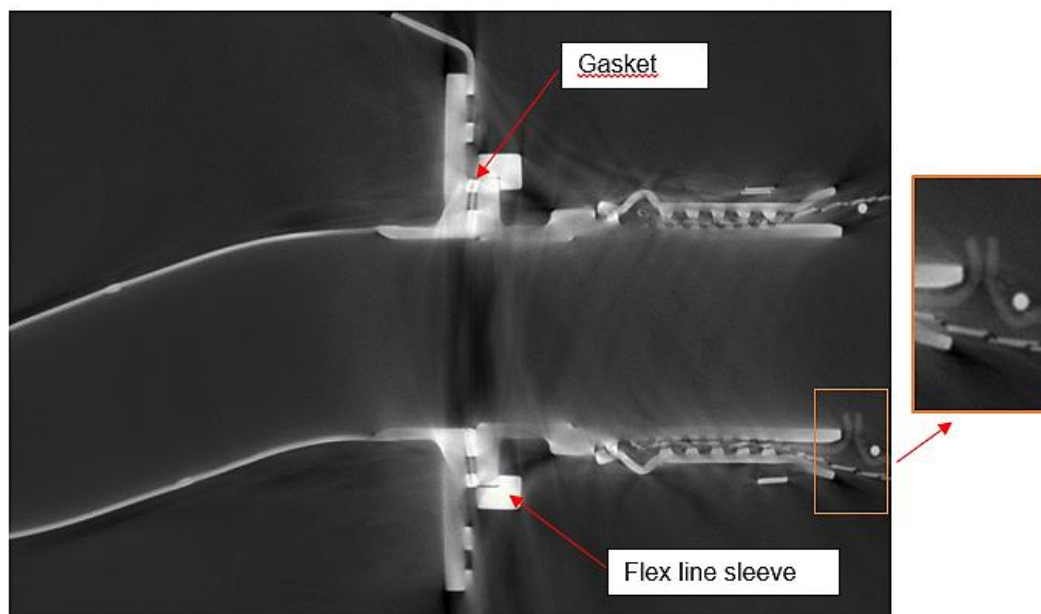
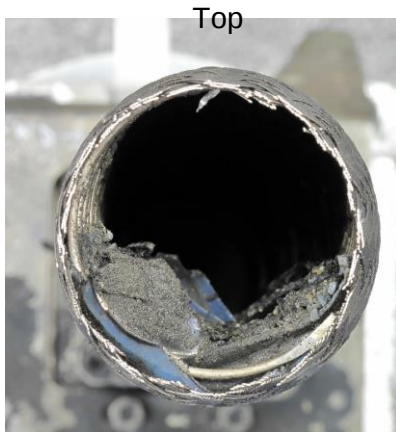


Figure 23: X-ray CT snapshot of the volume data, gasket installed between the flanges

Due to the event the PTFE tube has no longer its original structure and melted material was found on the bottom side of the flex line at the cut location.



FWD
→

Figure 24: Accumulation of PTFE melted on the lower side of the tube.

Flex line- view inboard direction on the cut as per event condition

The following CT scans will show the condition of the flex line PTFE hose along various planes of view:

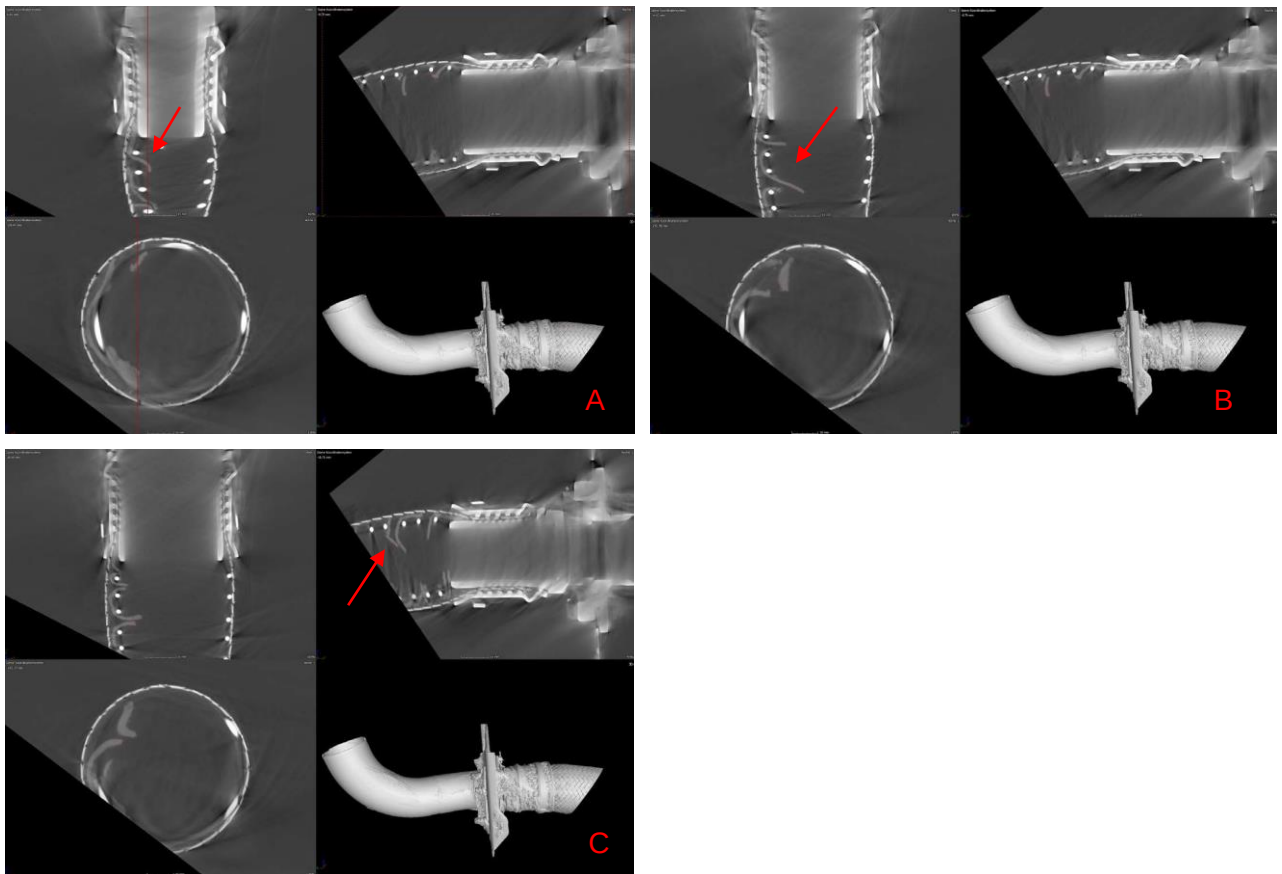


Figure 25: X-Ray CT scan showed single openings (indicated with arrows) of the PTFE tube - view A, B and C

The PTFE tube shows clear evidence of heated and melted residual besides the not melted areas.

Conclusion: Area highlighted with orange border in Figure 23 to be further investigated for checking if the PTFE shows signs of cracking.

4.4 Macroscopic Examination after stepwise disassemble of the Connection

To enable a detailed inspection of the components conditions the fuel connection assembly was disassembled in the lab. During disassembling the components have been removed step by step to expose those areas which have been hidden before. The components have been documented without cleaning.

Step 1: Disassembly of flex line (pylon fuel rigid pipe flange/gasket). The fuel/hydraulic disconnect panel was not disassembled, see Figure 26:

- Related to the cut-out of the fuel/hydraulic disconnect panel, the installation of the pylon fuel rigid pipe flange were orientated more in FWD direction.
- Residues in the rubber seal groove of the gasket has been found. It is supposed they are remains of the installed rubber seal. Thus, the rubber seal was no longer acting as seal after the fire event, explaining the leak reported in Chapter 3 (Figure 7).

Note: The gasket has been slightly moved during removal of flex line.

Step 2: Removal of gasket (pylon fuel rigid pipe flange/ fuel/hydraulic disconnect panel panel), see Figure 27:

- The pylon fuel rigid pipe flange shows residues on the sealing area which proves that the gasket was initially assembled with a rubber seal. However the seal was no longer acting as seal after the fire event.
- The gaskets pylon fuel rigid pipe and flex line side sealing surfaces show residues on the sealing surface area. These are probably caused by rubber seal, see Figure 28. However the seal was no longer acting as seal after the fire event.

Step 3: Pylon fuel rigid pipe flange (removal of fuel/hydraulic disconnect panel), see Figure 29:

- Contact marks of the long holes of the fuel/hydraulic disconnect panel and contact marks of the gaskets holes can be observed on the pylon fuel rigid pipe flange.

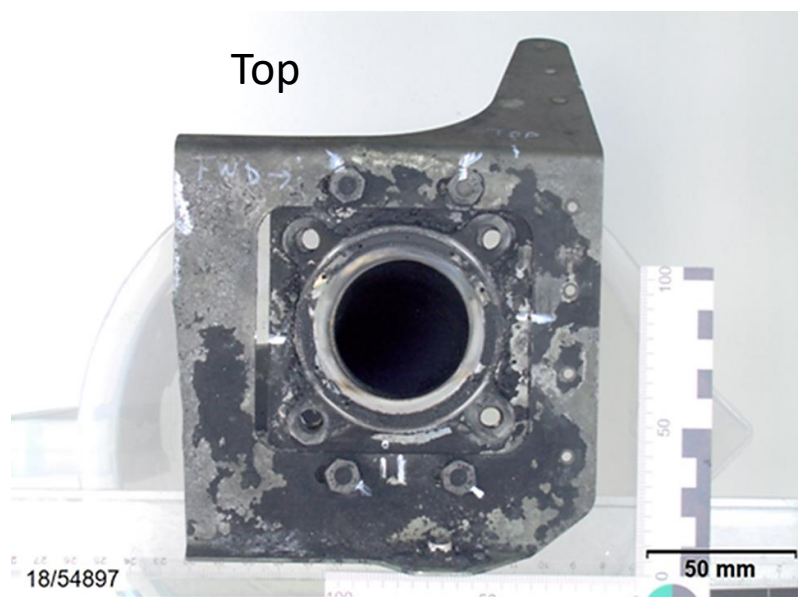


Figure 26: Pylon fuel rigid pipe flange + gasket + fuel/hydraulic disconnect panel, view from outboard side before cleaning

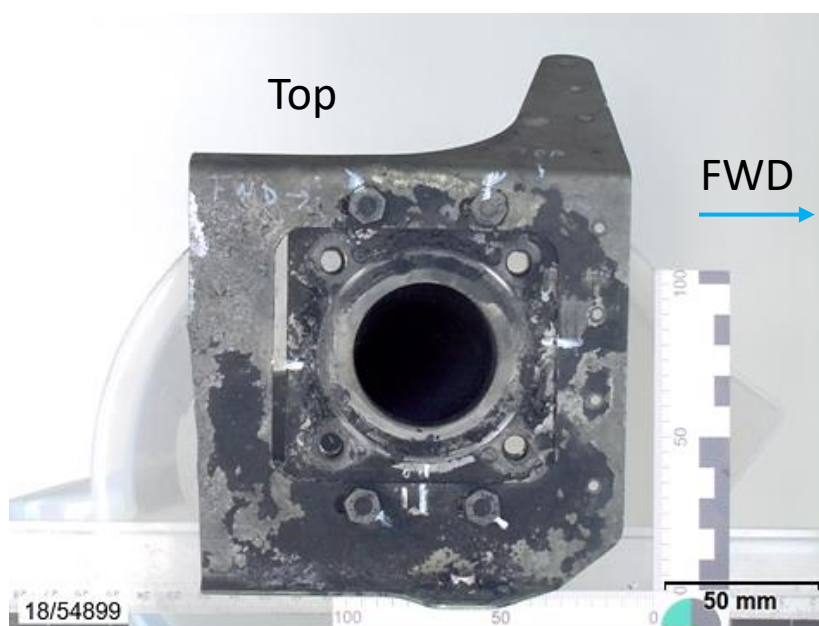


Figure 27: Pylon fuel rigid pipe flange + fuel/hydraulic disconnect panel, view from outboard side before cleaning

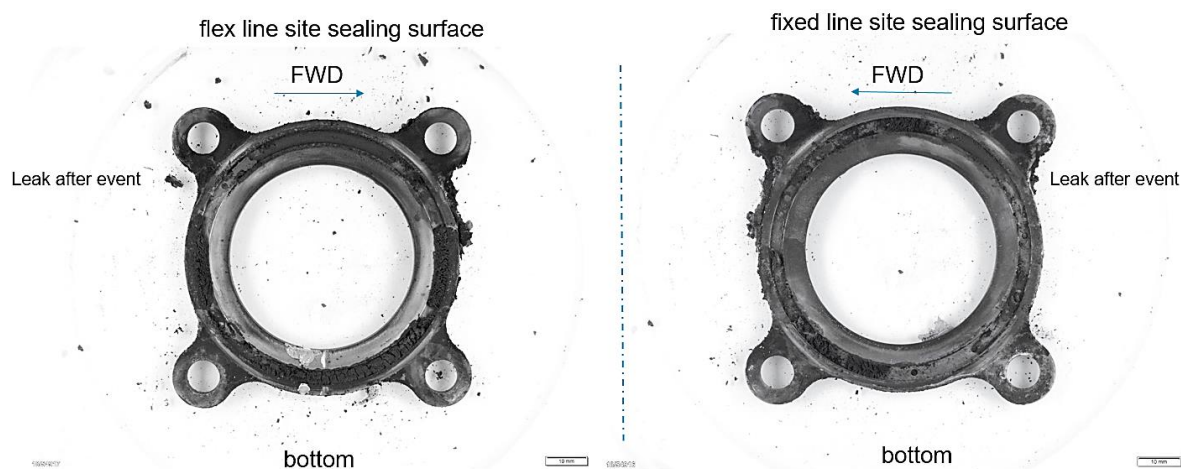


Figure 28: Gasket with residue in the rubber seal groove before cleaning

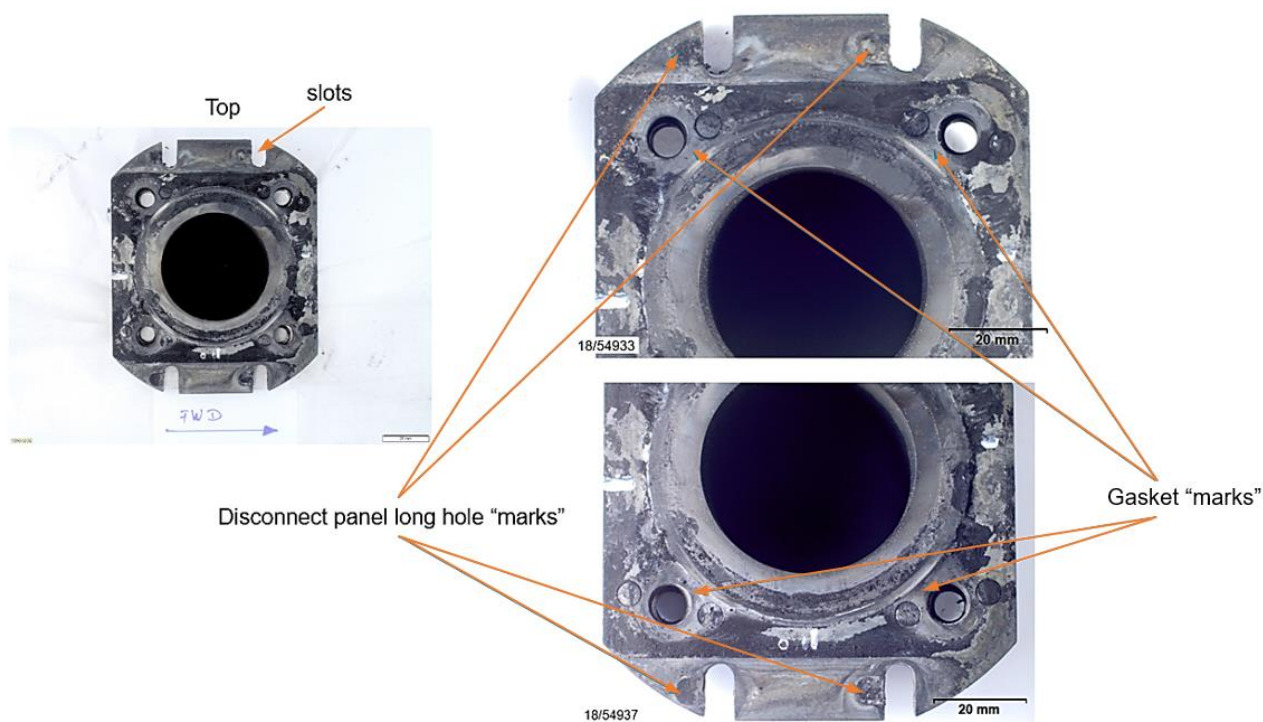


Figure 29: Pylon fuel rigid pipe flange with various contact marks, before cleaning

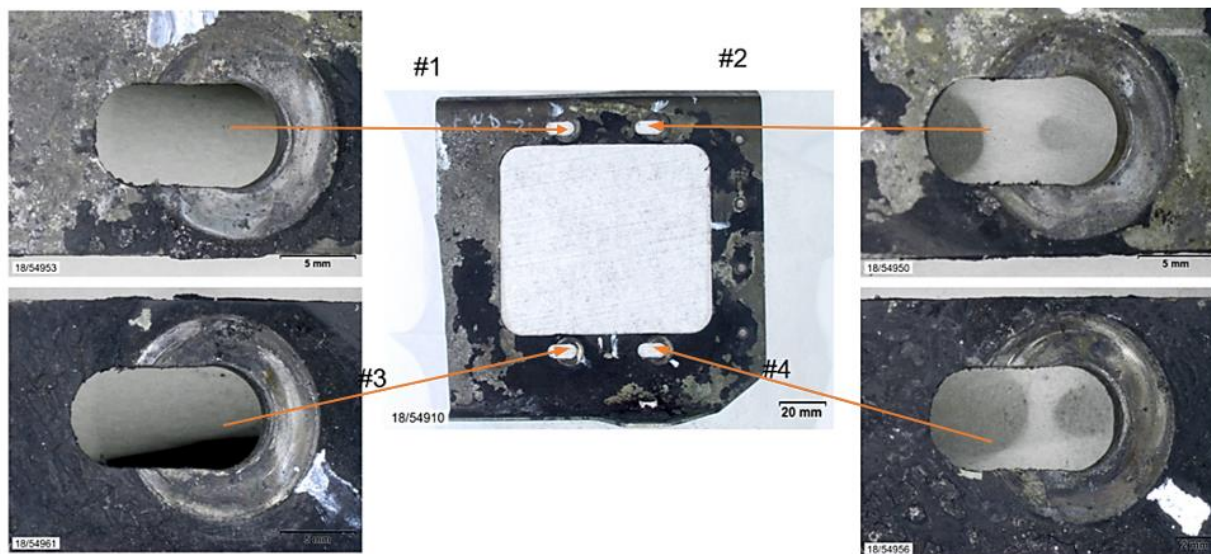


Figure 30: Fuel/hydraulic disconnect panel outboard side (before cleaning) - presenting abrasion from bolt head, partly discoloration and deformation of long holes

4.5 Breakaway torque measurement

In frame of the disassembly, the breakaway torques of the bolt connections were measured. The indication was, to check if a torque was applied and to get an idea of the possible dispersion of torque. The intention was not to perform a precise measurement of the applied torque. However, the breakaway torque values are stated in the following figures for information.

According to “AMM 73-11-18-400-801-A Installation of the Main Fuel Supply Line” document the torque tension for bolts #5, #6, #7 and #8 should be in a range between 180 lbf.in and 200 lbf.in.

According to the production torque values the torque tension for bolts #1, #2, #3 and #4 should be in a range between 73 lbf.in and 94 lbf.in.

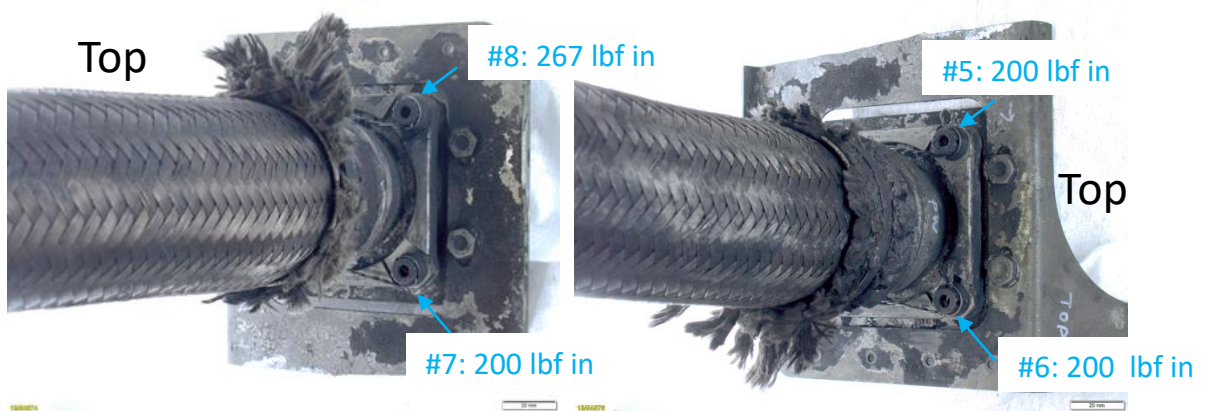


Figure 31: Breakaway torque of the bolt connections connecting the flanges and the gasket - gasket slightly moved during removal of flex line – view from outboard side

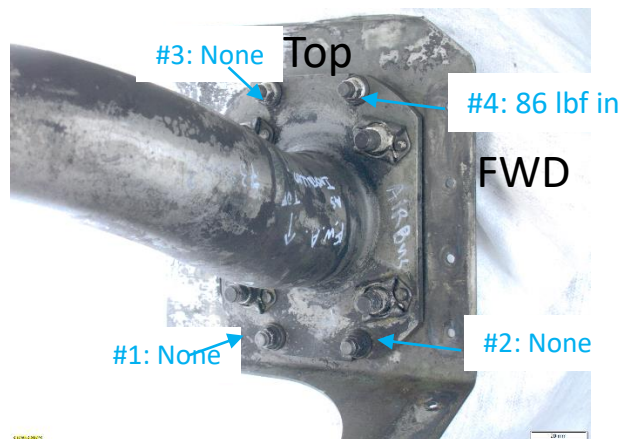


Figure 32: Breakaway torque of the bolt connections connecting the pylon fuel rigid pipe flange and the fuel/hydraulic disconnect panel – view from outboard side

Conclusion:

- Breakaway torque of the bolts connecting the pylon fuel rigid pipe flange and the fuel/hydraulic disconnect panel is in expected range 180 lbf.in and 200 lbf.in.
- Only 1 out of 4 bolts to connect the assembly with the disconnect panel, shows a torque value in the expected range 73 lbf.in and 94 lbf.in.

Note: Specification of the bolts as follows:

- The bolts connecting the pylon fuel rigid pipe with the flexible pipe
- The bolts connecting the pylon fuel rigid pipe flange to the fuel/hydraulic disconnect panel

4.6 Macroscopic Examination of Components after Disassemble and Cleaning

All parts were cleaned and then documented again. The standard cleaning procedure was as follows:

1. Soapy Water – US bath
2. documentation
3. Isopropanol – US bath
4. Documentation
5. Brush with soapy water
6. Documentation

It can be observed that the pylon fuel rigid pipe flange, the flex line flange and both sides of the gasket present marks caused by contact during assembly at the same position. This indicates contact and/or possible relative (micro) movement of these parts in assembled conditions (Figure 33).

The pylon fuel rigid pipe flange has presented various marks produced by the fuel/hydraulic disconnect panel assembly and the gasket, see Figure 34.

The fuel/hydraulic disconnect panel has presented abrasion from bolt heads and partial discoloration and deformation of long holes. After cleaning the fuel/hydraulic disconnect panel has presented imprints of the pylon fuel rigid pipe flange slots. The indication of abrasion is a result of movement between the assembled parts.

After cleaning of the gasket in one area possible remained traces of a part number can be identified but not readable. Another area shows an imprint of the manufacturer, see Figure 37.

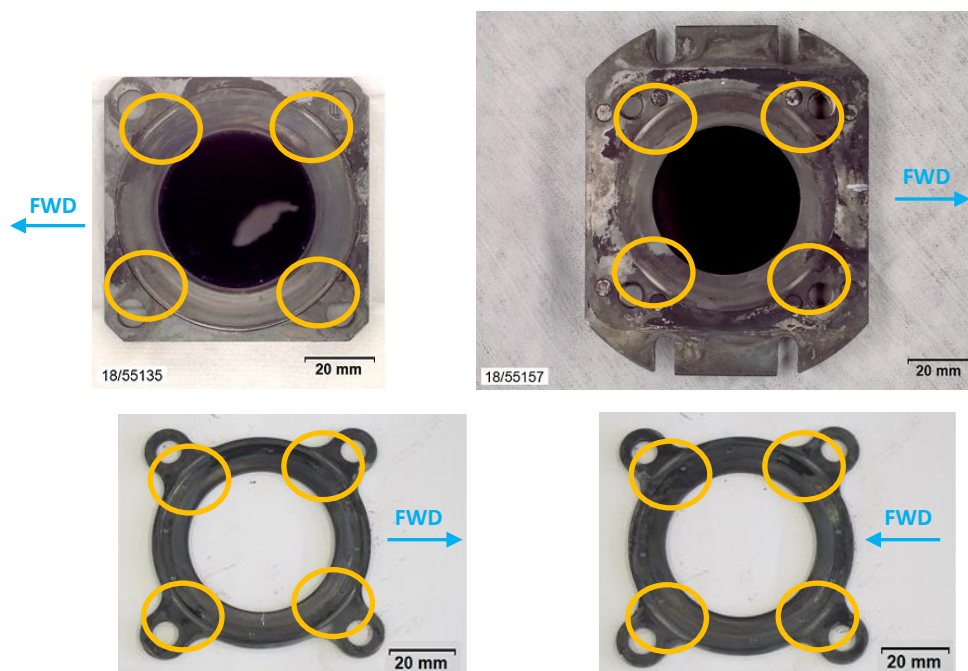


Figure 33: Pylon fuel rigid pipe flange, flex line flange and gasket with assembly marks at the same positions

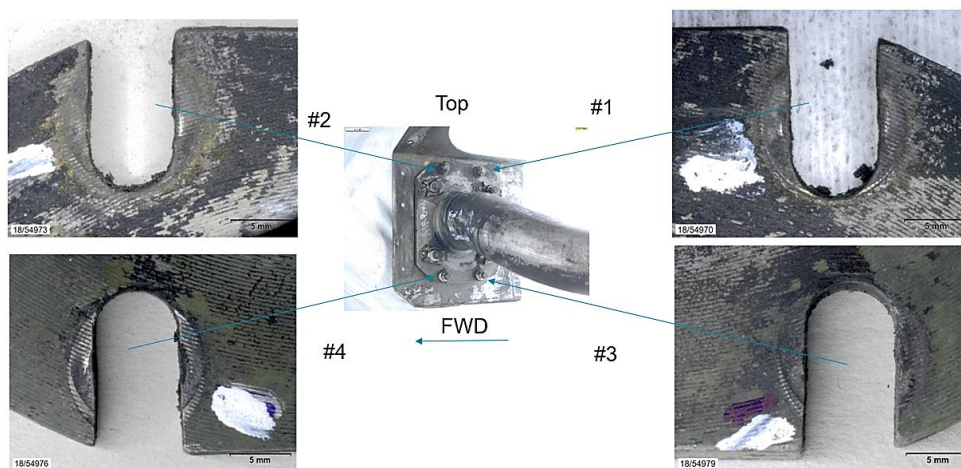


Figure 34: Pylon fuel rigid pipe flange after cleaning

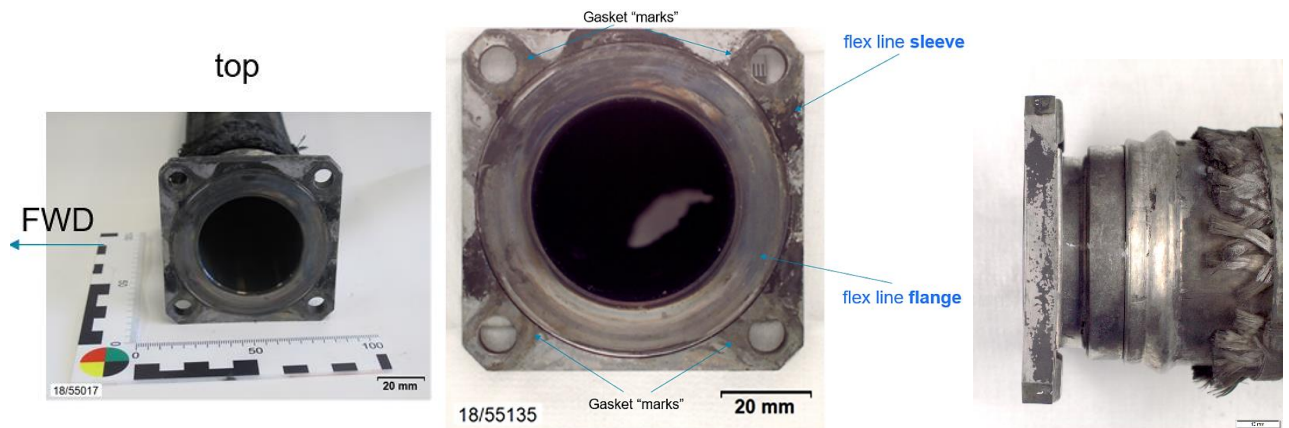


Figure 35: Flex line flange and sleeve with “marks” – after cleaning, flange and sleeve installed in the same plane (no tilt of sleeve)

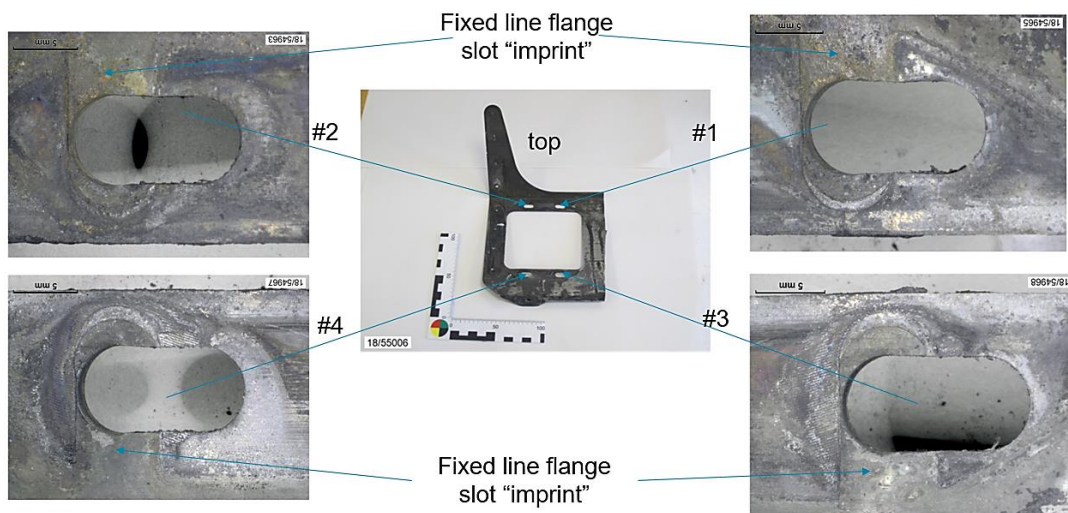


Figure 36: Fuel/hydraulic disconnect panel inboard side presenting Pylon fuel rigid pipe flange “imprints” – after cleaning

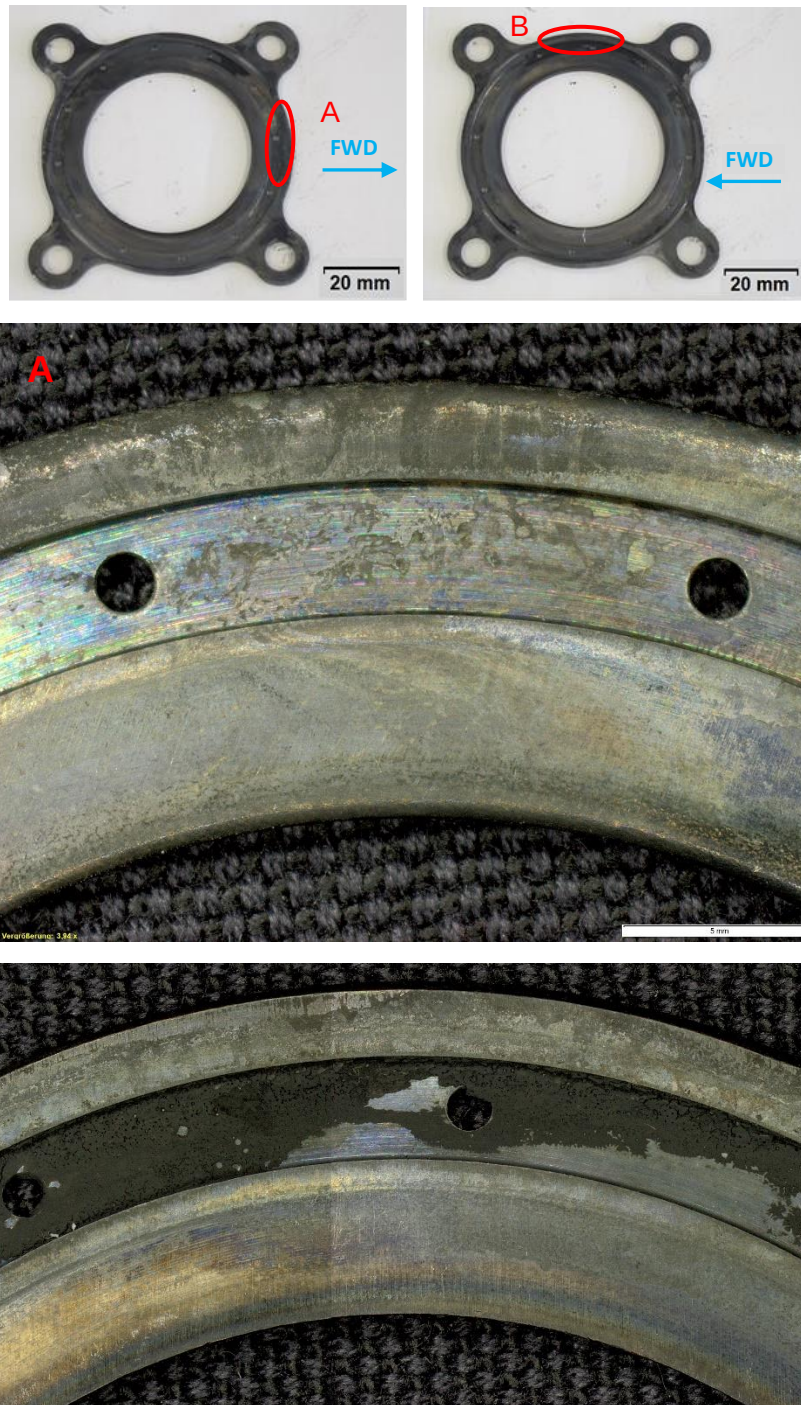


Figure 37: Possible remains of part identification and manufacturer imprint

4.7 Investigation of assembly as per drawing

In order to investigate if the fuel/hydraulic disconnect panel has been installed as per drawing at any point in time, theoretical contact surfaces (Figure 38) have been checked and measured (Figure 40 to Figure 46):

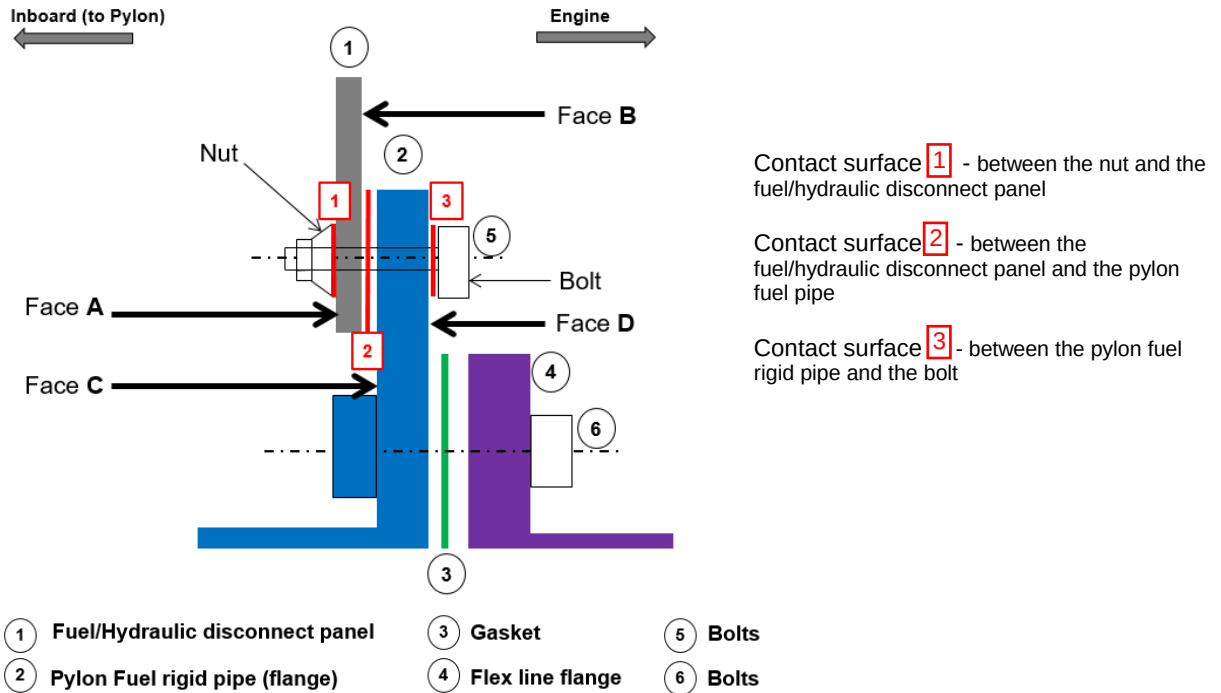


Figure 38: Installation as per drawing

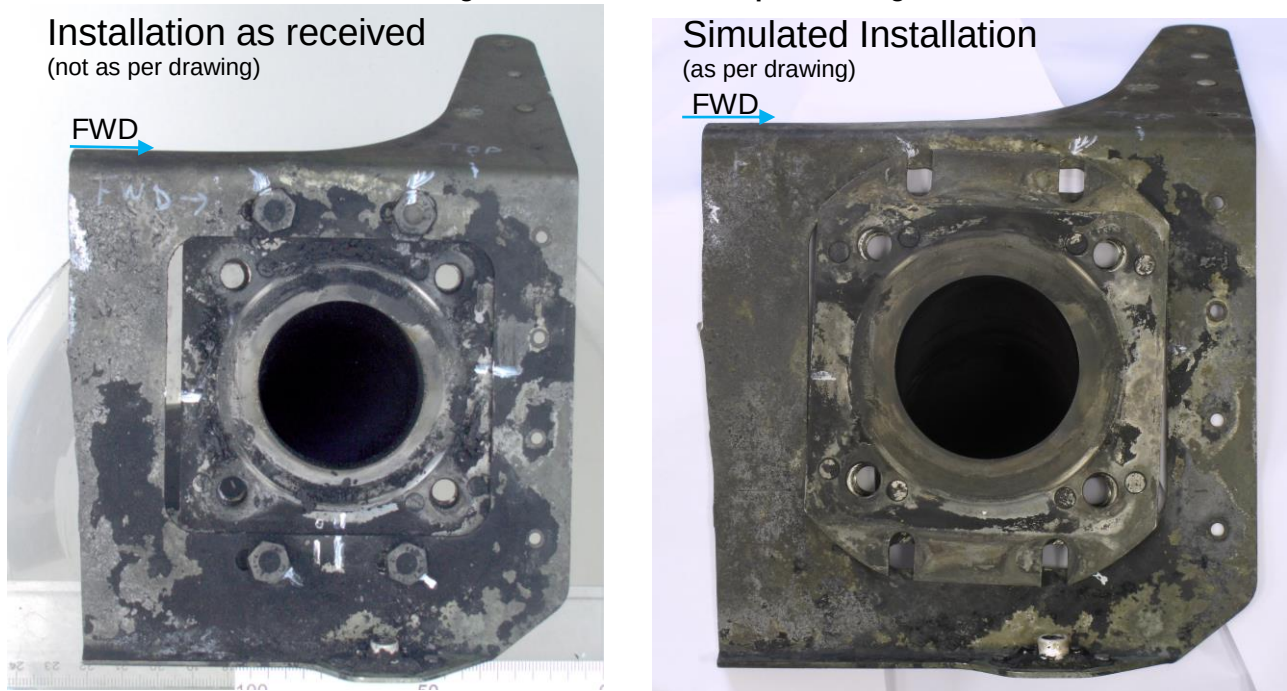


Figure 39: Both installation ways: as received and simulated with the investigated parts

4.7.1 Contact surface 1

Check for installation as per drawing: Contact between face A and the nut(Figure 38)

To review if the installation has been done as per drawing at some point in time, a measurement of nut imprints has been performed on the fuel/hydraulic disconnect panel and on the pylon fuel rigid pipe flange.

Outcome: The two imprints found on Face A (Figure 41) have the same approximate diameter as the imprints found on Face C (Figure 42).

Conclusion:

- Both Face A and C presents contact with the nut, confirming the assembly as per drawing at some point in time.
- The measurements of the markings ($\varnothing 11.5\text{mm}$) confirms the as per drawing installation at some point in time.
- Figure 42 confirms two installations not as per drawing.

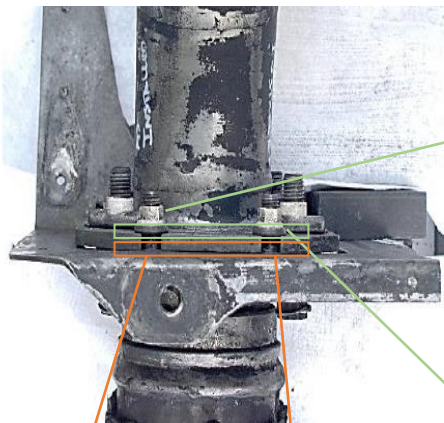


Figure 40: Assembly of parts as received

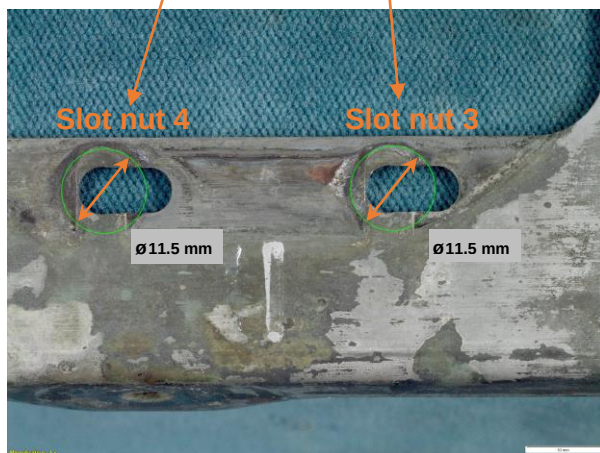


Figure 41: Face A- Measurements of imprints on the fuel/hydraulic disconnect panel

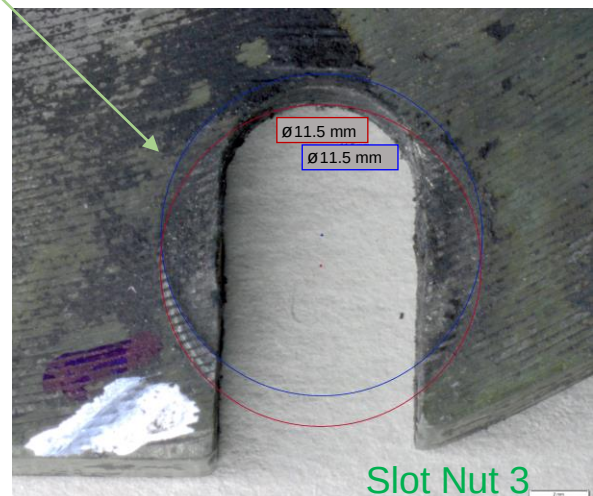
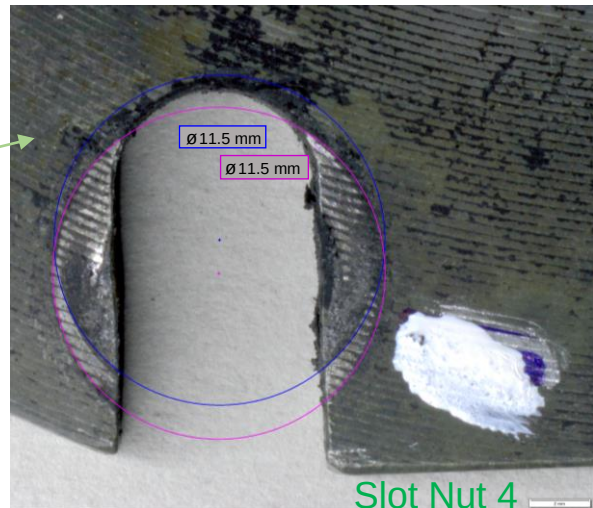


Figure 42: Face C- Measurements of imprints on the pylon fuel rigid pipe flange

4.7.2 Contact surface 2

Check for installation as per drawing: Contact between face B and face C (Figure 38)

To review if the installation was made as per drawing at some point in time, measurements have been made on the pylon fuel rigid pipe flange to check if the imprints found are produced by the fuel/hydraulic disconnect panel clearance edge.

Outcome: The measurements have shown that the opening of (Face A) the fuel/hydraulic disconnect panel clearance (Figure 44) does not match with the distance between the imprints found on the pylon fuel rigid pipe flange (Face C) (Figure 43).

Conclusion: Thus the outcome there is no evidence for installation as per drawing and also is confirmed the 2 instalations not as per drawing.

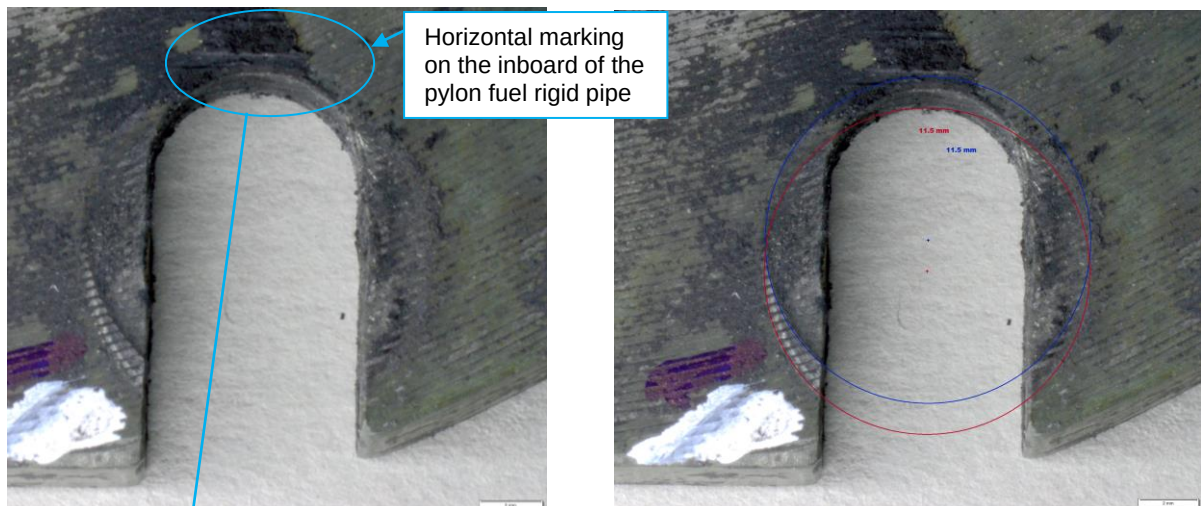


Figure 43: Face C - Imprint on the pylon fuel rigid pipe

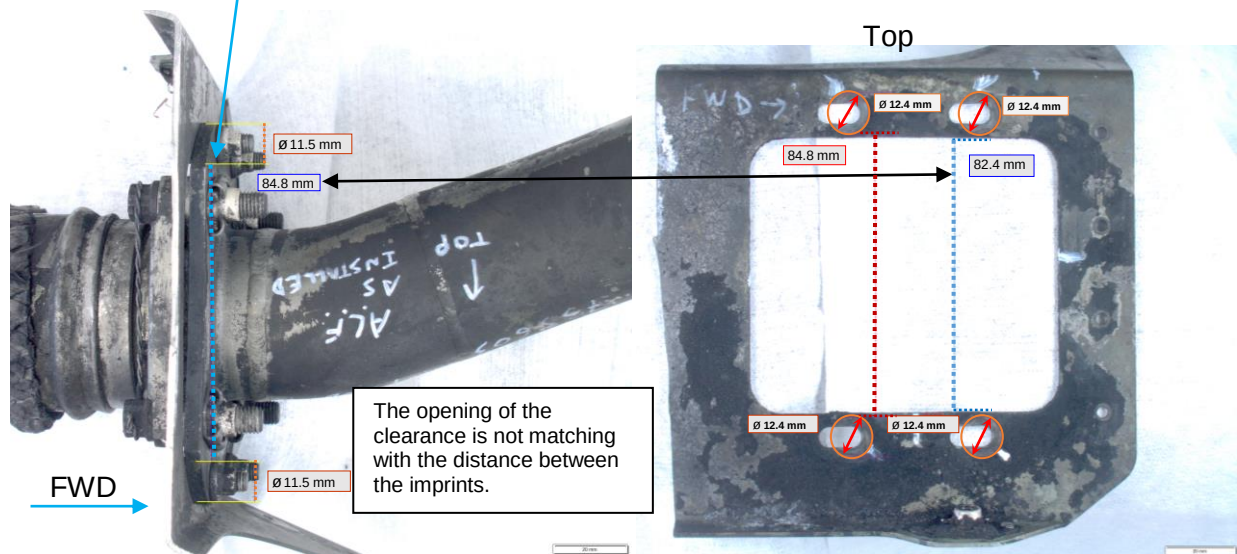


Figure 44: Face A- Distance measurement between the opening of the fuel/hydraulic disconnect panel clearance and distance on the rigid flange between the nuts.

4.7.3 Contact surface 3

Check for installation as per drawing: Contact between face D and bolt (Figure 38)

In order to check contact surface no. 3, measurements of imprints (Figure 45) and comparisons between the connect side of the fuel rigid pipe flange and the fuel/hydraulic disconnect panel have been conducted.

In the case of a as per drawing installation, the pylon fuel rigid pipe flange should display signs of the bolt imprint the same size as the fuel/hydraulic disconnect panel connect side Figure 46).

Outcome: The pylon fuel rigid pipe flange (Face D) shows imprints with the same size ($\varnothing 12.4\text{mm}$) as the bolt head and matching with the imprints on the fuel/hydraulic disconnect panel (Face B). It can also be observed that the imprint from the pylon fuel rigid pipe flange shows a deep mark highlighting the round pattern of the bolt head.

Conclusion: Hence the outcome, evidence of as per drawing installation has been identified.

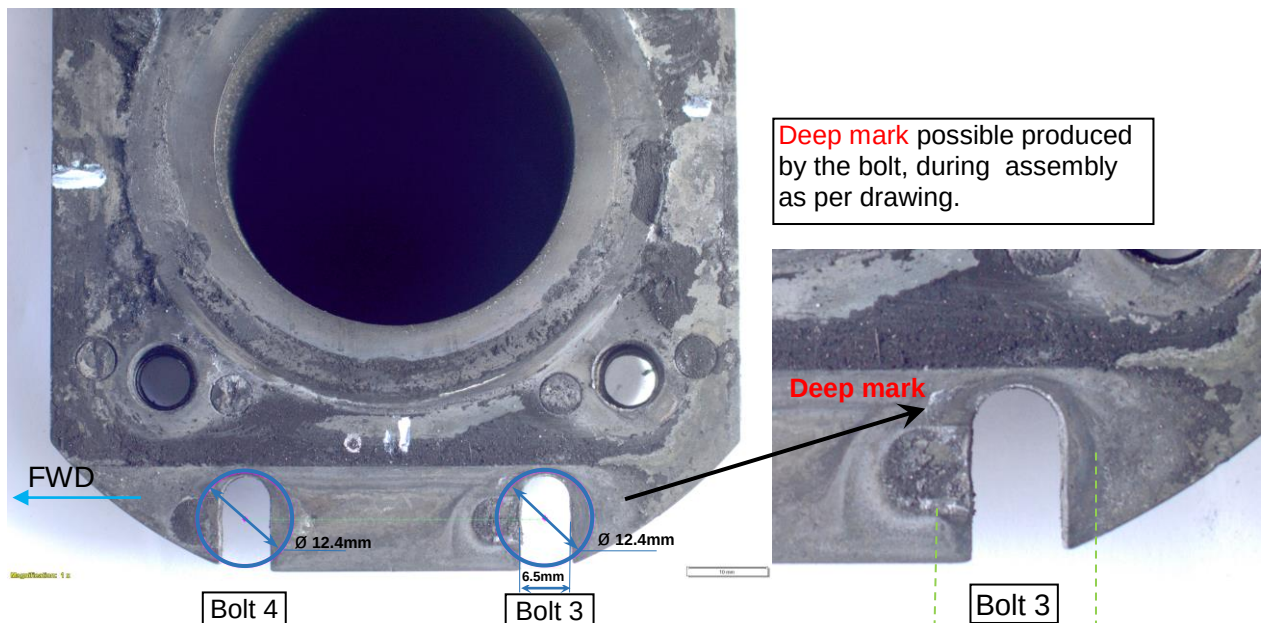


Figure 45: Face D-Fuel rigid pipe flange imprint measurements



Figure 46: Face B- Fuel/hydraulic disconnect panel bolt measurements

4.8 Flatness Check at the Flanges

A flatness check (De Meet 400, geometrical metrology machine) has been performed for the sealing surfaces of the Pylon fuel rigid pipe and flex line flange (circular matting surfaces covered by the gasket during assembly). The flatness check has been performed due to the deformation / non-flat of outer surfaces identified before the dissassembling of parts (Figure 14). Two measurements were performed per matting surface.

The Pylon fuel rigid pipe flange sealing surface has shown a maximum deviation from the matting surface of 0.131 mm and a flatness (distance of lowest and highest theoretical plane) of 0.233 mm (Figure 47 A)

The flex line flange sealing surface has shown a maximum deviation from the matting surface of 0.018 mm and a flatness of 0.034 mm (Figure 47 B).

An observation is, that the flatness values of the sealing surfaces of the flanges could not be compared with the requirements as these are not available.

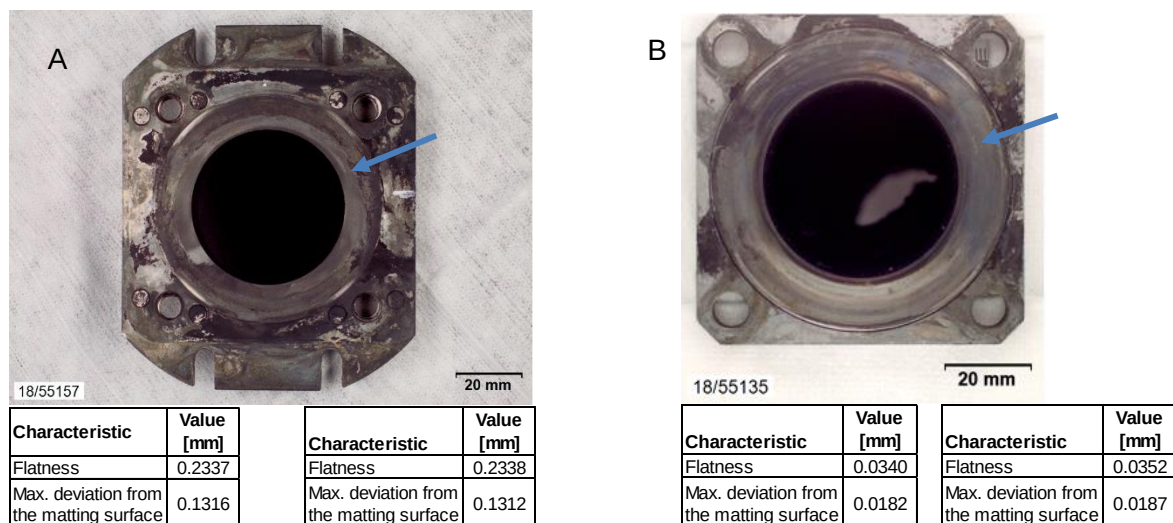


Figure 47: Flatness check performed for the pylon fuel rigid pipe and Flex Line Flange

4.9 NDT Inspection

It was reported that during a first inspection after the event a crack indication was identified at the pylon fuel rigid pipe pylon site end.

Therefore a penetrant inspection in the area was performed. The penetrant inspection revealed no crack.

Additionally an HFEC inspection was done without crack indication.



Figure 48: Penetrant inspection of pylon fuel rigid pipe pylon end without finding
Conclusion: Following the NDT inspection no findings have been recorded.

4.10 Geometrical Checks at the Gasket

Acc. to Pratt and Whitney Illustrated Part Catalog the gasket with part no. MS27196-32 (Parker) is assembled in the engine/pylon fuel connection. The rubber seal of the gasket is installed acc. to AS27196 rev. B. The question is if a incorrect goemetry of the gaskets seal groove might have caused a leakage. Therefore a geometrical check of the gasket seal groove was performed reporting back the results in Table 3 and Table 4. It has to be taken into account that the gasket, although it was cleaned, is still affected by carbon black which could not be removed.

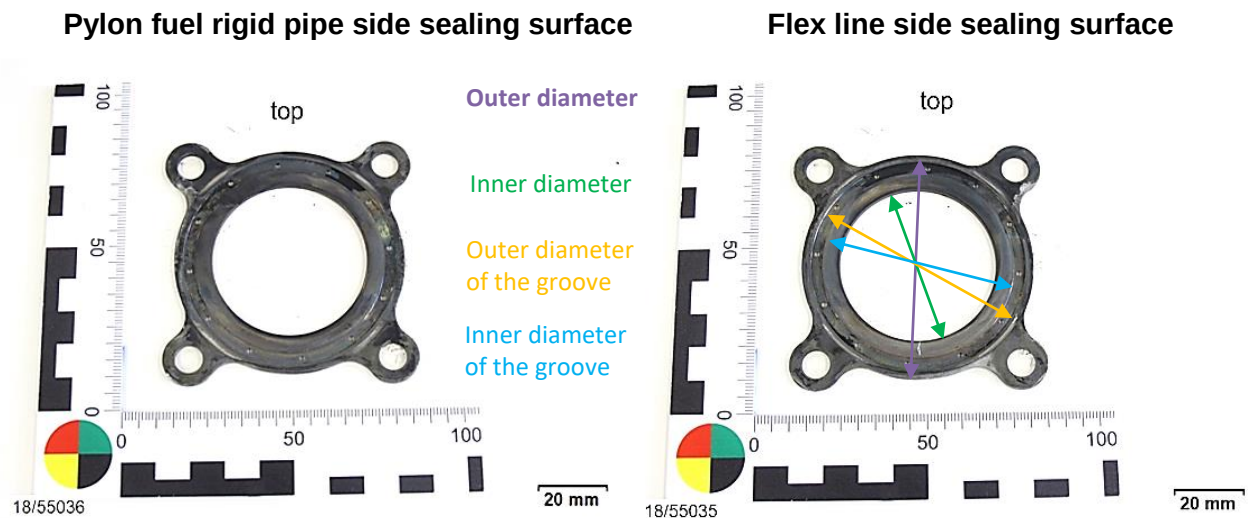


Figure 49: Gasket pylon fuel rigid pipe side sealing surface and flex line side sealing surface

Table 3: Gasket – flex line side sealing surface – geometrical measurement

Position from marking in clockwise direction	Measurement at gasket seal groove			
	Inner diameter [mm]	Outer diameter [mm]	Depth of groove (top) [mm]	Depth of groove (bottom) [mm]
0°	2.194	2.180	0.85	0.89
45°	2.209	2.213	0.88	0.90
90°	2.210	2.197	0.91	0.86
135°	2.207	2.207	0.83	0.86
180°	2.194	2.173	0.89	0.84
225°	2.207	2.216	0.87	0.86
270°	2.199	2.184	0.85	0.87
315°	2.193	2.196	0.80	0.82
mean	2.202	2.1957	0.86	0.86
	Measured with outside micrometer Type:40EX SN:51010246		Measured with J-Chadwick PN:8400-0 SN:11861	

Table 4: Gasket – geometrical measurement

Position from marking in clockwise direction	Outer diameter of the gasket [mm]	Inner diameter of the gasket [mm]	Lug thickness [mm]	
0° to 180°	69.96	46.74	45°	2.07
90° to 270°	69.95	46.75	135°	2.15
45° to 225°	-	46.76	225°	2.13
135° to 315°	-	46.76	315°	2.15

4.11 Material Check

4.11.1 Hardness Test

A hardness test has been performed for the pylon fuel rigid pipe flange. The specified material for this part is stainless steel Z6CNT18-10 acc. to ASNA3139. The standard ASNA3139 does not specify a hardness. However, it does specify the tensile strength (Rm-490MPa). The expected hardness has been calculated according DIN50150 (153HV10) based on the tensile strength required by the material standard.

Hardness test Brinell

Procedure DIN EN ISO 6506-1:2015-02 HBW 2,5/187,5
Test volume 3 indentations per test piece
Area of indentation surface

	Single values			Mean value
Result specimen				
5351	Hardness test not possible due to geometry			
5352 A	152	155	150	152
5352 B, side opposite to A	151	157	154	154

Hardness test Vickers

Procedure DIN EN ISO 6507-1:2006-03 HV10
Amount of inspection 3 indentations per test piece
Area of indentation surface

	Single values			Mean value
Result specimen				
5351	Hardness test not possible due to geometry			
5352 A	168	166	179	171
5352 B, side opposite to A	166	168	174	169

Note: Calculation of expected hardness:

- 480 MPa = 150 HV10 / 143 HB
- 495 MPa = 155 HV10 / 147 HB

The results show that the hardness values are higher than expected based on the calculation.

A hardness test has been performed for the flex line flange providing no valuable results due to clamping problems. Clamping was impossible without affecting/destroying the sealing surfaces of the part.

If it is relevant for further analysis a hardness test at the sealing surfaces of both flanges is recommended as far as no further system test with parts are needed.

4.11.2 Chemical Composition Check

No chemical composition check was performed as it would have caused a local destruction of the parts compromising the scheduled for subsequent tightness checks.

4.12 Infrared Analysis of Seal Residues

IR (Infrared) spectroscopy was performed on four different samples from the assembly (see Figure 50 to Figure 52). All samples were analyzed on a Perkin-Elmer Spectrum Two FT-IR with attached diamond-ATR unit. The recorded spectra was compared with existing sequences.

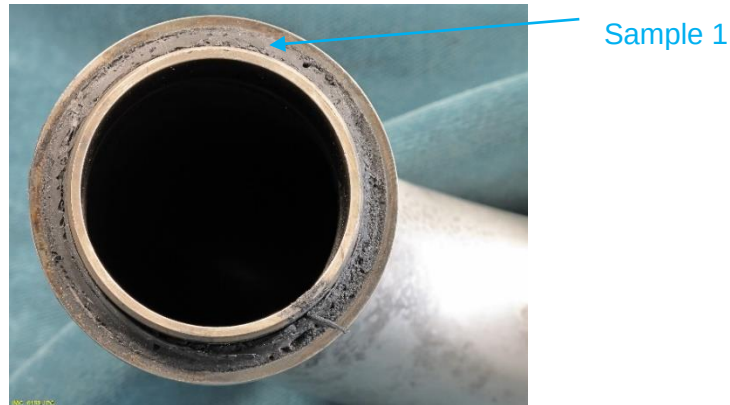


Figure 50: IR Sample 1: on the pylon fuel rigid pipe pylon site

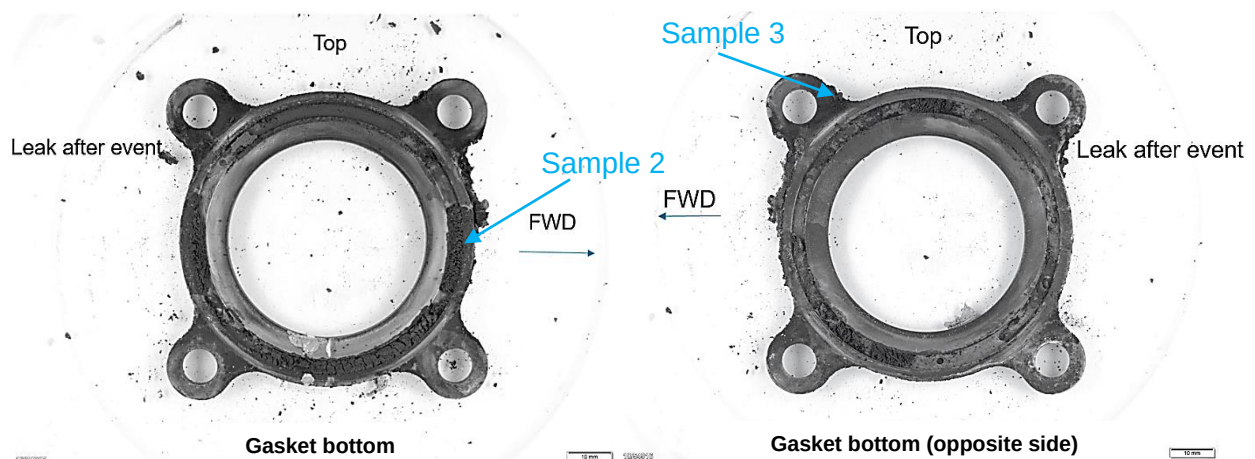


Figure 51: IR Sample 2 and 3: gasket in the area of seal and in the area of sleeve

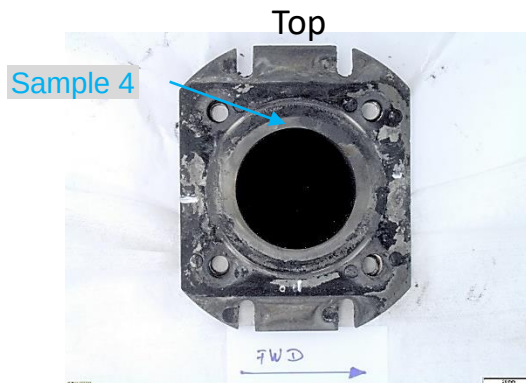


Figure 52: IR Sample 4 pylon fuel rigid pipe flange in the sealing area

It was possible to collect acceptable spectra from Sample 1 and Sample 2. The peaks in these spectra are weak, this may derive from the black, non-reflective material and a possible partial

thermal decomposition. Nevertheless, a match with fluorinated rubber was found as material which is a typical rubber seal material.

It was not possible, to obtain meaningful spectra from the other two samples (Sample 3 and 4).

The appended graph (Figure 53) displays all recorded spectra and the match with reference material fluorinated rubber.

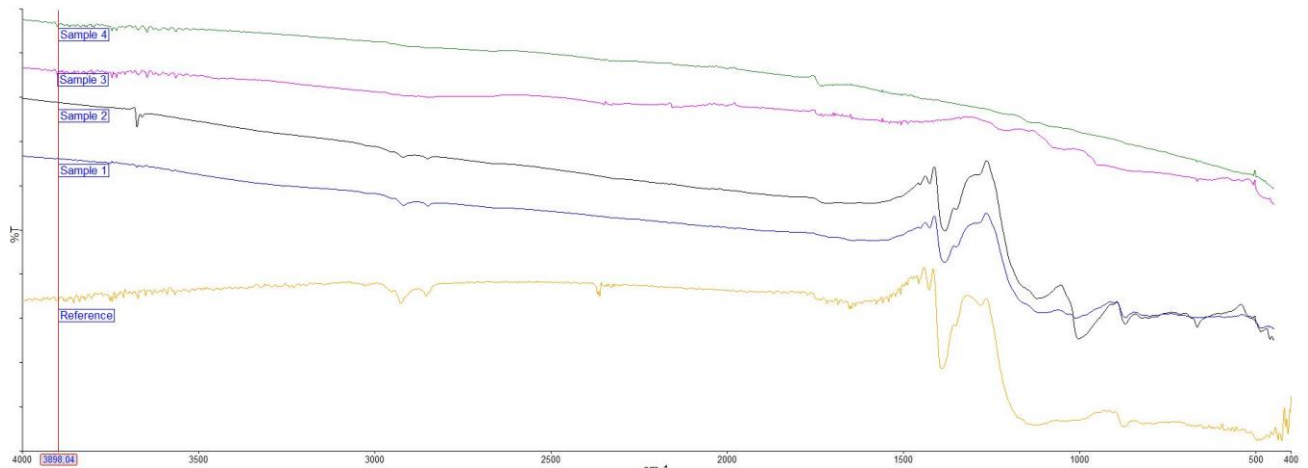


Figure 53: The results identifies the residue found in the gasket groove, as rubber seal (fluorinated rubber)

4.13 3D Scan after Disassemble and Cleaning

A second 3D scan has been done for the pylon fuel rigid pipe and flex line flanges after cleaning. The second scan was done with the same equipment and with same conditions as mentioned for the first scan in Chapter 4.2.

The CAD model has been available only for the pylon fuel rigid pipe flange therefore the deformation check has been performed only for this part.

The CAD model deviates from the real part meaning that the upper geometry in the sealing area is not available compared to the real part (Figure 54). For this reason for the overlay of CAD and 3D scan, the sealing plane (area of interest for leakage) was chosen as reference plane.

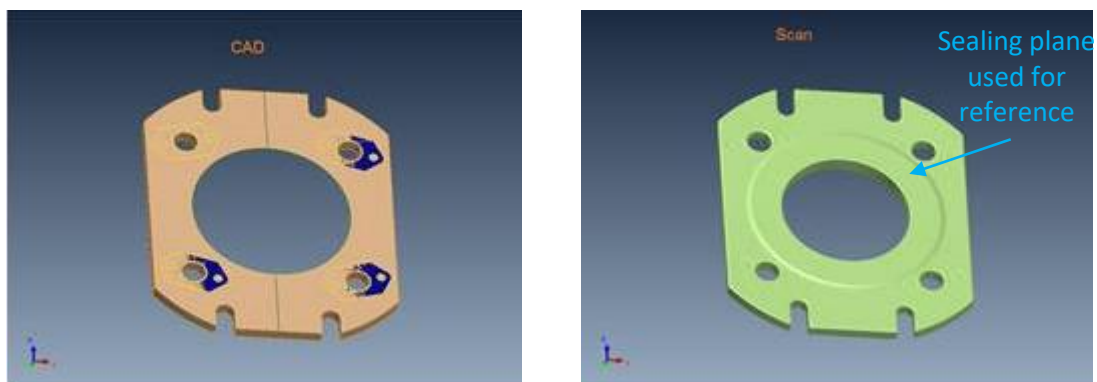


Figure 54: Pylon fuel rigid pipe Flange CAD version versus 3D Scan

Taking the boundary conditions mentioned above into account the flatness of the circular mating surface of the pylon fuel rigid pipe flange is identified as being out of plane by 0.201 mm. The outer deformation is identified via 3D scan as 0.501 mm (Figure 55).

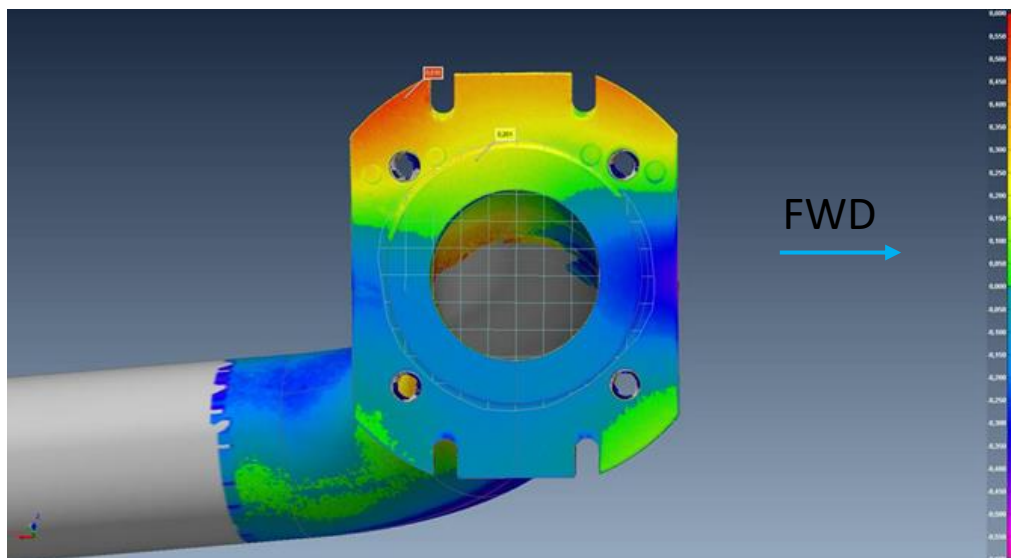


Figure 55: Pylon fuel rigid pipe flange deviation from CAD model represented by 3D scan, outboard side

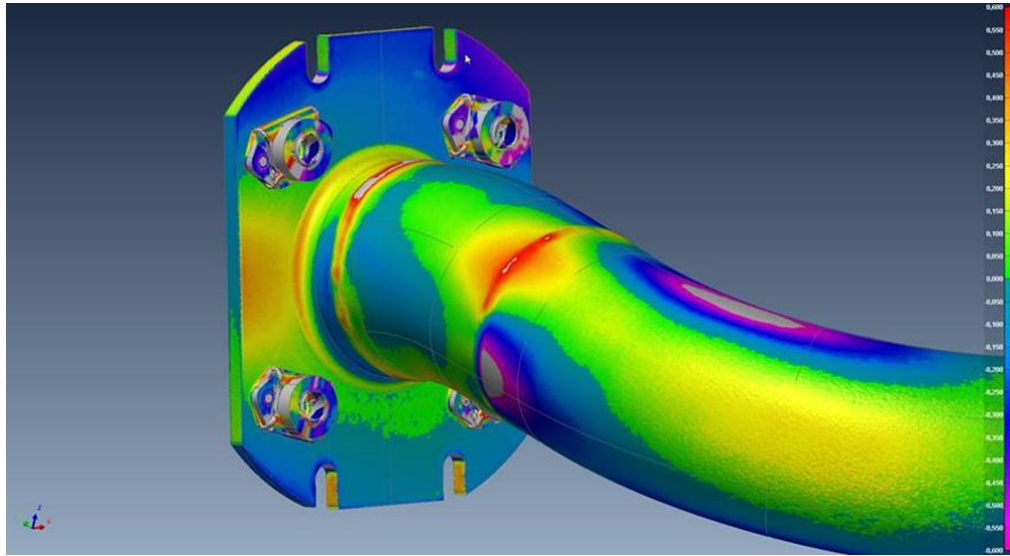


Figure 56: Pylon fuel rigid pipe flange deviation from CAD model represented by 3D scan, inboard side

If it is relevant for further analysis, the 3D scans of the flex line flange and gasket CAD model are needed.

5 Summary

On 18th of April 2018 shortly after take-off from Atlanta, during flight DL-30 to London Heathrow, the A330 MSN0578 (registration N806NW) powered by Pratt & Whitney PW4168 engines and operated by DAL has experienced fire at the right hand engine. An air turn back and overweight single engine landing at Atlanta airport could be performed successfully. An accident investigation was initiated.

In frame of a first inspection onsite after the event the engine/pylon fuel connection unit was identified as a possible driver of the event due to deviations in the assembly and reported previous maintenance tasks. Therefore the unit was disassembled from the A/C for examination at the failure analysis lab in Bremen. The results of the laboratory examinations can be summarized as follows:

Table 5: Summary of Examination and Results

Component	Examination	Result
Engine/pylon fuel connection unit	3D scan in as-received condition	3D scan was done to secure further analysis data, before disassembling.
Pylon fuel rigid pipe flange	Macroscopic examination before & after cleaning	The part shows marks from the gasket assembly at four locations along the circumference. This indicates contact and/or a possible relative (micro) movement during assembly conditions.
	Flatness check	Shows deviation from plane conditions. Further flatness measurements of the circular matting surface present a value of 0.233 mm. Comparison to specification is not possible due to missing specification data for flatness
	3D scan after disassembling & cleaning	The CAD model deviates from the real part. Therefore for the overlay of CAD and 3D scan, the sealing plane (area of interest for leakage) was chosen as reference plane. Taking this into account the flatness of the circular matting of the pylon fuel rigid pipe flange is 0.201 mm. The outer deformation is identified via 3D scan as 0.501 mm. For a detailed analysis it is recommended to consult the responsible design departments.
	Hardness test	The hardness requirement was calculated based on the tensile strength found in the standard. The results of the hardness test is higher than the expected calculated value. If relevant for further analysis it is recommended to redo the hardness test at the sealing surface.
	Residue analysis	It was not possible to obtain a meaningful spectra
Pylon fuel rigid pipe pylon end flange	Penetrant inspection	No crack (penetrant and HFEC)
	Residue analysis	The IR spectra identified fluorinated rubber

Component	Examination	Result
Flex line flange	Macroscopic examination before & after cleaning	The part shows from gasket assembly marks at four locations along the circumference. This indicated contact and/or possible relative movement during assembly conditions. Sleeve presents a slight non-flatness at outer by visual check.
	Flatness check	Shows deviation from plane conditions. Further flatness measurements of the circular matting surface shows a value of 0.034 mm.
	3D scan after disassembling & cleaning	Scan was done but no comparison to CAD data was possible as those were not available.
	Hardness test	Hardness test provides no valuable results due to clamping problems. If relevant for further analysis it is recommended to redo the hardness test at another plane of the part which makes proper clamping possible.
Fuel/hydraulic disconnect panel	Macroscopic examination before & after cleaning	The part presents abrasion from bolt heads and deformation of long holes. Partial discoloration is visible. This indicates likely relative movement between the assembled parts during assembly. No fretting.
Gasket	Macroscopic examination before & after cleaning	The part showed marks from the assembly of the flanges on both sides at four locations along the circumference indicating contact and/or possible relative movement during assembly conditions. Rubber Seal was fully burned and could not provide in this condition any sealing effect.
	Geometry check	Geometrical check of the gasket seal groove was performed. Measured geometry values are given for information. It is recommended that the values are evaluated by the responsible design department.
	Residue analysis	Infrared analysis has identified traces of Fluorinated rubber which confirms the existence of damaged seal in the gasket groove.

During the investigation committee meeting system tests with the original parts from the event and parts replaced in frame of maintenance have been agreed. Thus the relevant parts were send for system/tightness tests to Parker Stratoflex division.

6 Conclusions

Summarizing the main observations and findings the following conclusions can be made:

- All parts needed for the connection are present and found in assembled conditions; the specified securing wires were in place. → Insufficient connection due to missing parts can be excluded.
- Flanges and sleeve were found in plane conditions. → Insufficient connection due to tilt or wedged parts can be excluded.
- Clear indications for the presence of a rubber seal were found. → Insufficient connection due to complete missing rubber seal can be excluded.
- All bolts of the connection of the pipes flanges showed torque in the expected range.
- No crack findings on all metallic parts of the connections. → Insufficient or invalid connection due to metal cracks in the parts can be excluded.
- Although the surrounding geometry of the flanges show non-flat surfaces, the matting surfaces show a more flat characteristic. → The quantitative flatness of the flanges matting surfaces cannot be concluded from the outer geometry of the flanges.
- The pylon fuel rigid pipe flange was installed 2 times not as per drawing. This installation of the flange resulted in an offset of 6.27 mm which had to be bridged by the flexible line.
- There was indication found showing that the pylon fuel rigid pipe flange was installed as per drawing at one point of assembly life.

Conclusively the laboratory examination of the engine/pylon connection unit and its single components revealed no obvious finding which could have driven a failure and caused the event.

7 Appendix 1 – Used Lab Equipment

Table 6: List of Terms and Equipment

OPTICAL MACROSCOPE – Wild – “M420”
DIGITAL MICROSCOPE – Keyence – “VHX”
HANDY SCAN 3D – AMETEK
DE MEET 400 - GEOMETRICAL METROLOGY MACHINE
PERKIN-ELMER SPECTRUM TWO FT-IR
DIGITAL TORQUE SPANNER
DOCUMENTATION CAMERAS

8 Appendix 2 – 3D Scan as received

Tube – Non Hydraulic – CRES

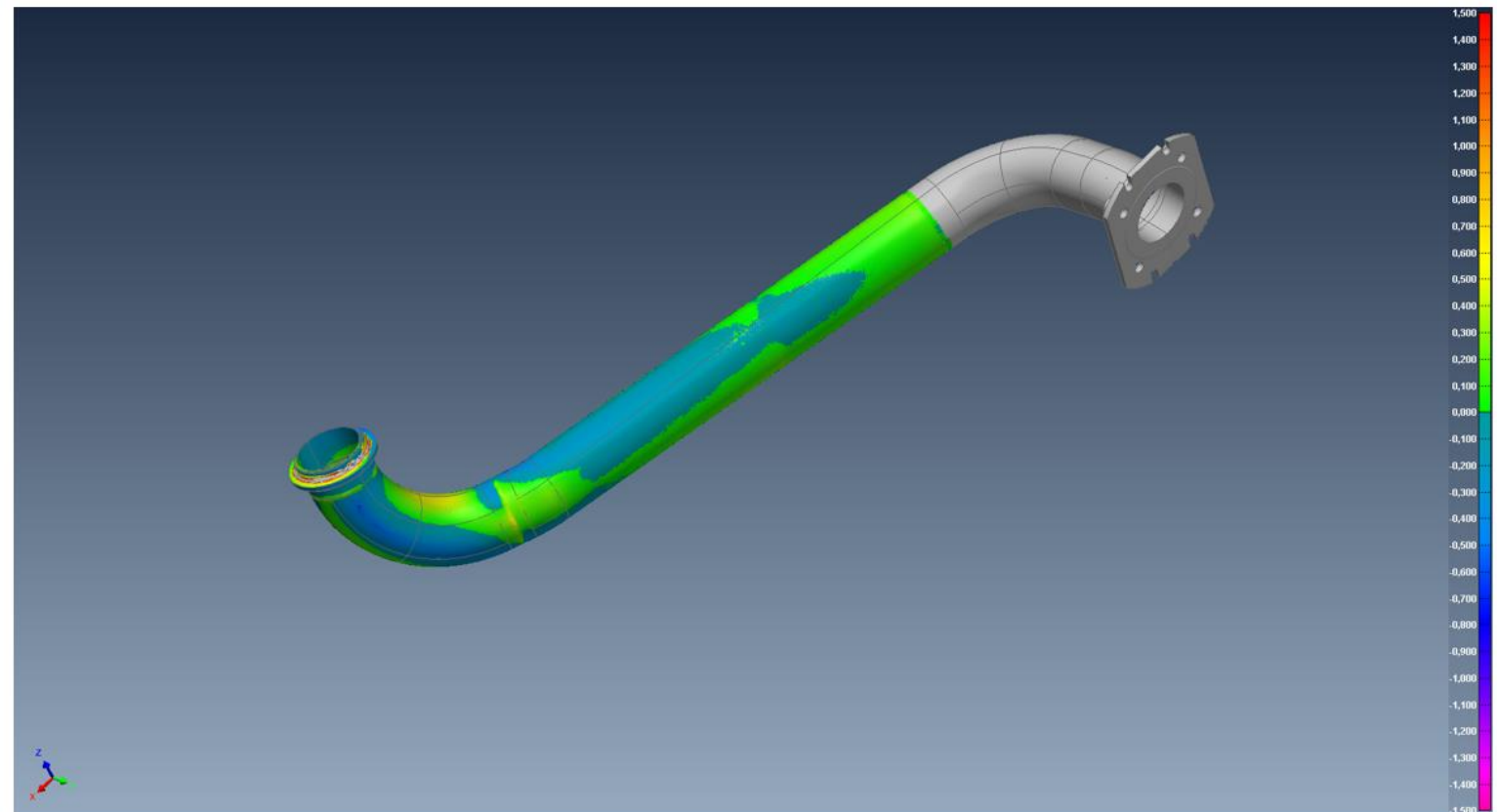
– Cut-Out 1 - View 1

Assembly Drawing

Ø-Code: 32 → 50.8 mm
Thickness-code: 19 → 1.02 mm

Tolerances

- 5.3.2 - Dimensional and form tolerances
- a) Tolerance on outside diameter :
 - + 0
 - 0.2 % of nominal D.
 - b) Tolerance on thickness :
 - + 10 % of nominal thickness.
 - c) Tolerance on straightness :
 - 2 mm per metre and 5 mm over entire length of tube.
 - d) Tolerance on circularity, defined by :
 - $D_{max} - D_{min} = 2 \%$
 - D_{max}
 - e) Tolerance on length :
 - + 10 mm
 - 0



Applied tolerance: ± 1.5 mm

Tube – Non Hydraulic – CRES

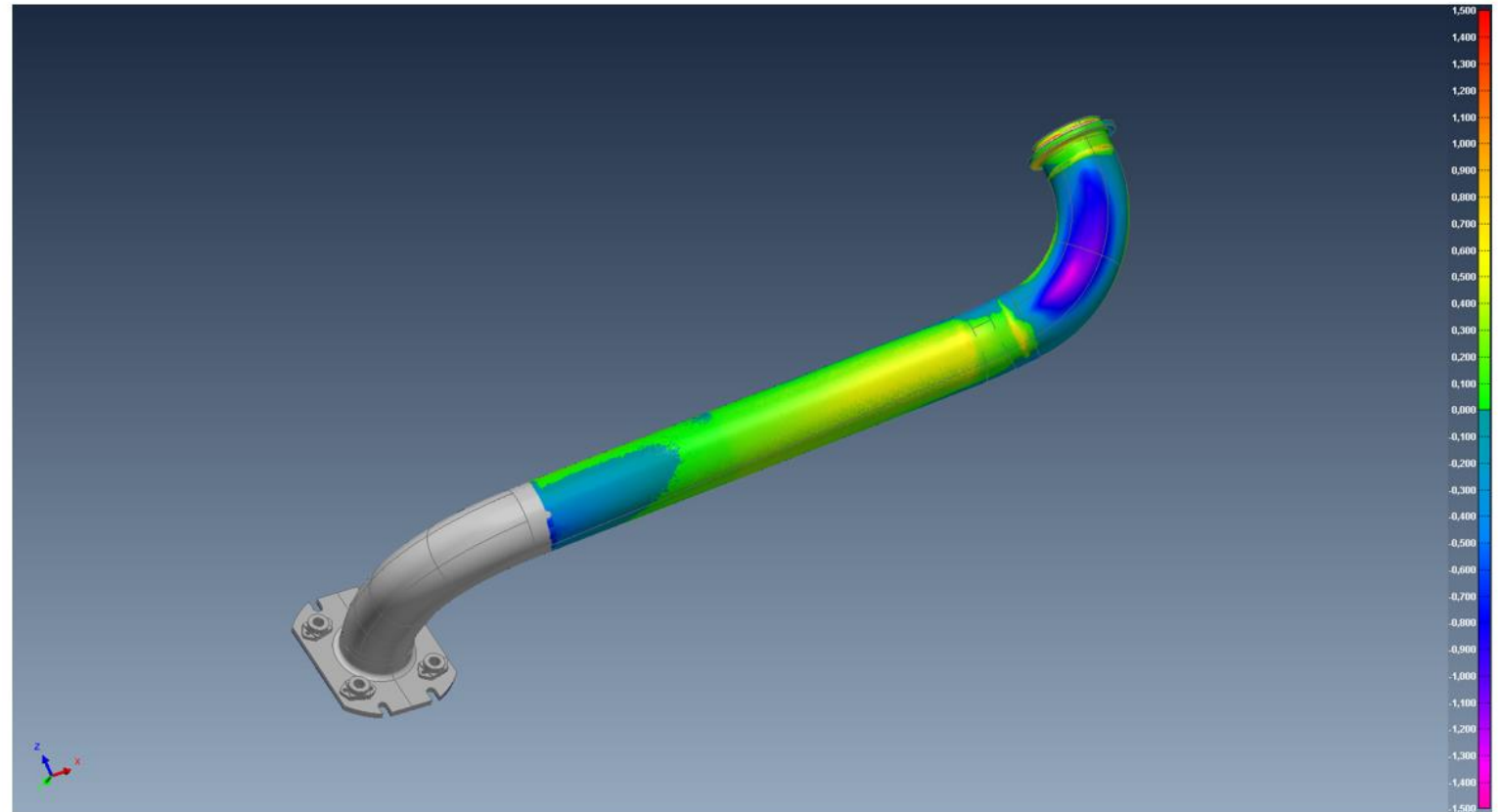
– Cut-Out 1 - View 2

Assembly Drawing

Ø-Code: 32 → 50.8 mm
Thickness-code: 19 → 1.02 mm

Tolerances IGC_

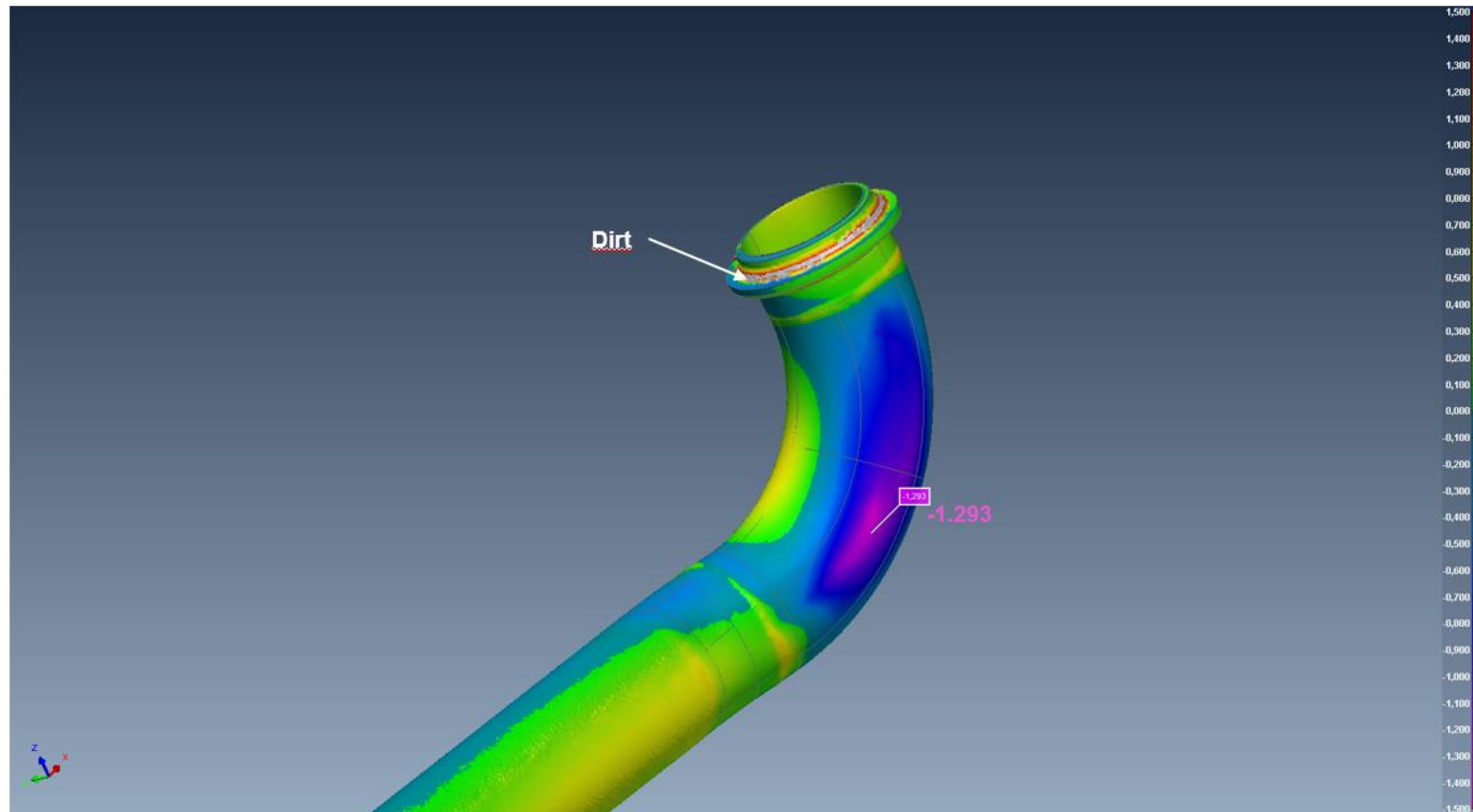
- 5.3.2 - Dimensional and form tolerances
- a) Tolerance on outside diameter :
+ 0
- 0.2 % of nominal D.
 - b) Tolerance on thickness :
+ 10 % of nominal thickness.
 - c) Tolerance on straightness :
2 mm per metre and 5 mm over entire length of tube.
 - d) Tolerance on circularity, defined by :
 $\frac{D_{max} - D_{min}}{D_{nom}} = 2 \%$
 - e) Tolerance on length :
+ 10 mm
0



Applied tolerance: ± 1.5 mm

1/8
Tube – Non Hydraulic – CRES

+ Lower Connection



Applied tolerance: ± 1.5 mm

Tube – Non Hydraulic – CRES

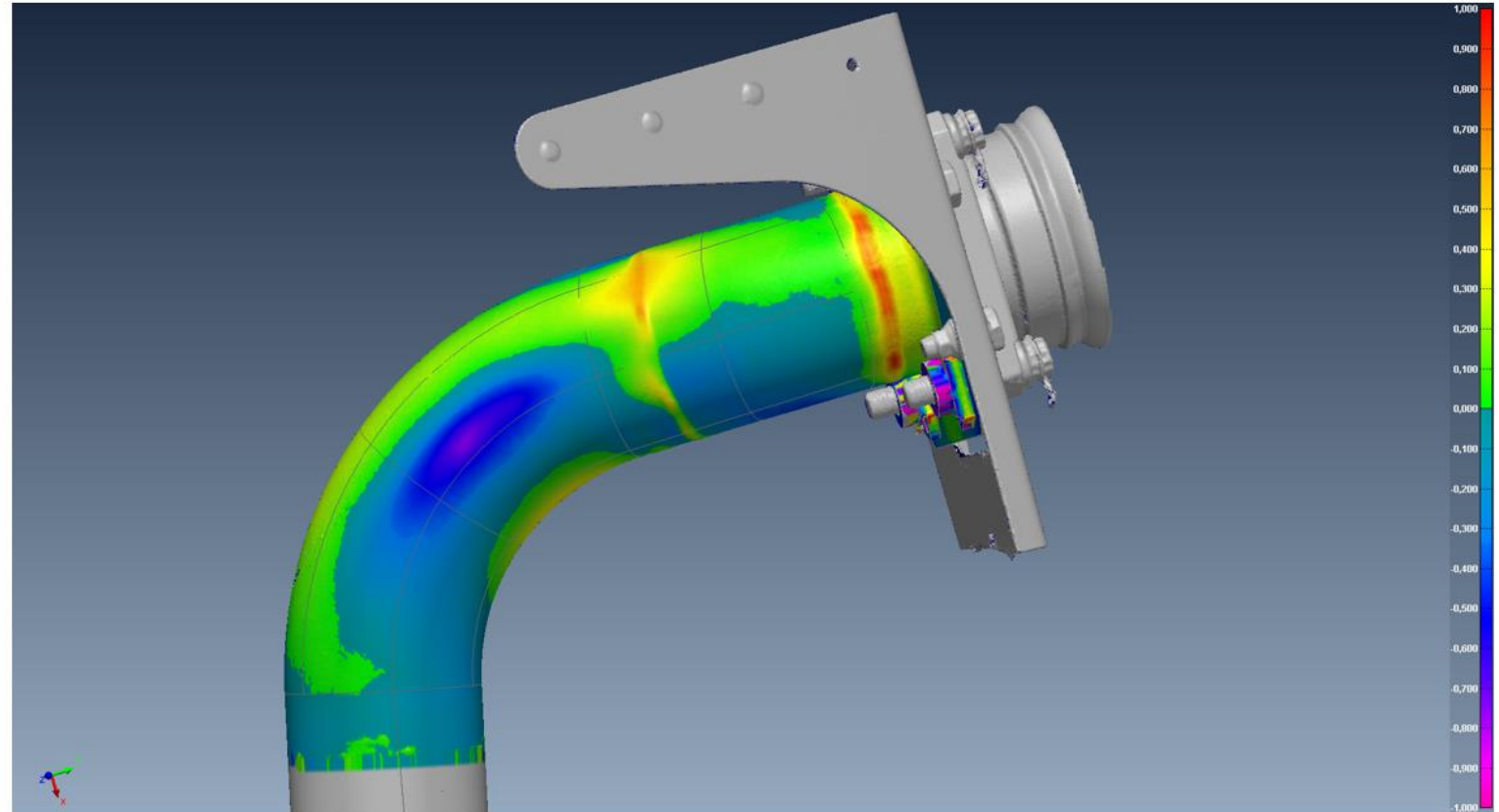
– Cut-Out 2 - View 1

Assembly Drawing

Ø-Code: 32 → 50.8 mm
Thickness-code: 19 → 1.02 mm

Tolerances

- 5.3.2 - Dimensional and form tolerances
- a) Tolerance on outside diameter :
 - + 0
 - 0.2 % of nominal D.
 - b) Tolerance on thickness :
 - + 10 % of nominal thickness.
 - c) Tolerance on straightness :
 - 2 mm per metre and 5 mm over entire length of tube.
 - d) Tolerance on circularity, defined by :
 - $\frac{D_{max} - D_{min}}{D_{max}} = 2 \%$
 - e) Tolerance on length :
 - + 10 mm
 - 0



Applied tolerance: ± 1.0 mm

Tube – Non Hydraulic – CRES

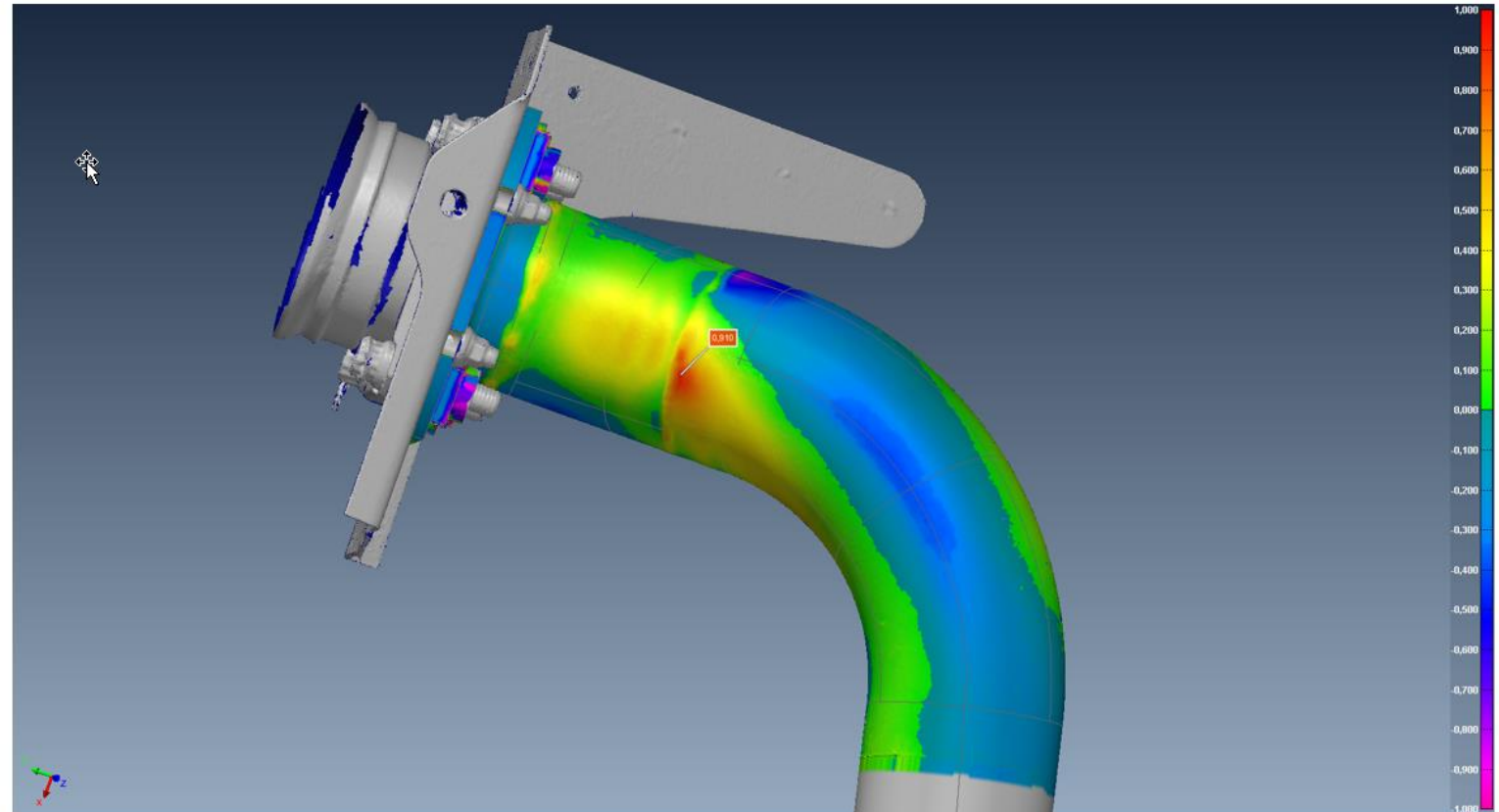
– Cut-Out 2 - View 2

Assembly Drawing

Ø-Code: 32 → 50.8 mm
Thickness-code: 19 → 1.02 mm

Tolerances

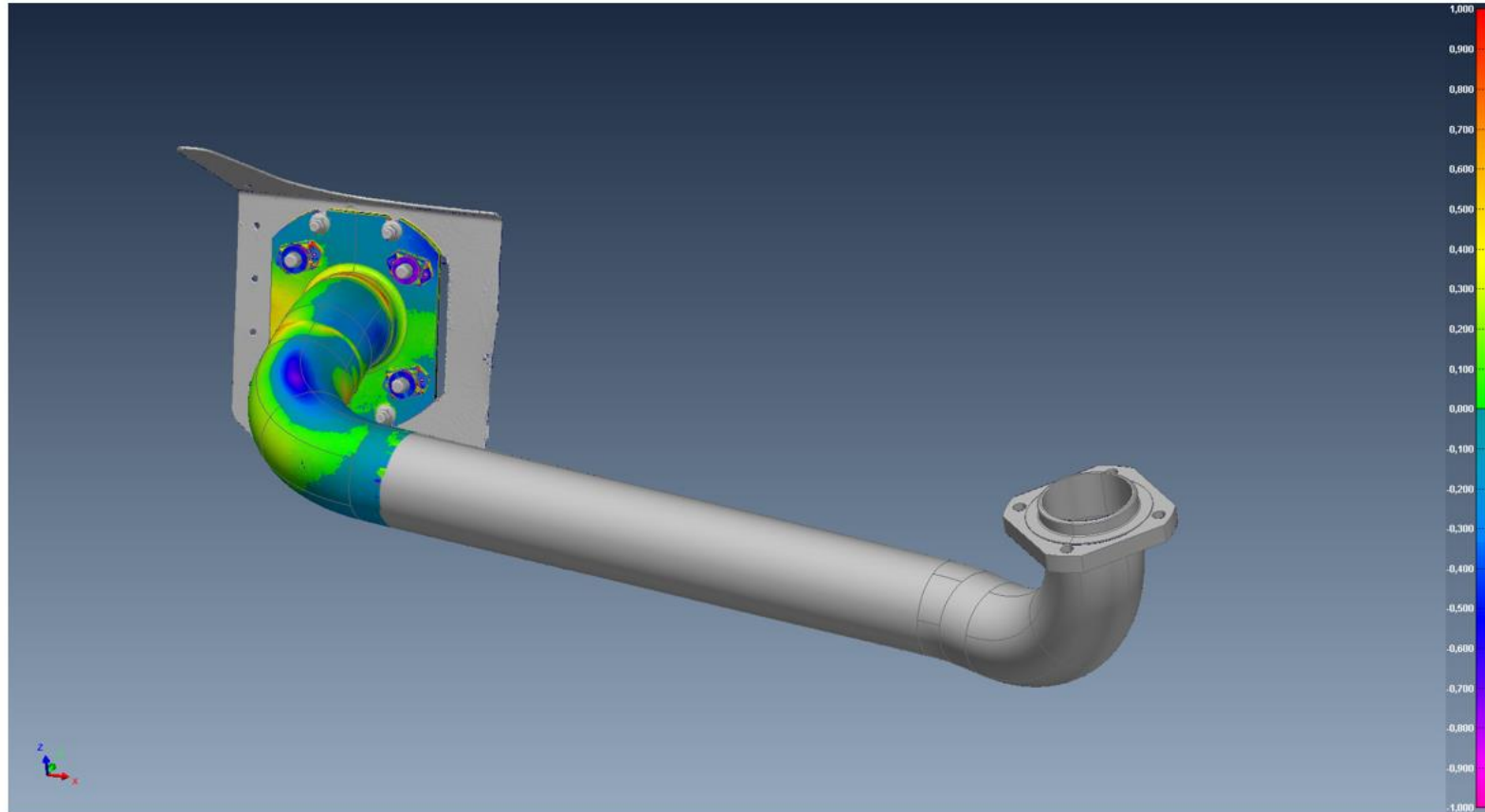
- 5.3.2 - Dimensional and form tolerances
- a) Tolerance on outside diameter :
+ 0
- 0.2 % of nominal D.
 - b) Tolerance on thickness :
+ 10 % of nominal thickness.
 - c) Tolerance on straightness :
2 mm per metre and 5 mm over entire length of tube.
 - d) Tolerance on circularity, defined by :
 $D_{max} - D_{min} = 2 \%$
 - e) Tolerance on length :
+ 10 mm
0



Applied tolerance: ± 1.0 mm

Tube – Non Hydraulic – CRES

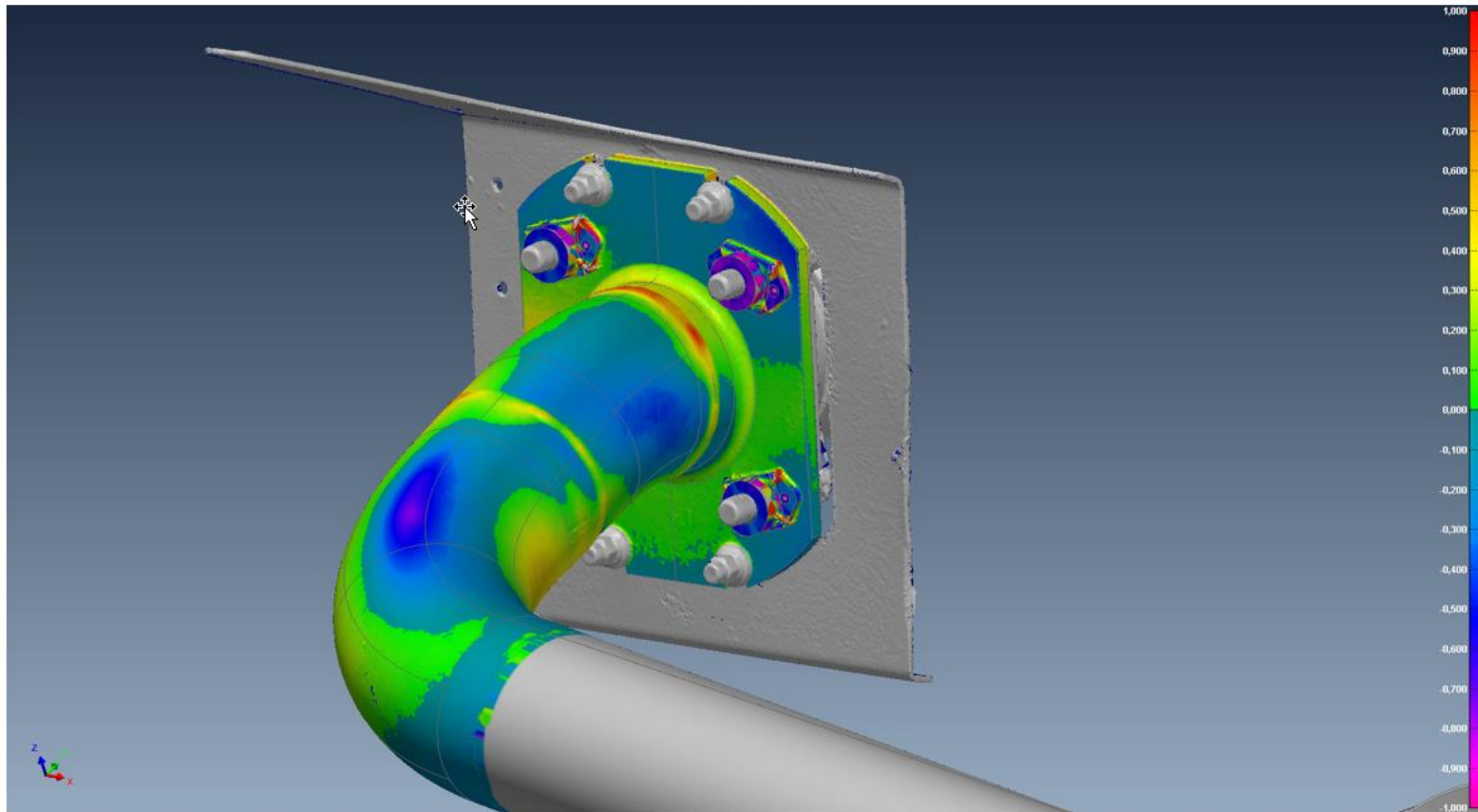
+ Ring Mounting



Applied tolerance: ± 1.0 mm

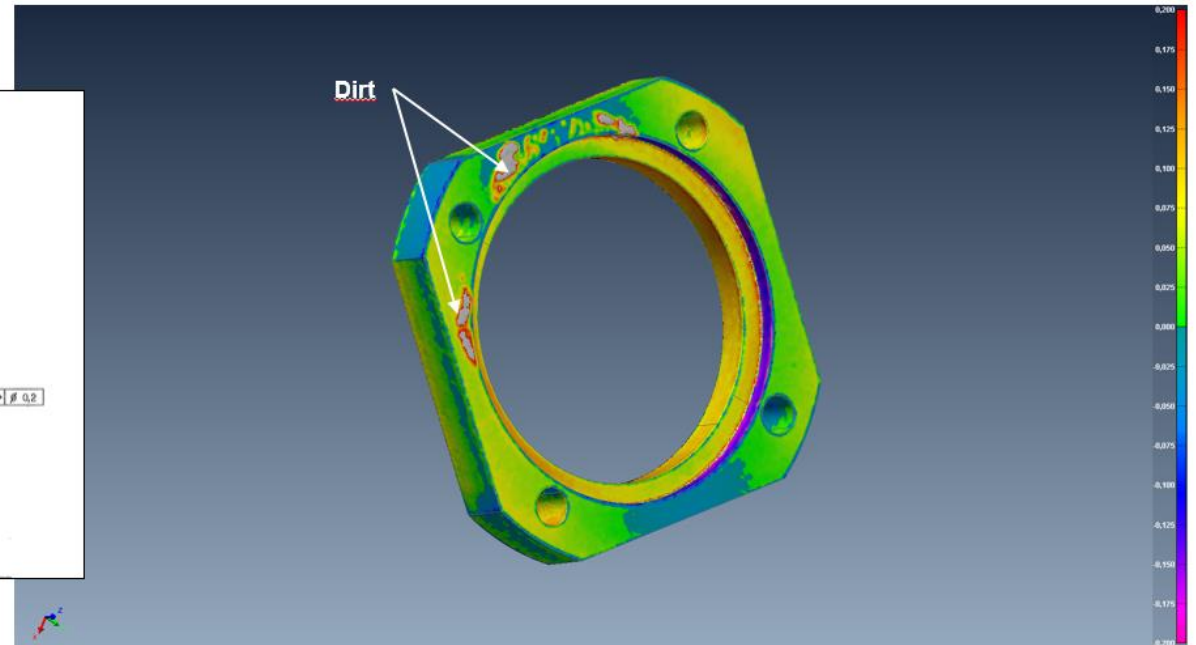
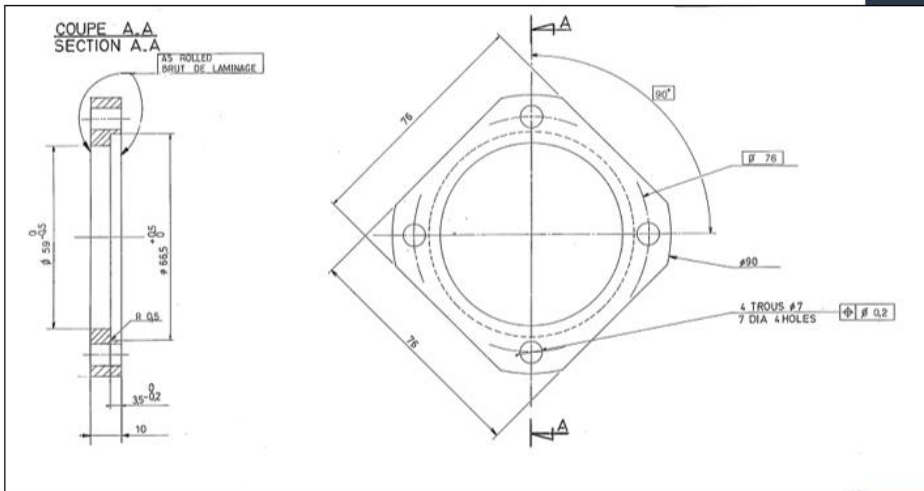
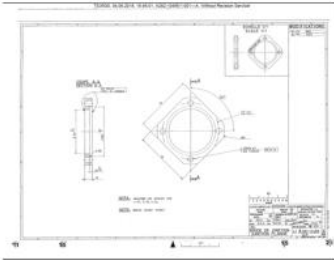
Tube – Non Hydraulic – CRES

+ Ring Mounting



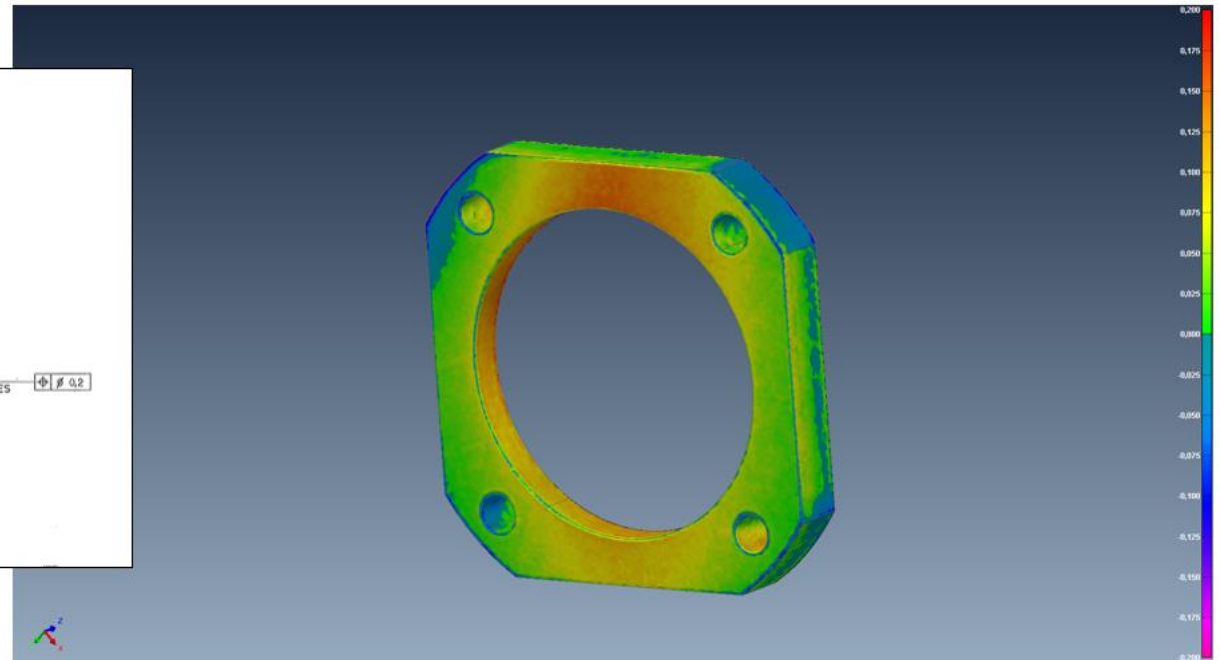
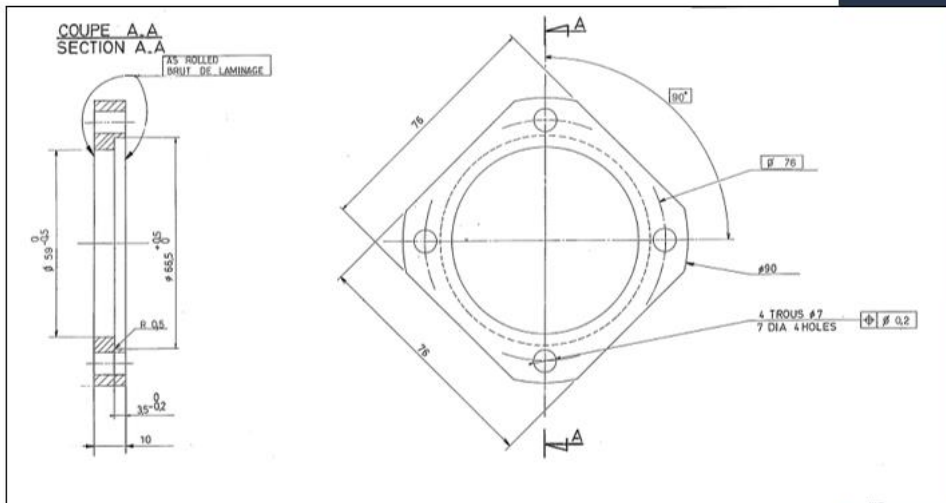
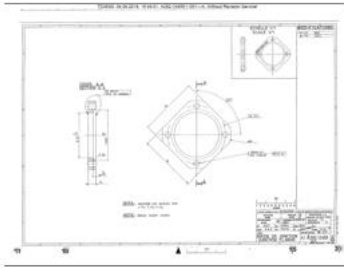
Applied tolerance: ± 1.0 mm

Junction Flange - Front



Applied tolerance: ± 0.2 mm

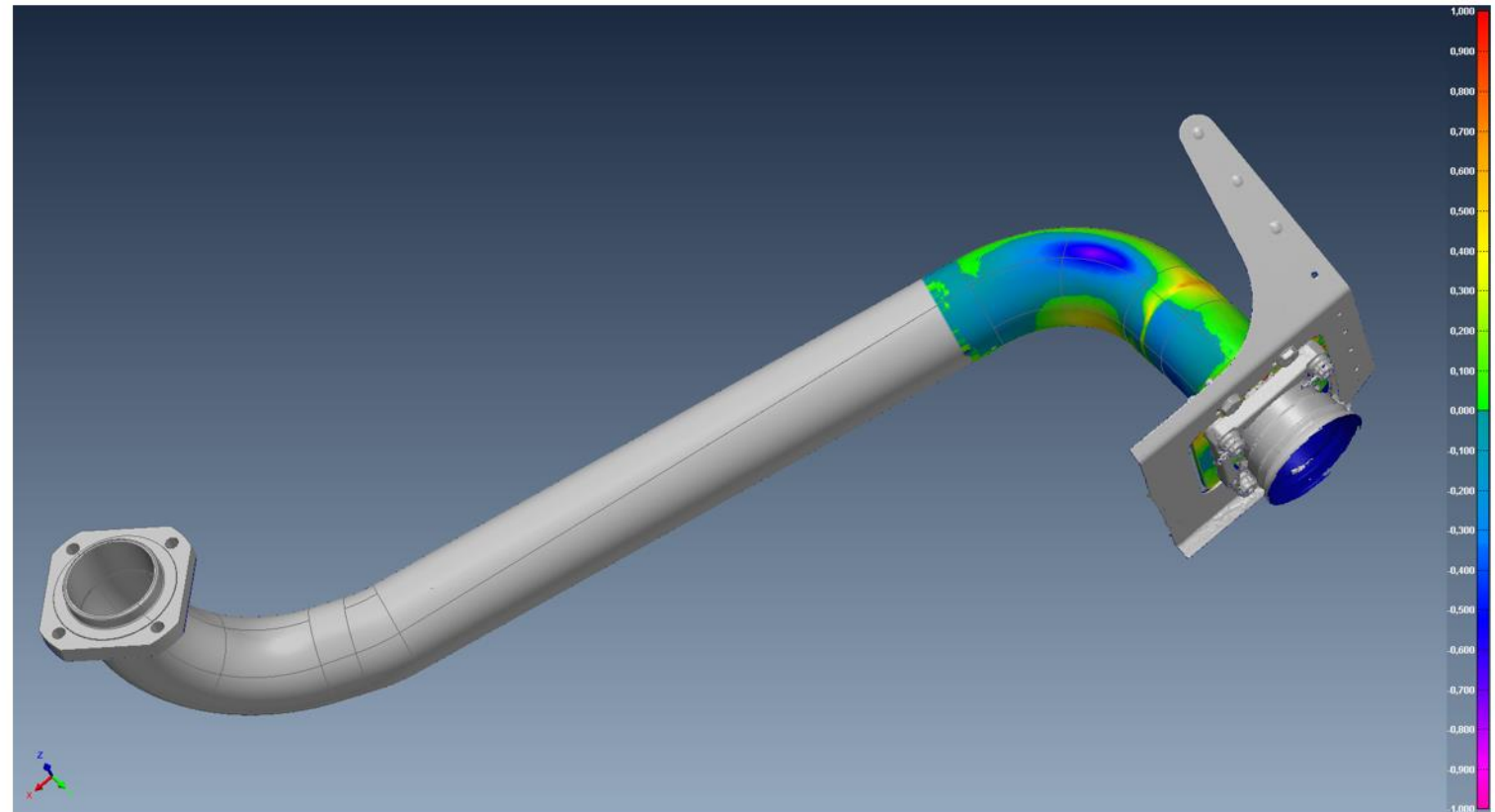
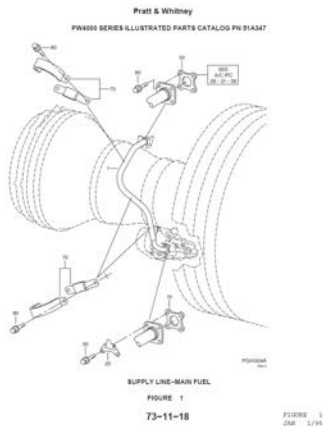
[Junction Flange](#) - Back



Applied tolerance: ± 0.2 mm

Fuel Pipe Engine / Pylon – Flange Connection - Overview

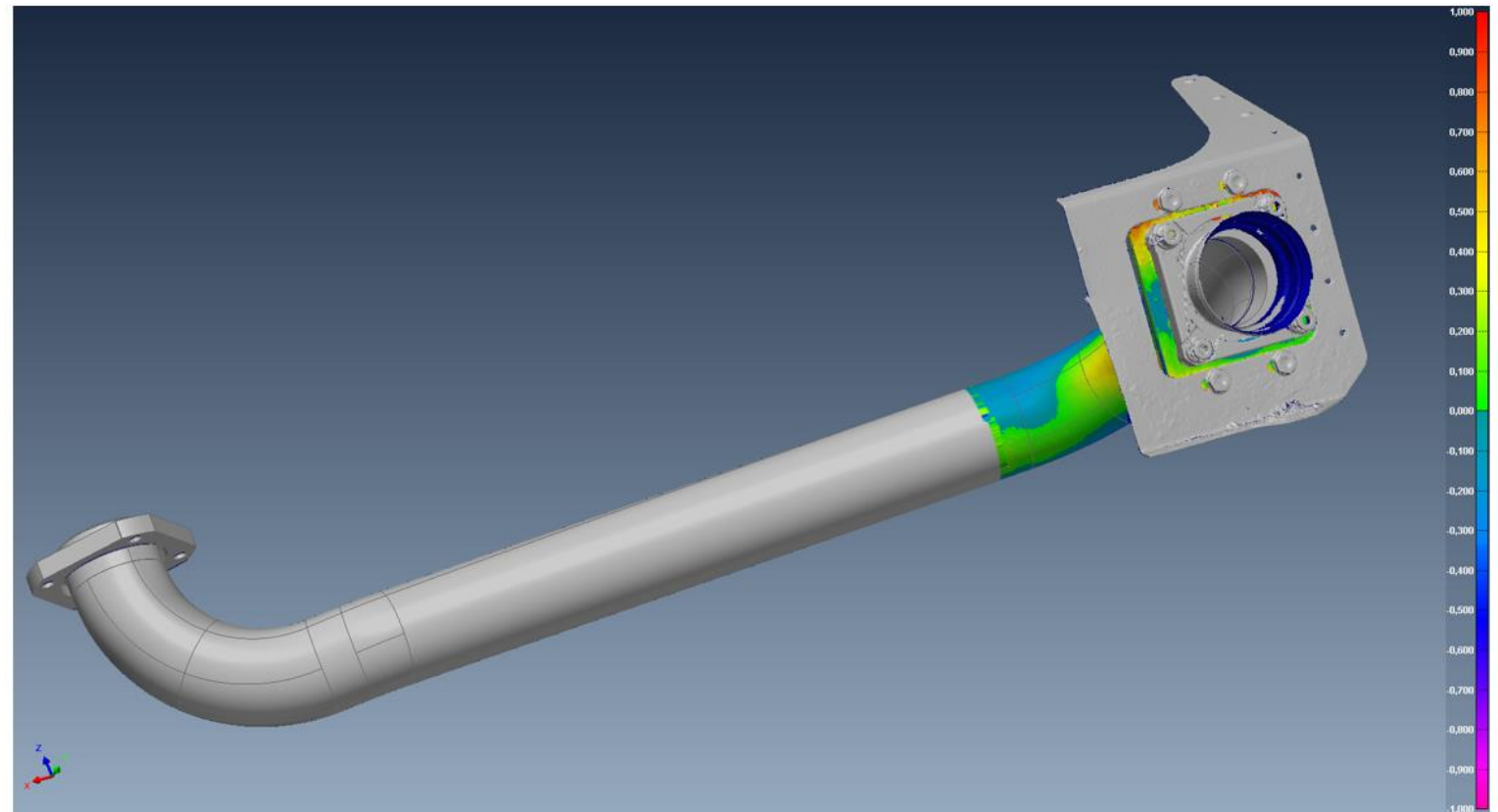
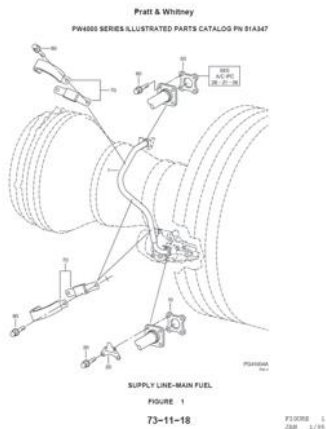
Assembly Drawing



Applied tolerance: ± 1.0 mm

Fuel Pipe Engine / Pylon – Flange Connection - Overview

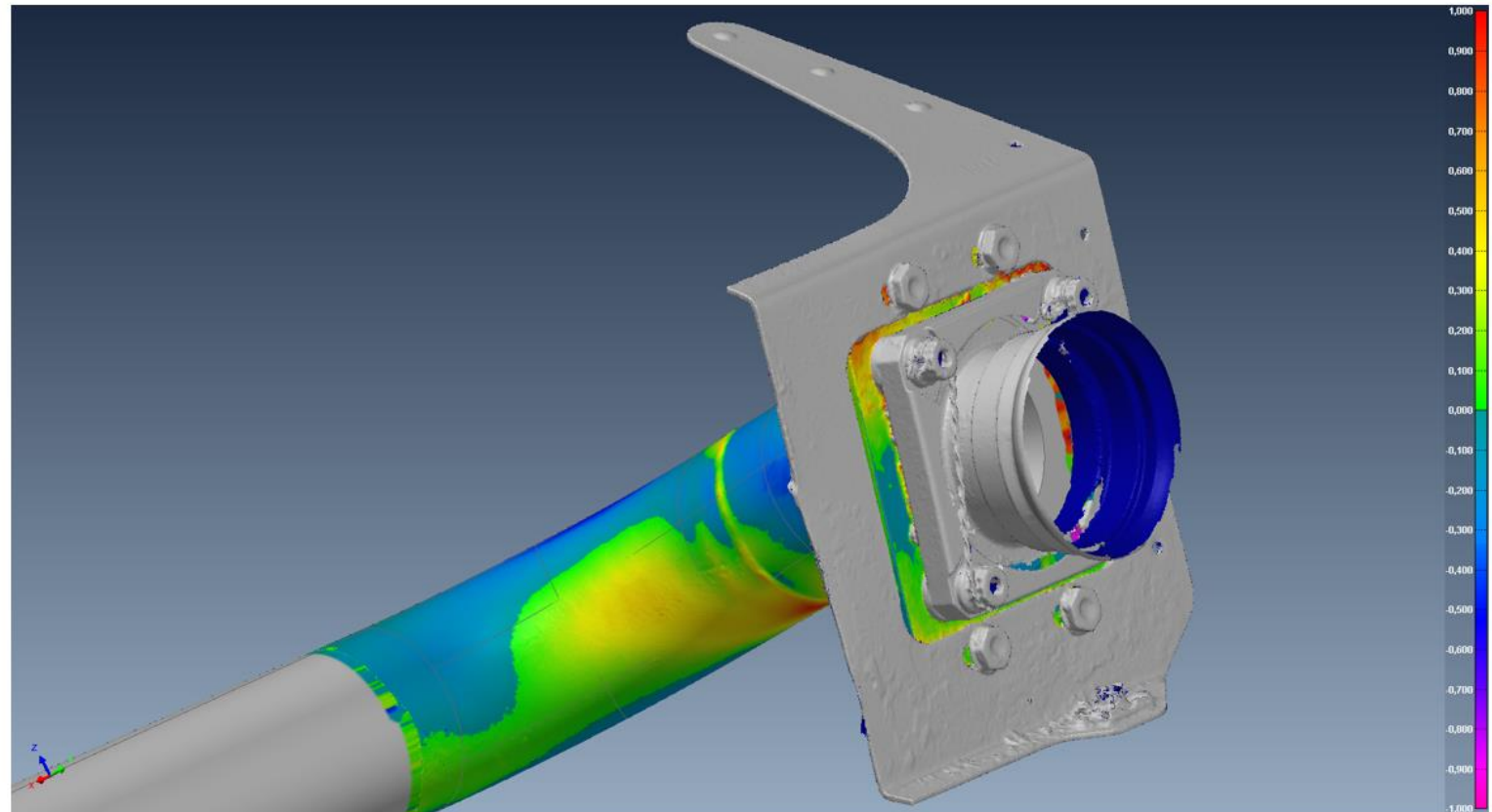
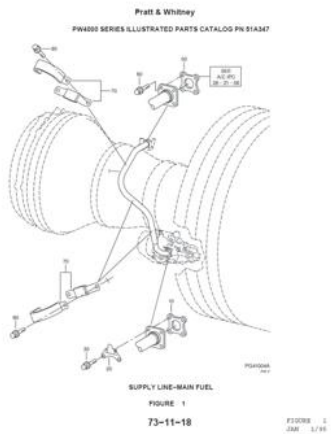
Assembly Drawing



Applied tolerance: ± 1.0 mm

Fuel Pipe Engine / Pylon – Flange Connection - Detail

Assembly Drawing



Applied tolerance: ± 1.0 mm