



# Materials Investigation of the Experimental OceanGate Submersible Titan



U.S. Coast Guard Marine Board of Investigation  
September 25, 2024

# Acknowledgements

NTSB Materials Laboratory colleagues.

U.S. Coast Guard technical advisor.

Bureau of Enquiry and Analysis for Civil Aviation Safety (BEA) and BEA-mer of France.

Transportation Safety Board of Canada.

# Outline

Nomenclature

Titan hull manufacturing history.

- Version 1 (V1).

- Version 2 (V2).

Titan V2 material anomalies.

Real-time monitoring system design and implementation.

Real-time data from dive Dive 80 on July 15, 2022.

Observations from Titan wreckage.

# Nomenclature

Composite: Engineering material made of more than one material. As applied to Titan: Unidirectional carbon fibers embedded in and reinforced by a hardened polymer (epoxy) matrix.

Wet winding: Dry carbon fiber that has been dipped into a liquid bath of resin (matrix precursor) by the user and then laid upon the mold/mandrel.

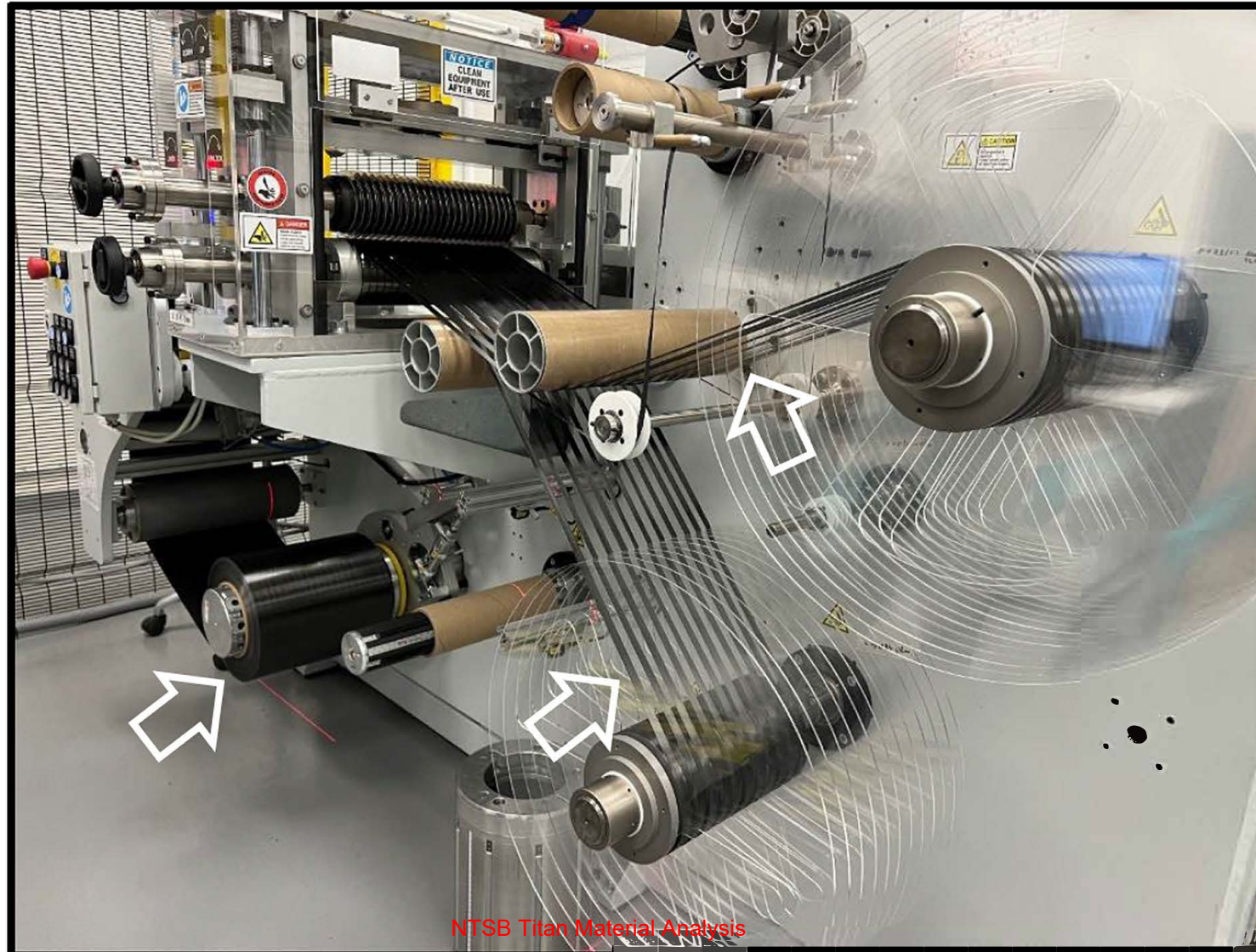
Pre-preg: Carbon fiber that has been pre-impregnated with a resin system (matrix precursor) by the fiber manufacturer. Delivered as a flat sheet on a roll. Often split into tapes/tows.

Ply/lamina: Single layer of composite material within a thicker laminated structure.



No part of a report of a marine casualty investigation shall be admissible as evidence in any civil or administrative proceeding, other than an administrative proceeding initiated by the United States, 46 U.S.C. § 6706

## Splitting Pre-preg Roll into Tape/Tows - Example



CG 107

NTSB Titan Material Analysis

Source: Senevirtane et al,  
JAMS Technical Review 2023.  
Page 5 of 67

# Nomenclature

Composite: Engineering material made of more than one material. As applied to Titan: Unidirectional carbon fibers embedded in and reinforced by a hardened polymer (epoxy) matrix.

Wet wound: Dry carbon fiber that has been dipped into a liquid bath of resin (matrix precursor) by the user and then laid upon the mold/mandrel.

Pre-preg: Carbon fiber that has been pre-impregnated with a resin system (matrix precursor) by the fiber manufacturer. Delivered as a flat sheet on a roll.

Ply/lamina: Single course (level) of composite material within a thicker laminated structure.

# Hull Manufacturing

# Titan Hull V1

Manufactured in 2017.

Carbon fiber epoxy matrix cylindrical hull.

Wet wound in cylindrical direction.

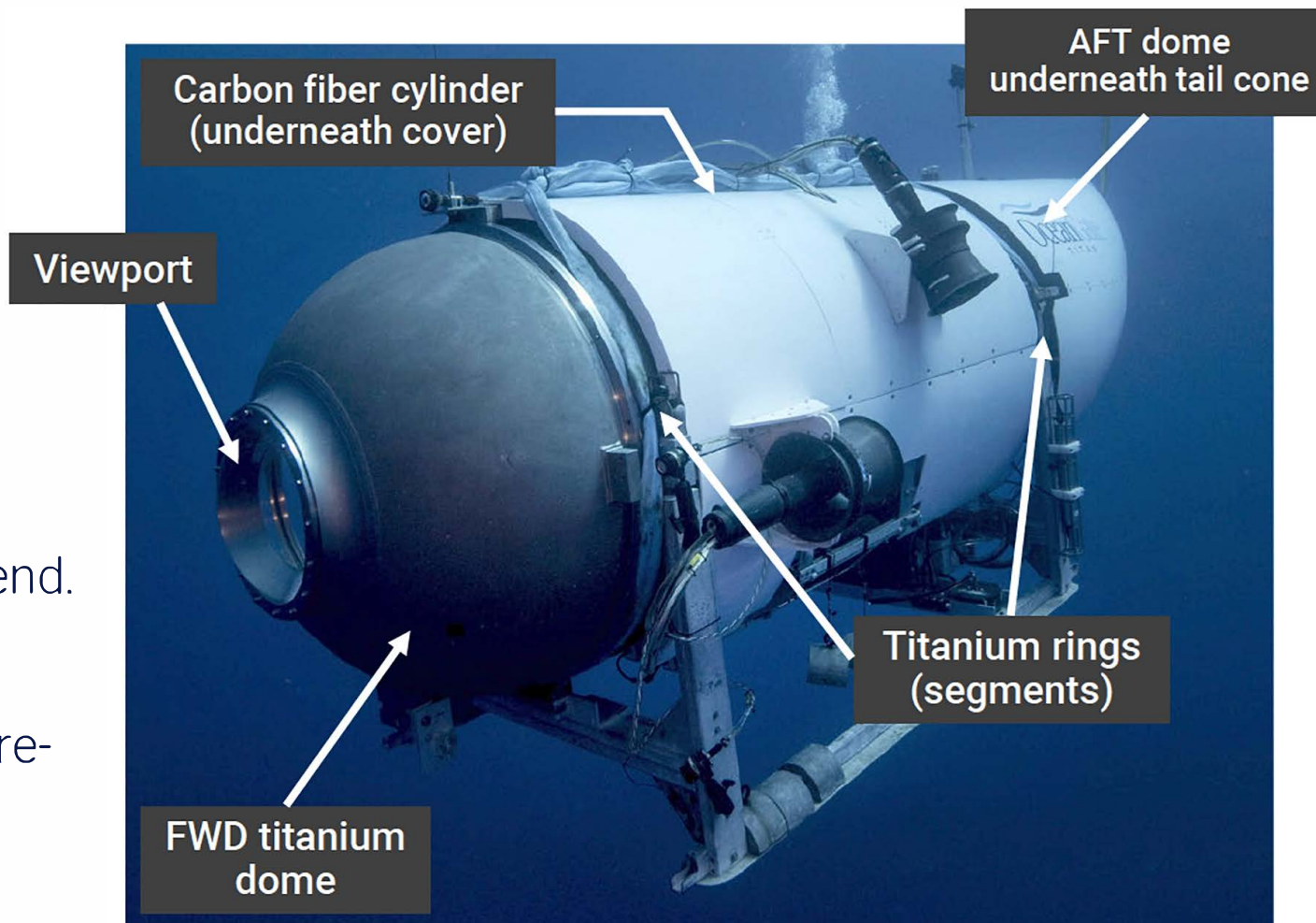
Pre-preg in longitudinal direction.

Titanium rings (segments) bonded to each end.

Capped by titanium domes.

Crack in composite hull discovered during pre-dive inspection spring 2019.

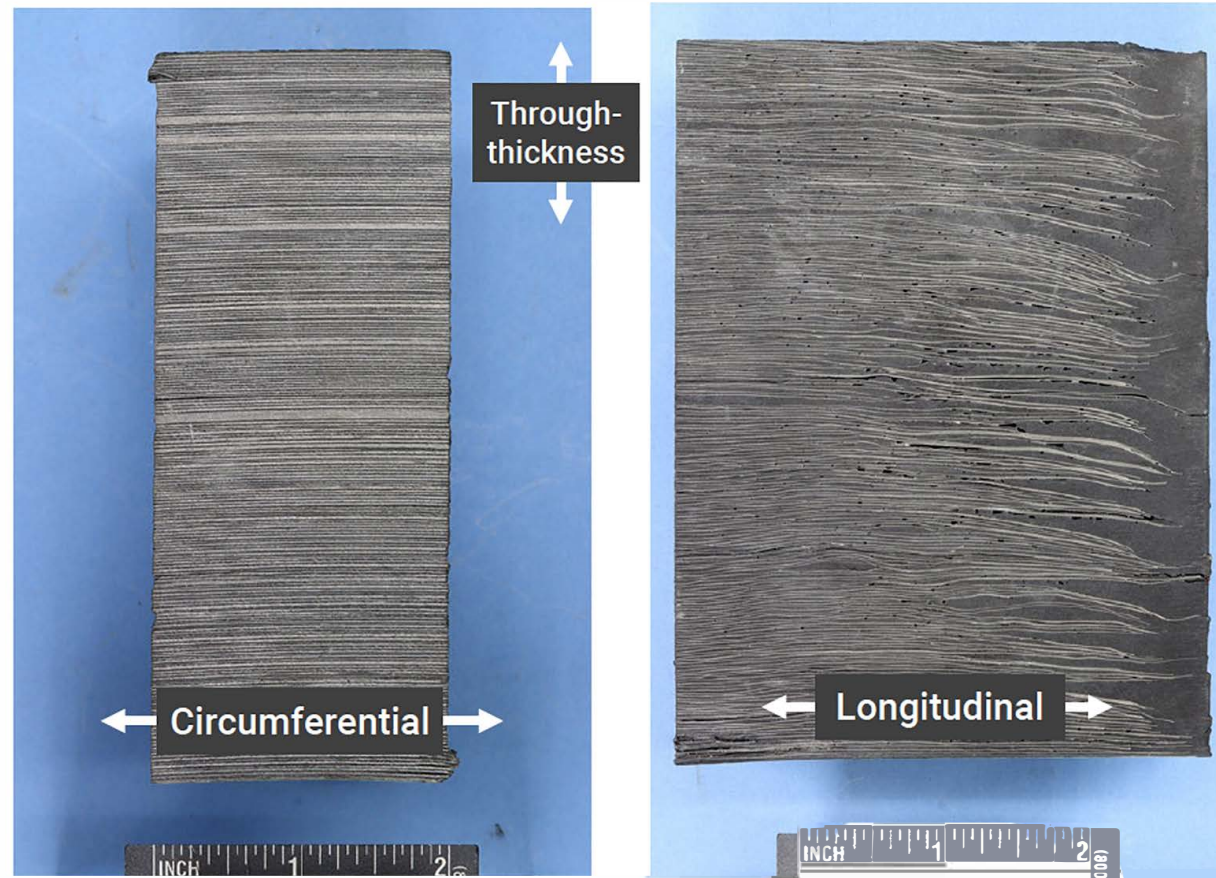
Retired from service in 2019.



**Titan Pressure Vessel with composite cylinder  
underneath fiberglass fairing**



# V1 Hull Mid-thickness Delamination



**Titan V1 trimmed end piece**

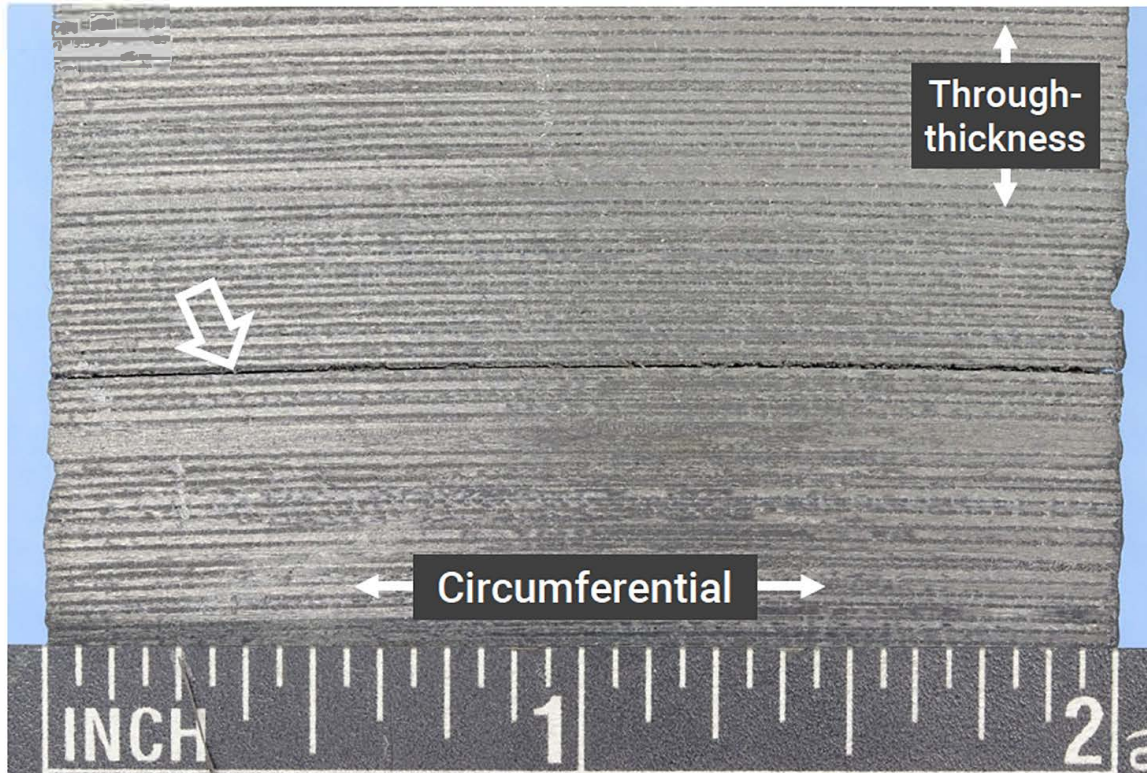
CG 107

NTSB Titan Material Analysis

Page 9 of 67

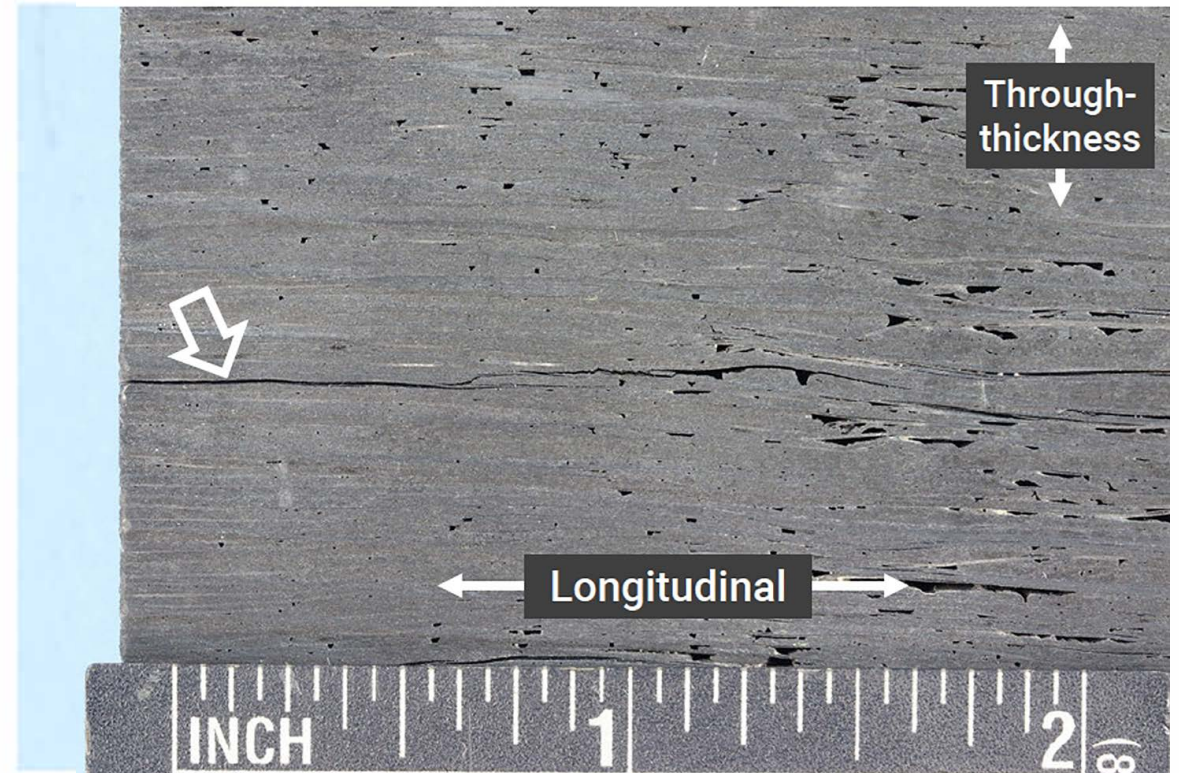


# Mid-thickness Delamination



CG 107 **Titan V1 trimmed end piece**

NTSB Titan Material Analysis



**Titan V1 trimmed end piece** Page 10 of 67



# Sub-scale Test Articles

Two sub-scale test articles build after V1 hull retired.

100% pre-preg construction.

Wrinkles.

Mid-thickness delaminations.

Imploded or on verge of imploding at or below 2,800 m.



CG 107

NTSB Titan Material Analysis

**First test article - trimmed end**

Page 11 of 67

# Titan Hull V2 Manufacturing

Subscale test article failure influenced by wrinkles.

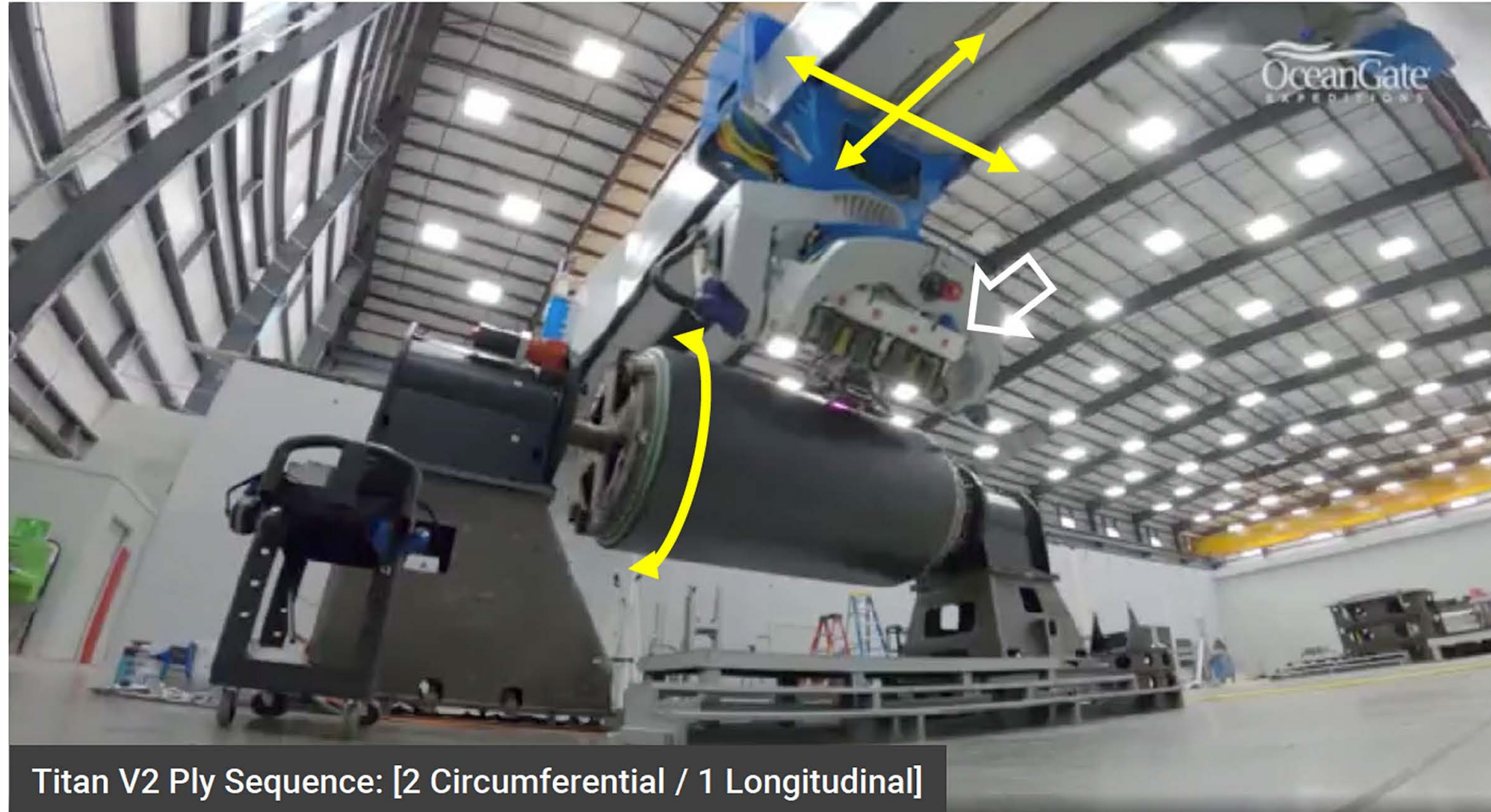
Co-bonding (multi-cure) process used for full-scale V2 hull.

100% pre-preg construction.

Build using fiber placement machine (FPM).



## Fiber Placement Machine







## Rough V2 Hull



CG 107

NTSB Titan Material Analysis

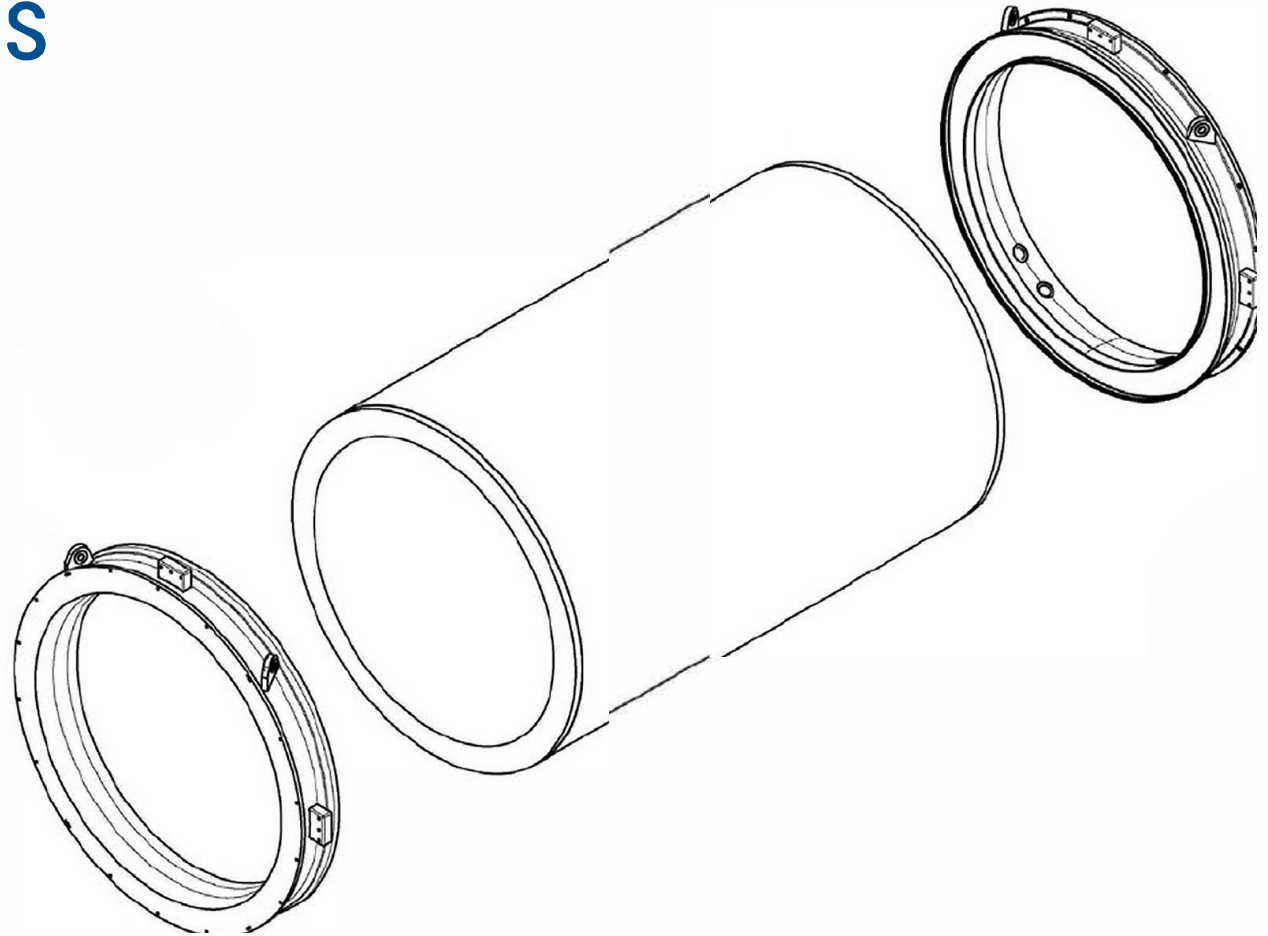
Source: OceanGate Titan Archive [GitHub Repository](#)

# Titan V2 Hull Anomalies

Waviness and wrinkles in trimmed ends.

Porosity between plies.

Voids in adhesive.





# Titan V2 Hull Trimmed End– Waviness and Wrinkles



CG 107

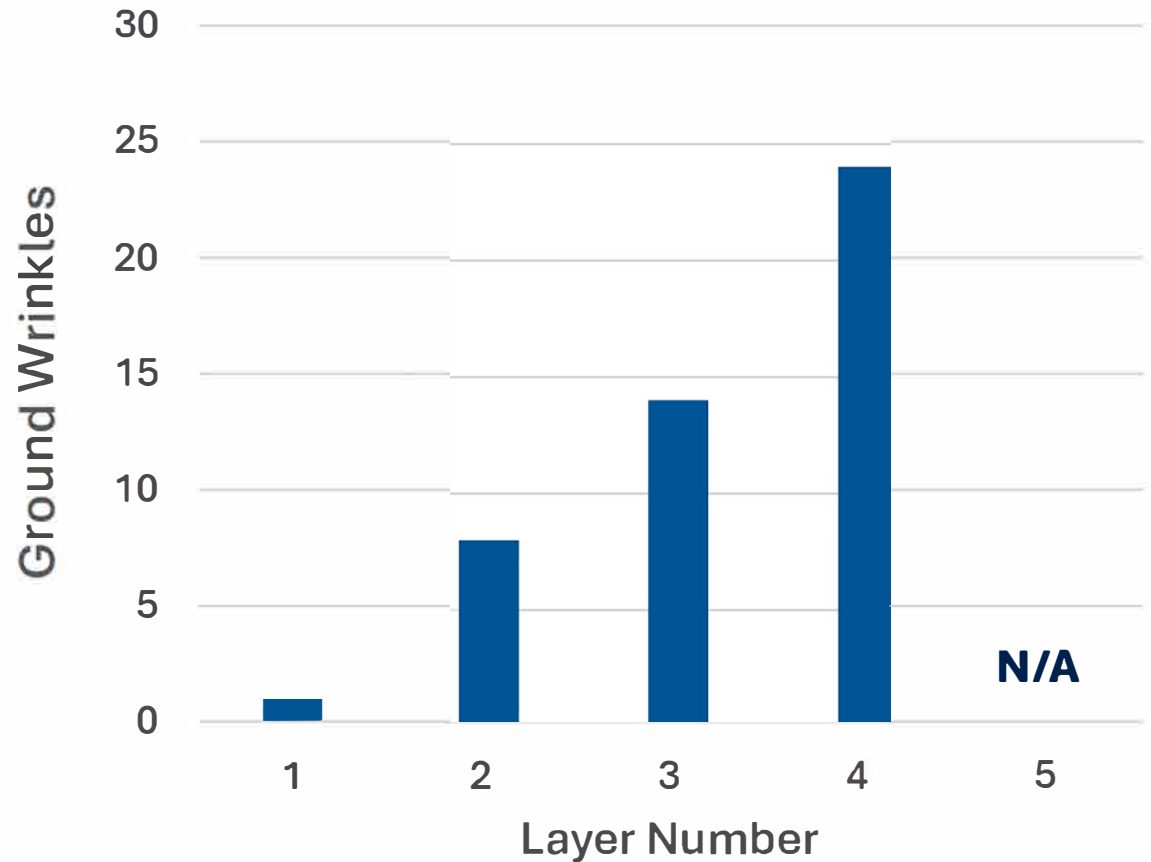
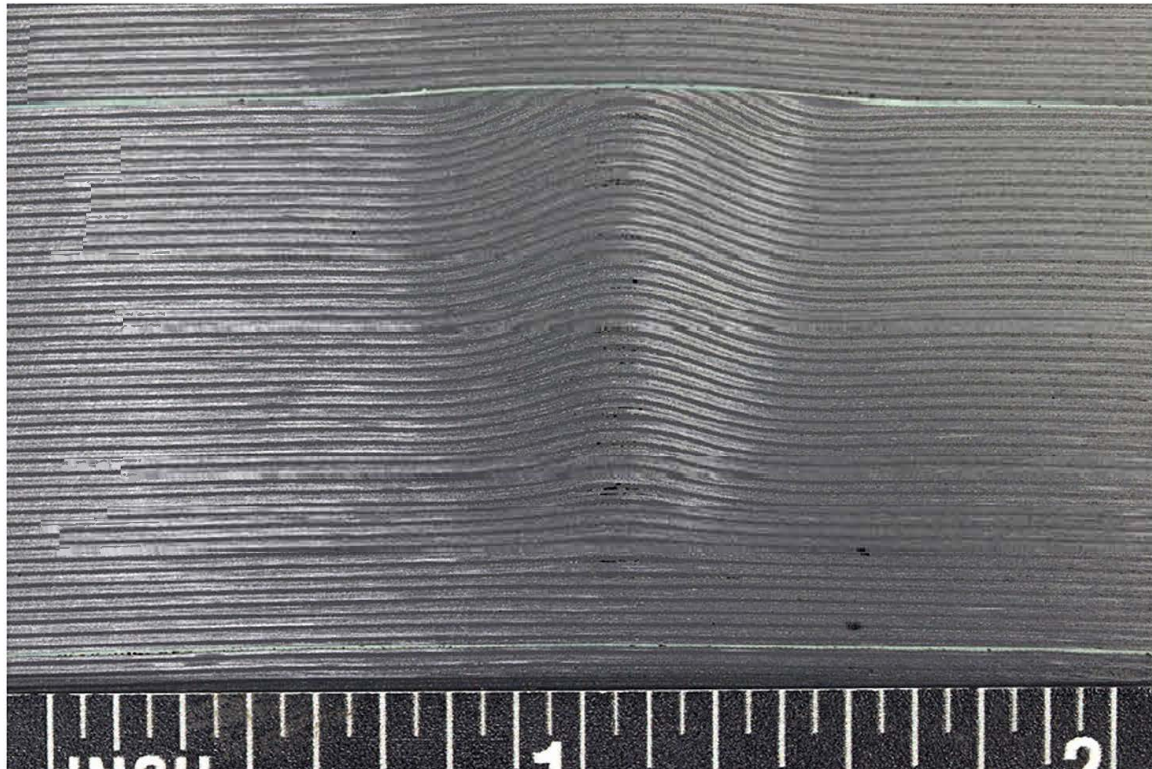


NTSB Titan Material Analysis

Page 17 of 67



# Titan V2 Hull Trimmed End – Wrinkles



CG 107

NTSB Titan Material Analysis

Page 18 of 67

# Titan V2 Hull – Porosity



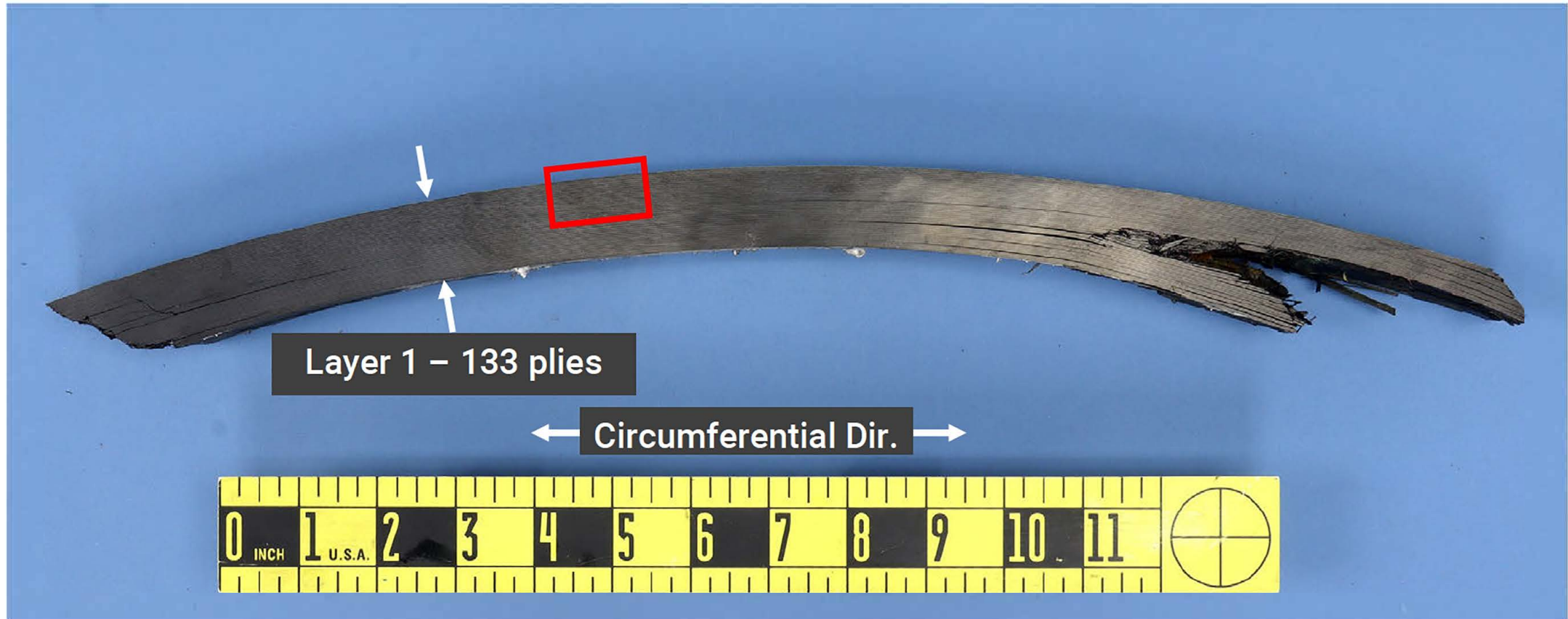
CG 107

NTSB Titan Material Analysis

Page 19 of 67



# Titan V2 Hull – Porosity



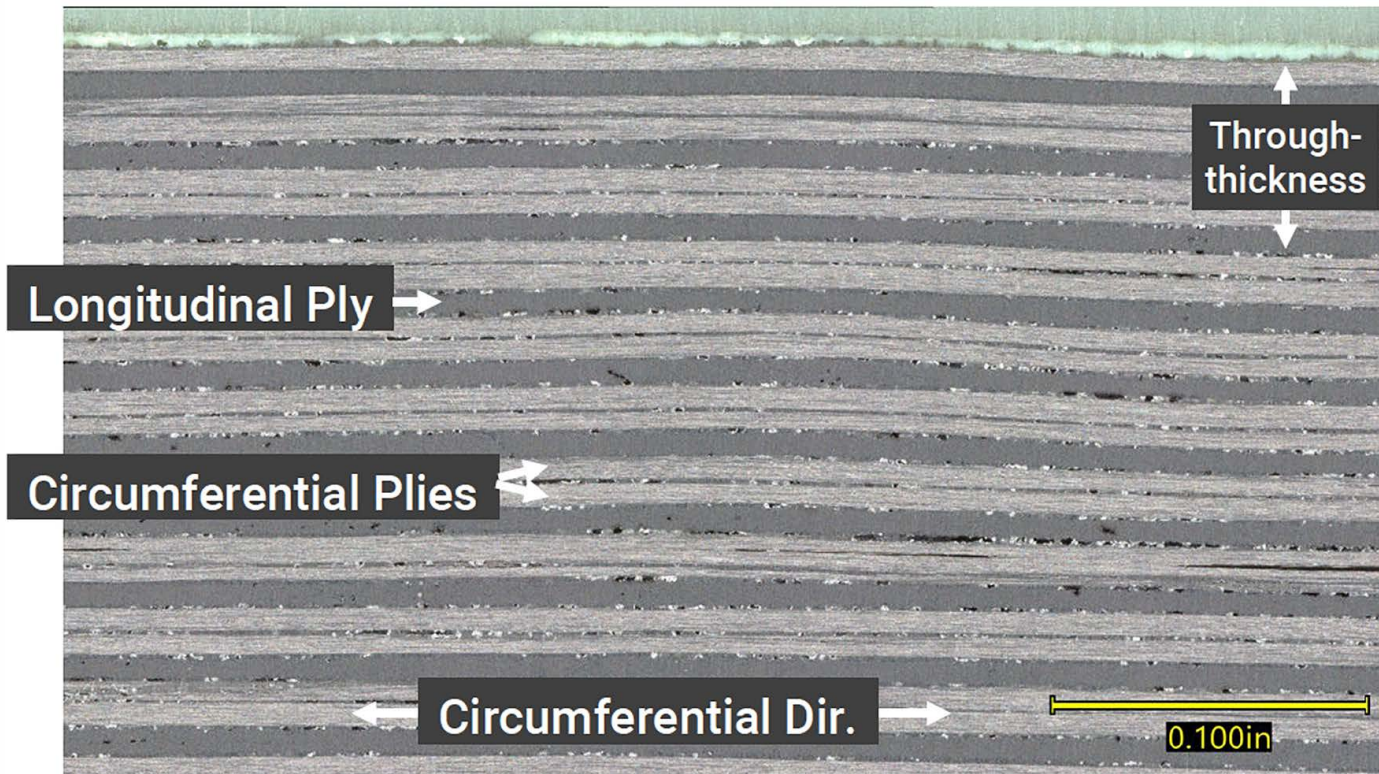
CG 107

NTSB Titan Material Analysis

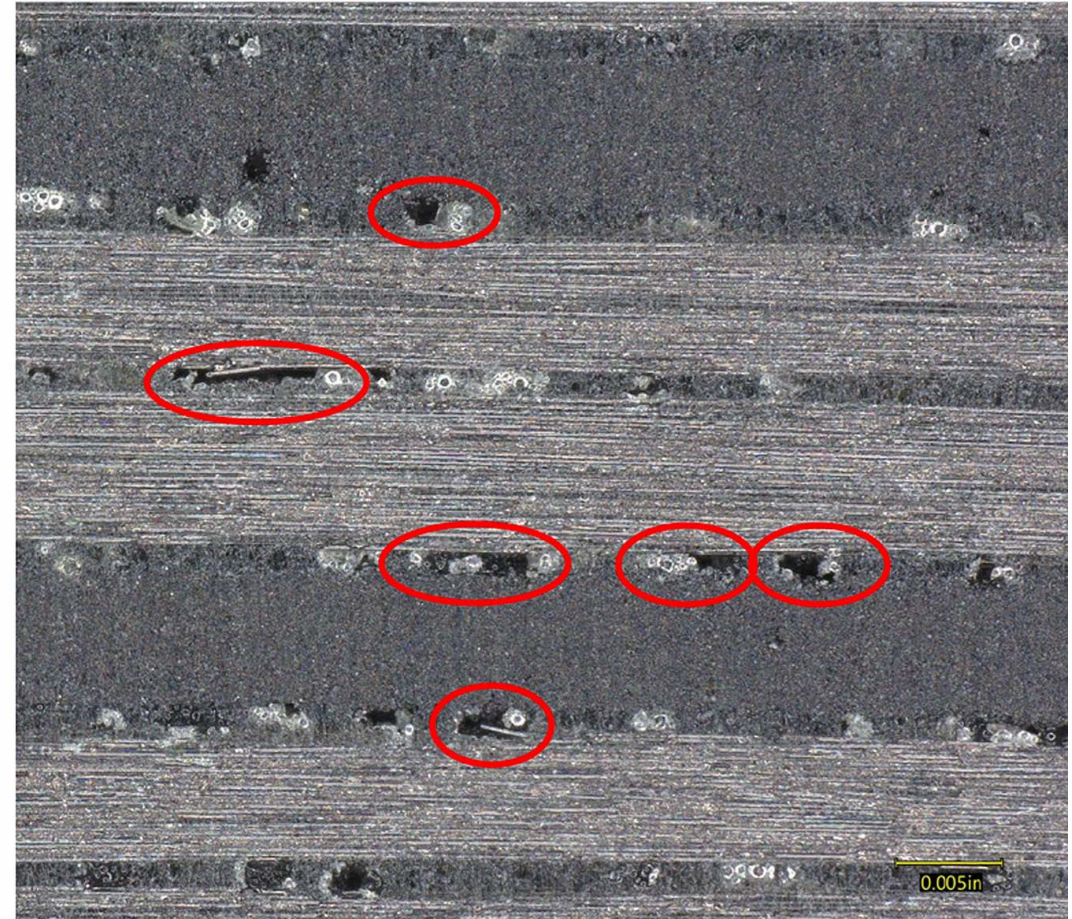
Page 20 of 67



# Titan V2 Hull – Porosity



Cross-section through layer 1



CG 107

NTSB Titan Material Analysis

Page 21 of 67

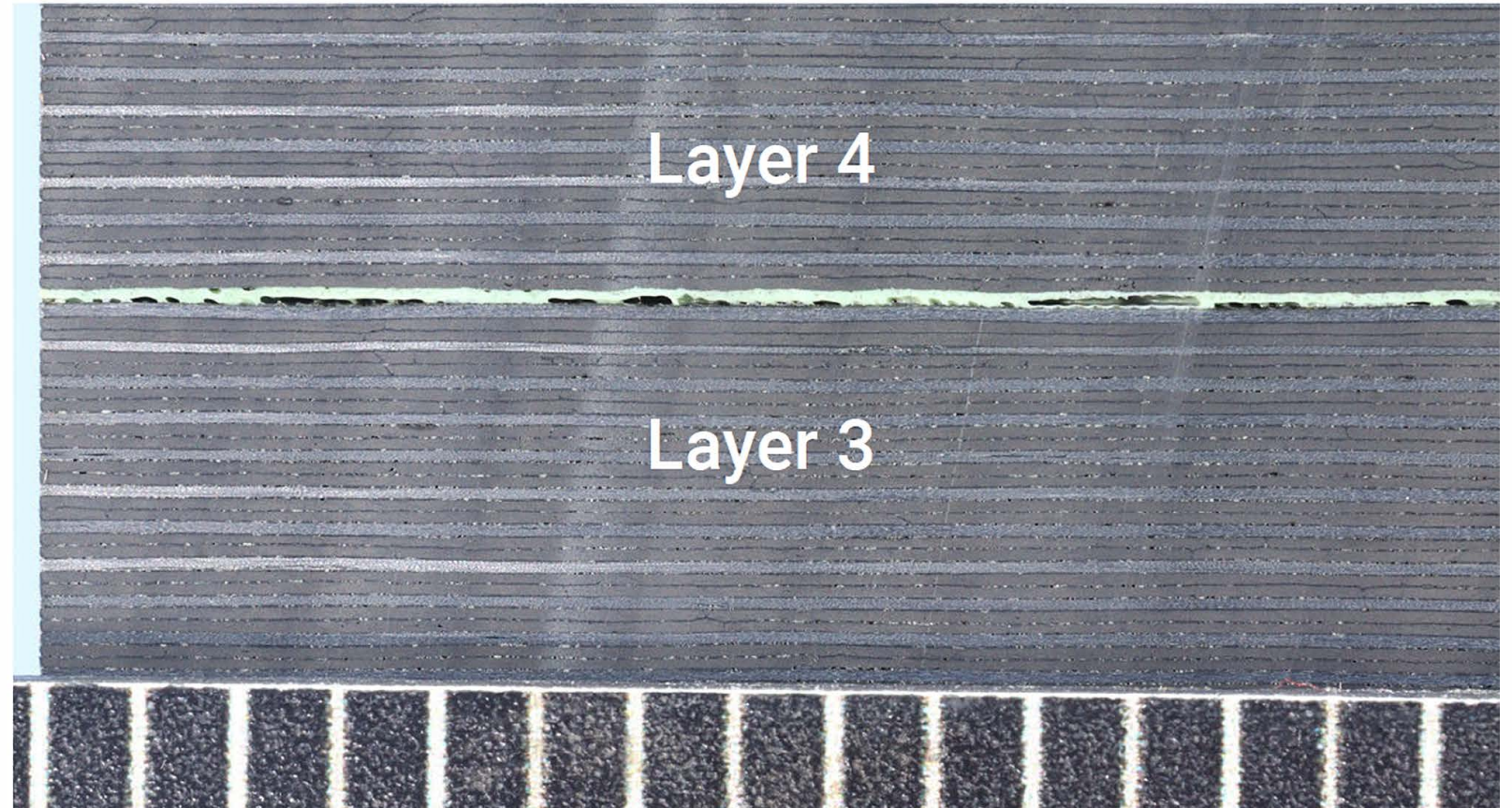


# Titan V2 Hull Trimmed End – Voids in Adhesive

Elongated void structures in adhesive.

Between layers 1 and 2.

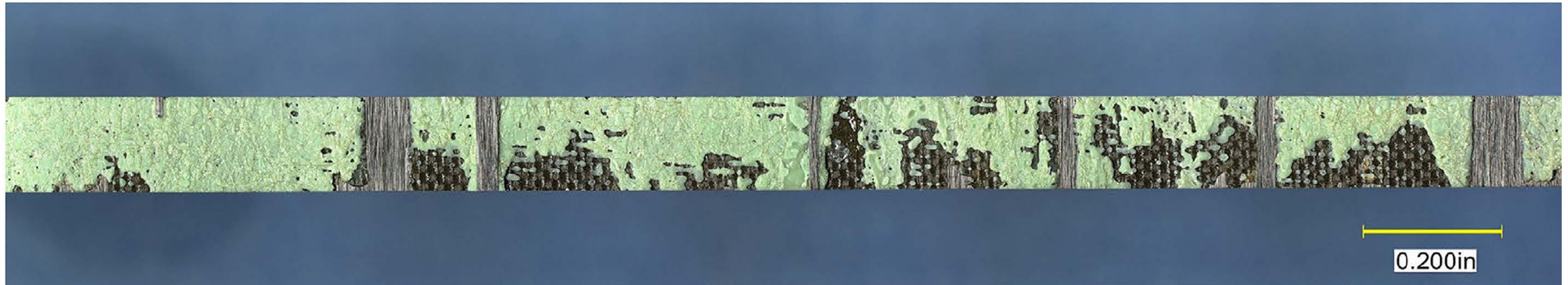
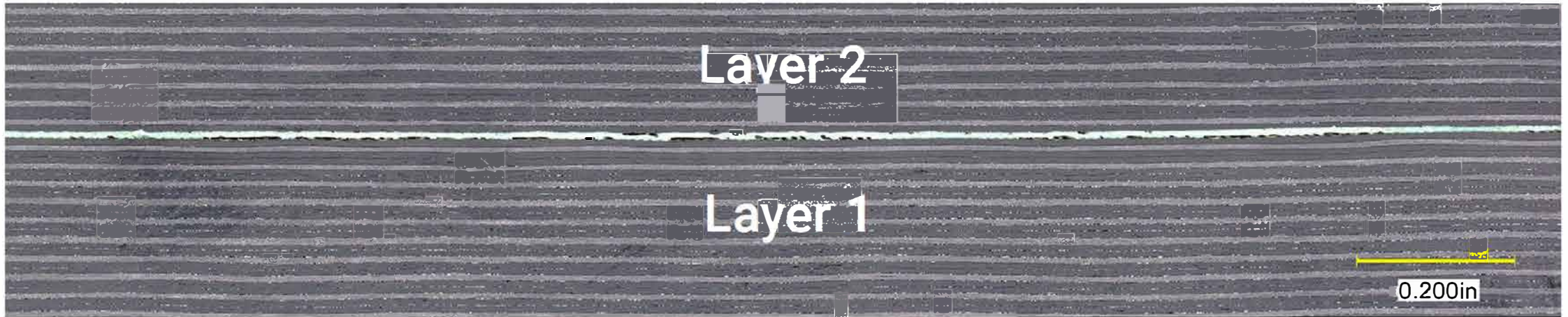
Between layers 3 and 4.



**Longitudinal cross-section**

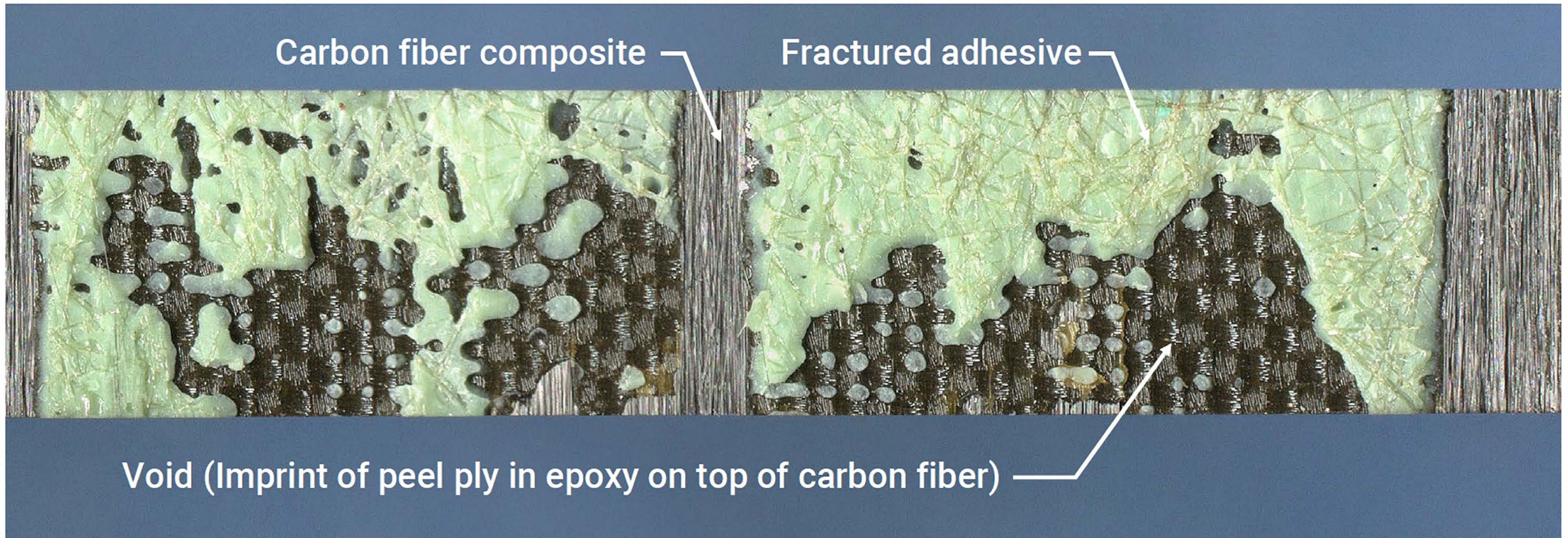


# Titan V2 Hull – Voids in Adhesive





# Titan V2 Hull – Voids in Adhesive





# Rubbing Damage – Retrieved Layer 1 Piece



CG 107

NTSB Titan Material Analysis

Page 25 of 67



# Rubbing Damage – Debris Collected in Voids



CG 107

**As recovered**

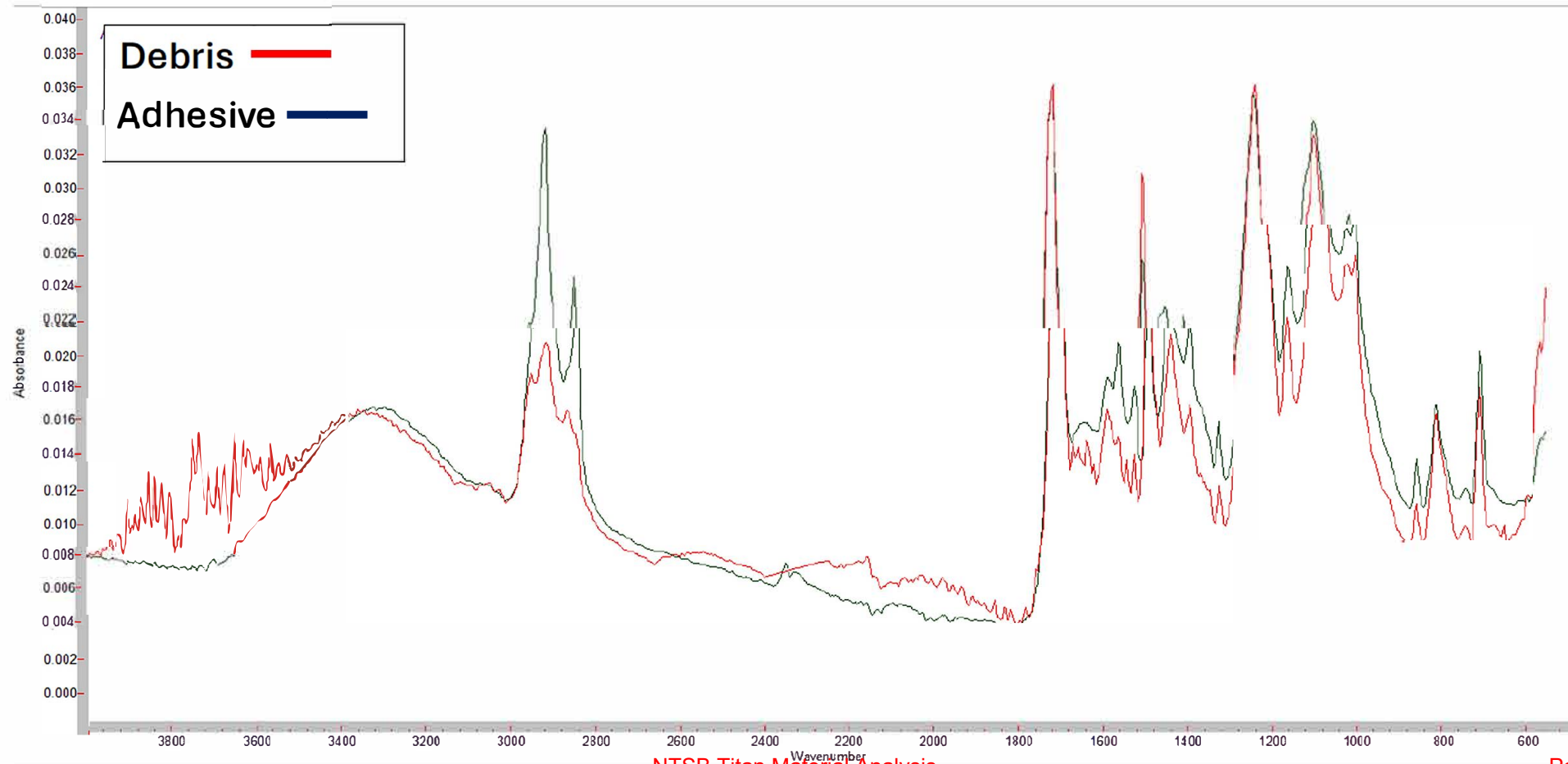


NTSB Titan Material Analysis

**Debris removed**

Page 26 of 67

# Rubbing Damage – Debris Consistent with Adhesive



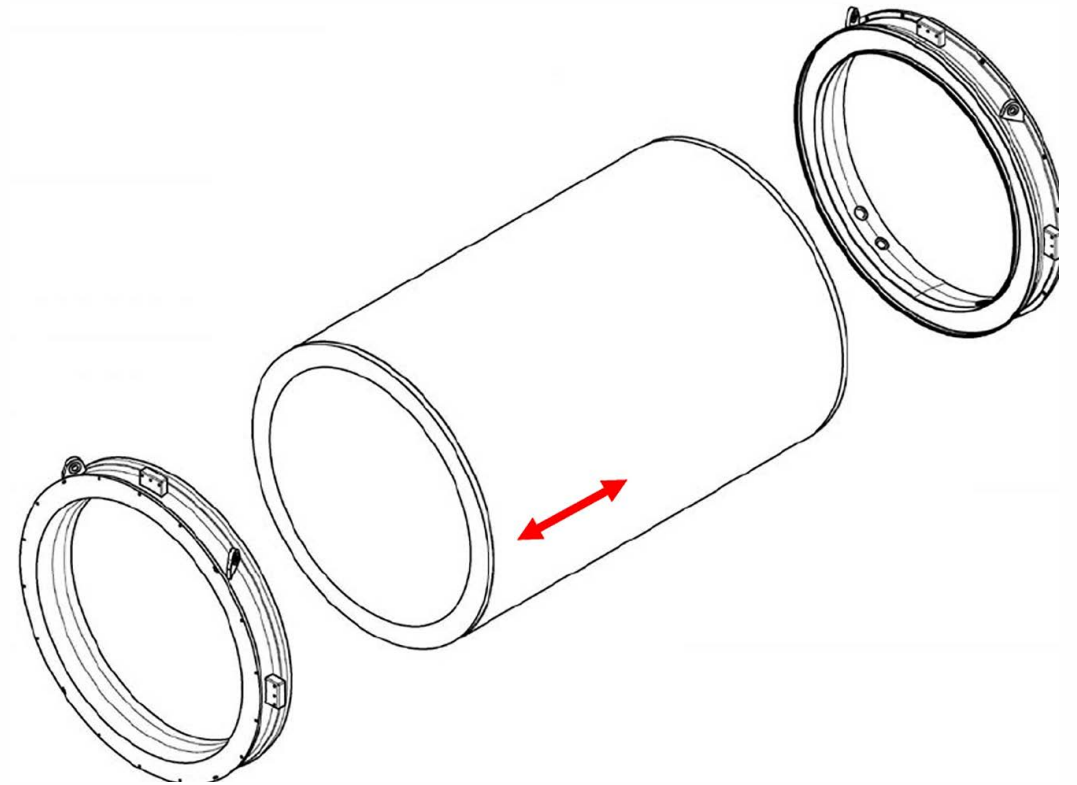
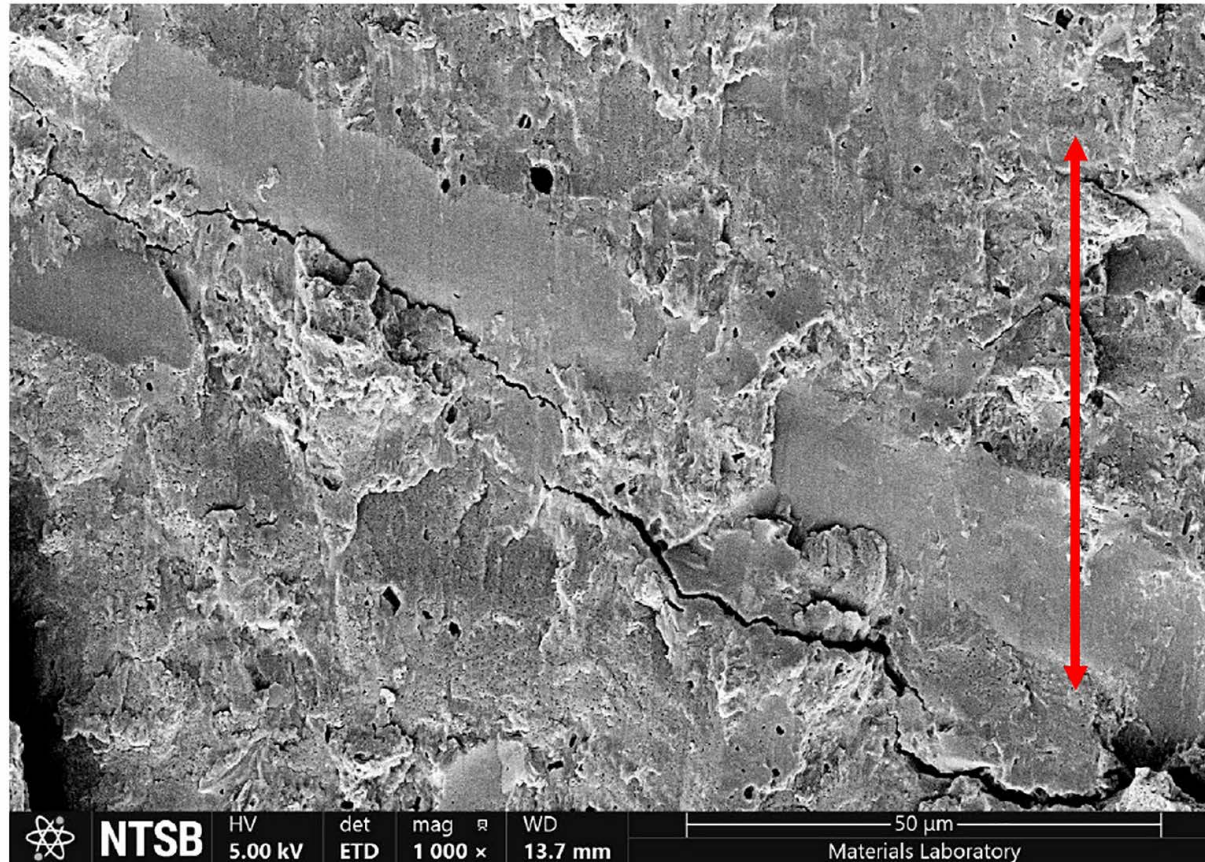
CG 107

NTSB Titan Material Analysis

Page 27 of 67



# Rubbing Damage – Longitudinal Rub Marks



CG 107 Rubbing in longitudinal direction

NTSB Titan Material Analysis

Page 28 of 67



# Titan Real-time Monitoring System (RTM)

# Acoustic Event Detection

Fractures, etc. within composite structure create sounds that travel through the material.

Acoustic sensors are tiny microphones that “listen” for these sounds.

Sensors can be trained to listen for certain volumes and/or frequencies.

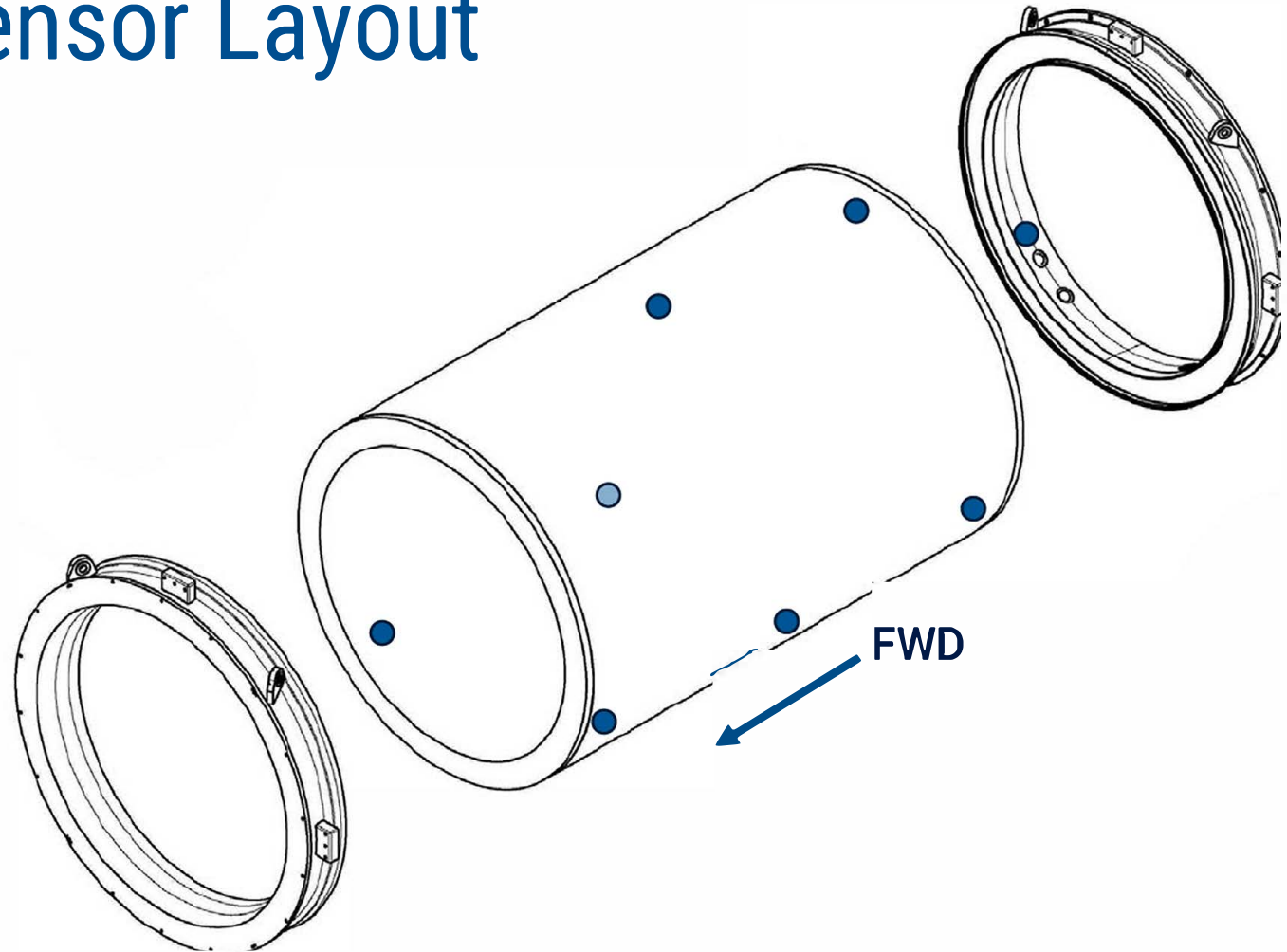
Complex but established field.



**General purpose acoustic sensor**

# Titan V2 Acoustic Sensor Layout

7 acoustic sensors on hull.  
1 sensor on aft segment



# RTM – Acoustic Emission – Implementation

RTM counted acoustic “HITS”.

First cumulative hit threshold - yellow alert

Second cumulative hit threshold = red warning – abort dive

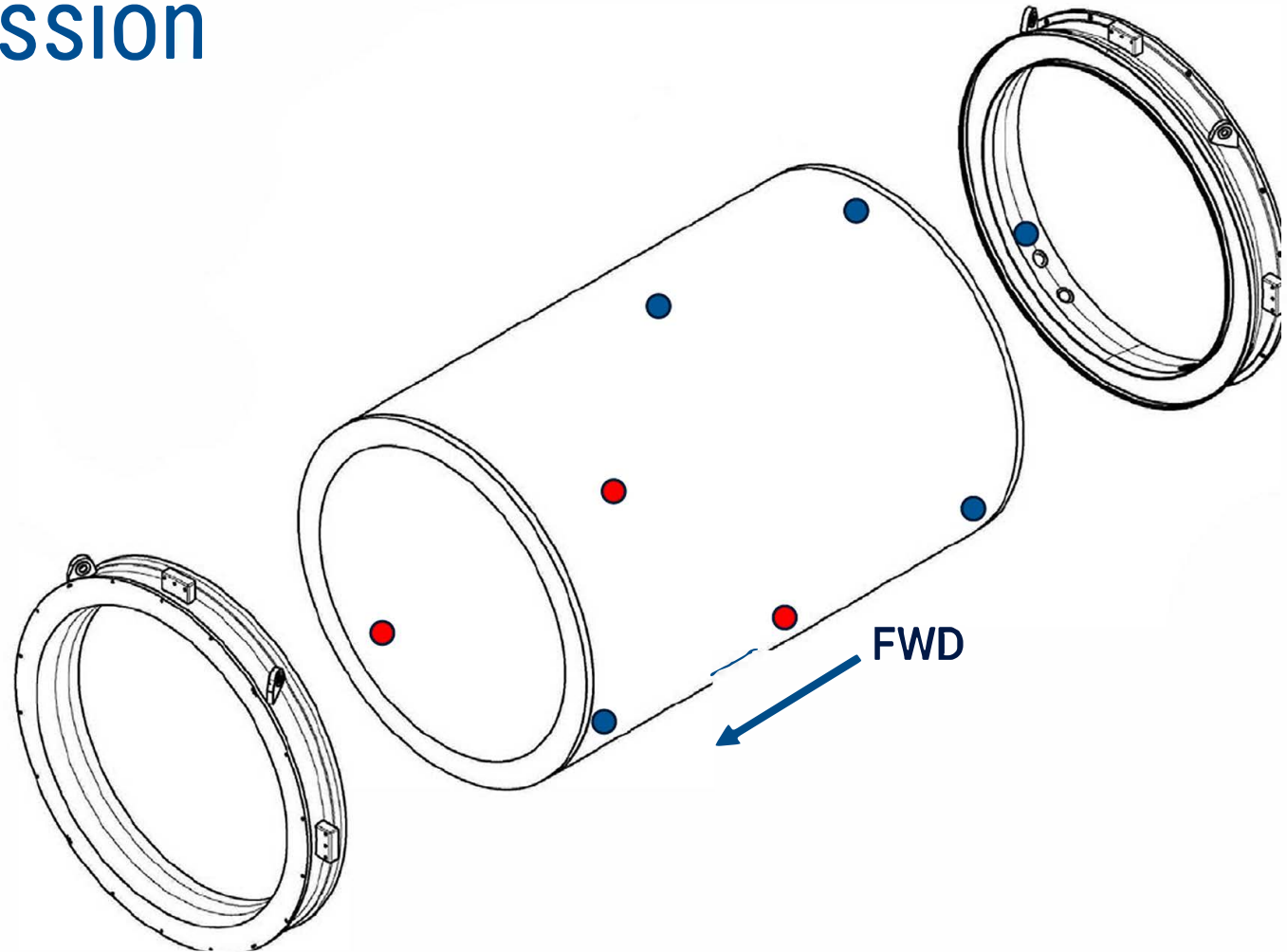
HIT amplitude and quantity for alerts based on retired V1 hull and sub-scale test articles.

# RTM – Acoustic Emission

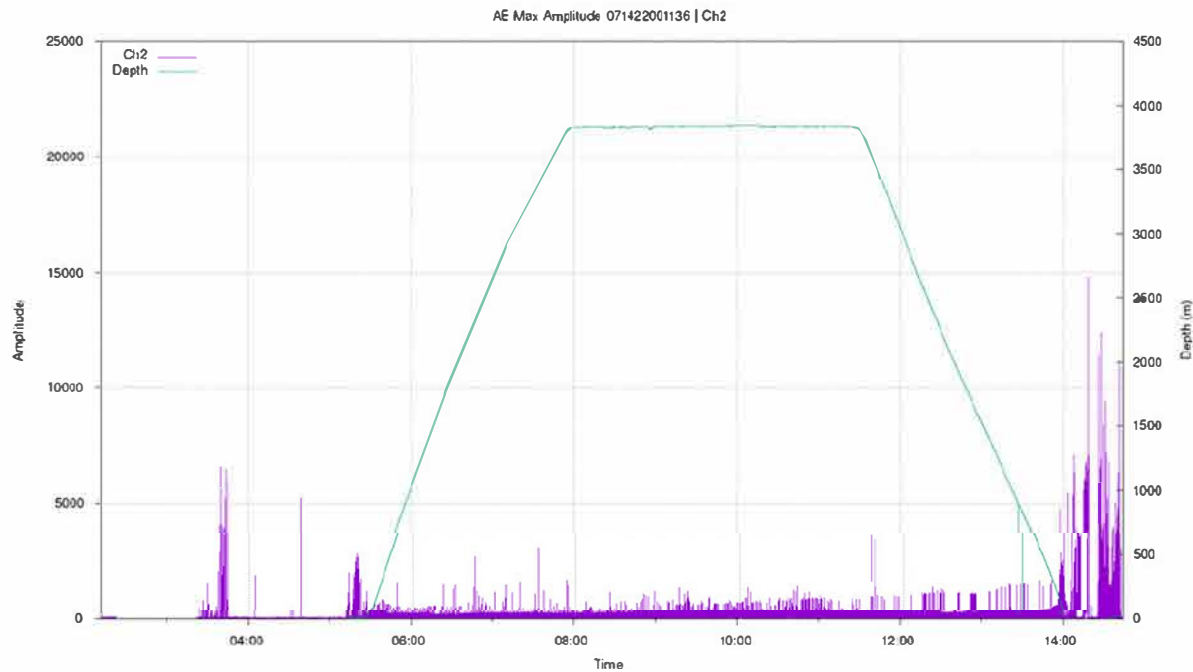
7 acoustic sensors on hull.

1 sensor on aft segment

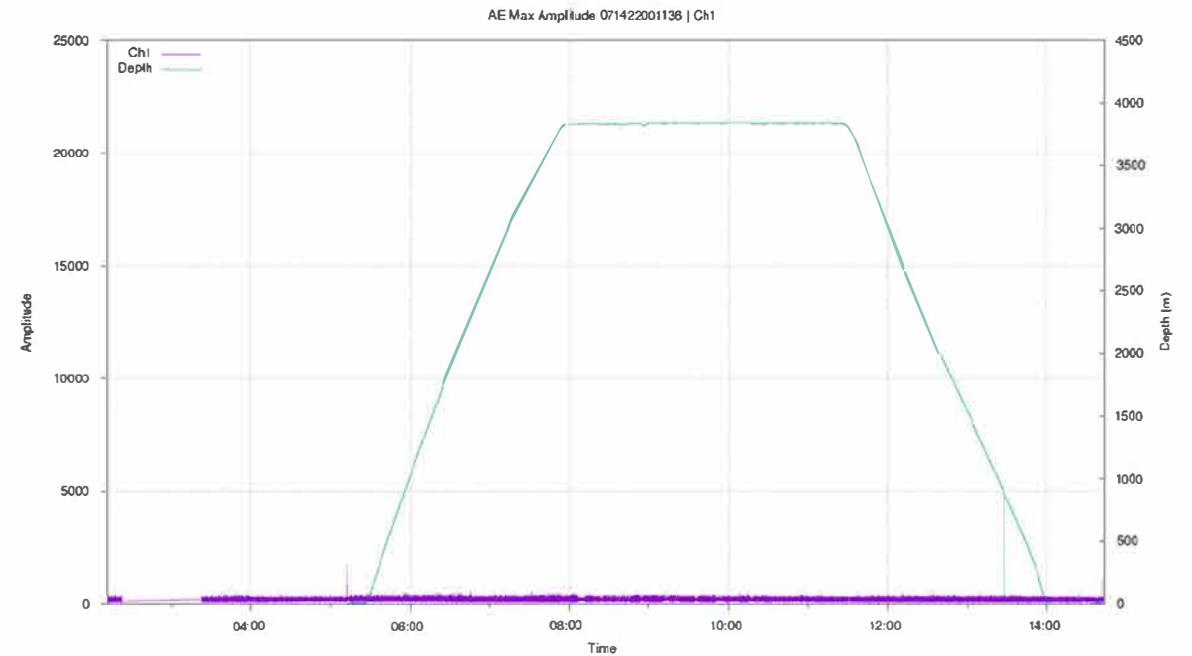
3 of 8 sensors did not appear to detect acoustic events.



# RTM – Acoustic Emission – Dive 76



Channel 2 – FWD port side



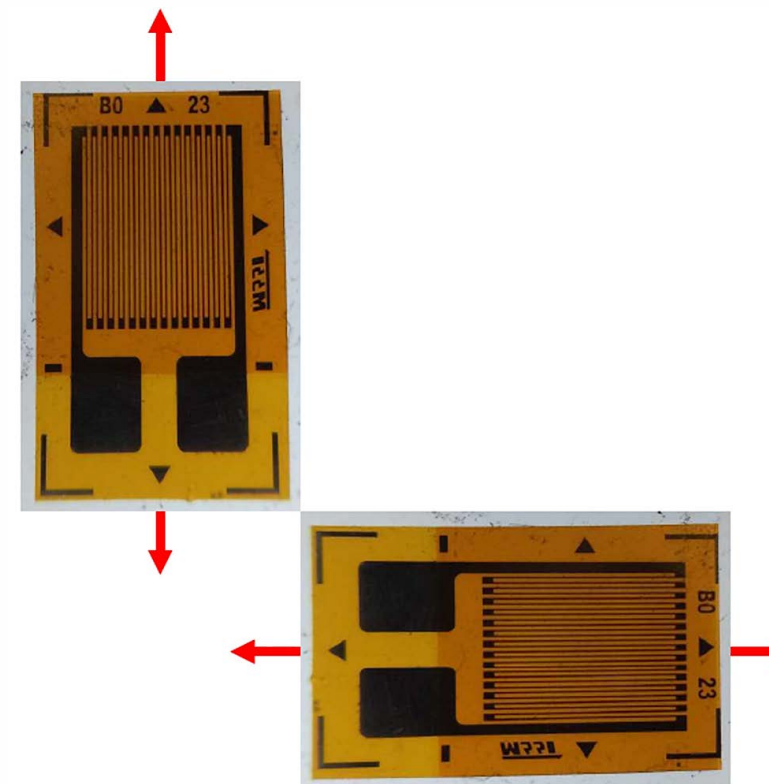
Channel 1 – FWD starboard side

# RTM – Strain Monitoring

Hull deformation measured using foil strain gages.

Elongation or compression of the foil changes its electrical resistance.

Strain gages right angle pairs.



General purpose foil strain gages.

# RTM – Strain Monitoring

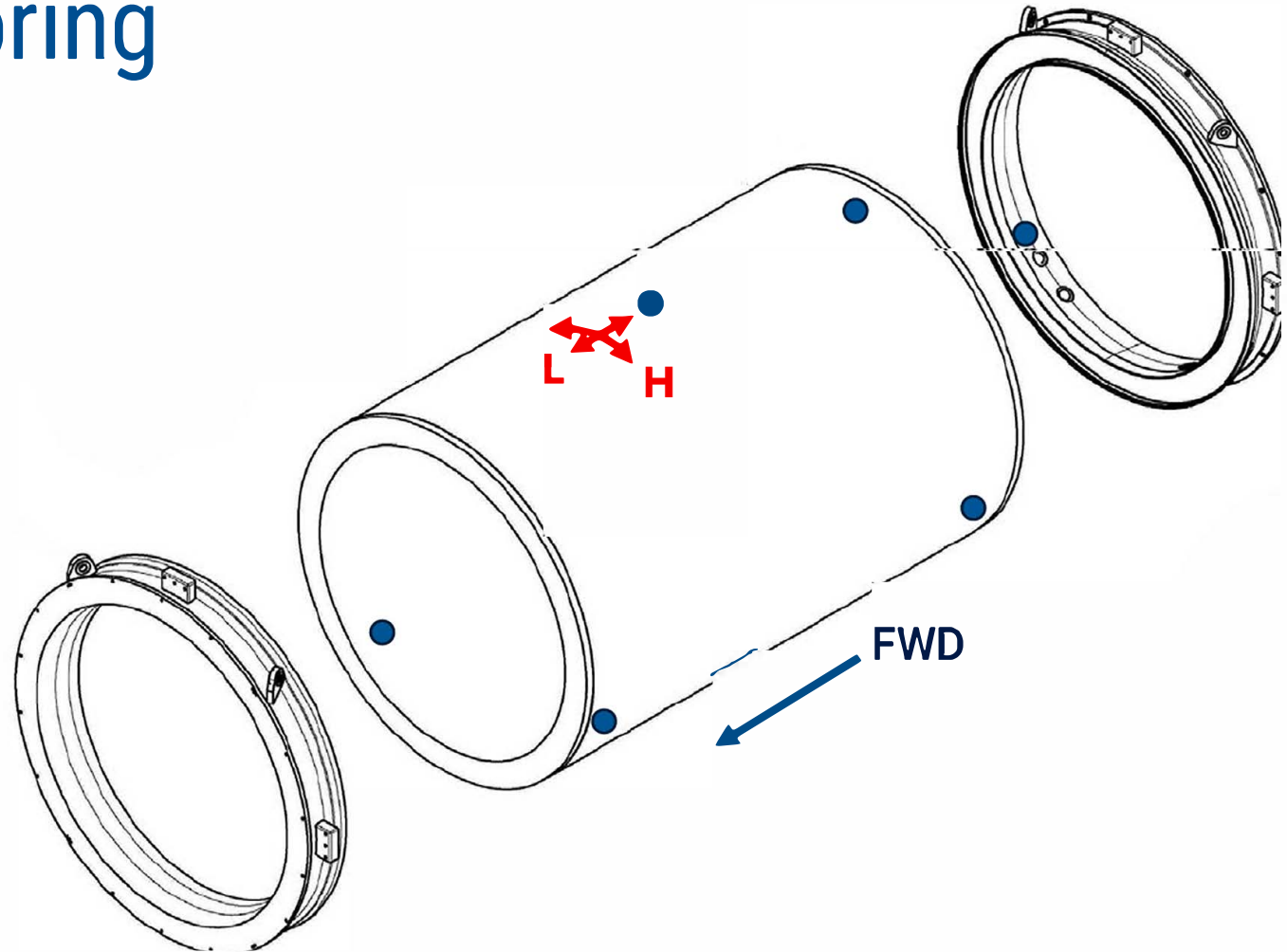
5 strain gage pairs on hull

1 pair on aft segment

2 strain gage pairs on forward dome at DOTF may have been moved to hull (not shown)

One gage measured hoop strain (H).

One gage measured longitudinal strain (L).



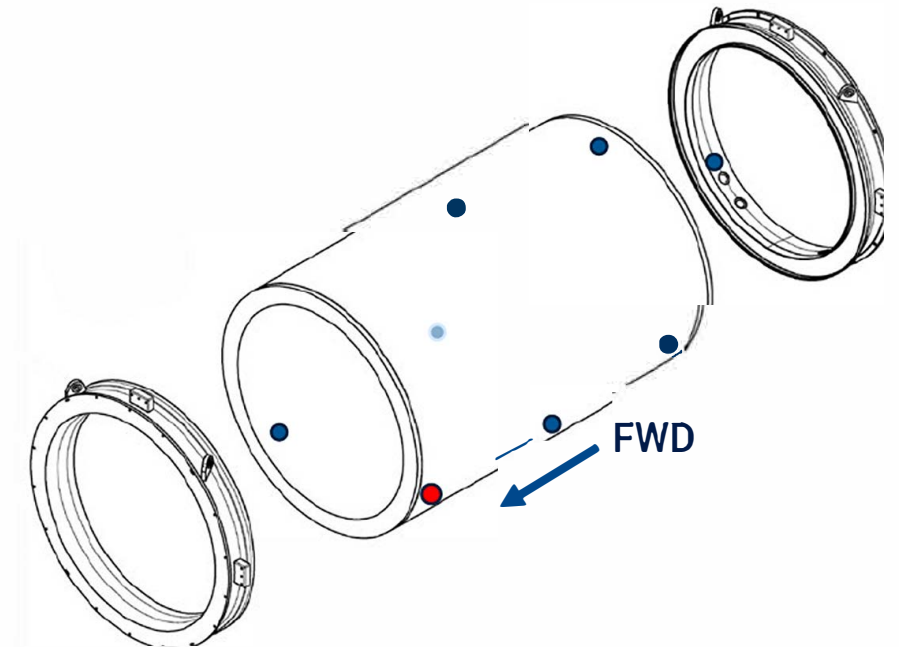
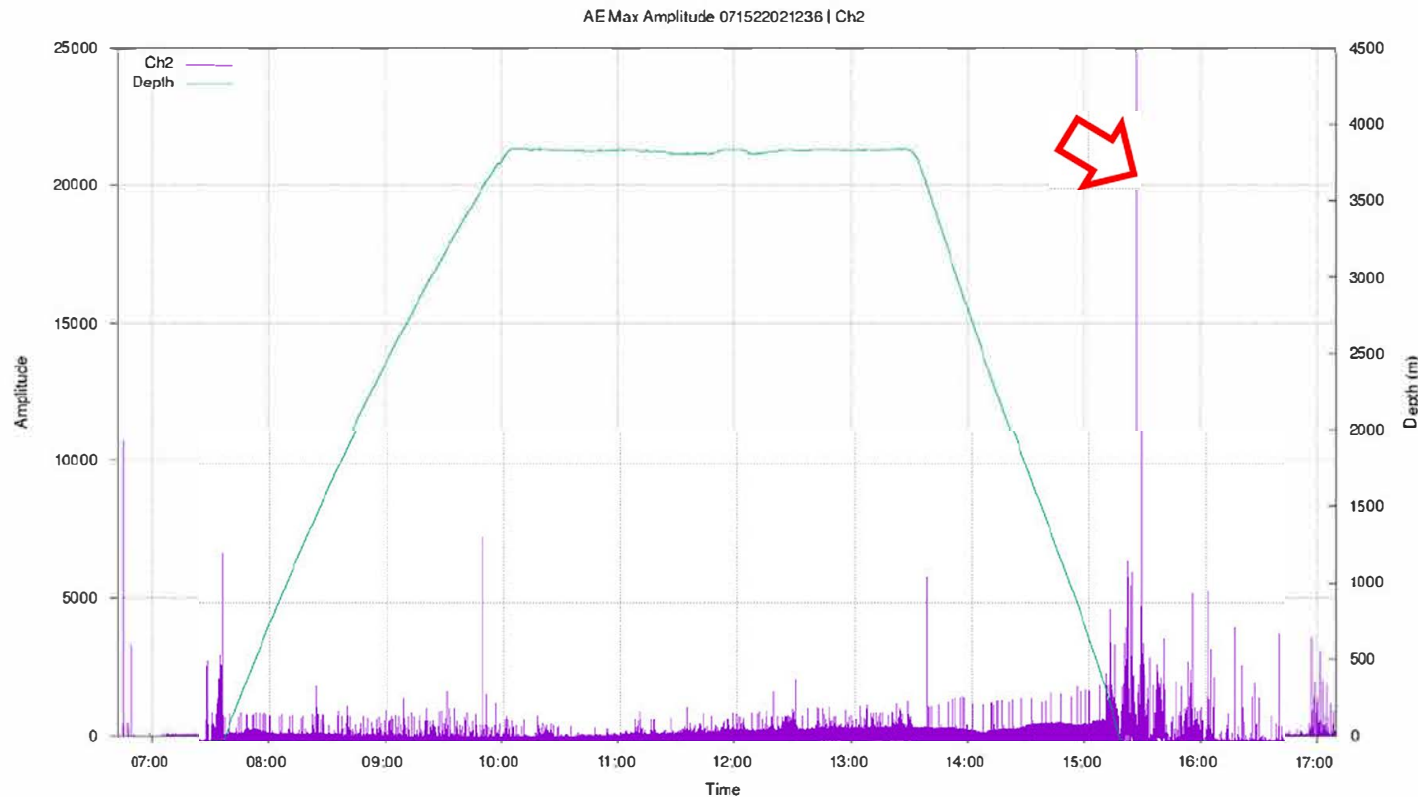


# Dive 80 Event, July 15, 2022

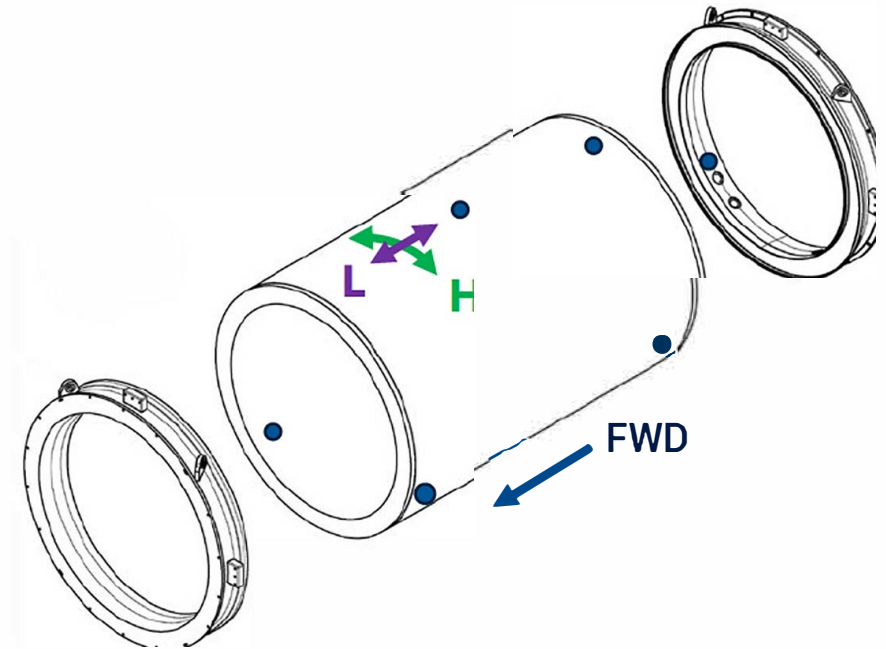
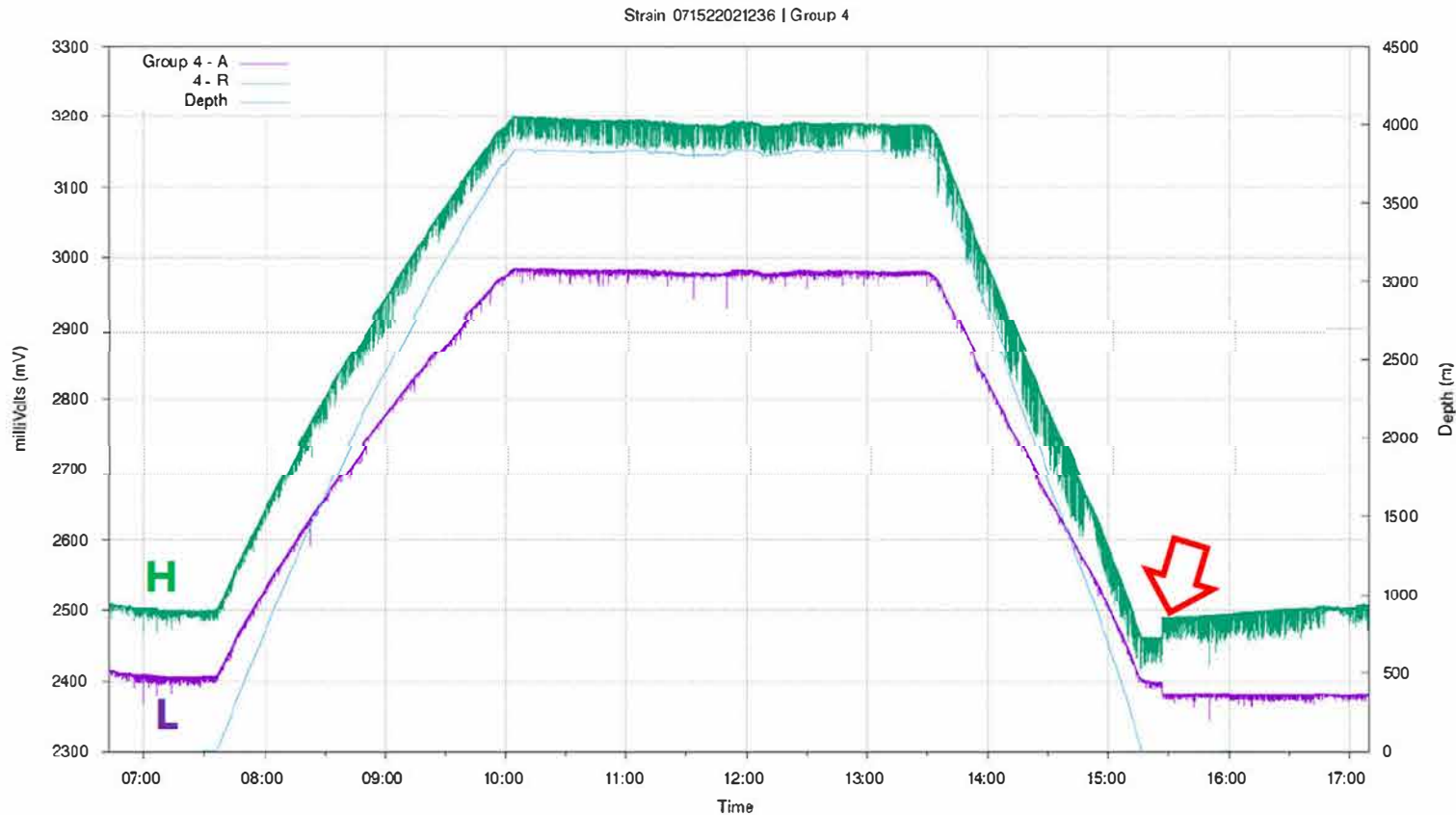
14<sup>th</sup> dive to notable depth

6<sup>th</sup> dive to notable depth in 2022

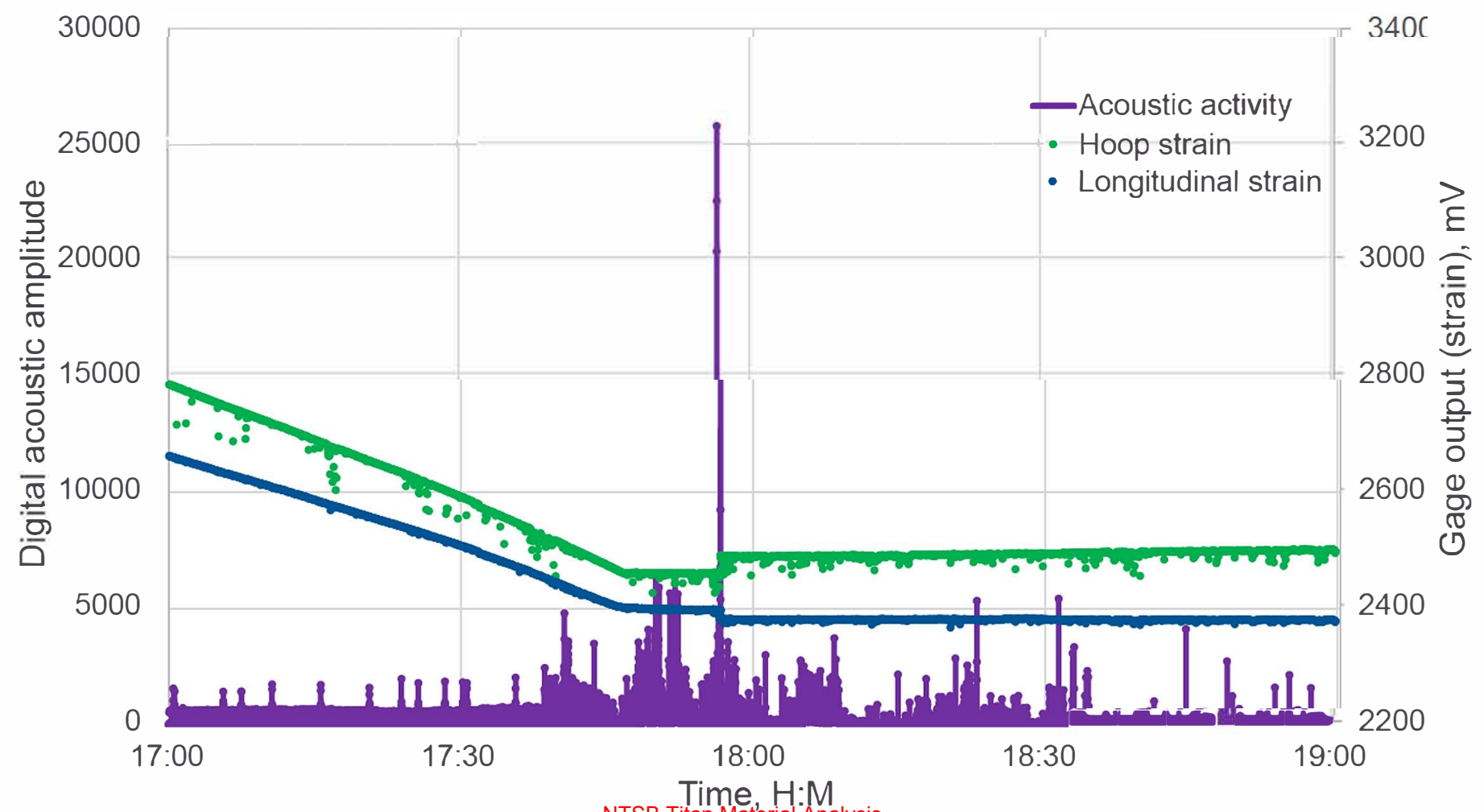
# Dive 80 – Acoustic Events



# Dive 80 – Strain Gage Response



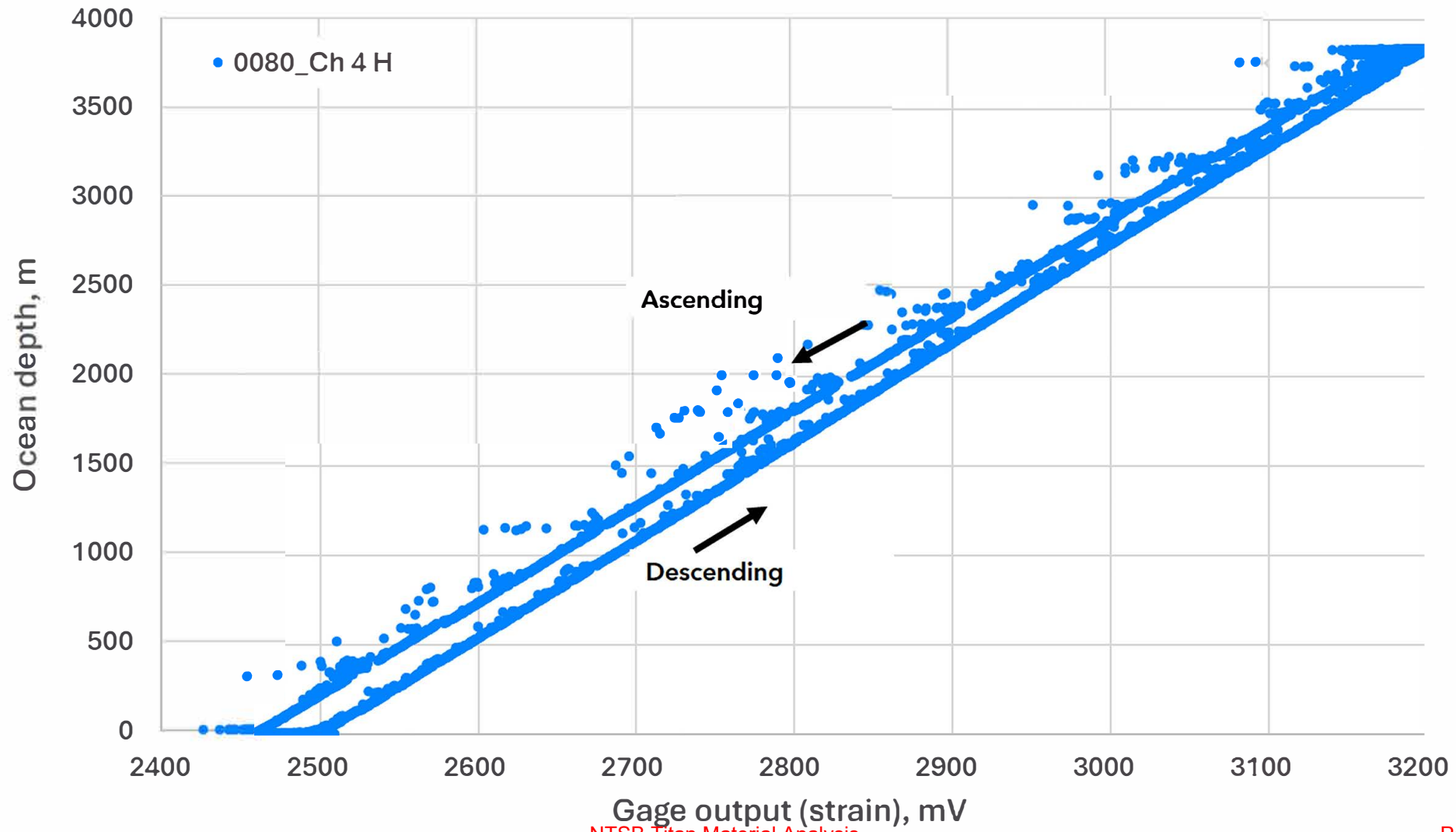
# Strain and Acoustic Events Coincide





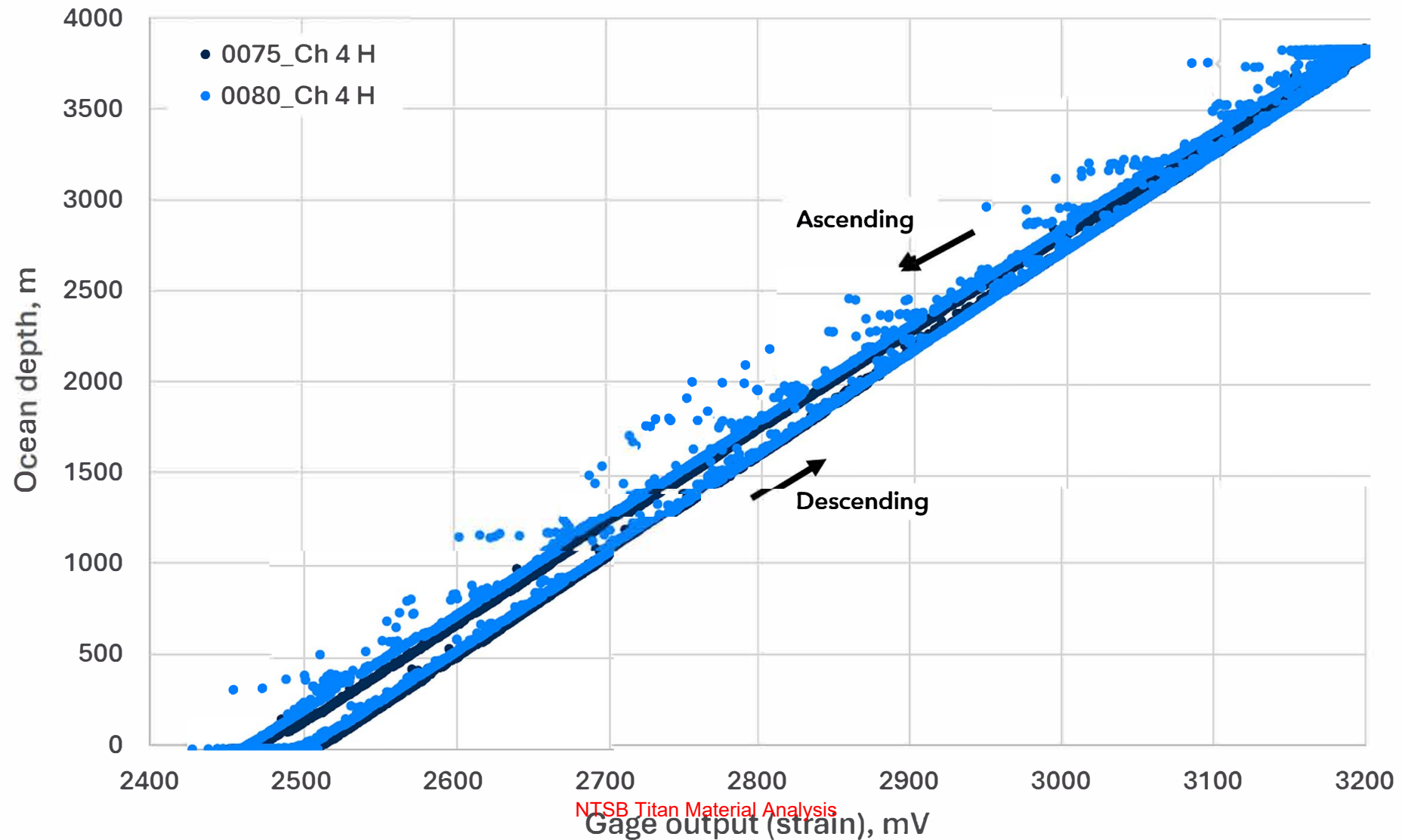
No part of a report of a marine casualty investigation shall be admissible as evidence in any civil or administrative proceeding, other than an administrative proceeding initiated by the United States. 46 U.S.C. § 6303.

## Dive 80 Depth-based Plot of Strain – Linear Relationship



No part of a report of a marine casualty investigation shall be admissible as evidence in any civil or administrative proceeding, other than an administrative proceeding initiated by the United States. 46 U.S.C. §6308.

## Dive 80 and Dive 75 (3 Dives Earlier) Compare



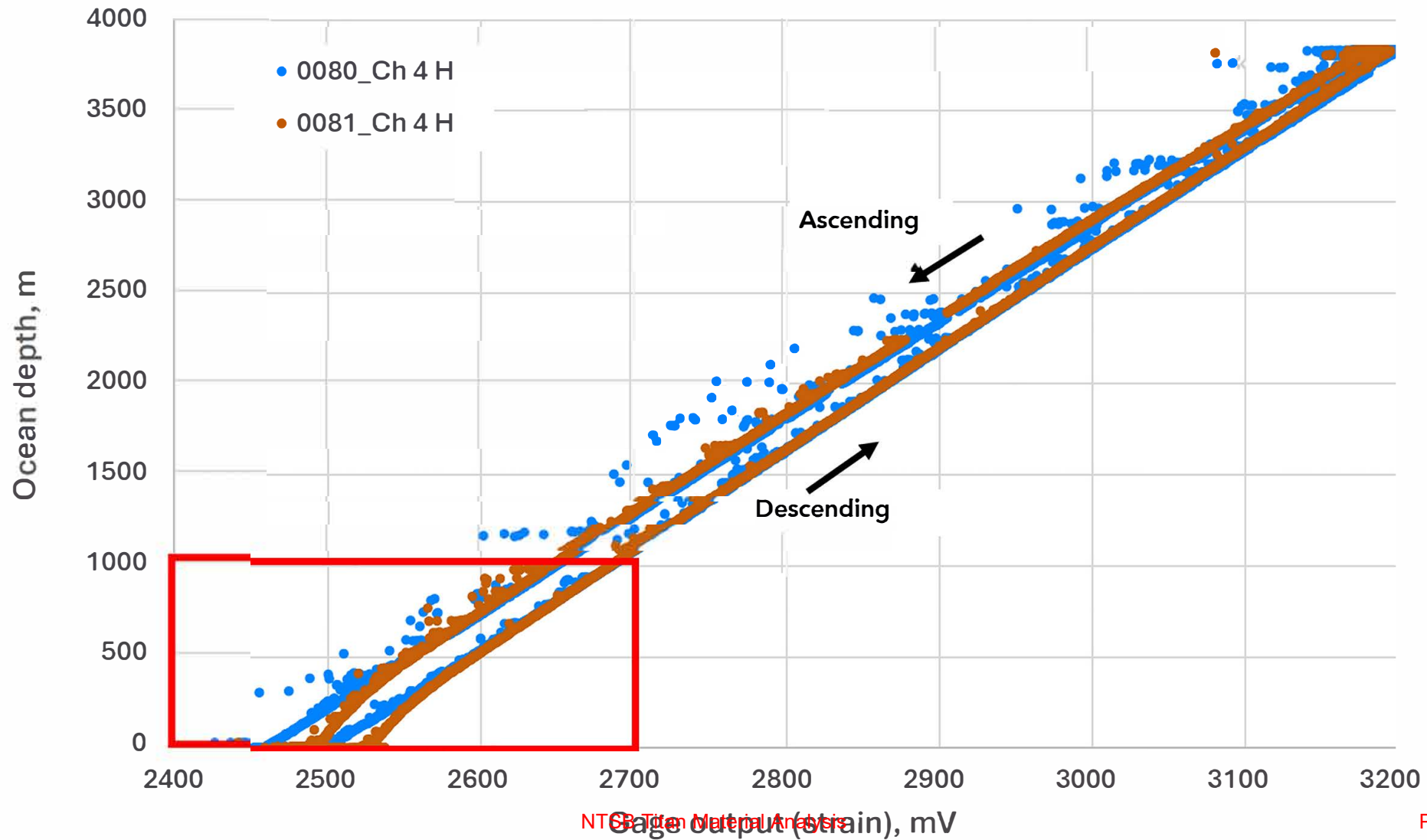
CG 107

NTSB Titan Material Analysis

Page 42 of 67

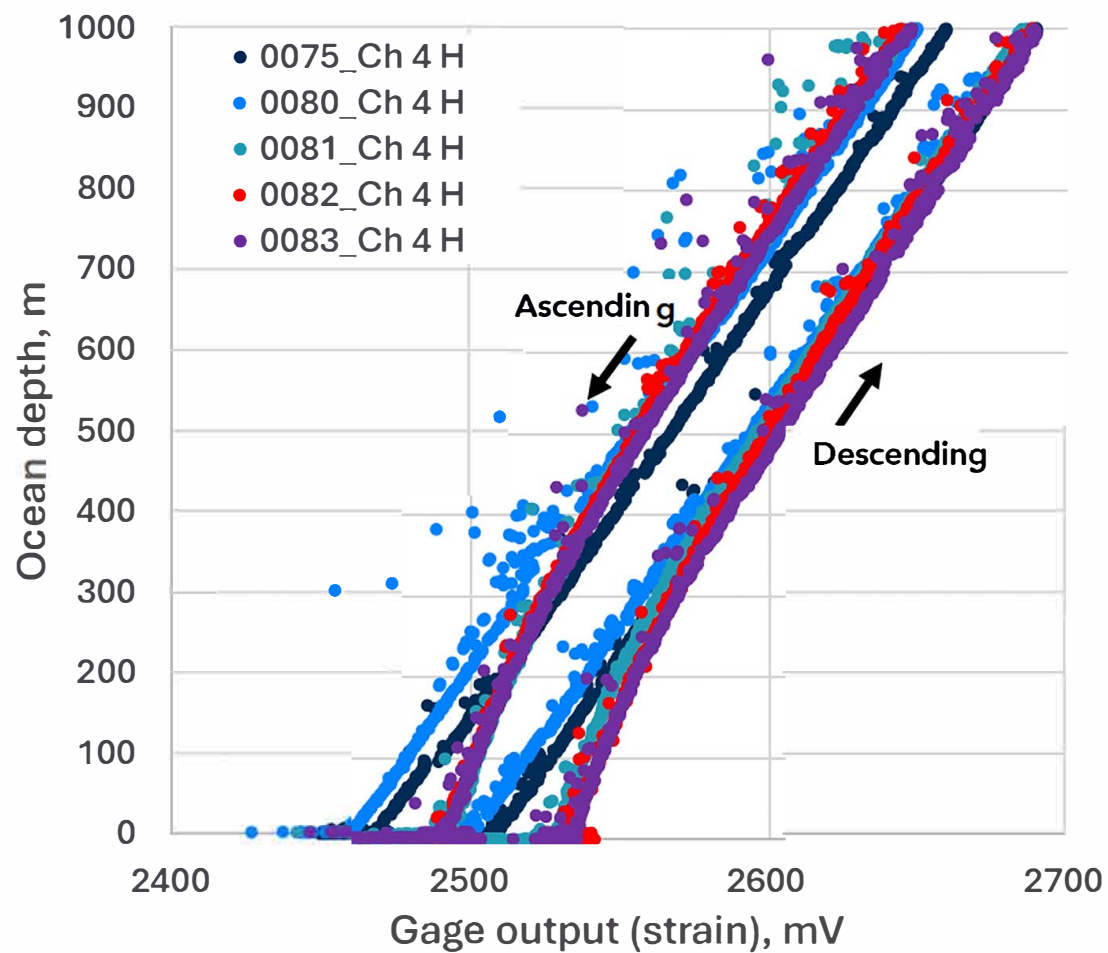
No part of a report of a marine casualty investigation shall be admissible as evidence in any civil or administrative proceeding, other than an administrative proceeding initiated by the United States, 46 U.S.C. § 6308.

## Dive 80 and Dive 81 Compare (Pre- and Post-audible event)

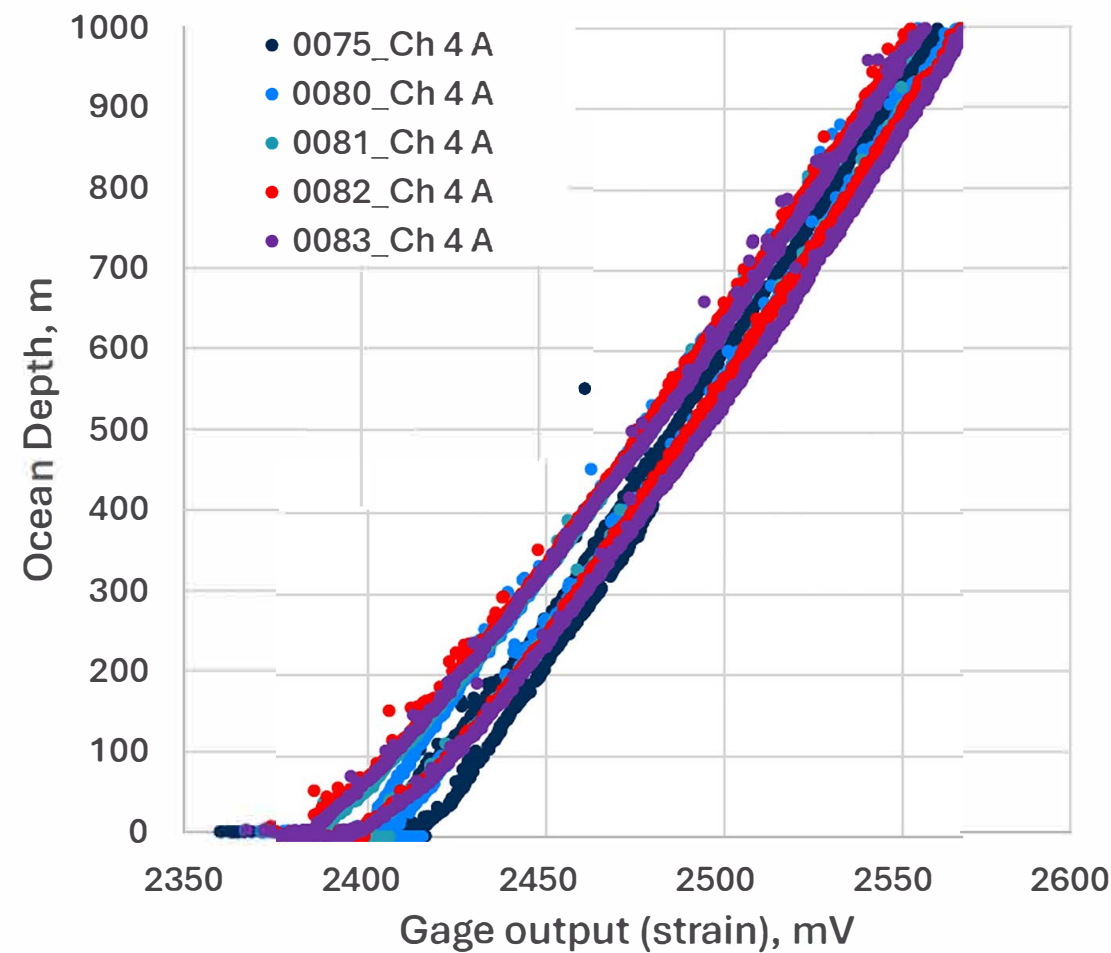


No part of a report of a marine casualty investigation shall be admissible as evidence in any civil or administrative proceeding, other than an administrative proceeding initiated by the United States. 46 U.S.C. §6308

# Group 4 Hoop and Longitudinal Strain Response – Successive Dives



Hoop strain



Longitudinal strain

CG 107

NTSB Titan Material Analysis

Page 44 of 67

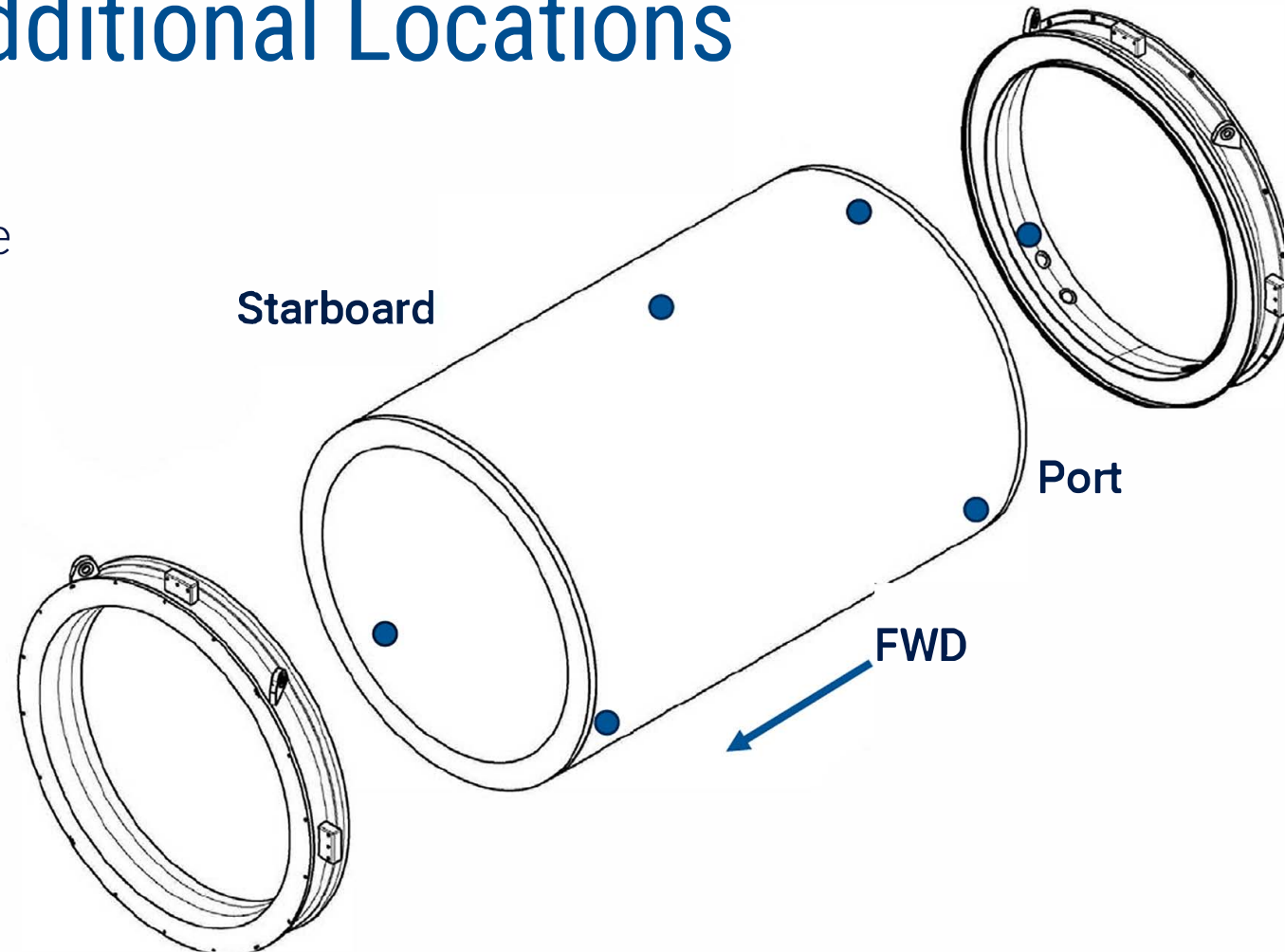


# Strain Changes at Additional Locations

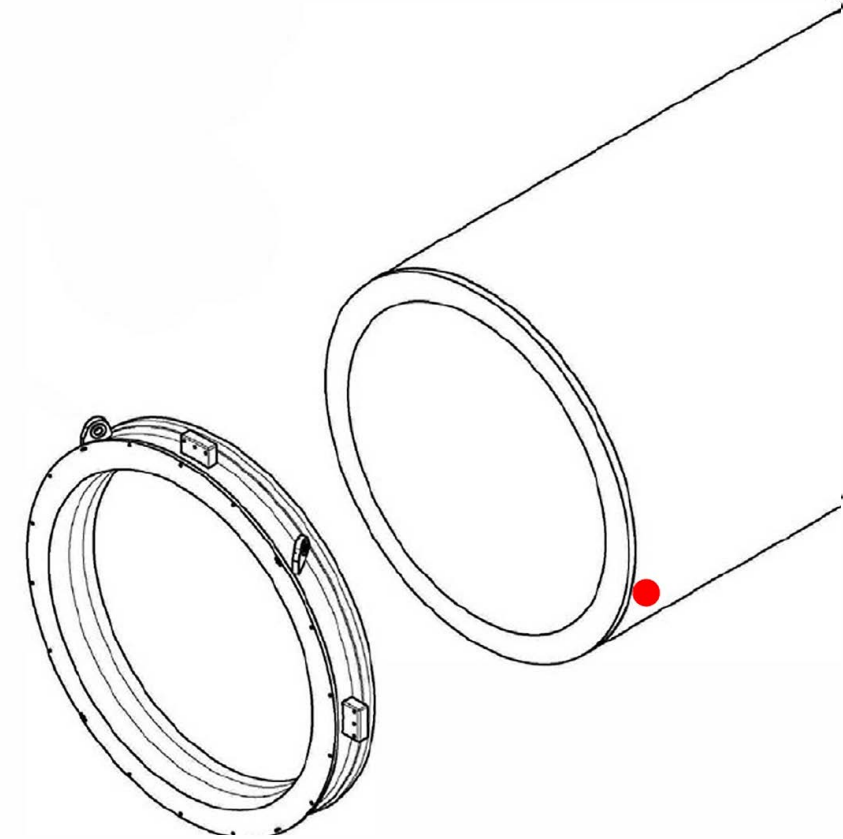
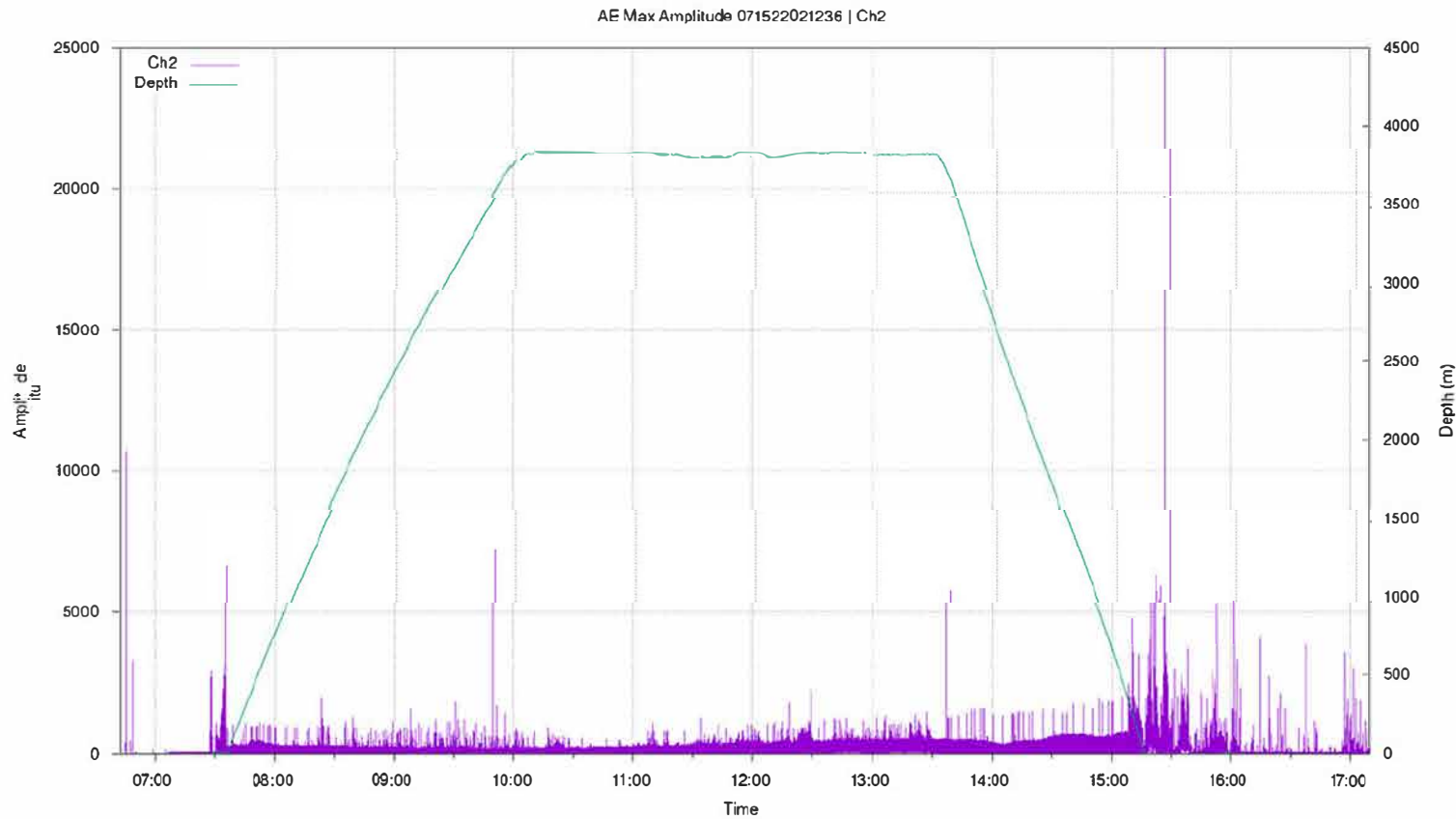
Changes in strain response after Dive 80 also seen for groups 5 and 8.

Changes persisted for Dives 81 – 83.

No changes for groups 3 or 7.



# Acoustic Emission Response – Dive 80

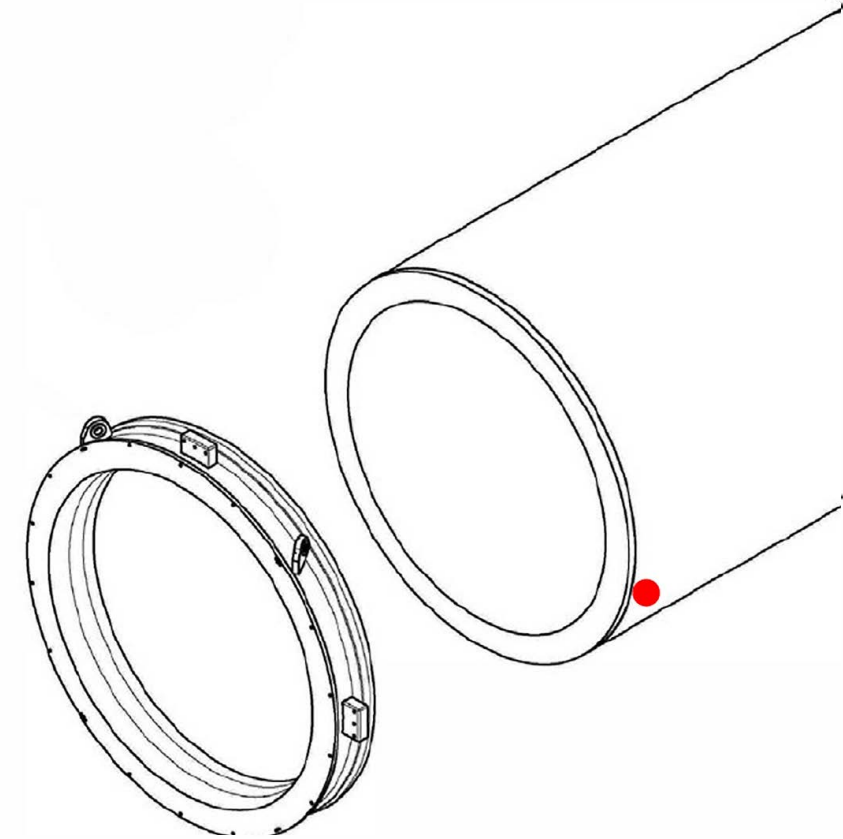
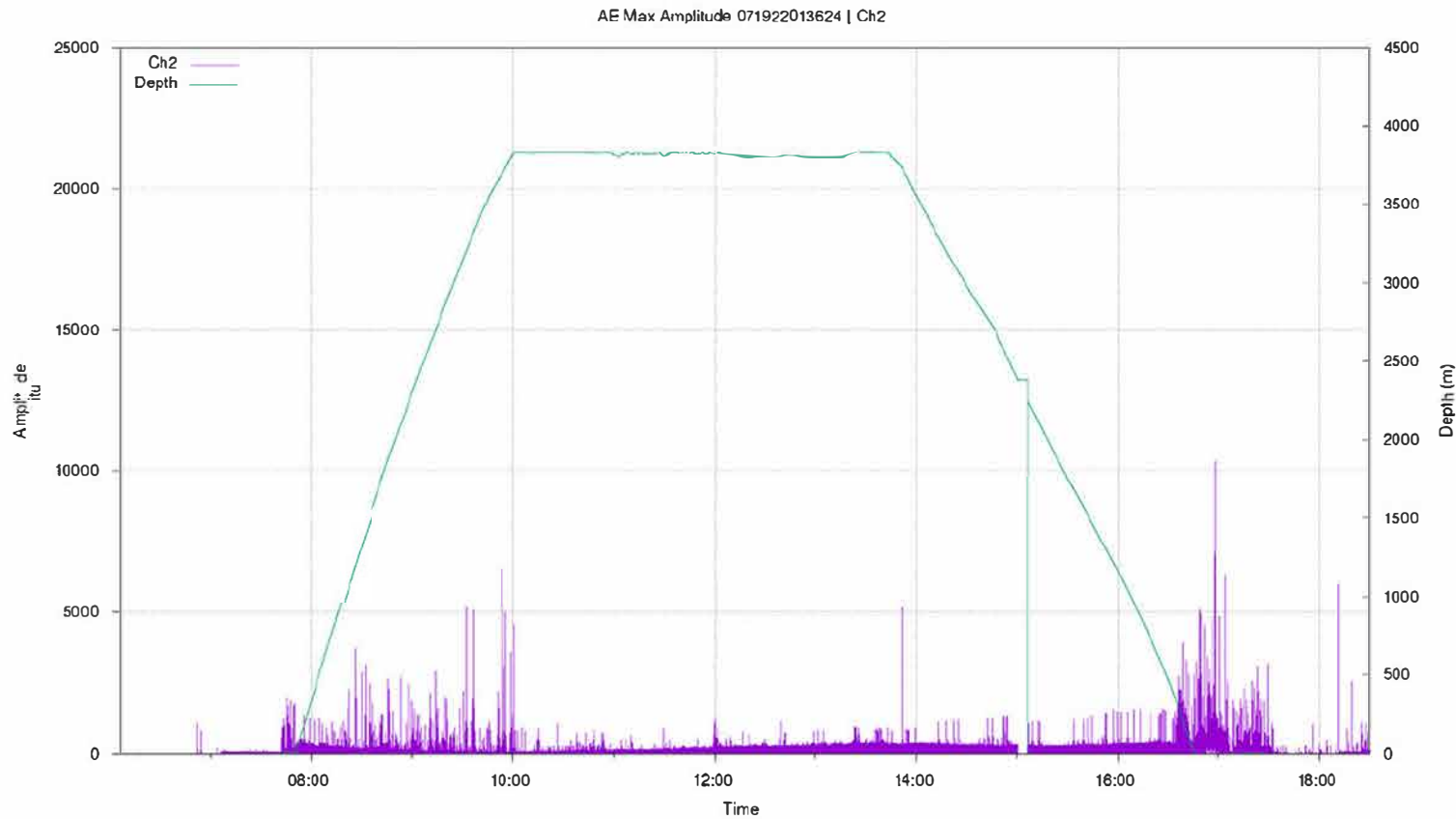


CG 107

NTSB Titan Material Analysis

Page 46 of 67

# Acoustic Emission Response – Dive 81



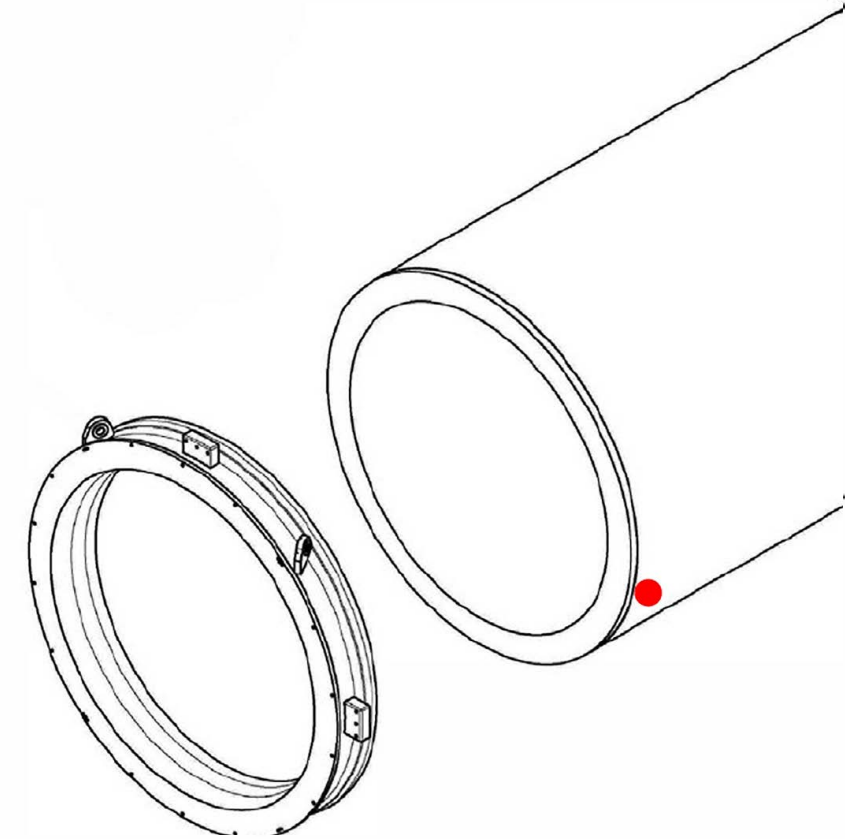
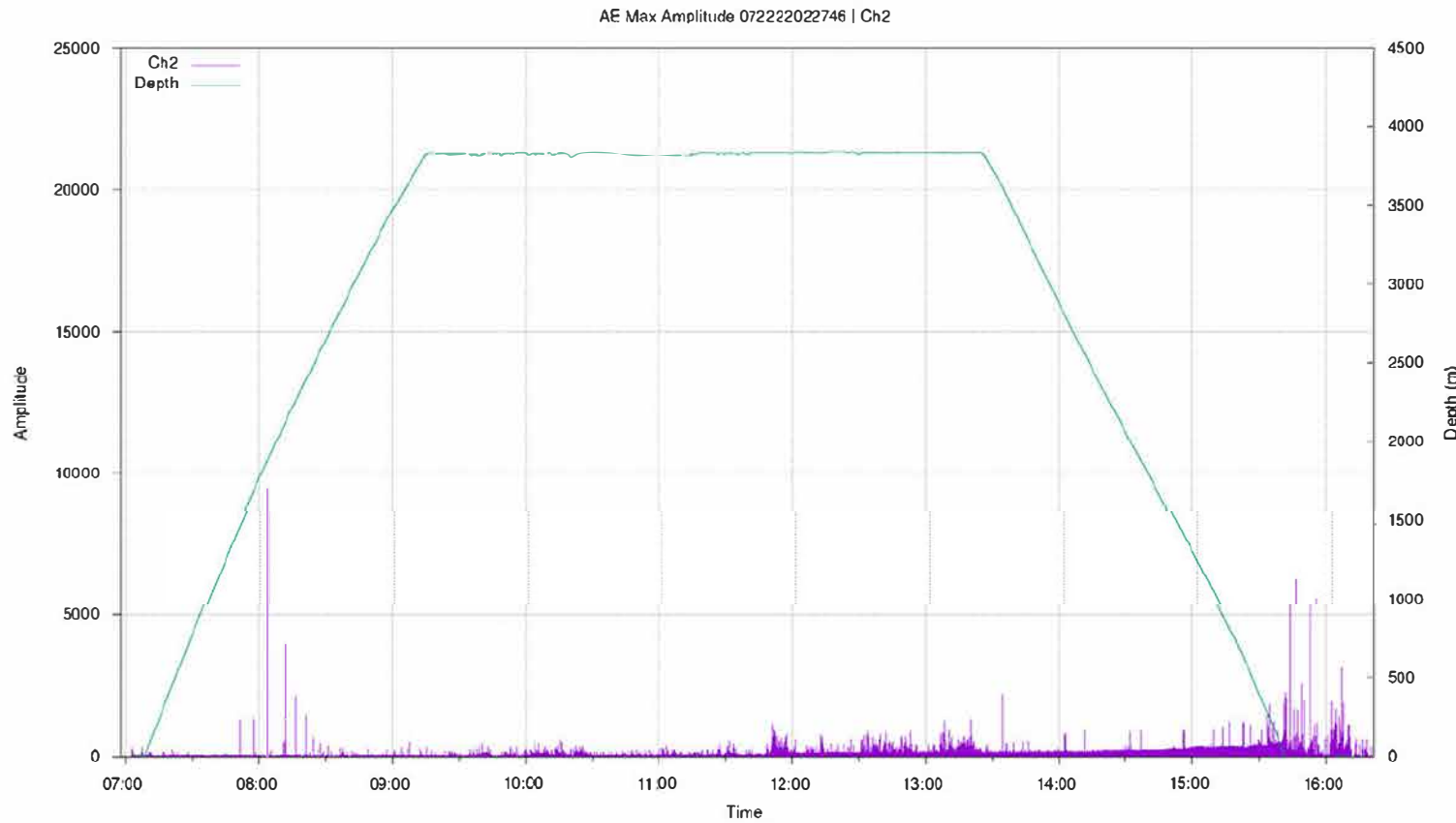
CG 107

NTSB Titan Material Analysis

Page 47 of 67



# Acoustic Emission Response – Dive 82

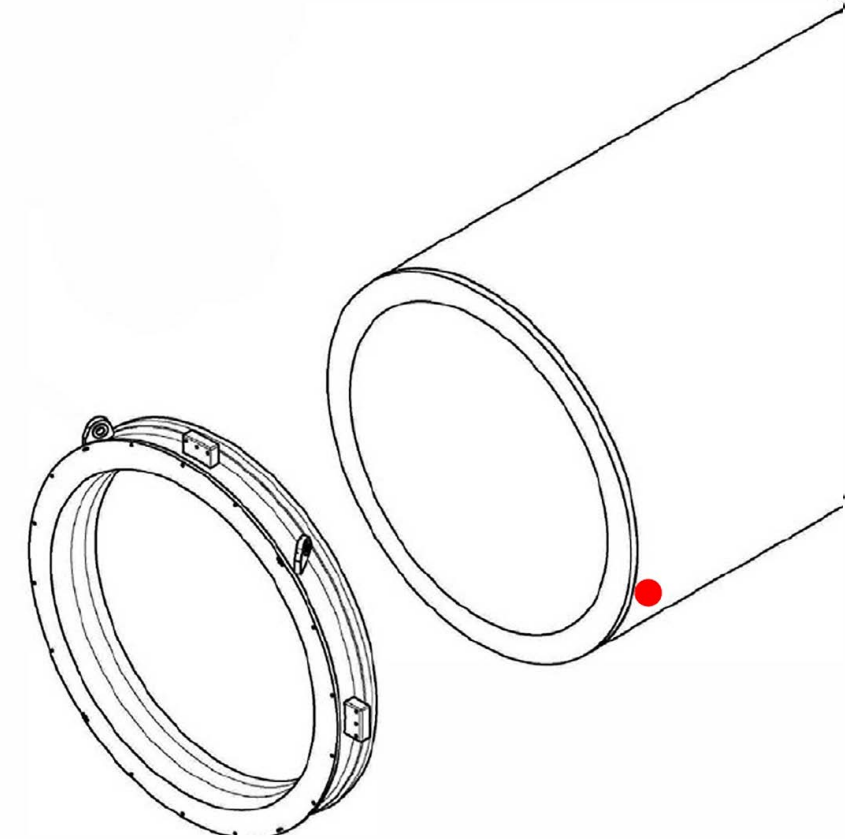
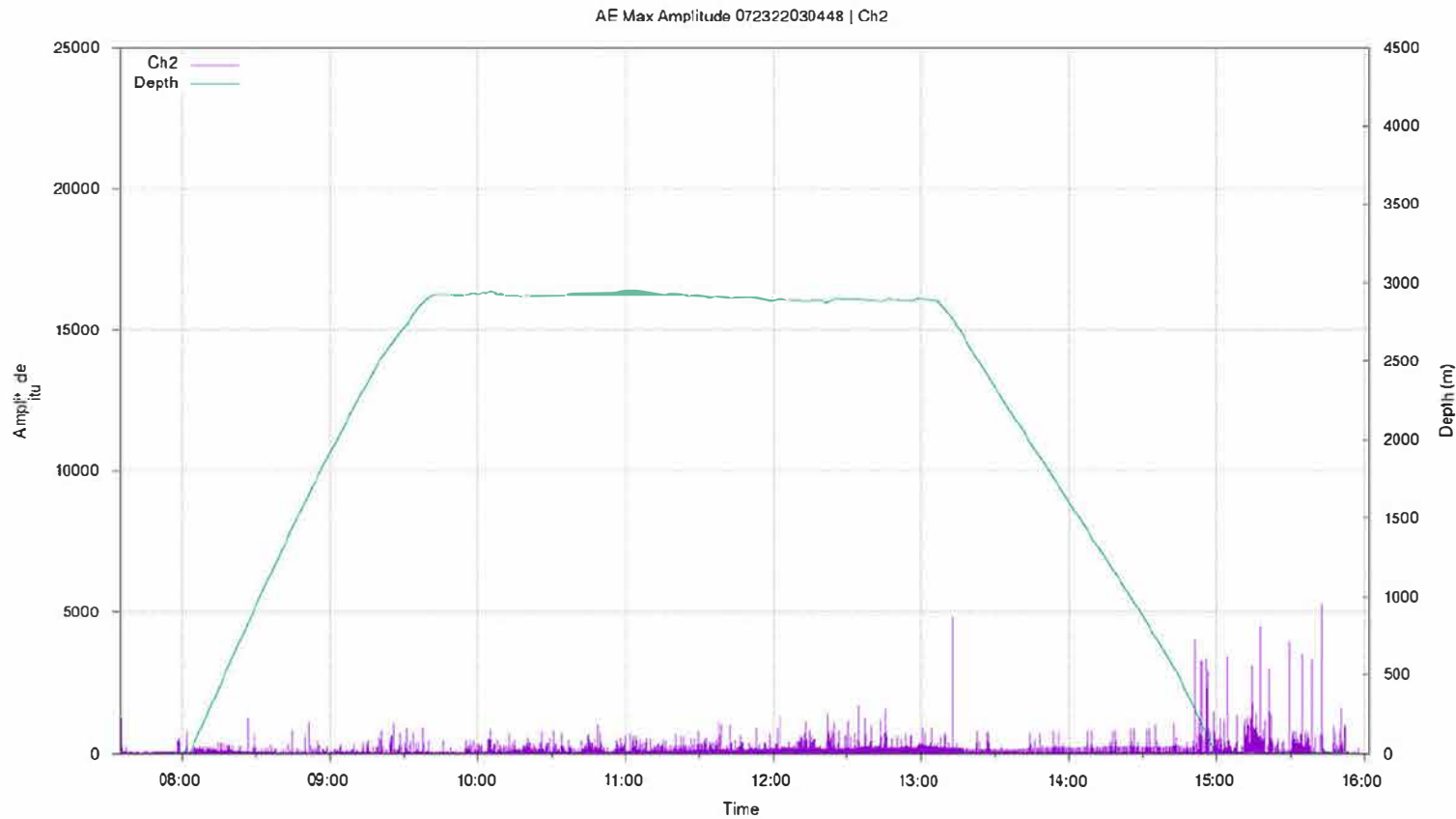


CG 107

NTSB Titan Material Analysis

Page 48 of 67

# Acoustic Emission Response – Dive 83

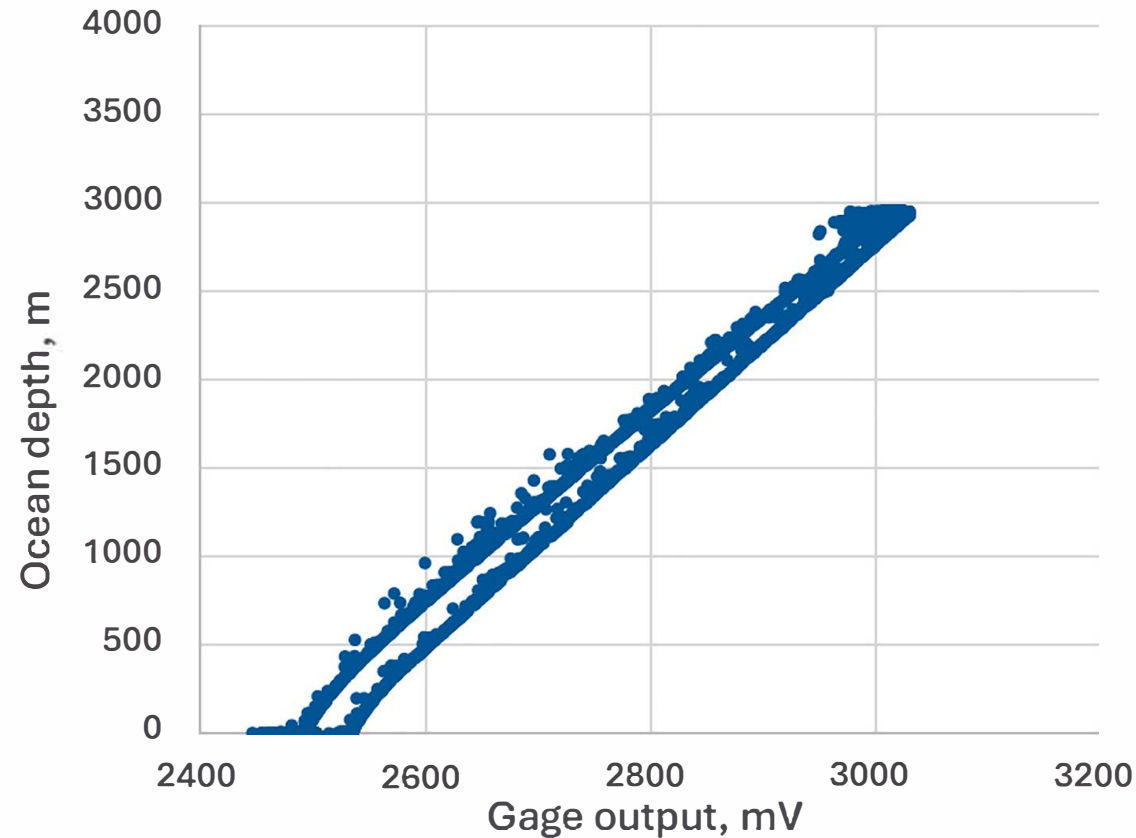


CG 107

NTSB Titan Material Analysis

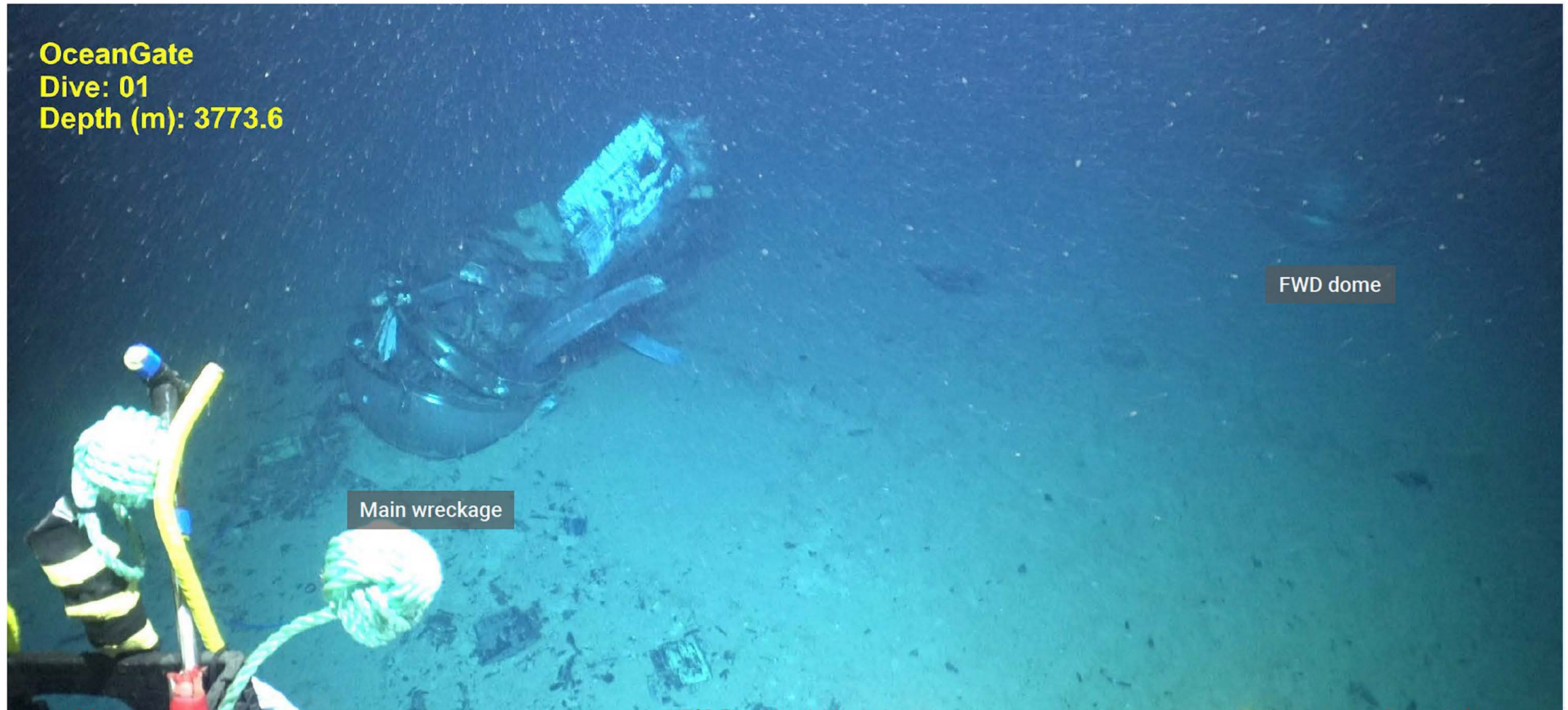
Page 49 of 67

## Dive 83 – Last Dive of 2022 to Less than 3,000 m





# Titan Wreckage Review



OceanGate  
Dive: 01  
Depth (m): 3773.6

FWD dome

Main wreckage

CG 107

NTSB Titan Material Analysis

Page 52 of 67



## Retrieved Single Layer 1 Piece



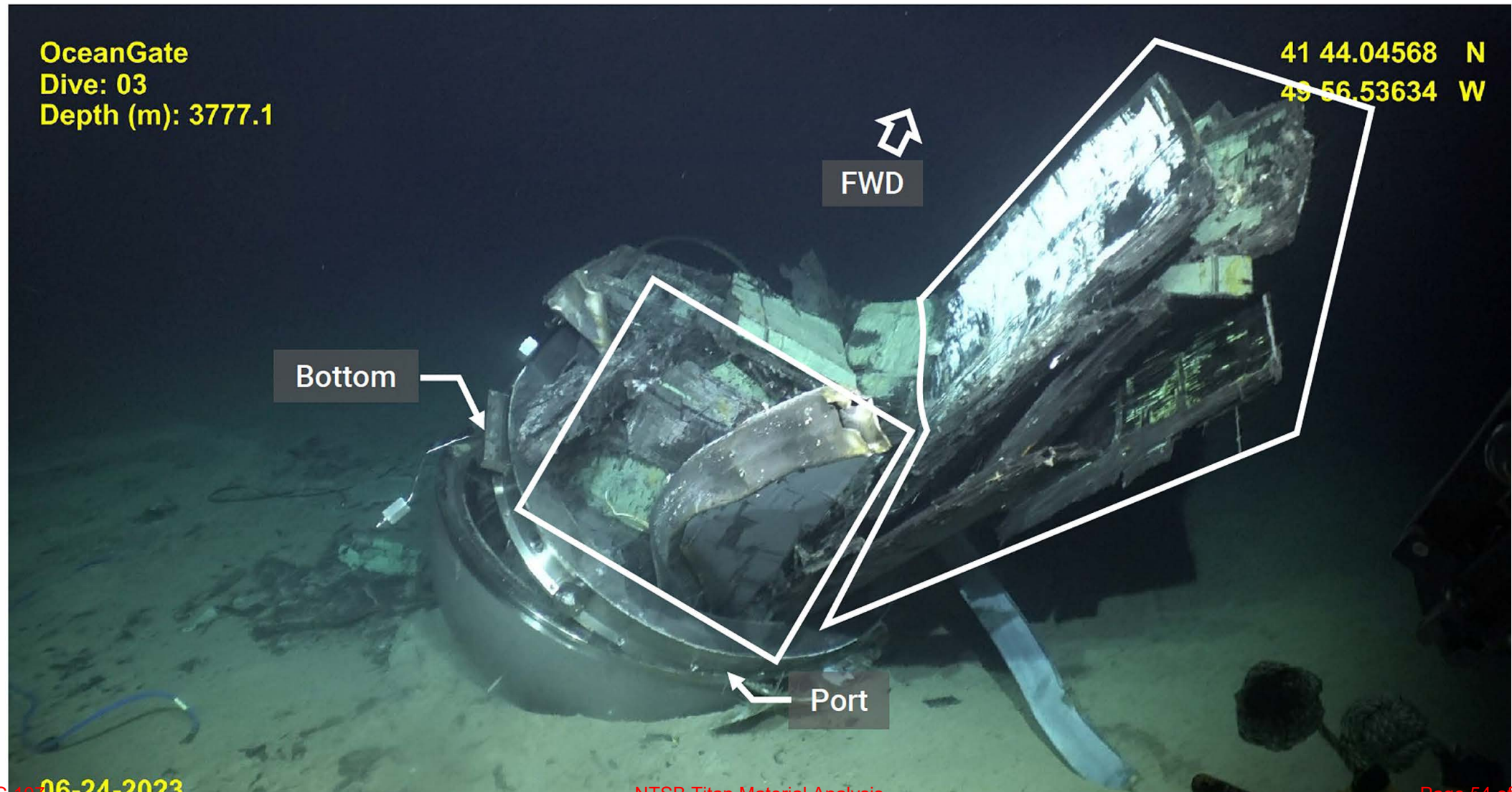
CG 107

NTSB Titan Material Analysis

Page 53 of 67



## Main Wreckage As Found



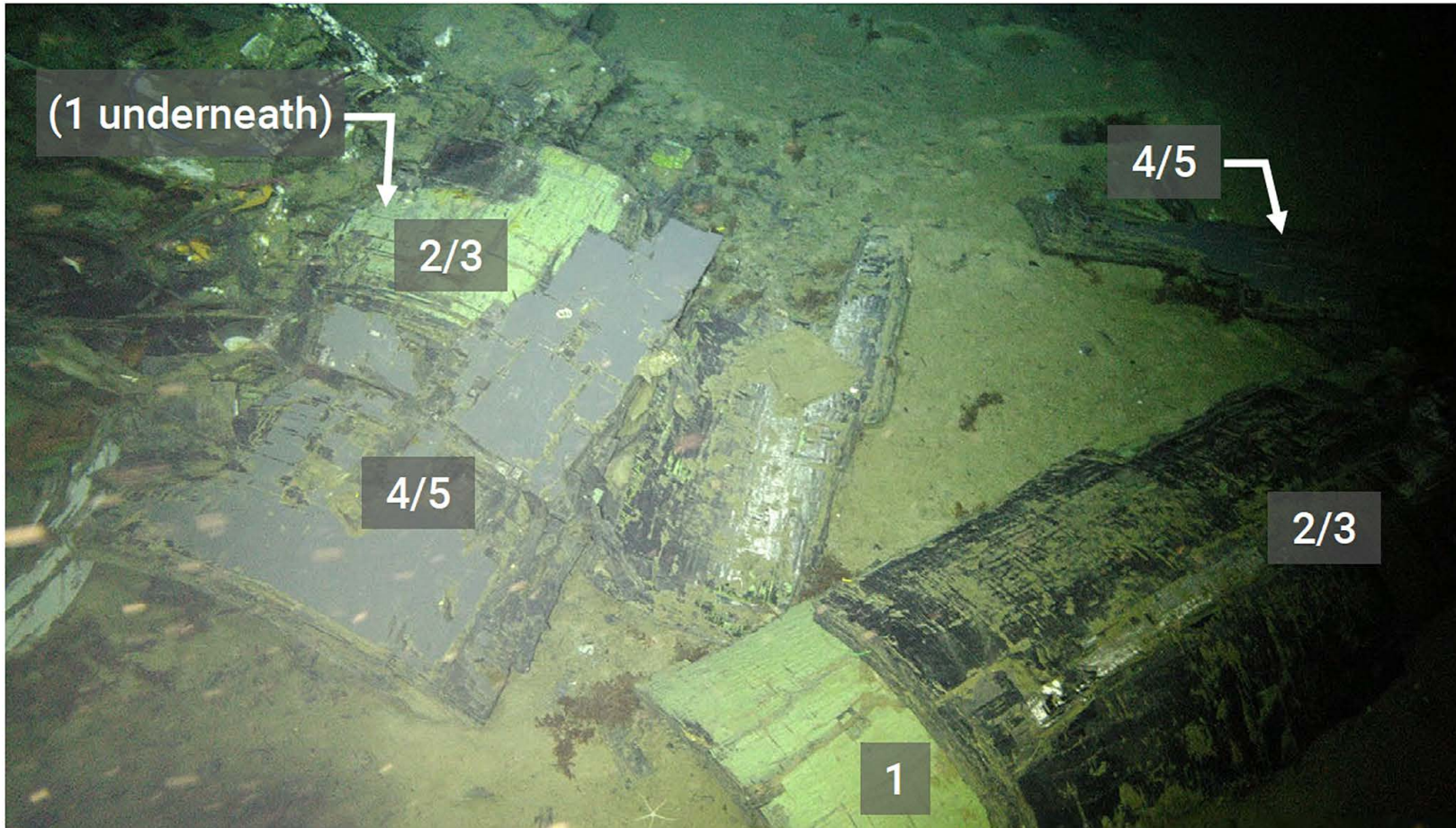
CG 107

NTSB Titan Material Analysis

Page 54 of 67

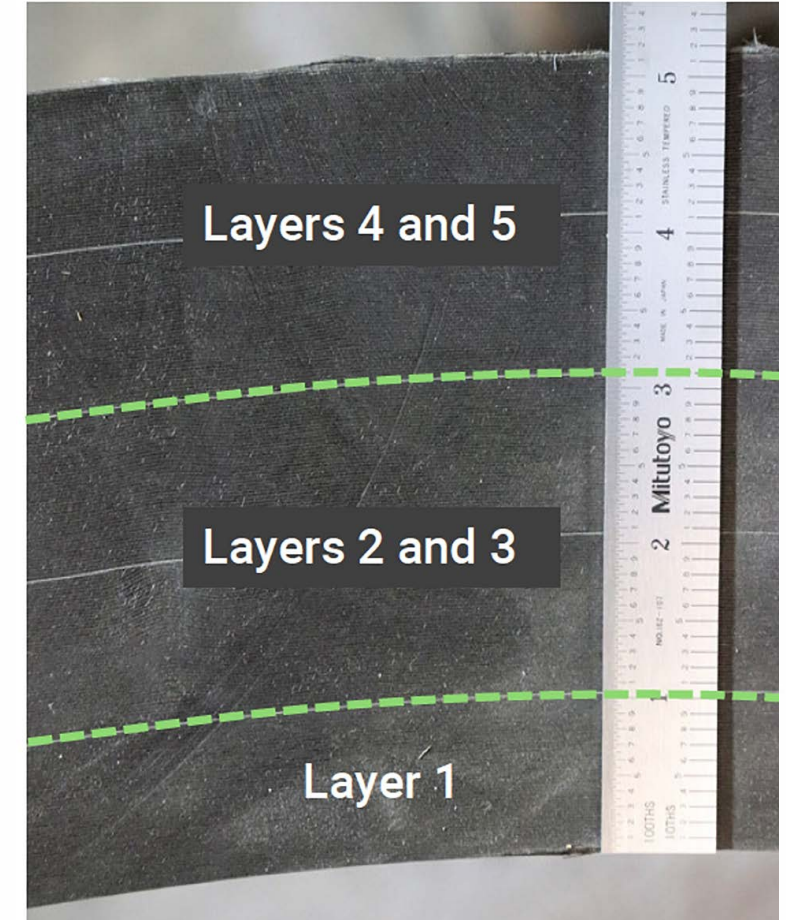


# Hull Fragments Exhibit Delaminations



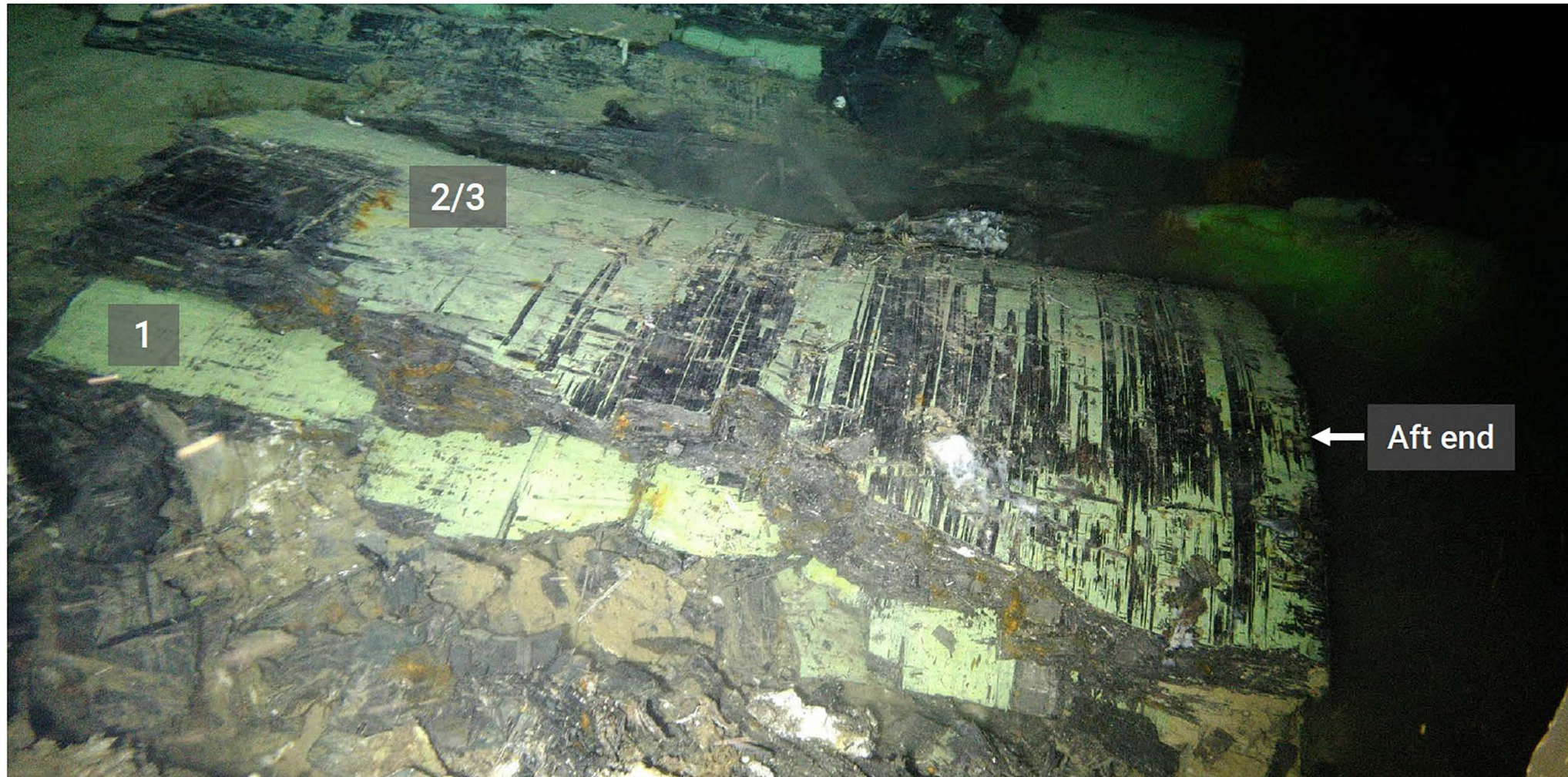
CG 107

NTSB Titan Material Analysis



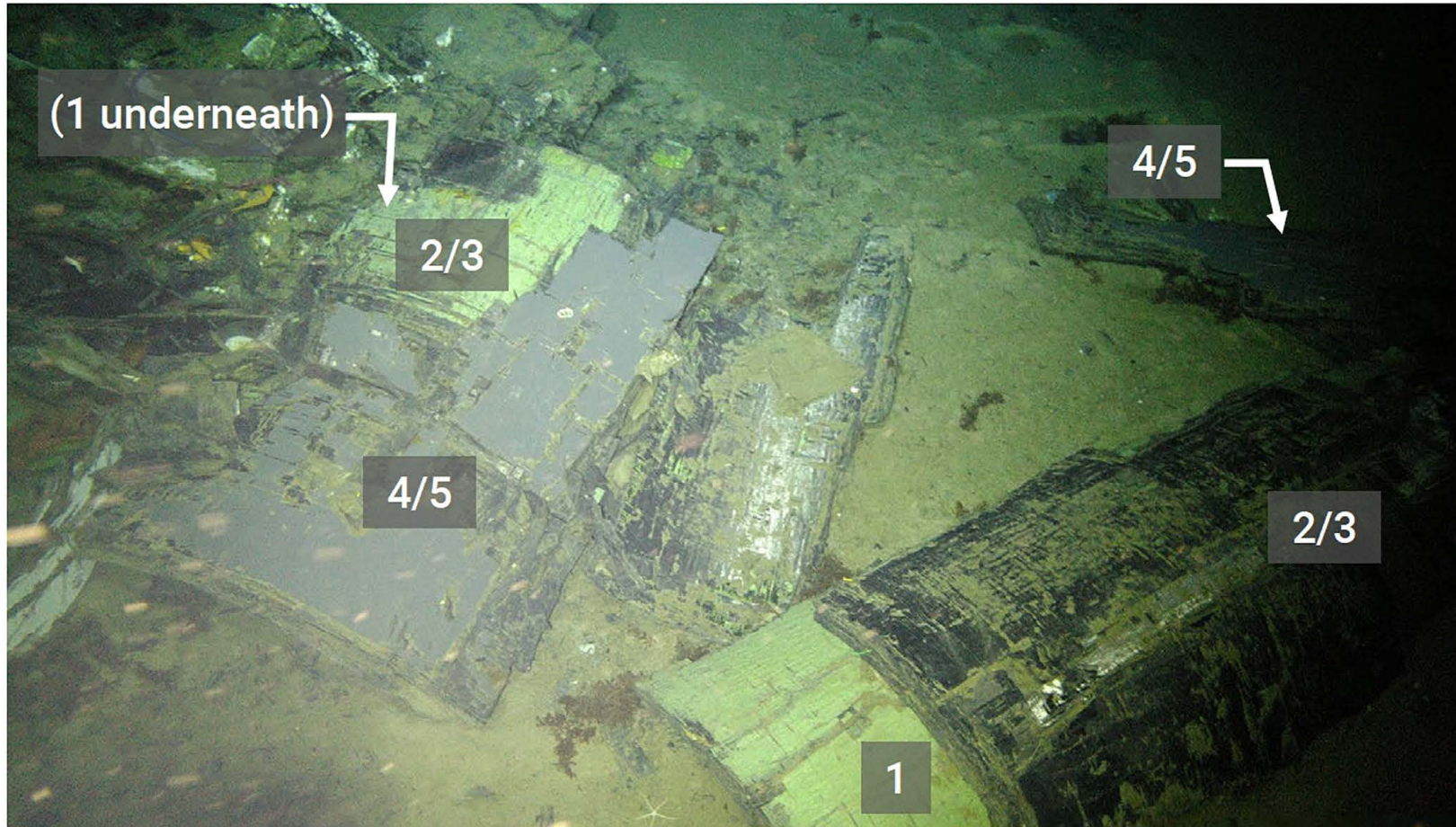
Page 55 of 67





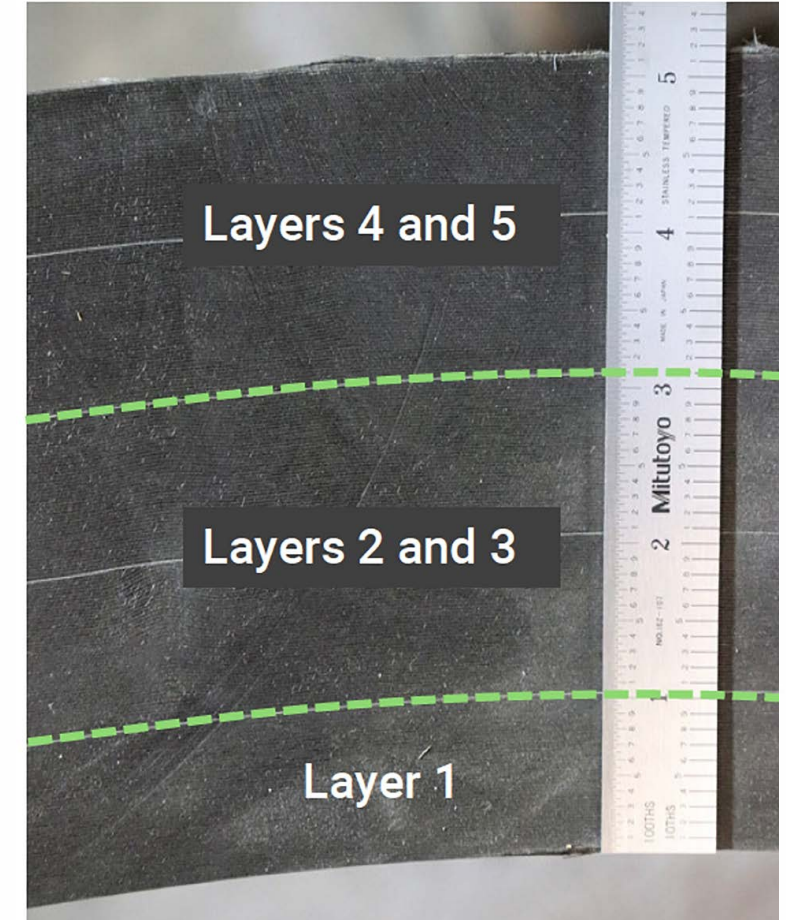


# Hull Fragments Exhibit Delaminations



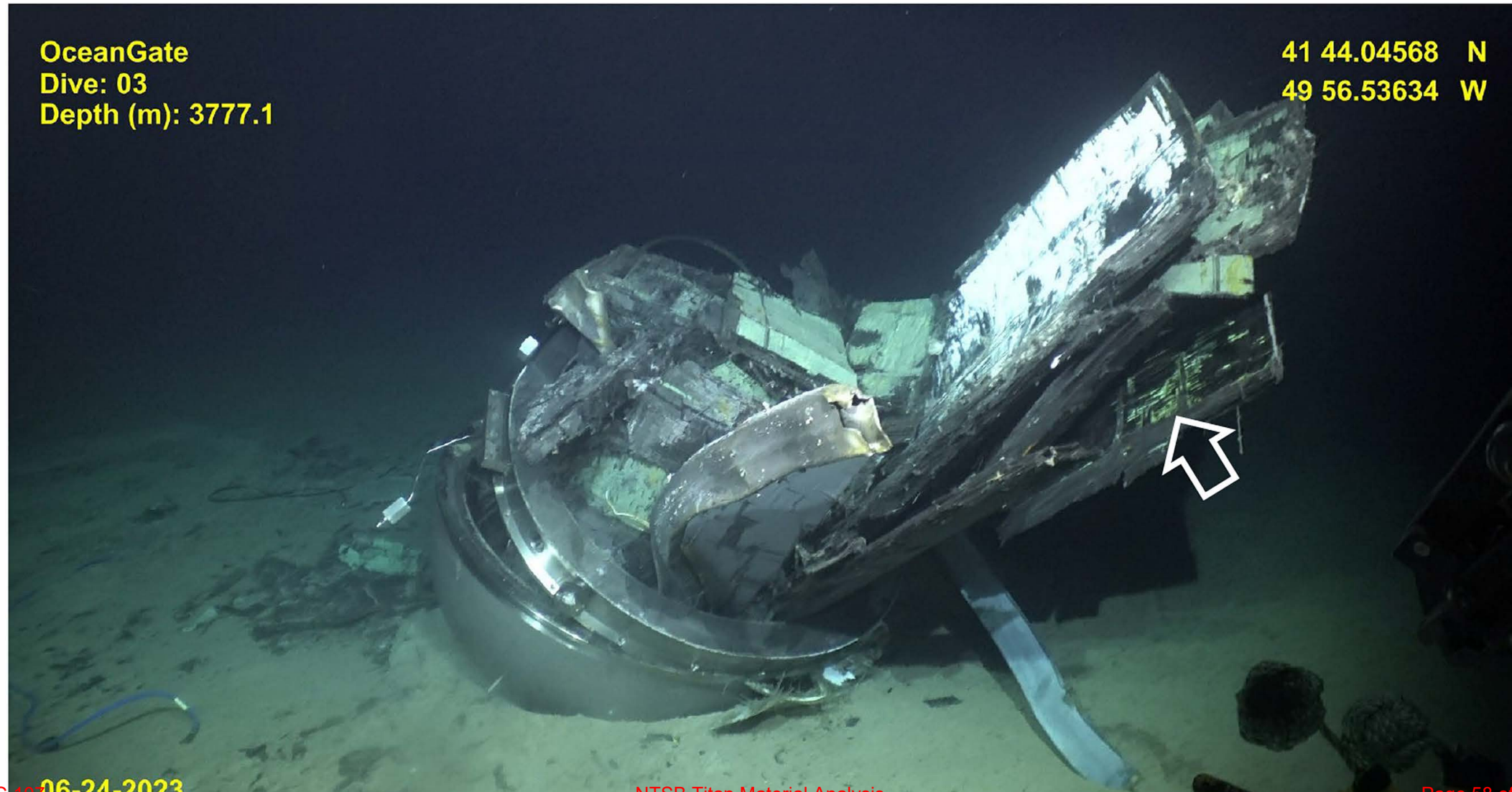
CG 107

NTSB Titan Material Analysis



Page 57 of 67





CG 107

NTSB Titan Material Analysis

Page 58 of 67

# Summary

Titan V2 hull manufactured using co-bonding process.

Wrinkles, porosity, voids found in multi-layered hull structure.

Rubbing features found at the layer 1/2 interface.

Load bang heard at end of dive on July 15, 2022 after surfacing.

Strain response changed for four gages across three locations after event.

Changes persisted from dive to dive

Hull wreckage shows significant delamination into three shells.

First shell – Layer 1

Second shell – Layers 2/3

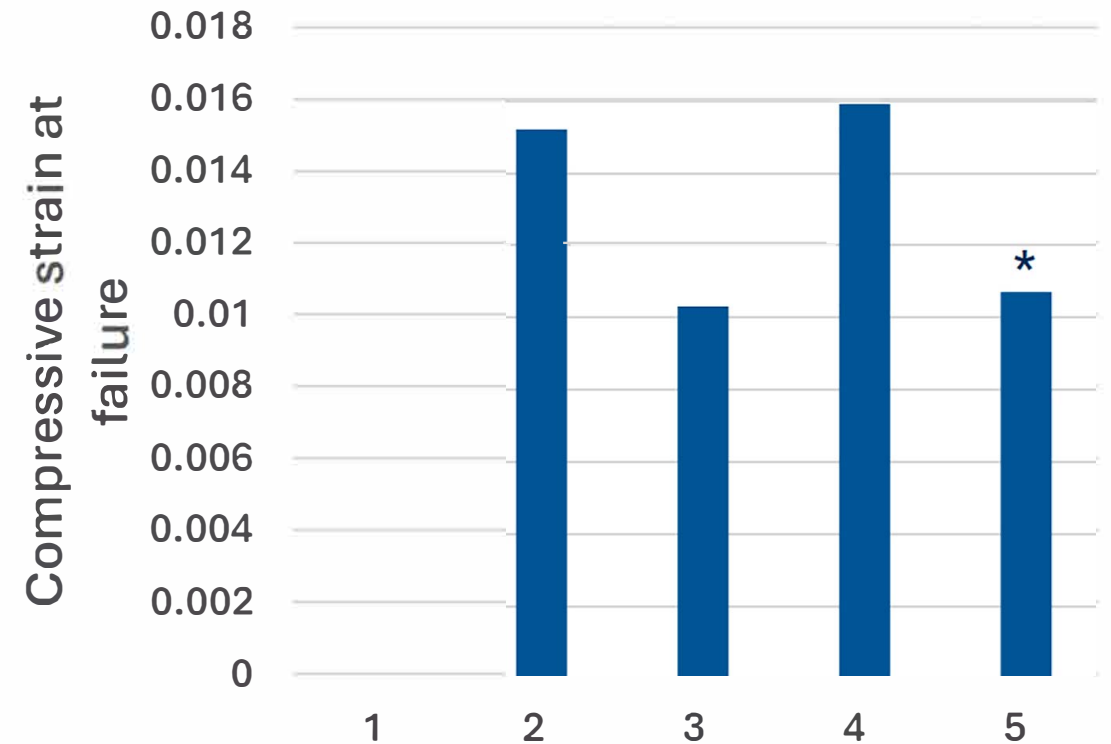
Third shell – Layers 4/5



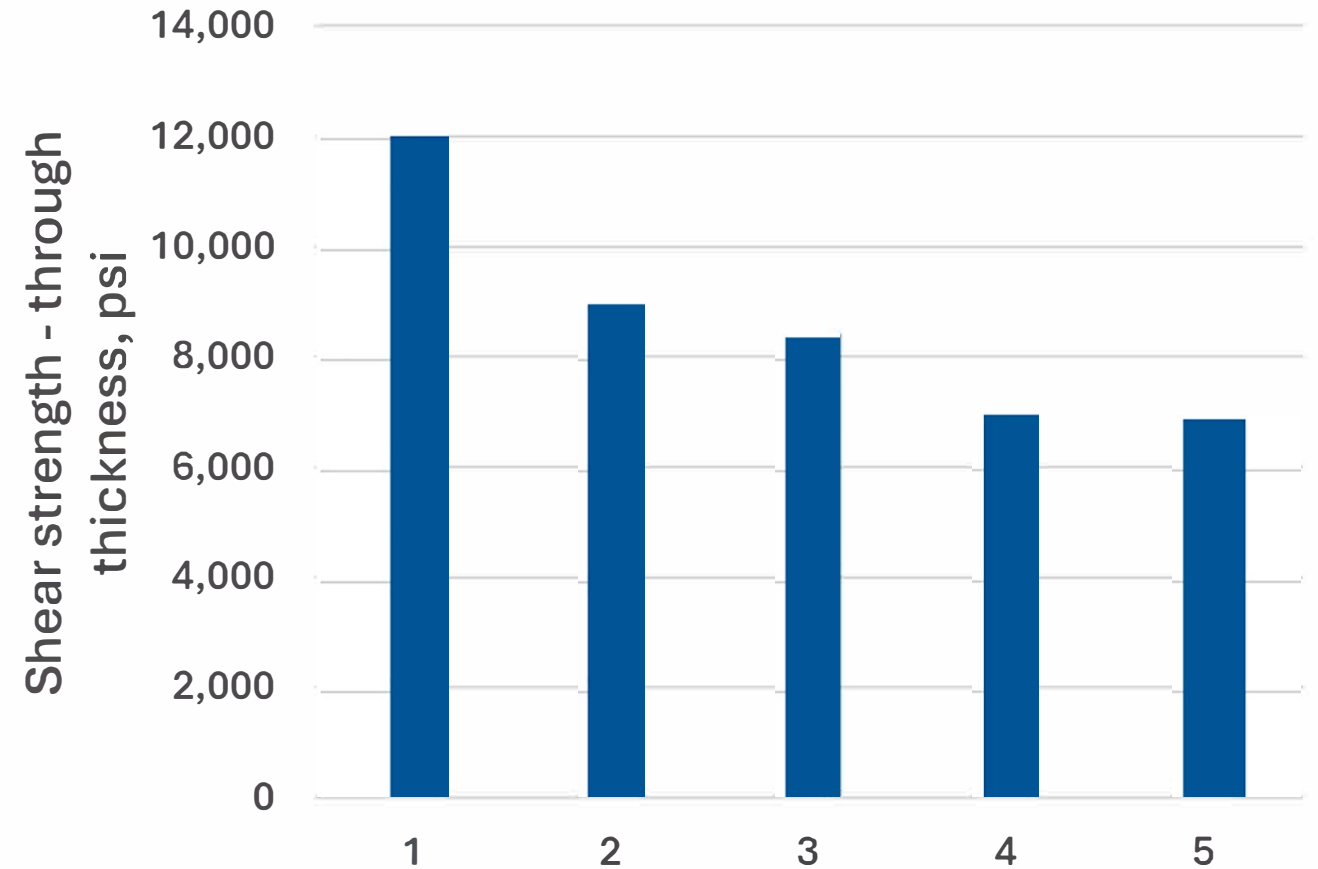
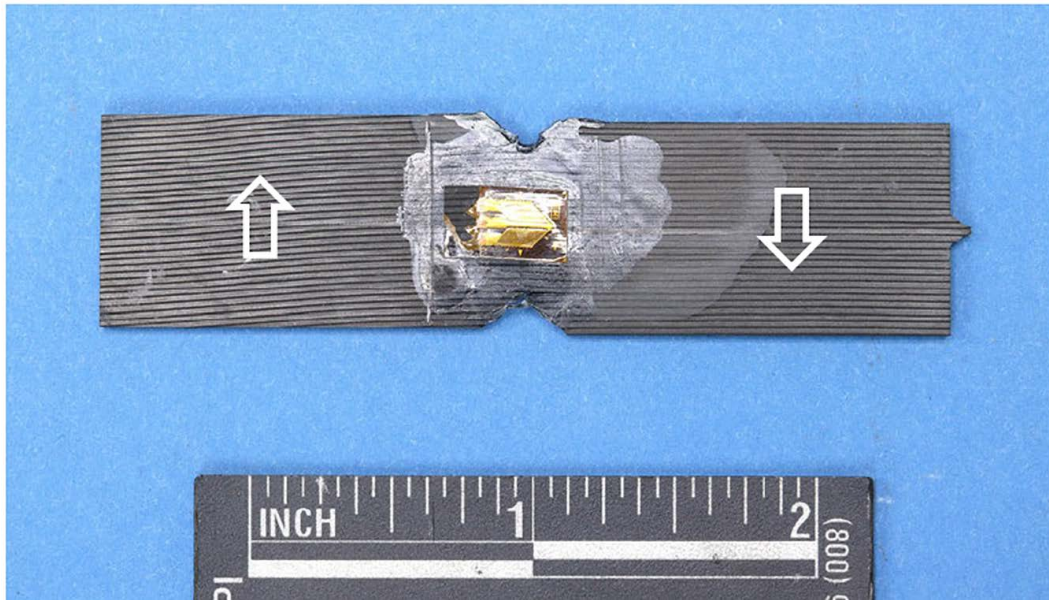
No part of a report of a marine casualty investigation shall be admissible as evidence in any civil or administrative proceeding, other than an administrative proceeding initiated by the United States. 46 U.S.C. §6308.



# Titan V2 Hull – Compressive Strength

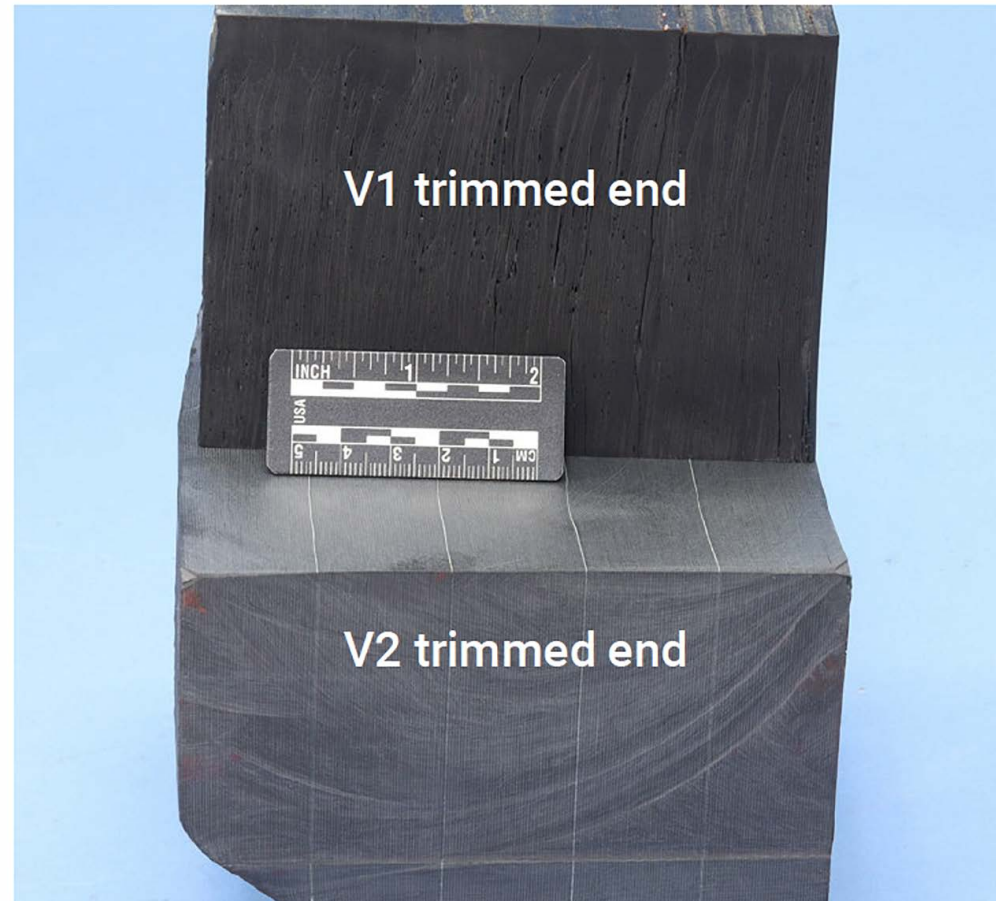


# Titan V2 Hull – Through-thickness Shear Strength

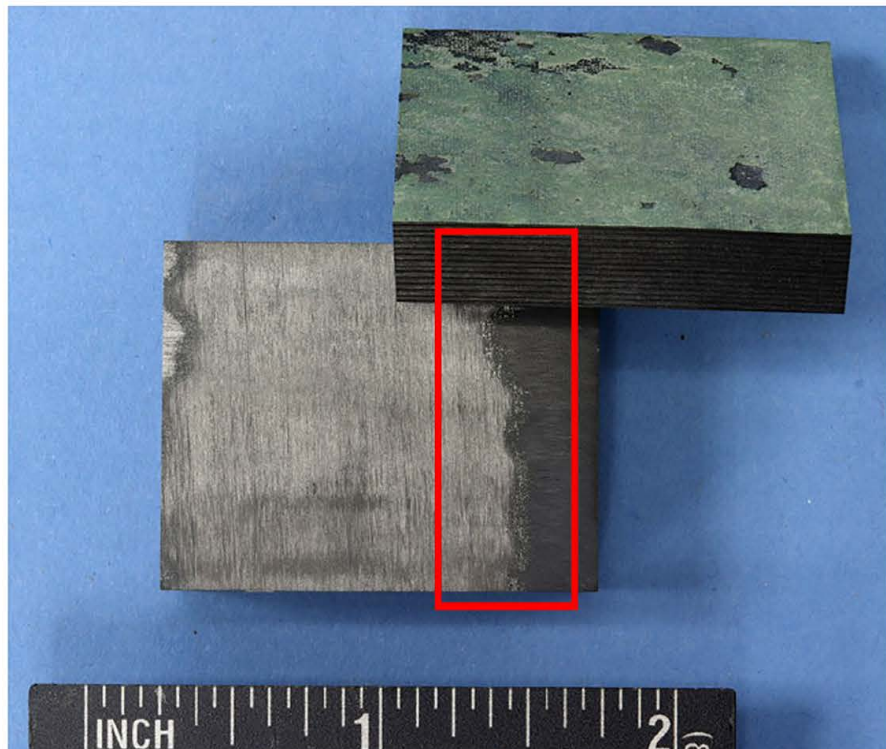




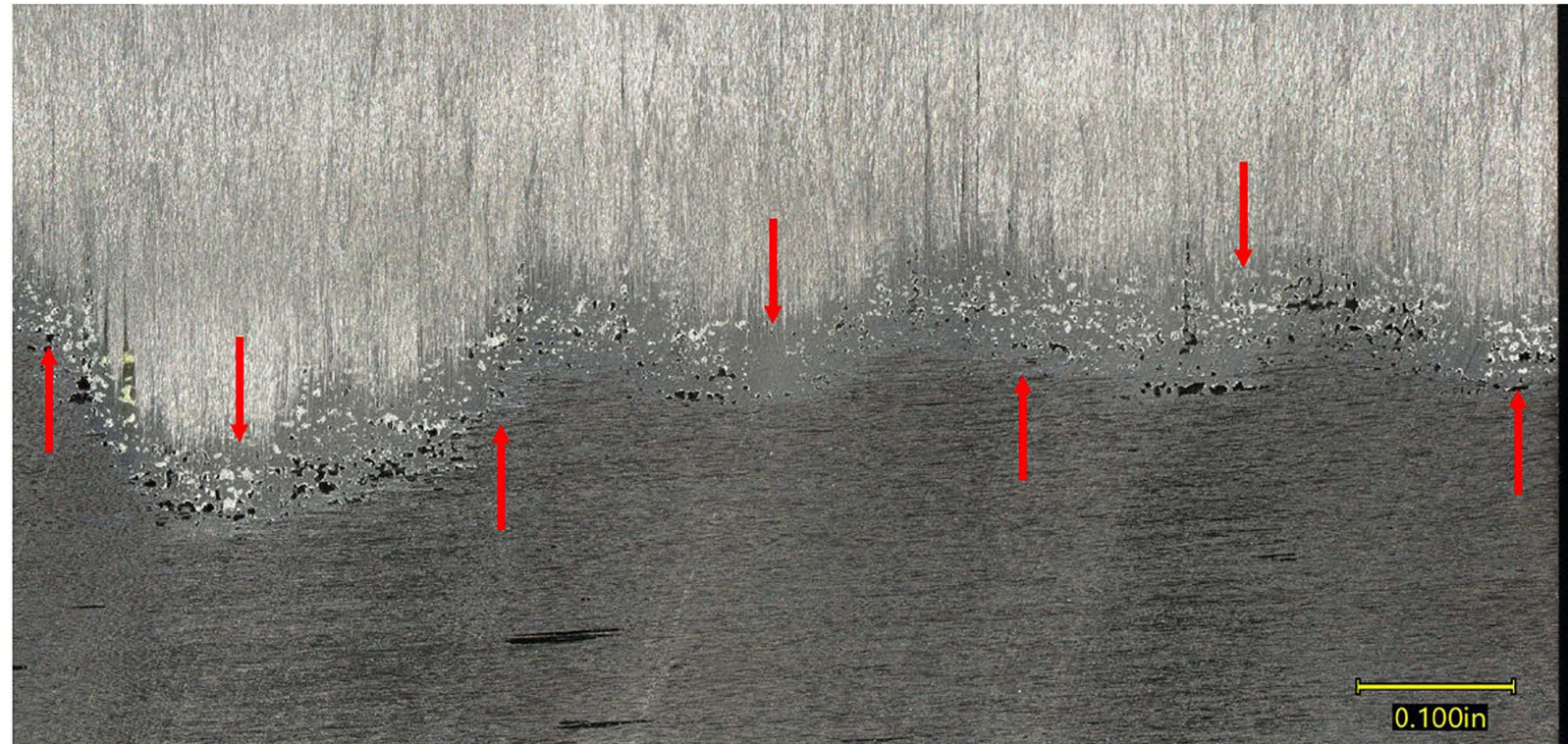
# Thickness of V1 and V2 Trimmed Ends



# Titan V2 Hull – Porosity



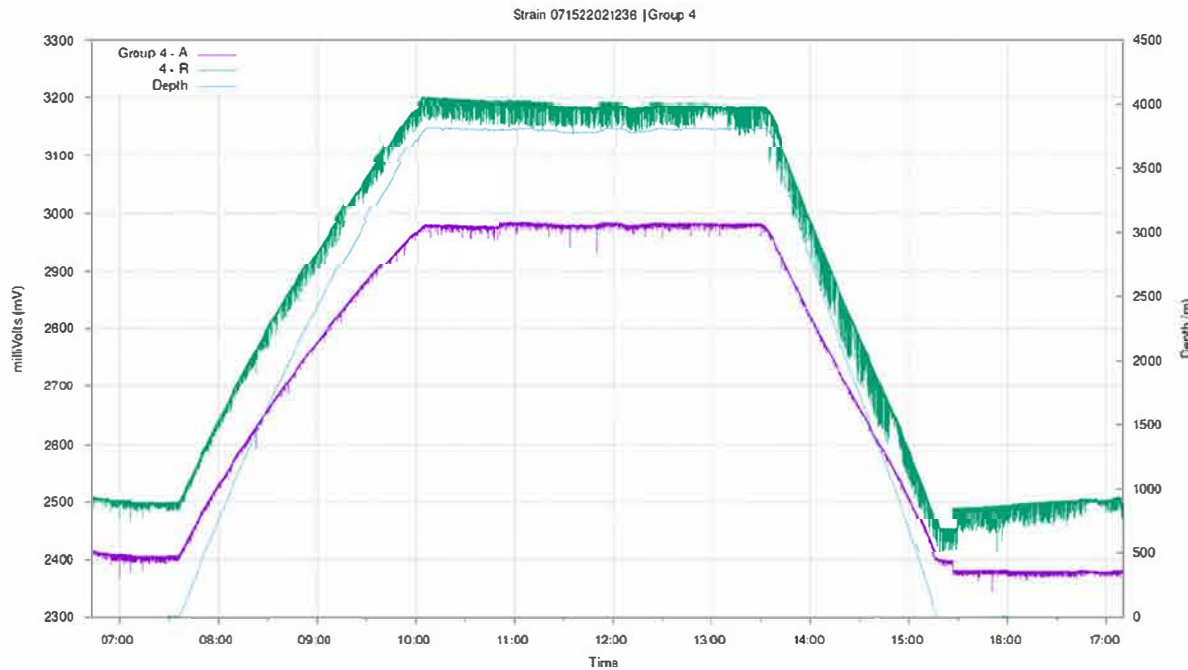
CG 107



NTSB Titan Material Analysis

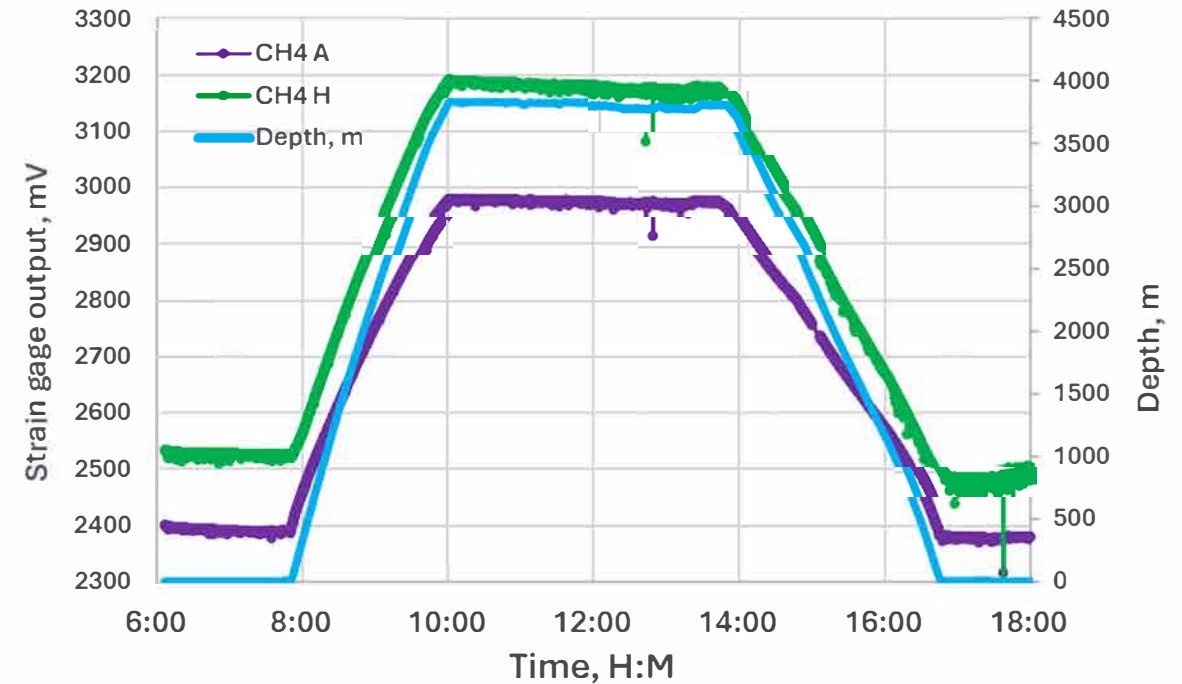


# OceanGate-produce Time-based Plots of Strain



Dive 80 – hoop and longitudinal strain  
group 4

CG 107

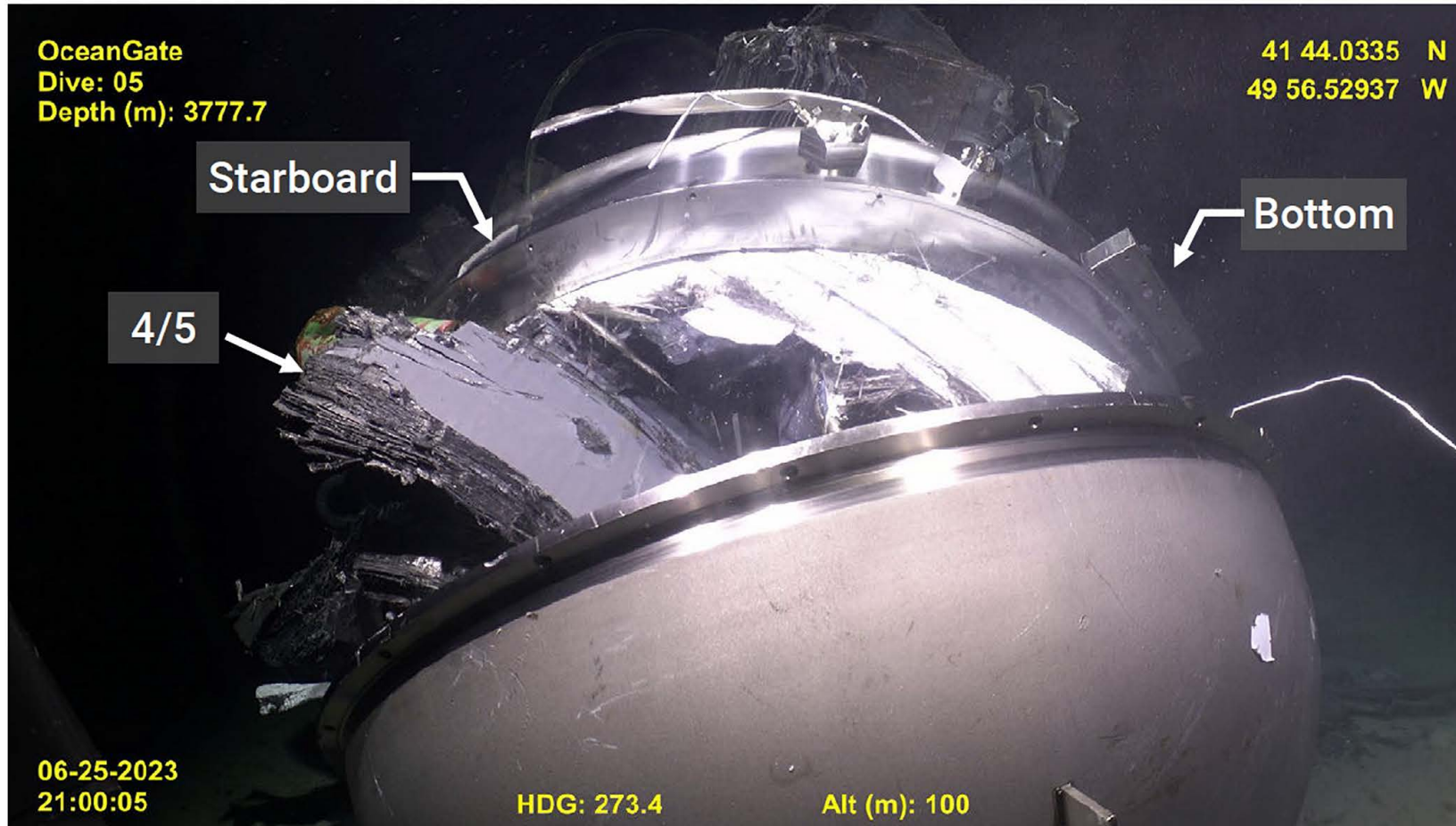


Dive 81 – hoop and longitudinal strain  
group 4

Page 65 of 67

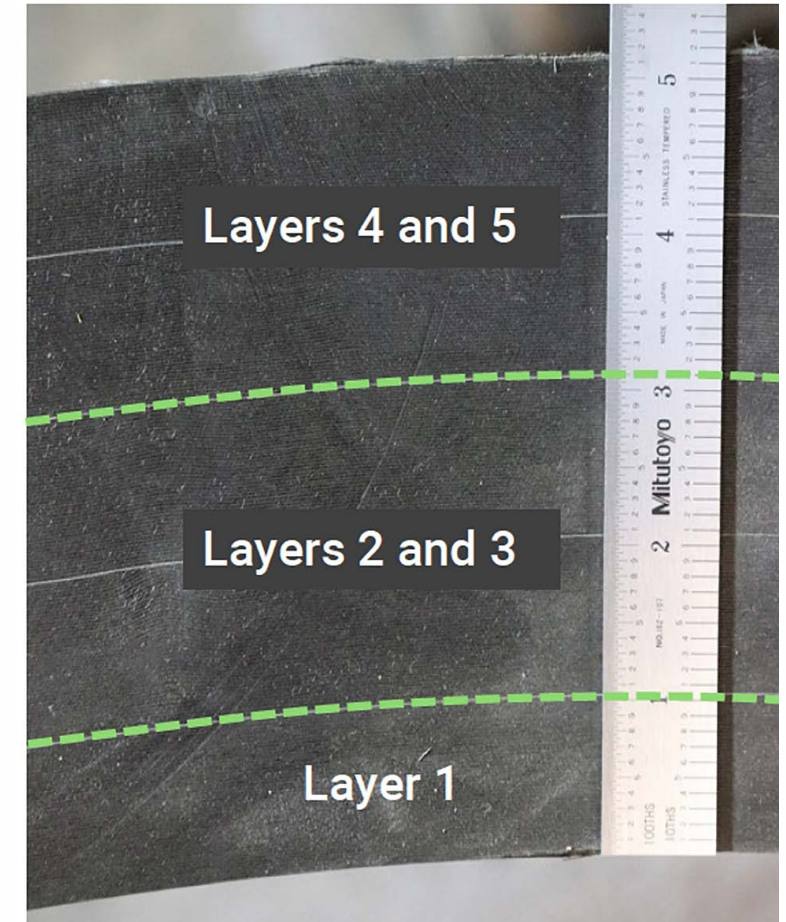


# Starboard Hull Piece



CG 107

NTSB Titan Material Analysis



Page 66 of 67

# Starboard Hull Piece

