National Transportation Safety Board

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Morgan Turrell

Deputy Director, Office of Marine Safety
National Transportation Board

Andy Bowen

Principal Engineer and Director of the National
Deep Submergence Facility, Woods Hole
Oceanographic Institution


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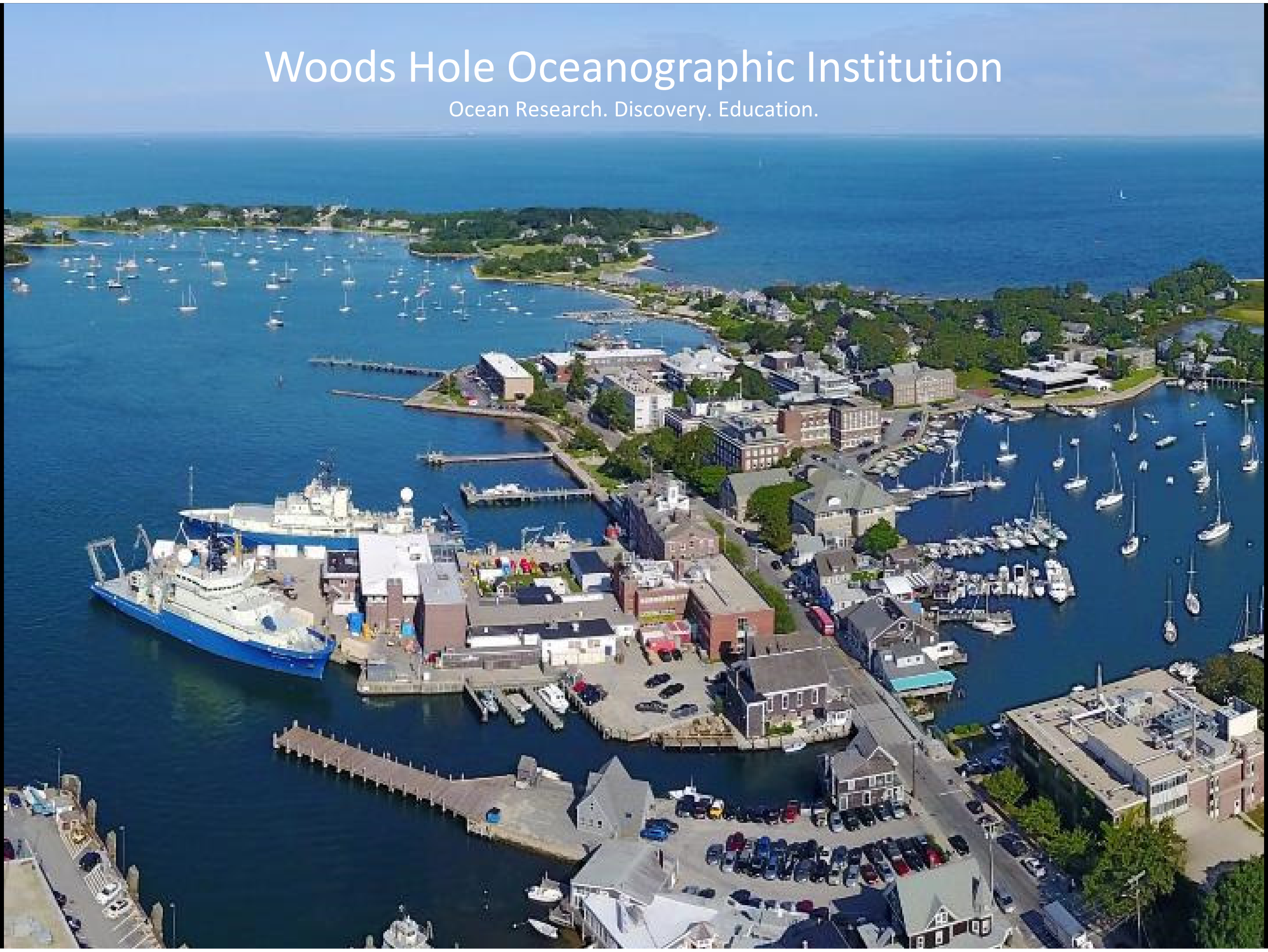
Safety Board


Woods Hole Oceanographic Institution
Ocean Research. Discovery. Education.

Woods Hole Oceanographic Institution (WHOI)

- Leading efforts to explore and understand the ocean since 1930
- Home to more than 450 ocean scientists and engineers
- $240 million annual operating budget, nearly $200 million sponsored research (~800 projects)
- Broad range of ocean experience, expertise, capabilities, and resources
- Goal to advance knowledge of ocean science and technology
- Unparalleled research facilities, technology, and sea-going capabilities
- MIT-WHOI Joint Program in Oceanography, over 900 students since 1969

A Legacy of Successful Operations

Titanic

Air France Flight 447

Deepwater Horizon

WHOI Marine Robotics

- Recognized leader in development of innovative and proven marine robotics and associated technologies
- Field-tested R&D and operations teams
- Culture of innovation, creative problem-solving, and discovery
- Multiple underwater vehicles and sensors
- Home to National Deep Submergence Facility

Proven record of success at sea and in the lab

Woods Hole Oceanographic Institution

National Deep submergence Facility

Woods Hole Oceanographic Institution

Landmark Survey of the MV Derbyshire

Launched December 1975

Largest British ship ever lost at sea

All hands Perished September 1980

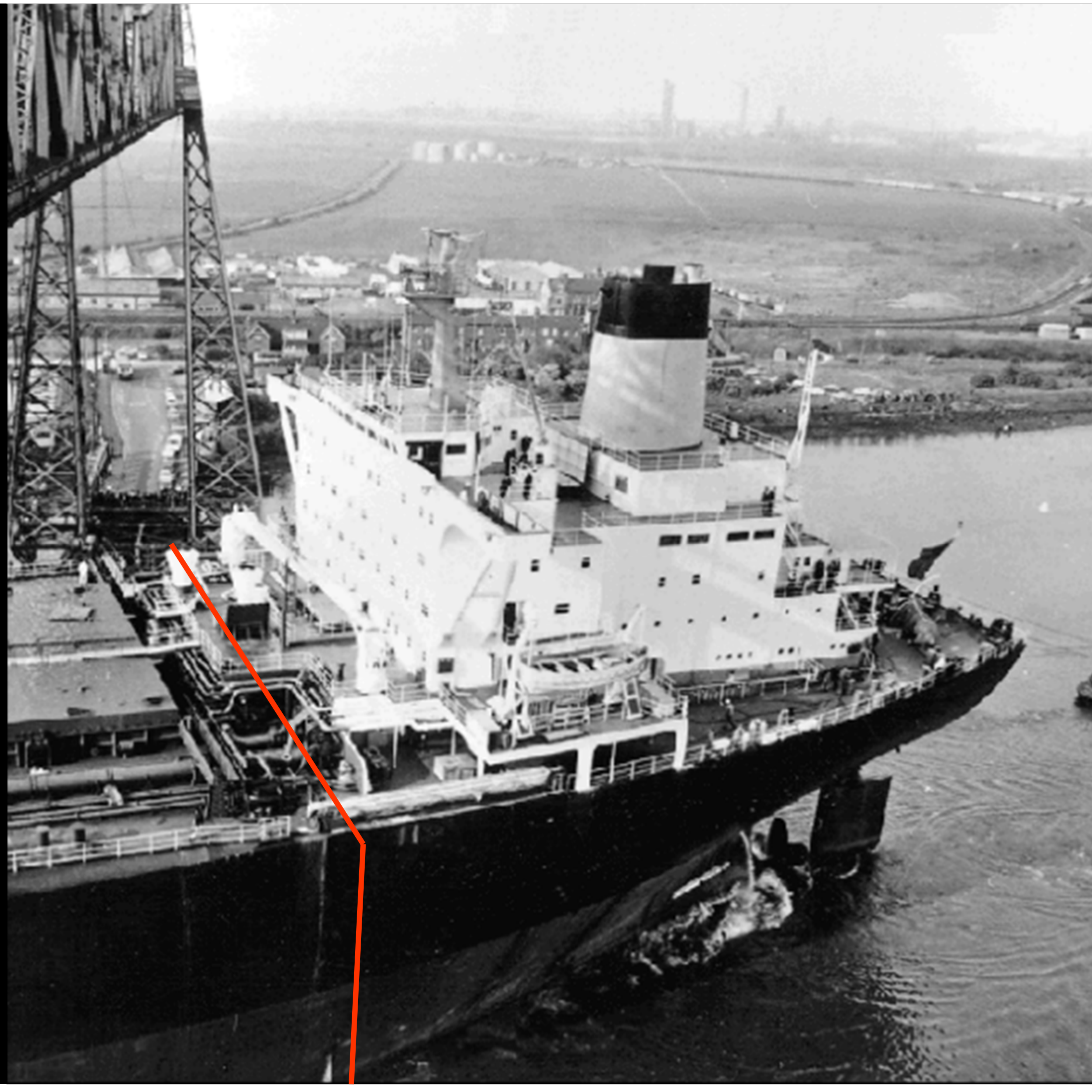
No Distress call

Located 5,000 meters depth

First of kind survey Leads to revision in class requirements

A view of the Derbyshire laden with cargo

Woods Hole Oceanographic Institution



Lord Donaldson's 13 Scenarios

C1. DECK CRACKING AT FRAME 65

C2. DECK CRACKING AT MID-SECTIONS

C3. TORSIONAL WEAKNESS

C4. HATCH COVER COLLAPSE

C5. HATCH COVER ATTACHMENTS

C6. FORE DECK CORROSION AND FRACTURE

C7. FLOODING OF FORWARD SPACES

C8. CARGO SHIFT / LIQUEFACTION

C9. PROPULSION LOSS

C10. RUDDER LOSS / STEERING FAILURE

C11. EXPLOSION AND/OR FIRE IN THE ENGINE ROOM

C12. POOPING - FROM FORWARD WAVES

C13. POOPING - RUNNING WITH THE SEA

C14. THE UNFORESEEN

THE KEY PRINCIPLE ADOPTED FOR THE SURVEY WAS TO SEEK EVIDENCE NOT ONLY TO **PROVE** A PARTICULAR LOSS SCENARIO BUT ALSO TO **DISPROVE** ALL OTHERS. ARGUMENTS AGAINST A SCENARIO SHOULD BE AS DETAILED AS THOSE **FOR**.

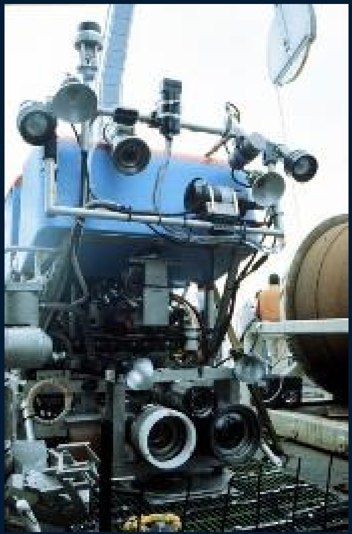
THE KEY PRINCIPLE ADOPTED FOR THE ASSESSMENT WAS THAT WE WOULD CONCERN OURSELVES ONLY WITH **HOW** THE VESSEL WAS LOST AND NOT **WHY**.

FOR EXAMPLE: **HOW** DID THE TYPHOON CONTRIBUTE TO THE LOSS - NOT **WHY** SHE WAS IN THE TYPHOON IN THE FIRST PLACE

State of the Art 1997

Argo towed Camera/Sonar

Jason ROV

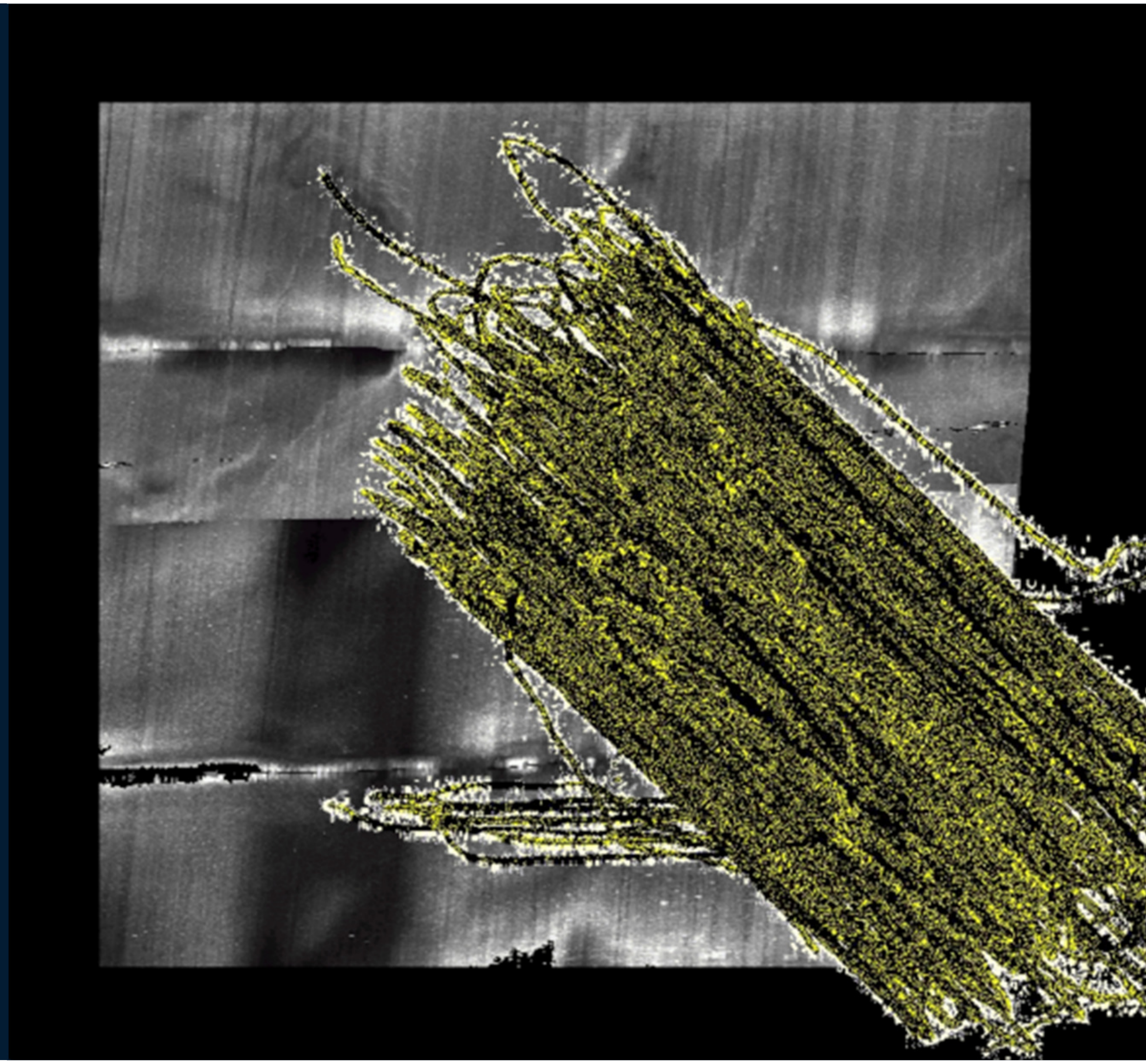


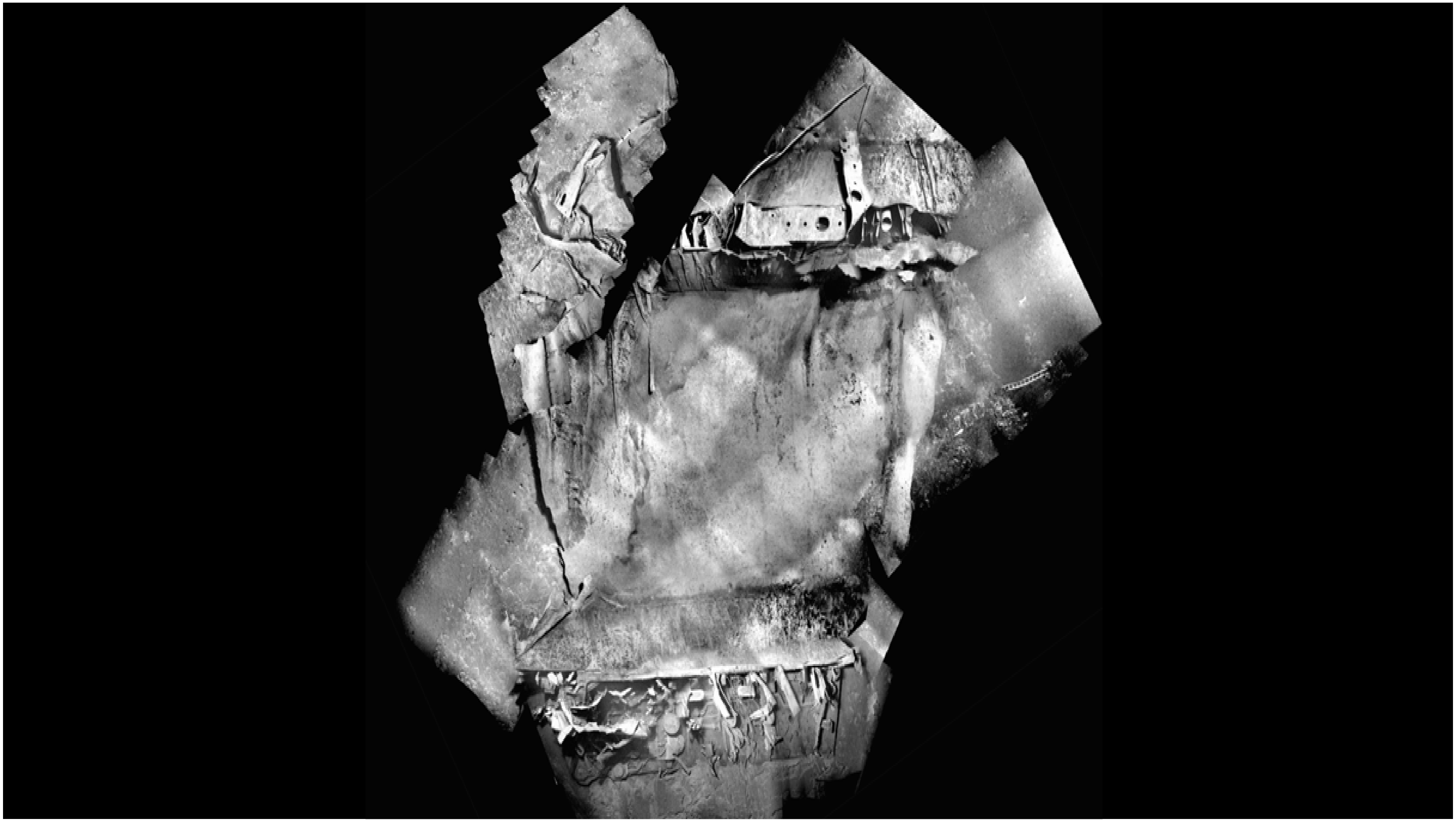
120 KHz Sonar

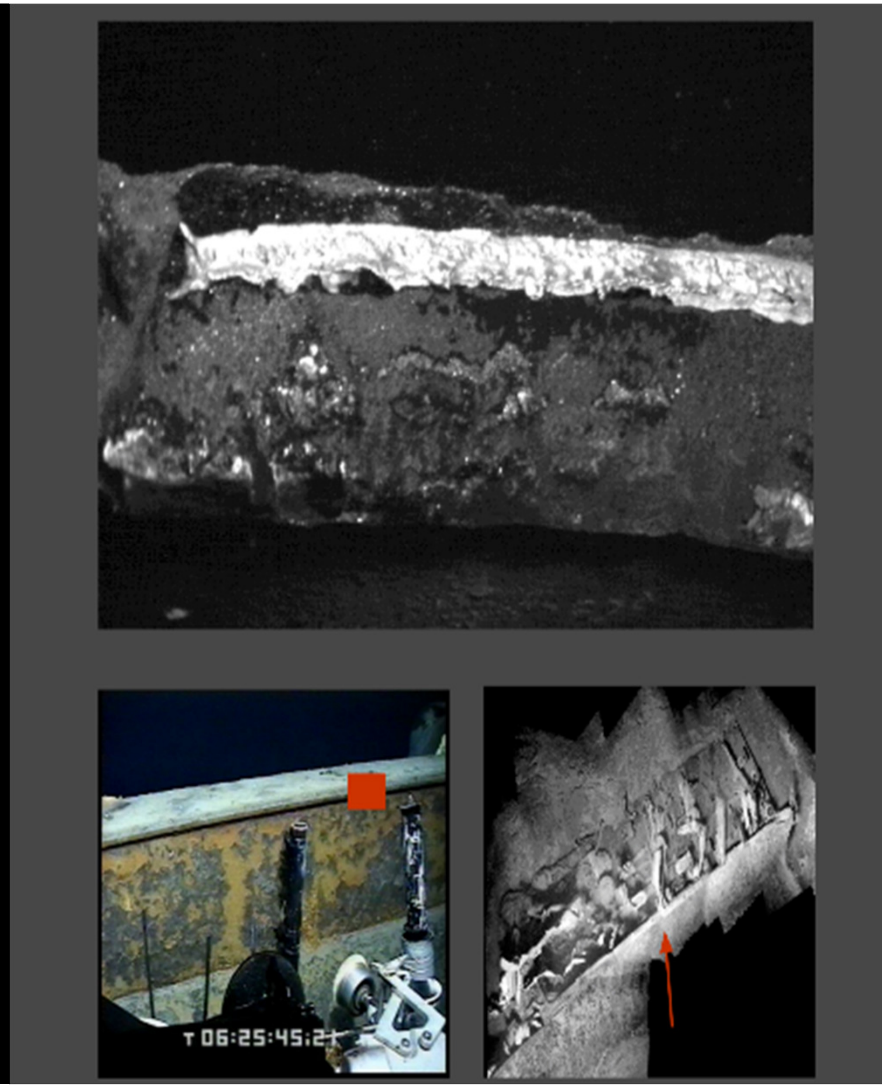
Woods Hole Oceanographic Institution

Multi-scale approach

- Sonar Map
- ARGO Tracks



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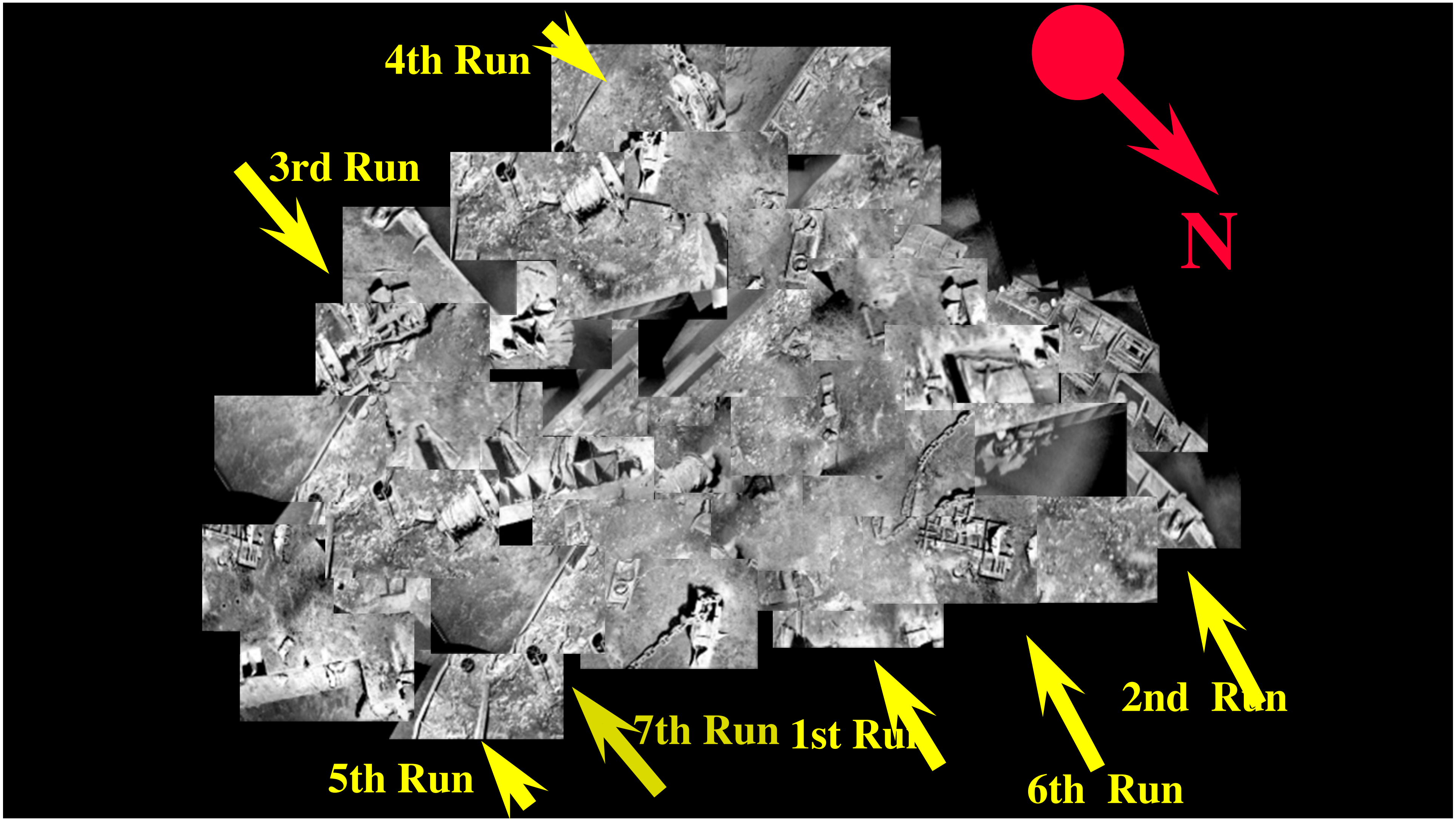
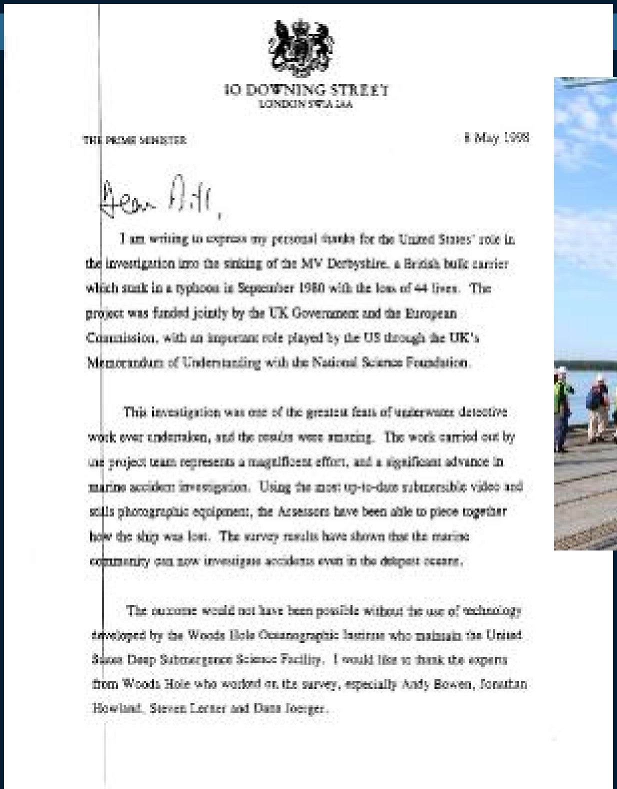

4th Run
3rd Run
N
2nd Run
7th Run
1st Run
5th Run
6th Run

A Legacy



10 DOWNING STREET
LONDON SW1A 2AA

THE PRIME MINISTER

8 May 1998

Dear Bill,

I am writing to express my personal thanks for the United States' role in the investigation into the sinking of the MV Derbyshire, a British bulk carrier which sank in a typhoon in September 1980 with the loss of 44 lives. The project was funded jointly by the UK Government and the European Commission, with an important role played by the US through the UK's Memorandum of Understanding with the National Science Foundation.

This investigation was one of the greatest feats of underwater detective work ever undertaken, and the results were amazing. The work carried out by the project team represents a magnificent effort, and a significant advance in marine accident investigation. Using the most up-to-date submersible video and stills photographic equipment, the Assessors have been able to piece together how the ship was lost. The survey results have shown that the marine community can now investigate accidents even in the deepest oceans.

The outcome would not have been possible without the use of technology developed by the Woods Hole Oceanographic Institute who maintain the United States Deep Submergence Science Facility. I would like to thank the experts from Woods Hole who worked on the survey, especially Andy Bowen, Jonathan Howland, Steven Lerner and Dana Yoerger.

THE MOST LIKELY SEQUENCE OF EVENTS

- The vessel was caught in the most dangerous sector of a significant Typhoon system
- The spaces forward of the collision bulkhead at Frame 339 became more or less flooded over a period of time
- The flooding resulted in a substantial reduction in the freeboard of the vessel at the forward end and a reduction in the ability of the vessel to ërise toí the waves prevailing in the Typhoon conditions.
- As a consequence, the forward cargo hatch covers were subjected to considerably increased wave heights and dynamic pressures. These heights, in excess of the design parameters, resulted in the failure of the hatch covers and subsequent foundering of the vessel.

GENERAL SIMPLE TRUTH No. 1

SHIP LOSSES ARE NOT GENERALLY CAUSED BY ONE EVENT. THEY ARE CAUSED BY A NUMBER OF EVENTS, PERHAPS MINOR WHEN CONSIDERED INDIVIDUALLY IN ISOLATION, WHICH CONSPIRE TOGETHER IN A SEQUENCE WHICH LEADS ALMOST INEVITABLY TO SINKING. EACH CONTRIBUTES A PERCENTAGE TO THE BUILD-UP OF THE PROBABILITY OF THE LOSS

GENERAL SIMPLE TRUTH No. 2

SHIP DESIGN IS THE INTEGRATION AND BALANCE OF MANY FACTORS, SOME OFTEN CONFLICTING, INTO A COHERENT VIABLE SOLUTION.

CHANGING JUST ONE ELEMENT IN ISOLATION FROM OTHERS, ALTHOUGH EFFECTING AN IMPROVEMENT IN ITSELF, MAY CAUSE AN IMBALANCE WHICH IS DETRIMENTAL TO THE OVERALL SOLUTION.

[redacted]

NUI provides telepresence and intervention capability under ice at large standoff distance

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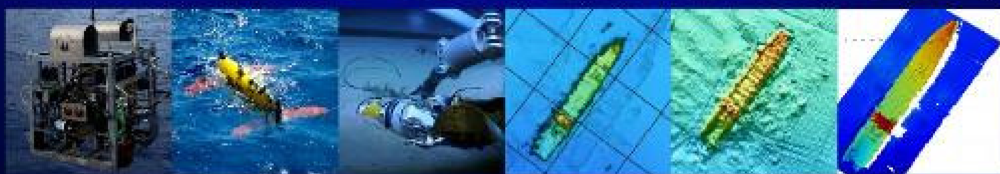
NTSB SEAFLOOR INVESTIGATIONS WORKSHOP

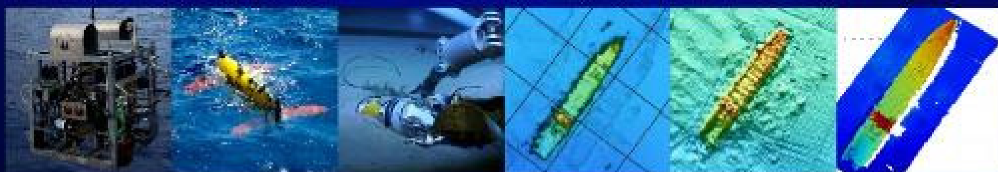


Morgan Turrell

Deputy Director, Office of Marine Safety

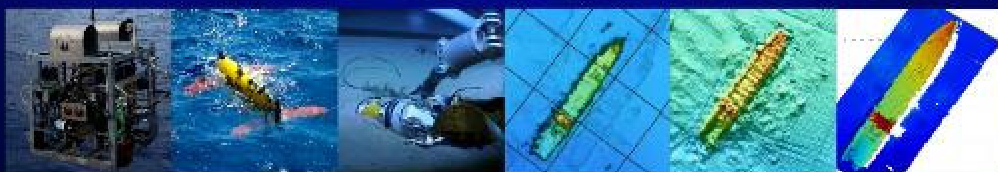
NTSB

NTSB SEAFLOOR INVESTIGATIONS WORKSHOP

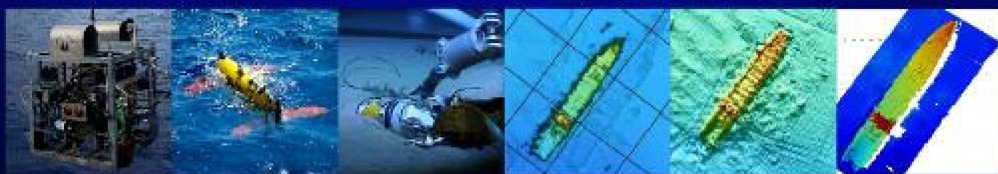


History of the Seafloor Investigation Workshop project

- Years of Aviation Investigation operations
- Marine investigations are not generally paid for by companies, insurance
- Decision to broaden to include aviation, keep learning from recent operations
- Coordination with partners
- Early decision making (Government or Commercial)
- Senior Leadership support and communications plan with stakeholders and public



- Rapid response and contracting complications
- Project scoping and expectations
- Search, survey and recovery becoming best practice
- Funding availability
- Integration with investigation
- Two-phase approach to future operations (immediate search and follow-up)



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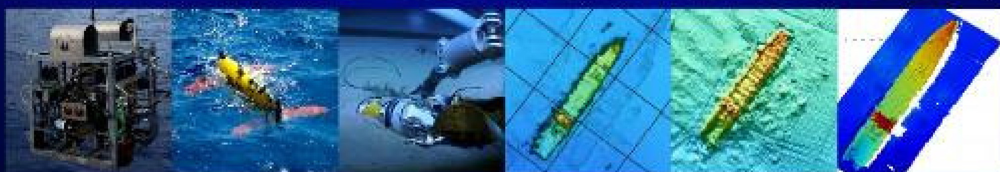
NTSB SEAFLOOR INVESTIGATIONS WORKSHOP

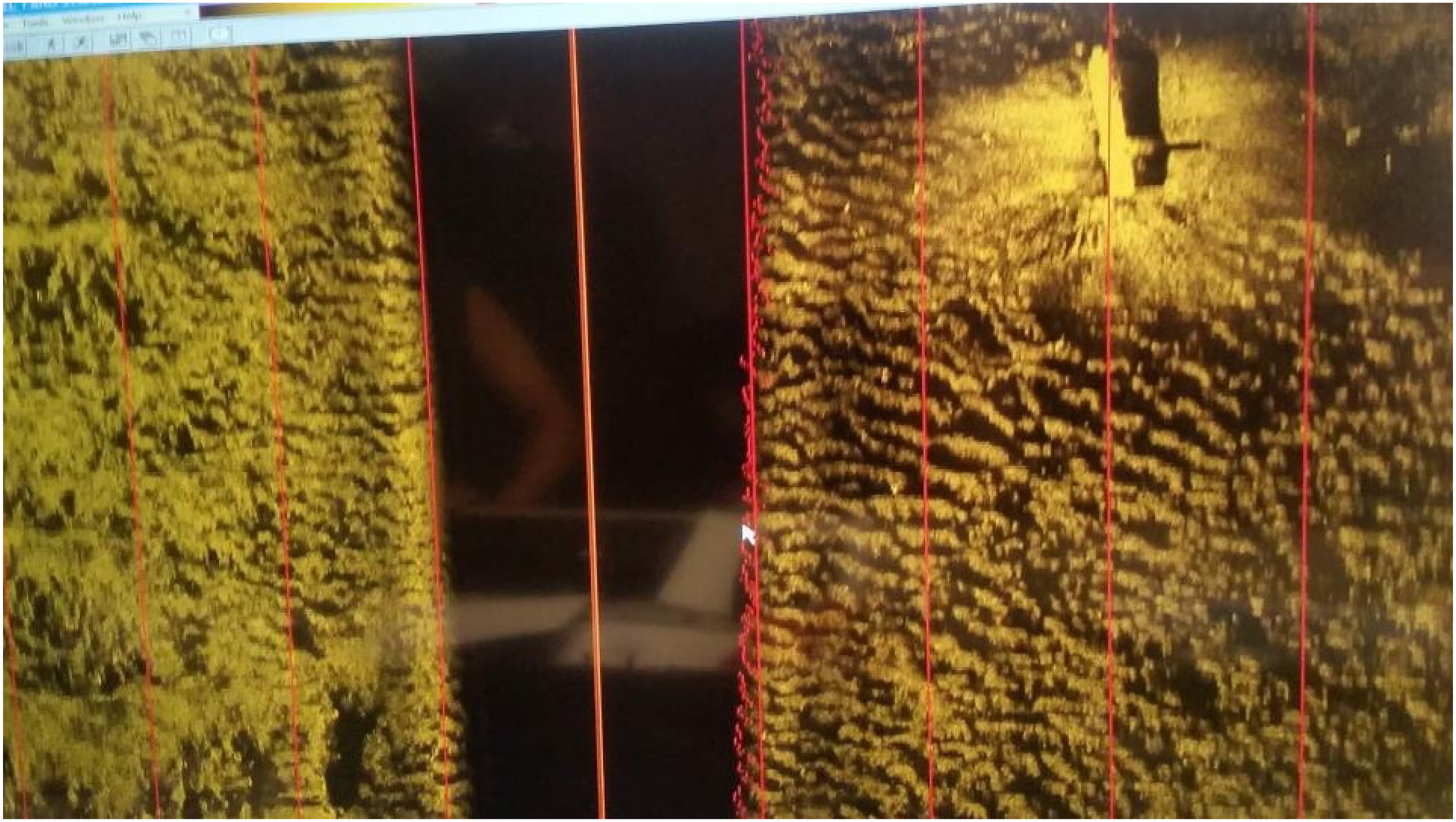


El Faro Investigation

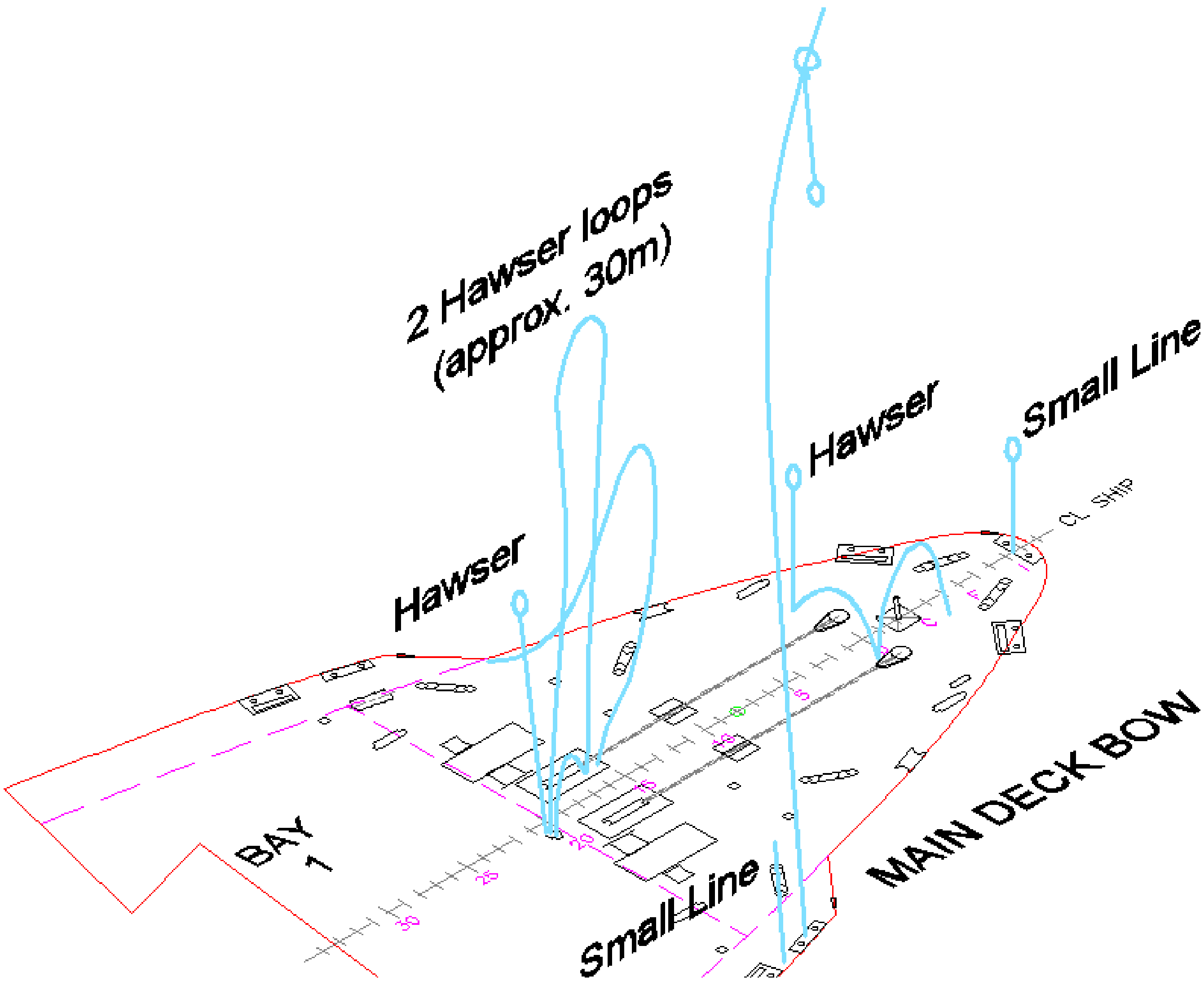

HANJUNG
SS EL YUNQUE


NAVY
SUPSALV

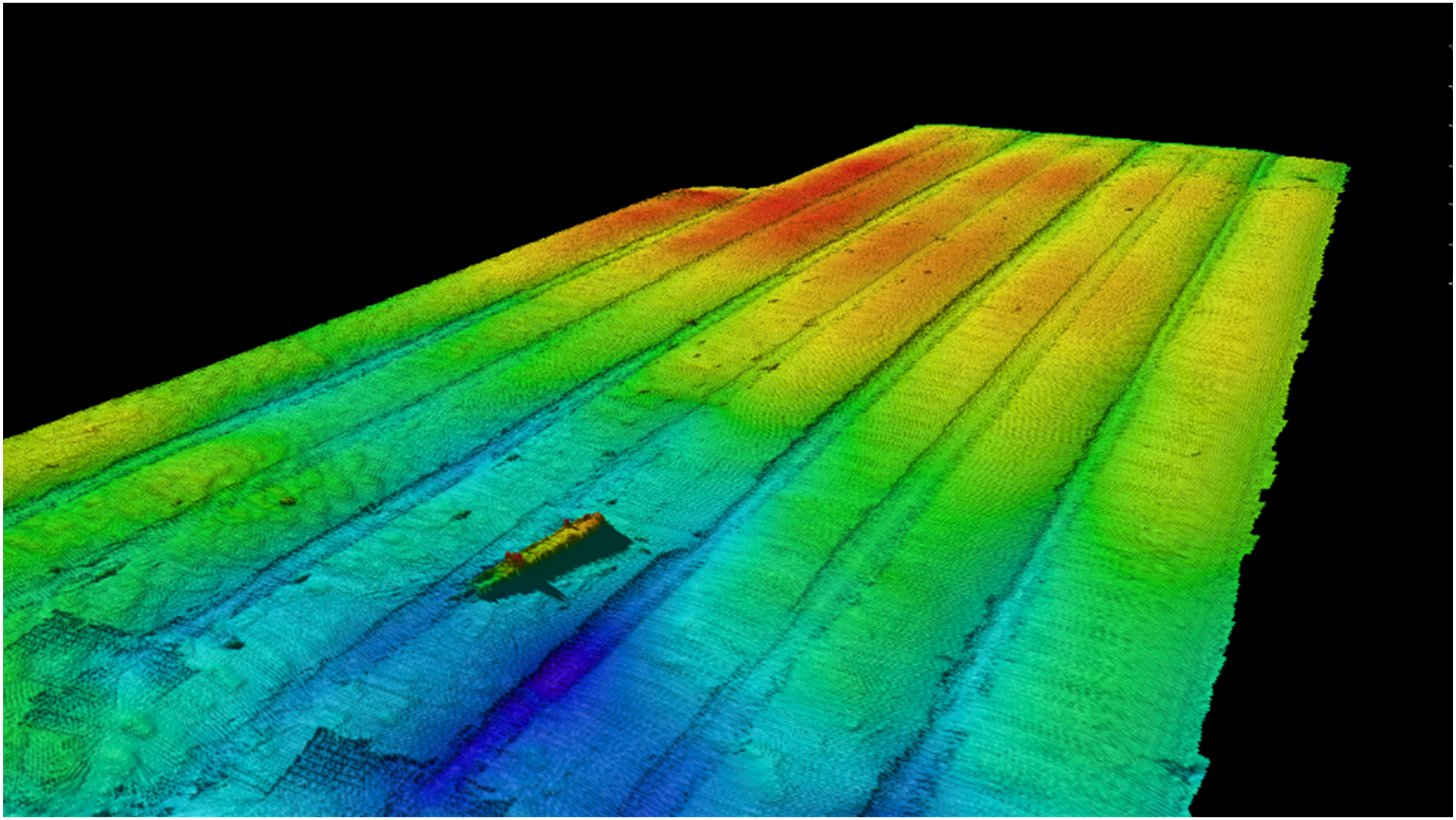

ORION
NAVY SUPSALV



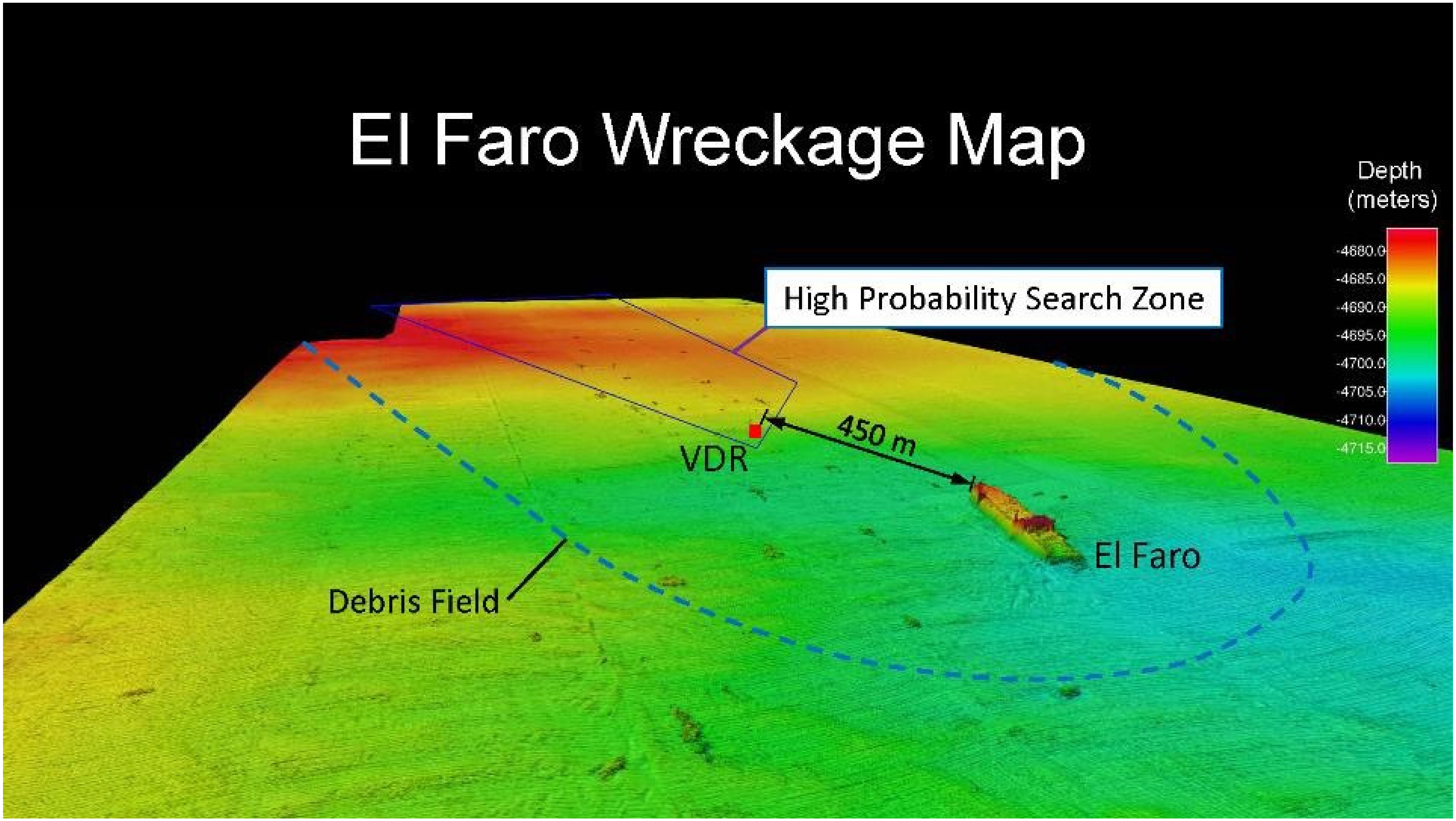

CURV
NAVY SUPSALV
USNA0000023

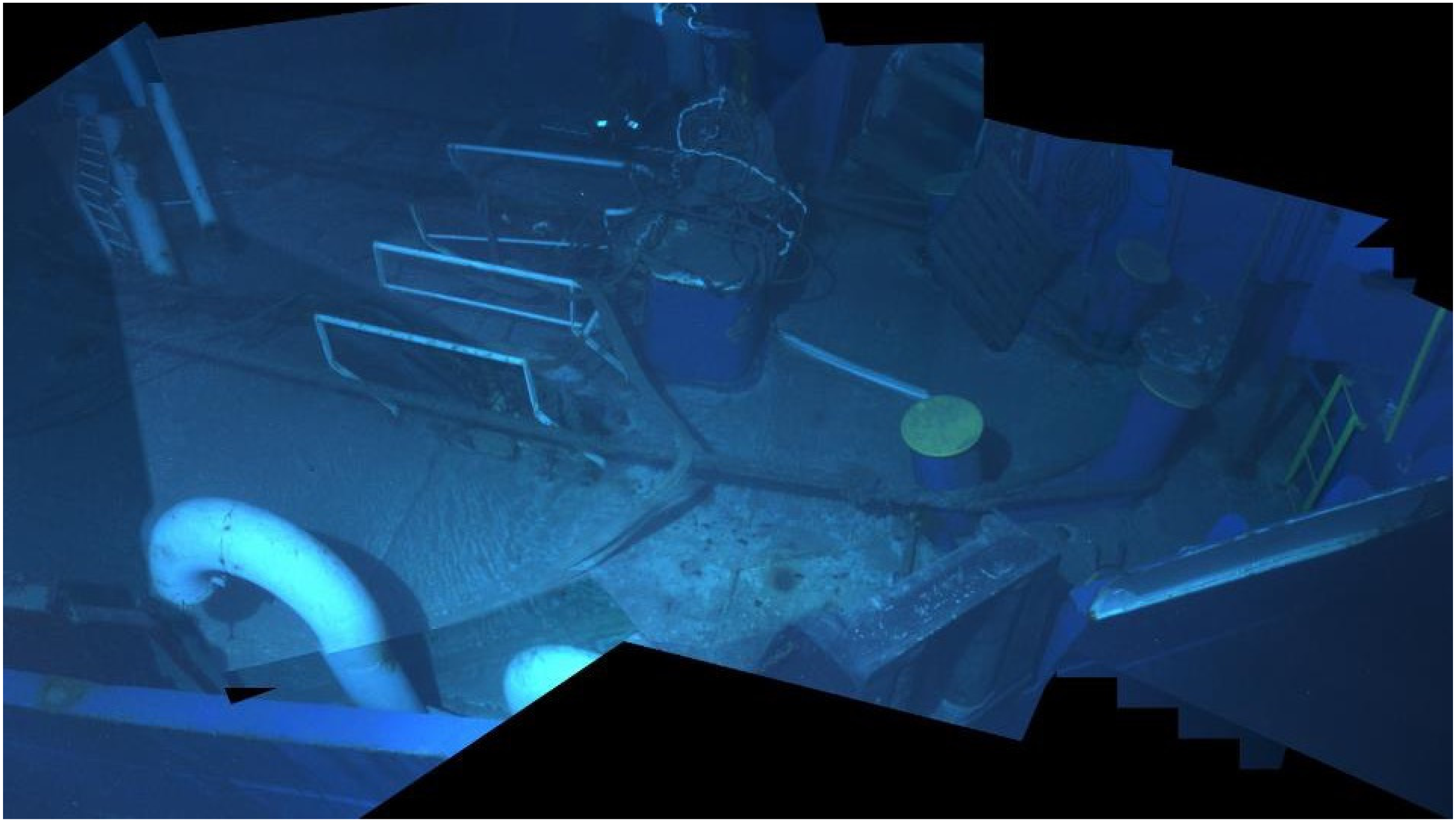


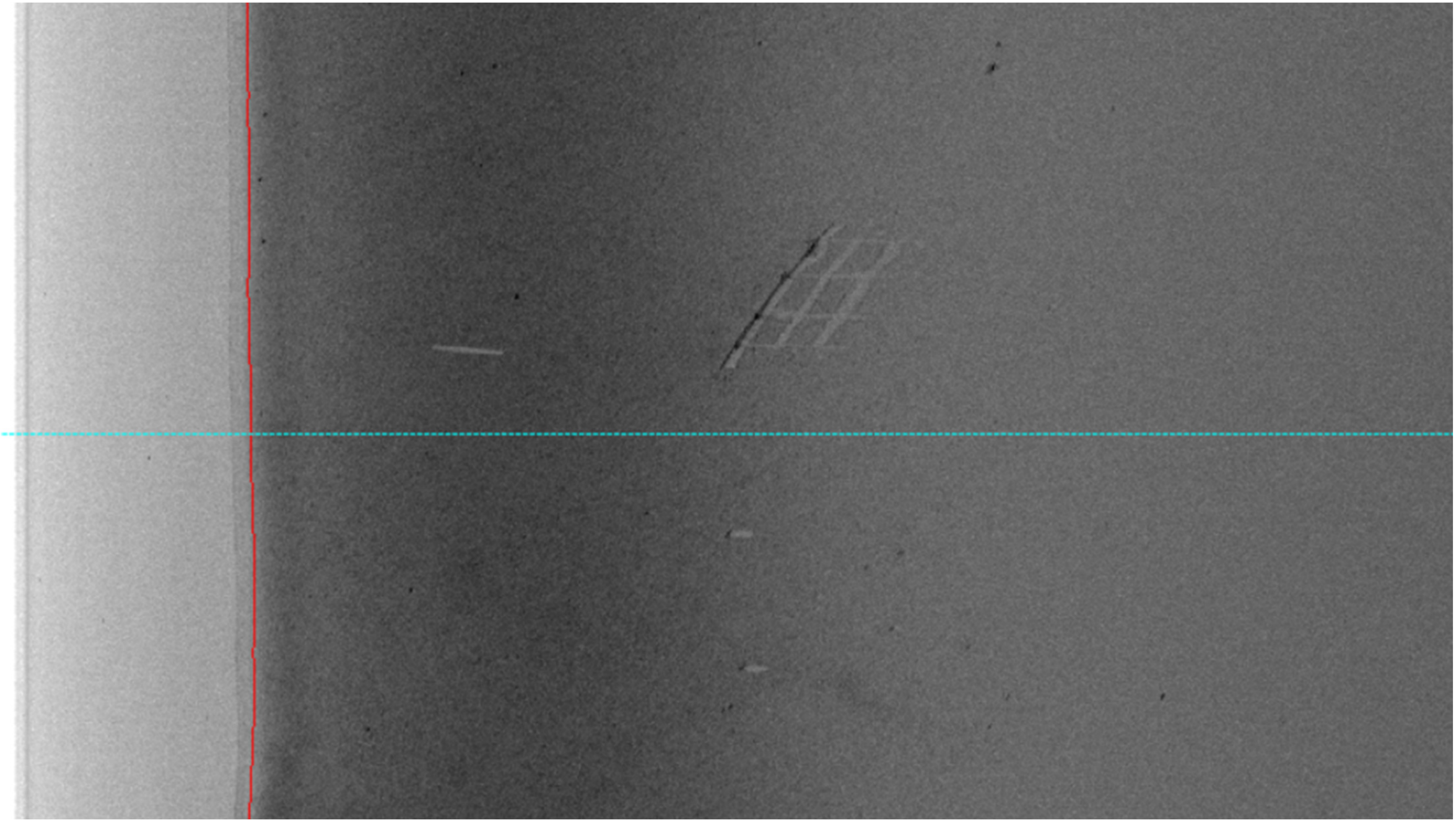
2 Hawser loops
(approx. 30m)
Hawser
Hawser
Small Line
CL SHIP
BAY
1
Small Line
MAIN DECK BOW

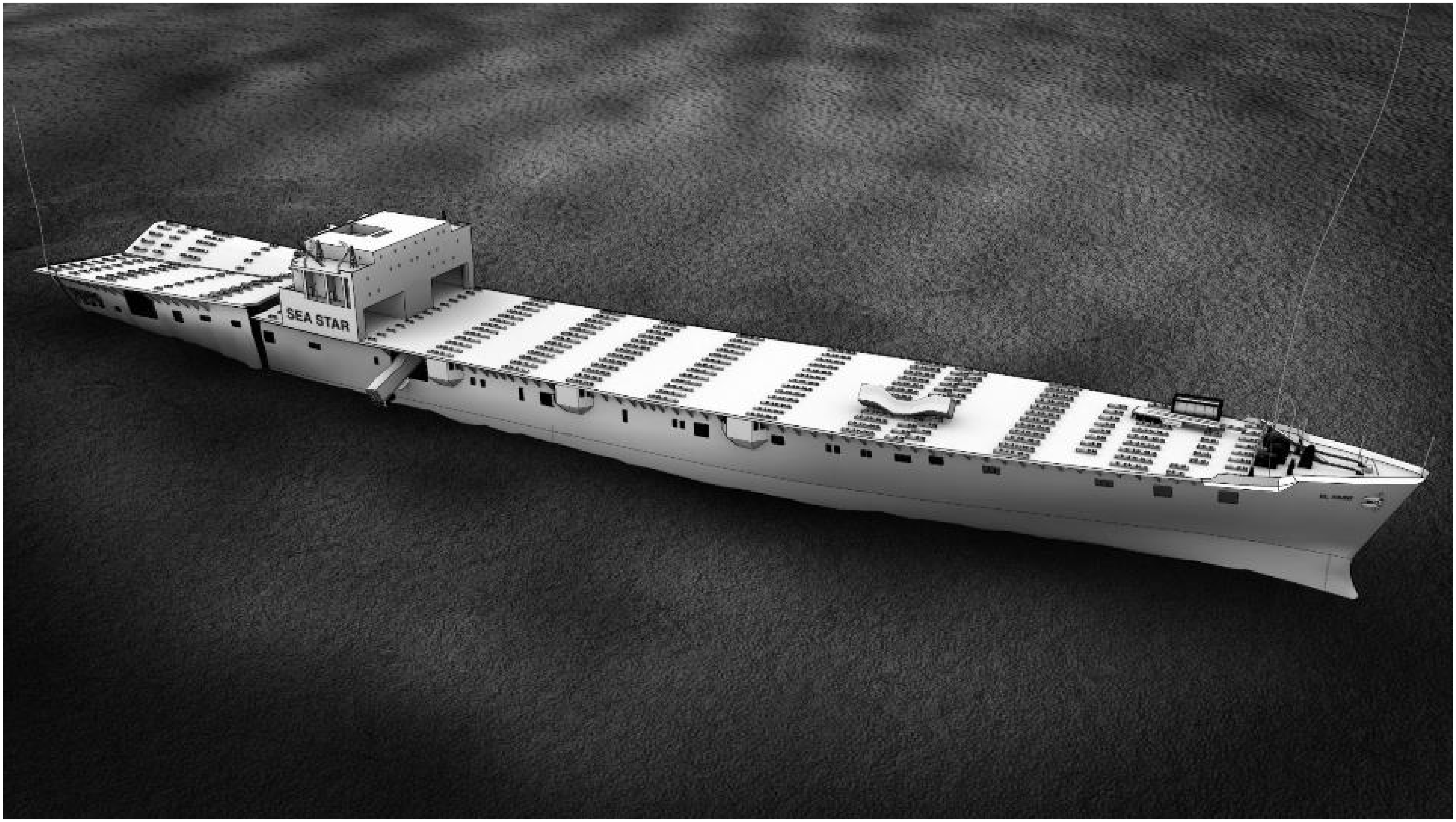



11:13:49 SSAS
11:15:57 SSAS
MB-Contact009_I (Lifeboat)
MB-Contact006_F (Bridge)
SUPSALV El Faro Bridge
S381-Contact0112 (Bow)
SUPSALV El Faro Wreckage

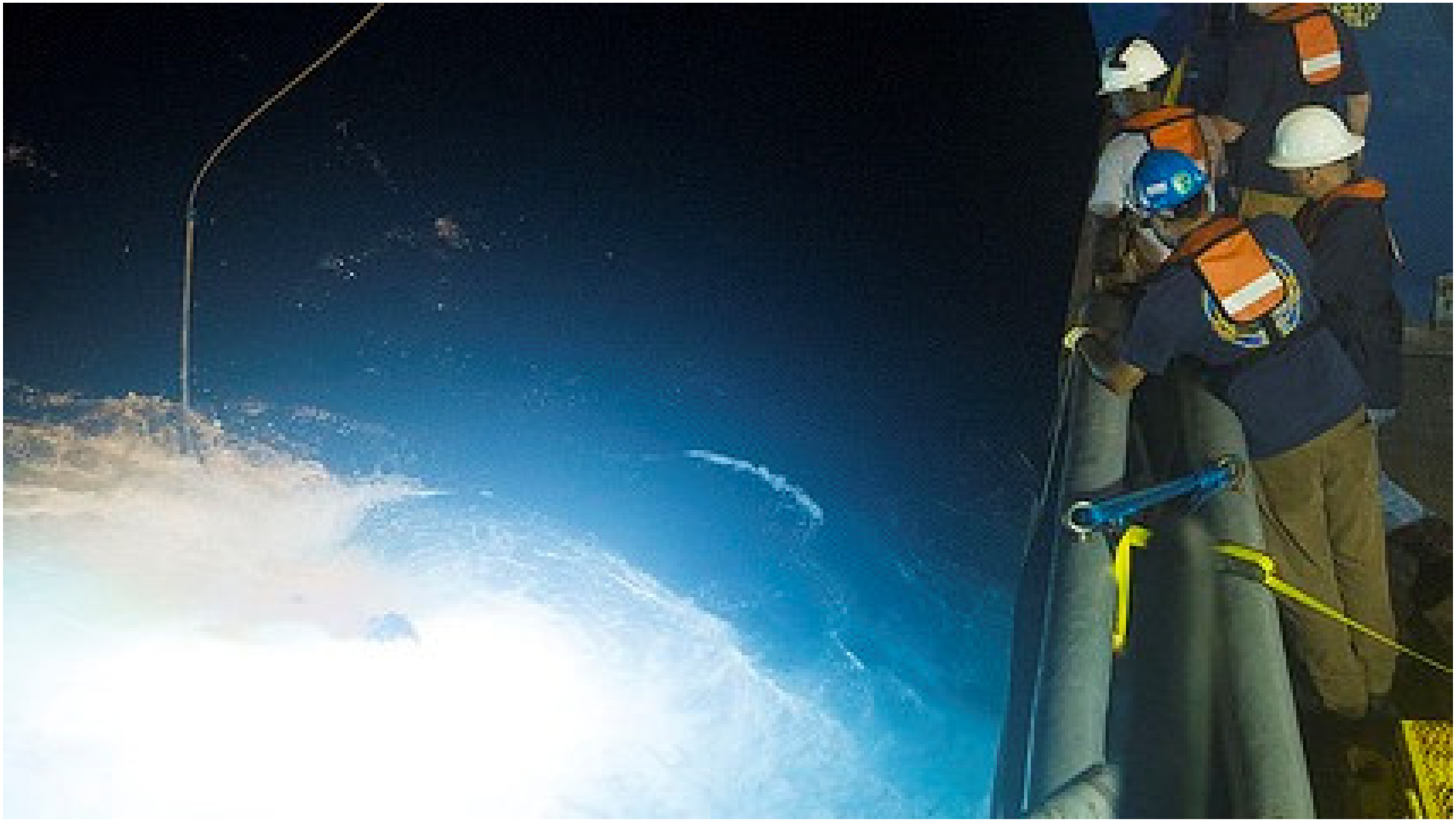

El Faro Wreckage Map
Depth (meters)
-4680.0
-4685.0
-4690.0
-4695.0
-4700.0
-4705.0
-4710.0
-4715.0
High Probability Search Zone
450 m
VDR
El Faro
Debris Field

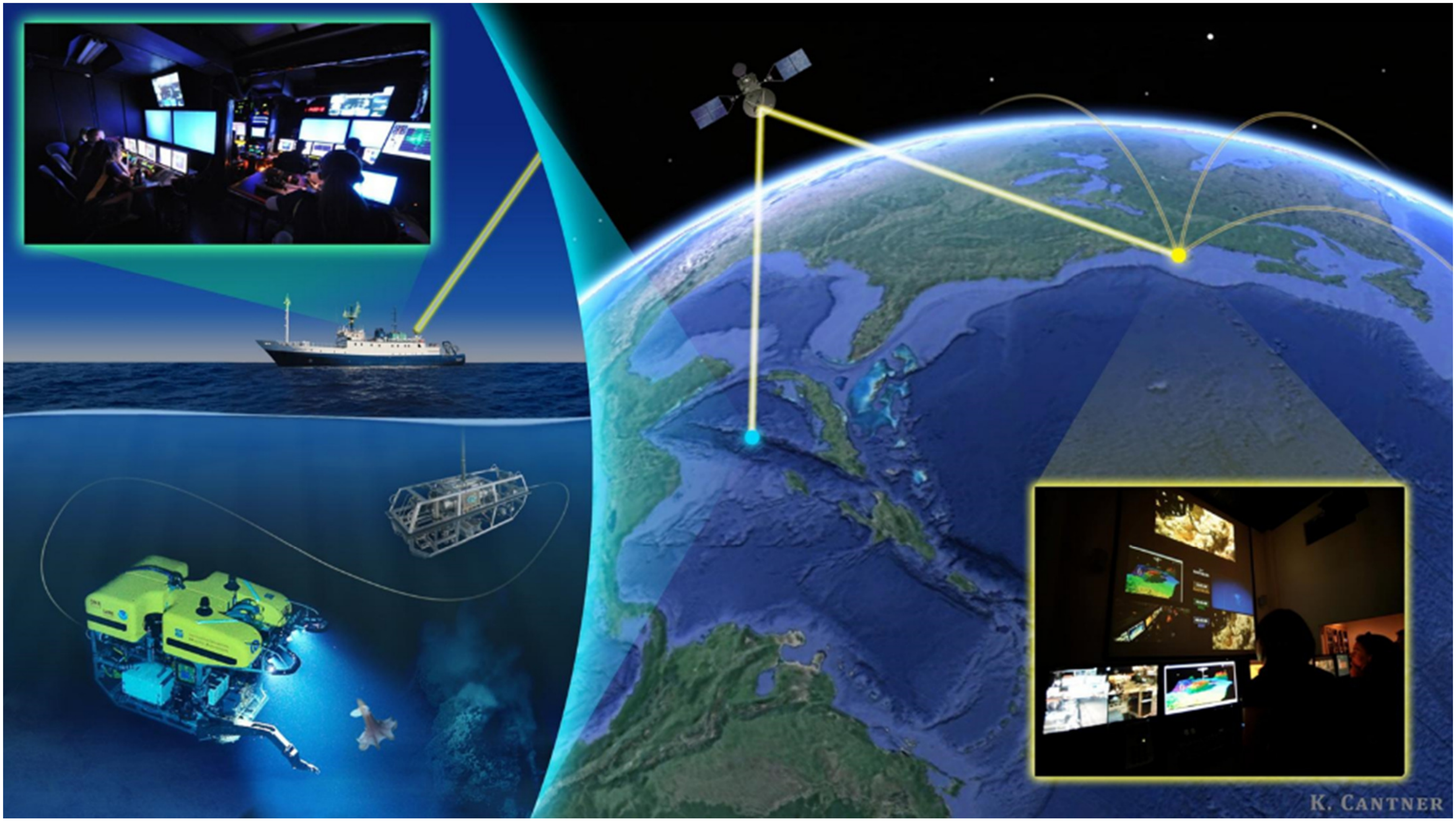


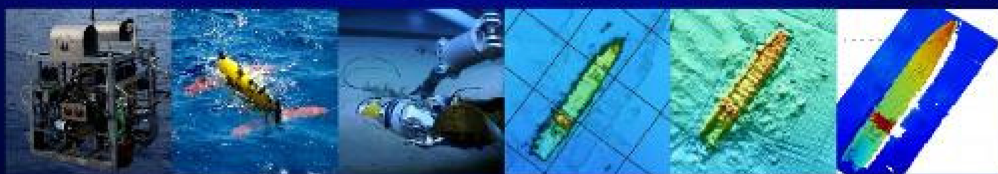



SEA STAR


NAVY
SUPSALV

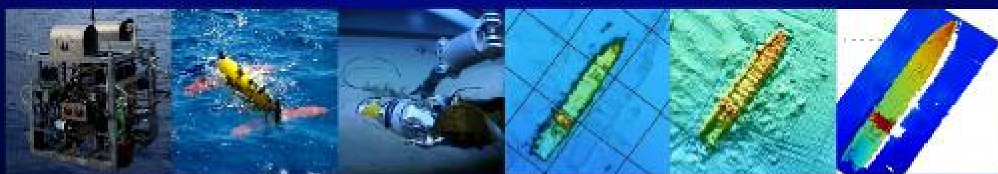



K. Cantner

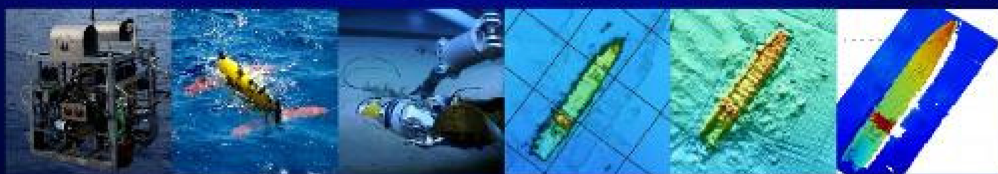


Operational Lessons from El Faro

- Clear objectives for operations
  - Selection of who will be at sea, and in charge of operations
  - Estimated time
  - Search area and methodology
  - Goals to achieve
  - Prioritize areas of the wreck for examination, exploration
  - Identify what you are not going to do
  - Salvage, recovery of surface items (rafts, etc.)
- Communications from operational platforms at sea and data handling



- Photogrammetry and surveying navigation at depth
- More photos, video and documentation of the entire debris field and operation
- Hazards to ROV and AUVs such as mooring lines
- Preparedness for human remains
- Need for all available data to begin search
- Need for all personnel involved to be aware of sensitivities around investigation
- Communication plan for findings, release of photographs, video



TOP TEN LESSONS

1. Have a plan coordinated with all appropriate parties
2. Have resources identified
3. Know what you are looking for
4. Identify limits of the search and operations
5. Use best available and appropriate technology
6. Have a communication strategy for operations and investigation
7. Plan for Human Remains recovery
8. Be flexible
9. Results are not guaranteed
10. Gather as much information as possible on scene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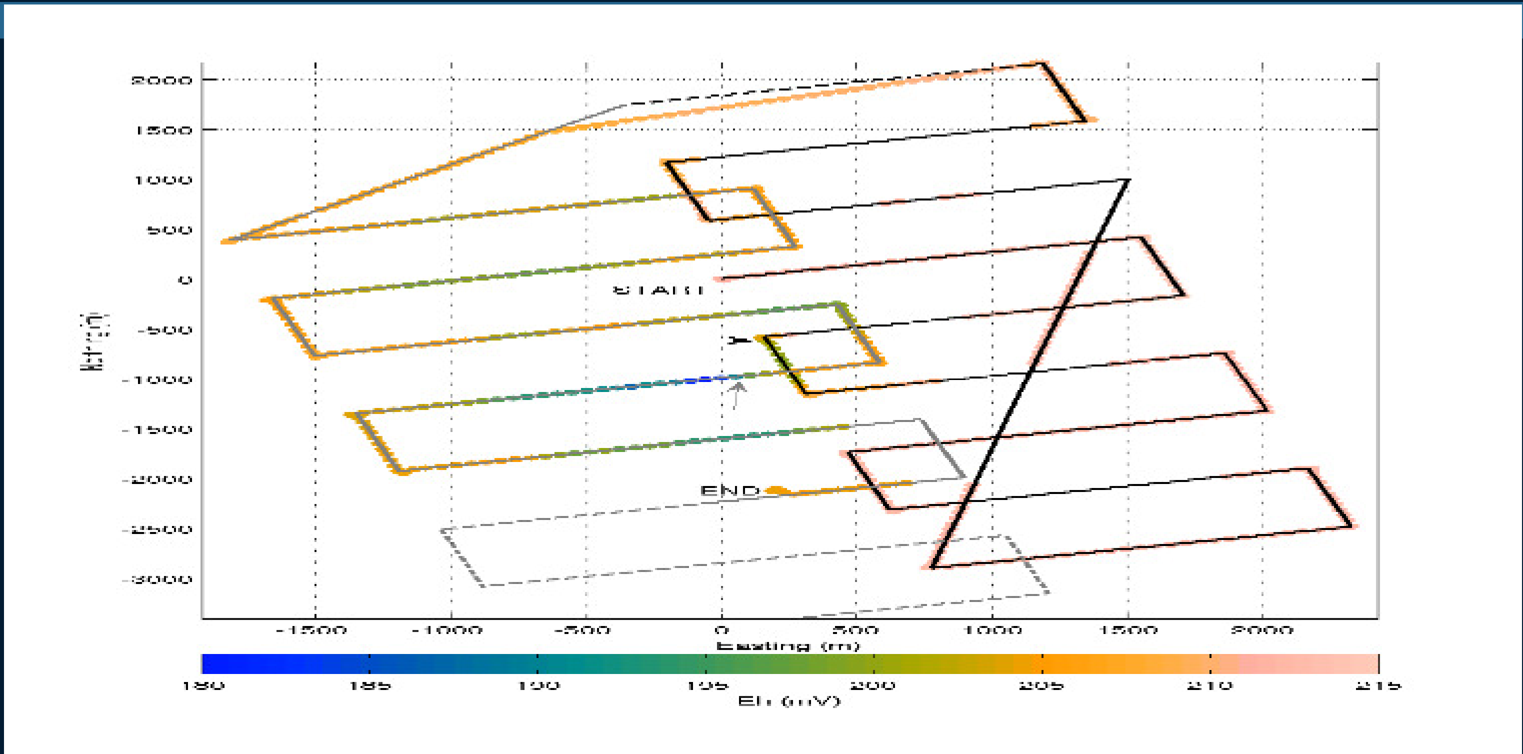
Handover to Andy to talk about future tech 5 min

Family Tree of Underwater Vehicle Technology



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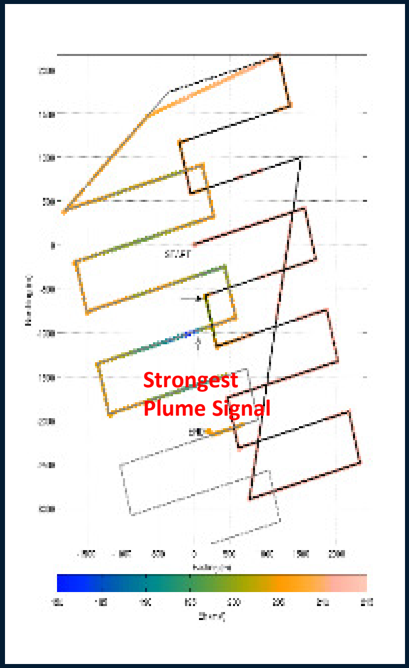
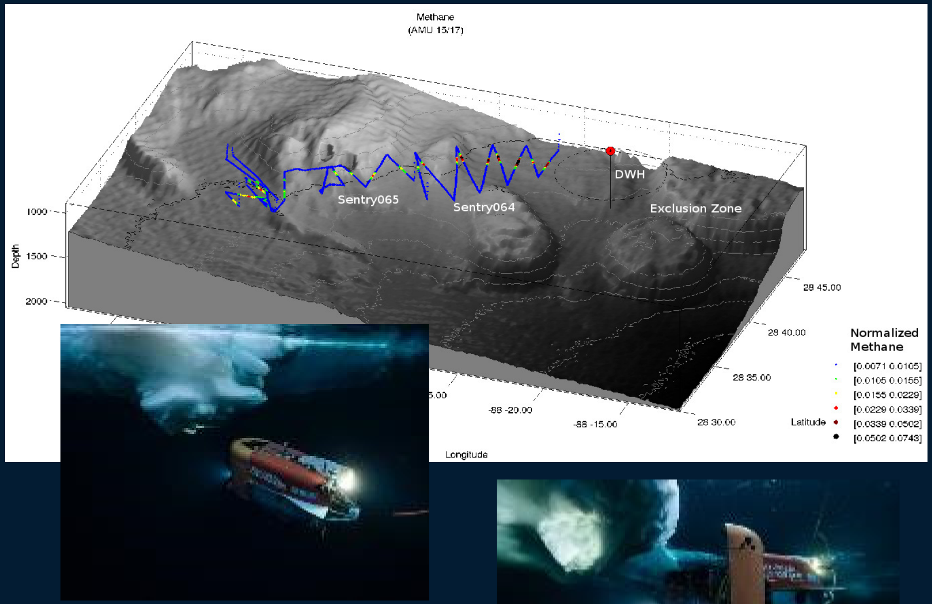
Improved Human-Robot Interaction

- Scalable autonomy depending on communications available
- Adaptive behaviors and re-tasking
- Smaller, less costly and more
- An Internet of Things Underwater!!
- A Polar imperative

Adaptive and Simultaneous Operations





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[redacted]

NUI provides telepresence and intervention capability under ice at large standoff distance

Back to Morgan for:

planning and factors, lessons learn, key components of a good survey

5 min.


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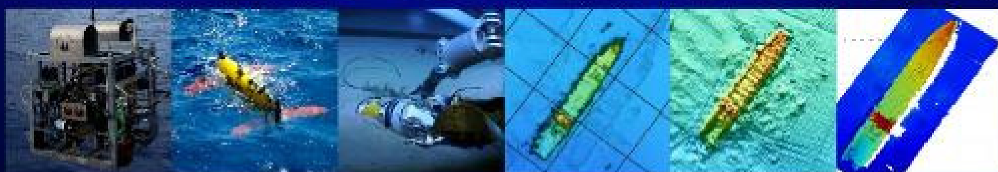
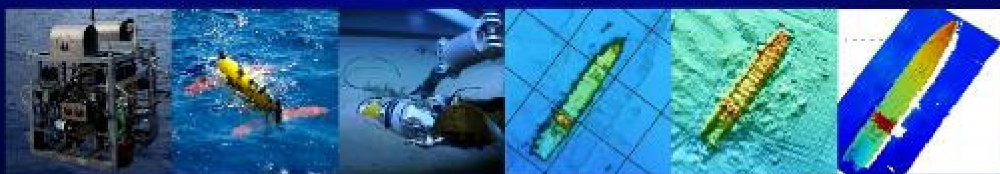
NTSB
SEAFLOOR INVESTIGATIONS



WORKSHOP

Closing



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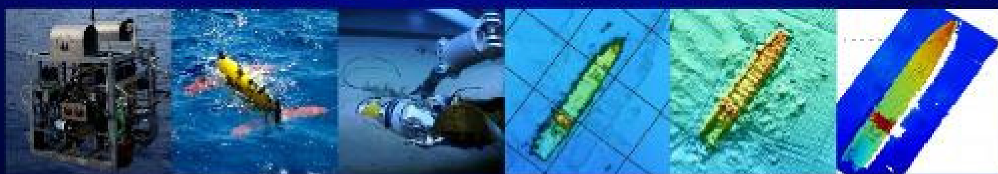

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25 min with Kevin discussion and audience Q&A

Post-Action Observations - WHOI

- Egypt Air, Macondo, AF447, Derbyshire etc. helps to reinforce the value of collaborations but also helps to drive application of emerging capabilities. Integration of of TRL 3-4 should be possible but likely require non-traditional approaches
- Collaborative framework reinforced via Federal Agency partnerships and working groups in place – don't wait to develop this in the heat of battle!

AND

- Interfaces for VDR recovery should be examined to ensure compatibility with subsea intervention hardware

Observations

Plan on a two-phase operation after Search and Rescue efforts are complete

- Search, using portable assets
  - Rapid deployment onto ships of opportunity with pre-determined search criteria (VDR, Hull, cargo, etc.)
  - Shorter mission time frame (10-14 days)
  - AUVs are capable and can search large areas with both photography and sonar – multiple systems coming soon
  - AUVs can be flown and deployed on wide variety of vessels with minimal handling equipment
- Recovery and survey
  - Second mission requires more planning, more capability
  - Mission flexibility—lot of unknowns, so being over-equipped is not a bad thing
  - More capable platform, with more deck space, additional berthing and longer range and durability (Ocean, Arctic, etc.)
  - Heavier ROV for salvage and time on wreckage site
  - More sophisticated communication ability (secure, bandwidth, etc.)

US Assistance

- What happens if a MAIIF member needs help in the future and requests assistance?
  - WHOI cannot speak on behalf of US government, however, NTSB and USCG proposed that WHOI come and present to provide insight and lessons from the El Faro operations
- Governments use past practices to help determine what is possible.
  - UK asked US for help on the Derbyshire on a government to government request
  - WHOI, largely funded by the US government, provided MAIB with assistance. The Derbyshire helped WHOI push its technology forward
  - Lessons from all of these activities, including aviation (Air France & MH370) are useful and governments should learn and share the details of the search and recovery to improve

Lessons Learned

- VDRs are not presently configured to be located or recovered from deep-water wreckage. Steps should be take to:
  - Improve range and endurance of the sonar mounted to the VDR
  - Consider implications of "float-free" VDR designs
  - Enable removal from "typical" intervention platforms
- A diverse, fully engaged team (Nav-arch, data, vehicles, USCG, vessel operator, etc) on the vessel with widely varying tool sets, backgrounds, and the ability to invent on the fly was extremely beneficial
- Mooring lines and other obstructions could warrant specialized techniques are developed NOW
- Integration of Telepresence should become standard protocol for investigations involving difficult logistics with real-time demands – opportunity cost is high TP extends and fortifies the field team
- Sensitive information within a "connected" expedition with multiple layers is challenging
- NTSB drift and ballistics modeling was very accurate and useful, if further improvement is possible, it would be useful
- Finding a lone VDR at that depth was on the edge of c. 2016 sensor technology but technology is advancing quickly.

Observations

- Remote area activities (Range and time on scene)
- Composition of investigative group, scientists, crew, technicians (How much berthing space is available?)
- Size and capability of assets (recovery and storage of wreckage—if you recovering large parts, you'll need deck space)
- Communications and information security
- Wreckage hazards (mooring lines, large area debris fields, etc.)
- Sensitivity to issues related to human remains and families
  - Families (NTSB Transportation Disaster Assistance coordinated communications with families)
- Operations in coastal waters—US contacted Bahamas for permission
  - Politics and government relations need to be handled properly
  - Media needs to be coordinated
- Cost control requires tight mission planning, commercial v. government costs are consideration
  - Commercial is more expensive, but more responsive time wise
  - Government takes longer, may be limited in capabilities, less expensive

Post-Action Observations - WHOI

- One size does not fit all – seek to develop best practice by consensus and via example – commercial service not yet viable in all cases
- Robust assessment and continuous willingness to modify should be built-into processes – Frequent interactions between the stakeholders
- Response time challenges (priority by agreement) but technology is resolving some of these.
- Common sensor suites – interfaces, data management/archive. Keeping advanced developments as an active part of the available tool-set.
- Prepare to adjust (telepresence, diversity and exposure of key staff to SOA capabilities)
- Exchanges of personnel between stakeholders via meetings and joint field trials open pathways – consider training for specific casualties only remotely appreciated (e.g. Polar ice?)

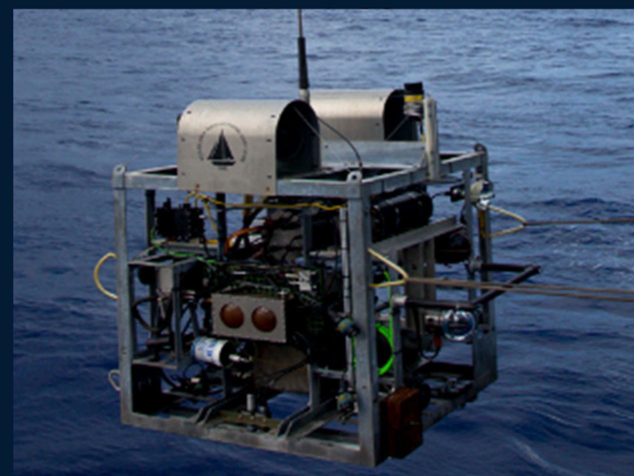
Why Am I Here?

- To present background and information regarding the search and survey of underwater wreckage, past present and future.
- Illustrate the importance of partnerships and begin planning for ocean operations (NTSB/USGC/Owners/WHOI/URI)
- To present some lessons from the El Faro experience and inform MAIIF members about considerations of aviation and marine accident ocean operations
- To ensure MAIIF members are prepared to benefit from the El Faro loss with a view into the technologies and techniques used
- To encourage MAIIF members to consider what they would do and engage in helpful discussions relating to similar future events

International Collaborations

Specifications:

ISIS ROV



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Sentry AUV

- Depth: 6000m
- Extreme maneuverability
- Top Speed: 2.0knts
- Payload: 155lbs in sea water
- Endurance: >60hrs @1.4knt, >28hrs @ 2knt
- Multibeam, sidescan, camera, sub-bottom, water chemistry, magnetics, and other sensors standard
- Can integrate custom sensors and new missions

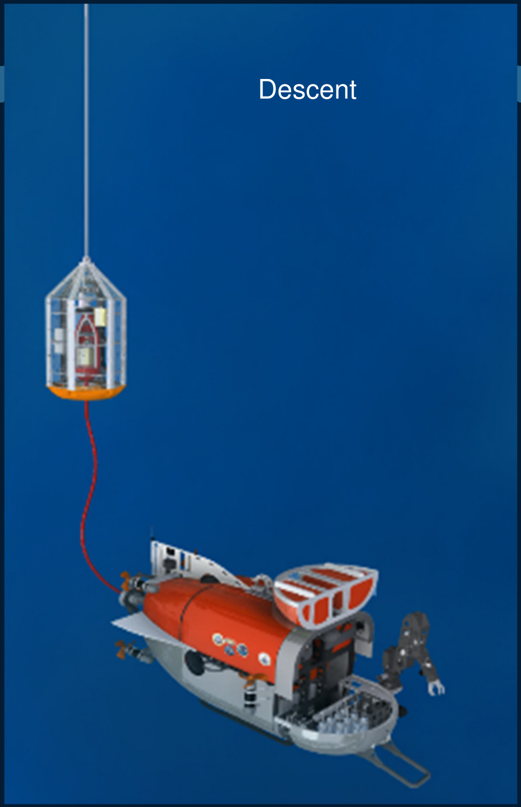
- 430 Dives with dedicated operators
- Nearly 12,000 km total km of survey track
- More than 6000 hours in the water

Woods Hole Oceanographic Institution

Observation Vehicle

Alvin Observation Vehicle

- First developed and used in 2007 as Arctic Sampling/Imaging Vehicle
- Modified in 2013 to serve as Alvin Observation Vehicle
- El Faro:
  - still camera borrowed from OSL
  - Added telemetry bottle borrowed from Singh Lab
  - HD camera and sonar from Alvin,
  - Used software from Jason and Alvin systems
- Used for visual verification/location and hull/debris inspection



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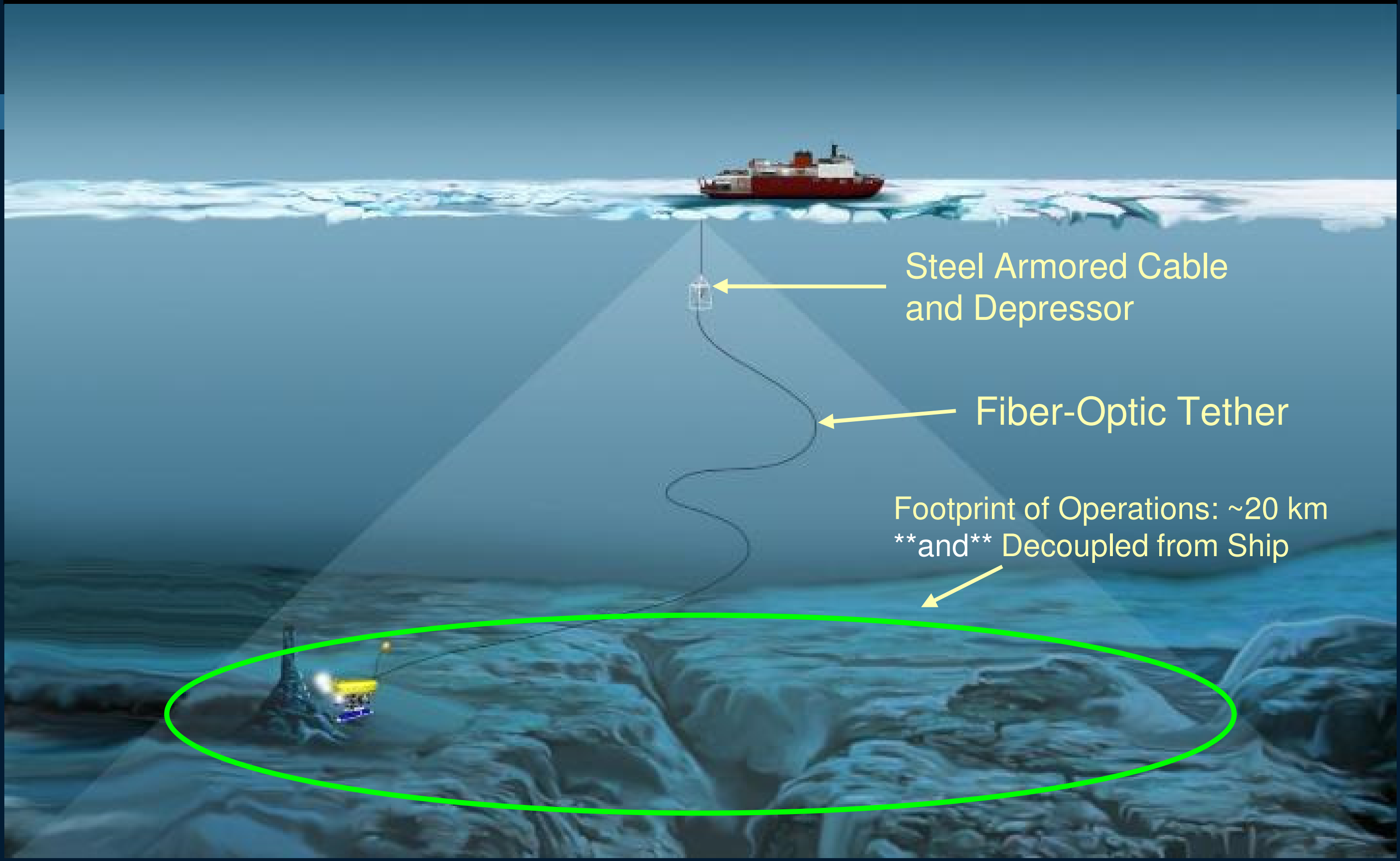
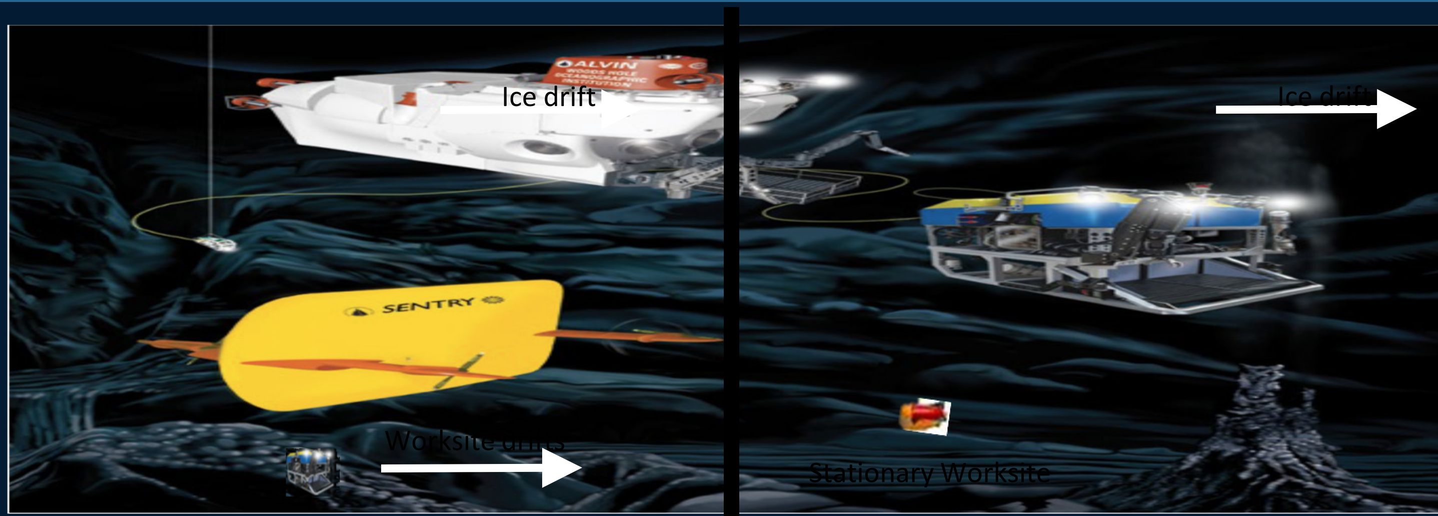
Concept of Operations: Seafloor Interface



Bridge Class Ships

Woods Hole Oceanographic Institution

Decoupling vehicle from vessel enables ROV operations under ice

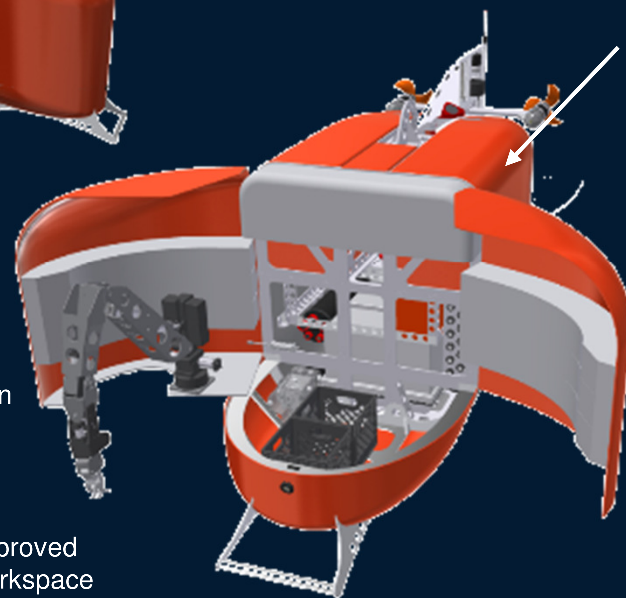


Conventional Tether
(<1 km)

Micro-Tether
(20 km)

NUI's depth rating is being increased to 5000 m in preparation for 2019 fieldwork

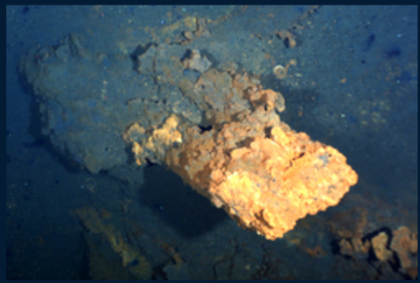
Al 6061 housings replaced with Al 7075 housings



5000 m Foam Pack

In situ conversion between AUV and ROV configurations

Improved workspace



Aurora Hydrothermal Field, Gakkel Ridge, 82 N [Boetius et al., 2014]

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Events During the Cold War Drive Deep Sea Technology

USN Thresher
1963


New York Times.

LATE CITY EDITION

ATOM SUBMARINE WITH 129 LOST IN DEPTHS 220 MILES OFF BOSTON; OIL SLICK SEEN NEAR SITE OF DIVE

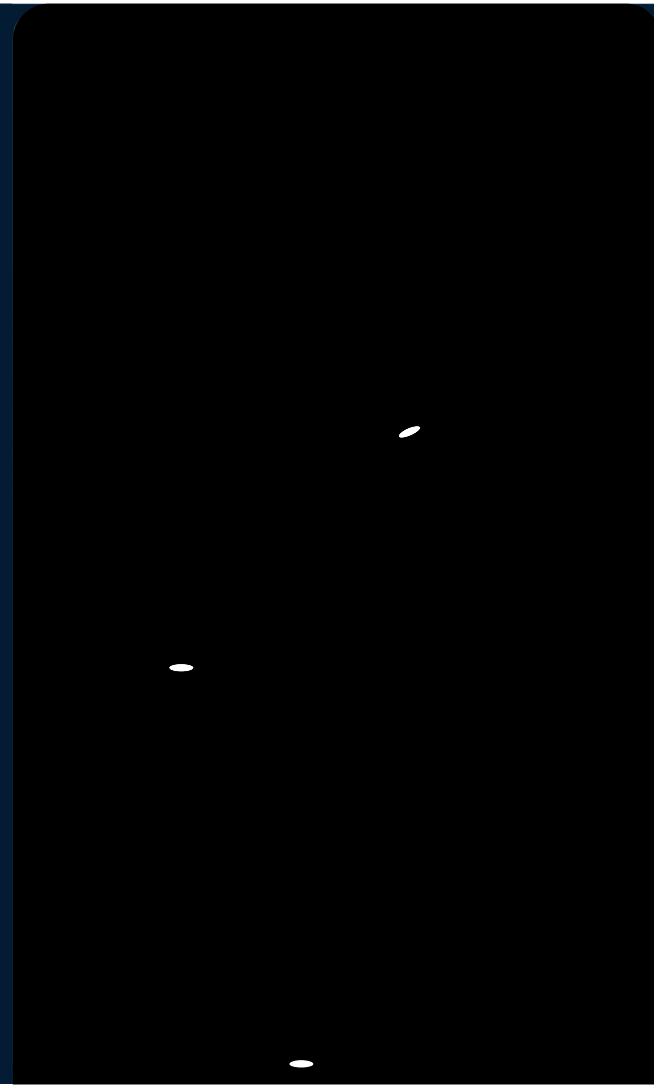
THRESHER HUNTED

Rescue Craft Search Area of Last Test in 8,400-Foot Water

House Votes Works Plan; Backs President, 228-184

Loss of Naval submarines in the 1960/70s demand advances in the technology used to search and survey the deep ocean

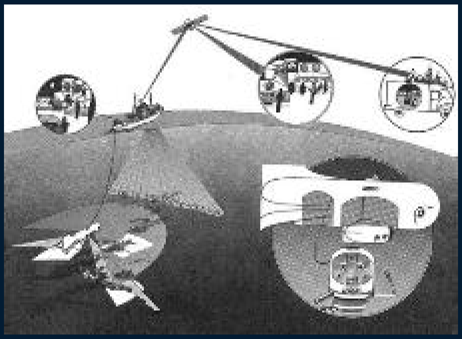
State of the Art
in the 1960-70s



Deep Submergence Evolves

Dr. Robert Ballard builds a team

Argo/Jason System



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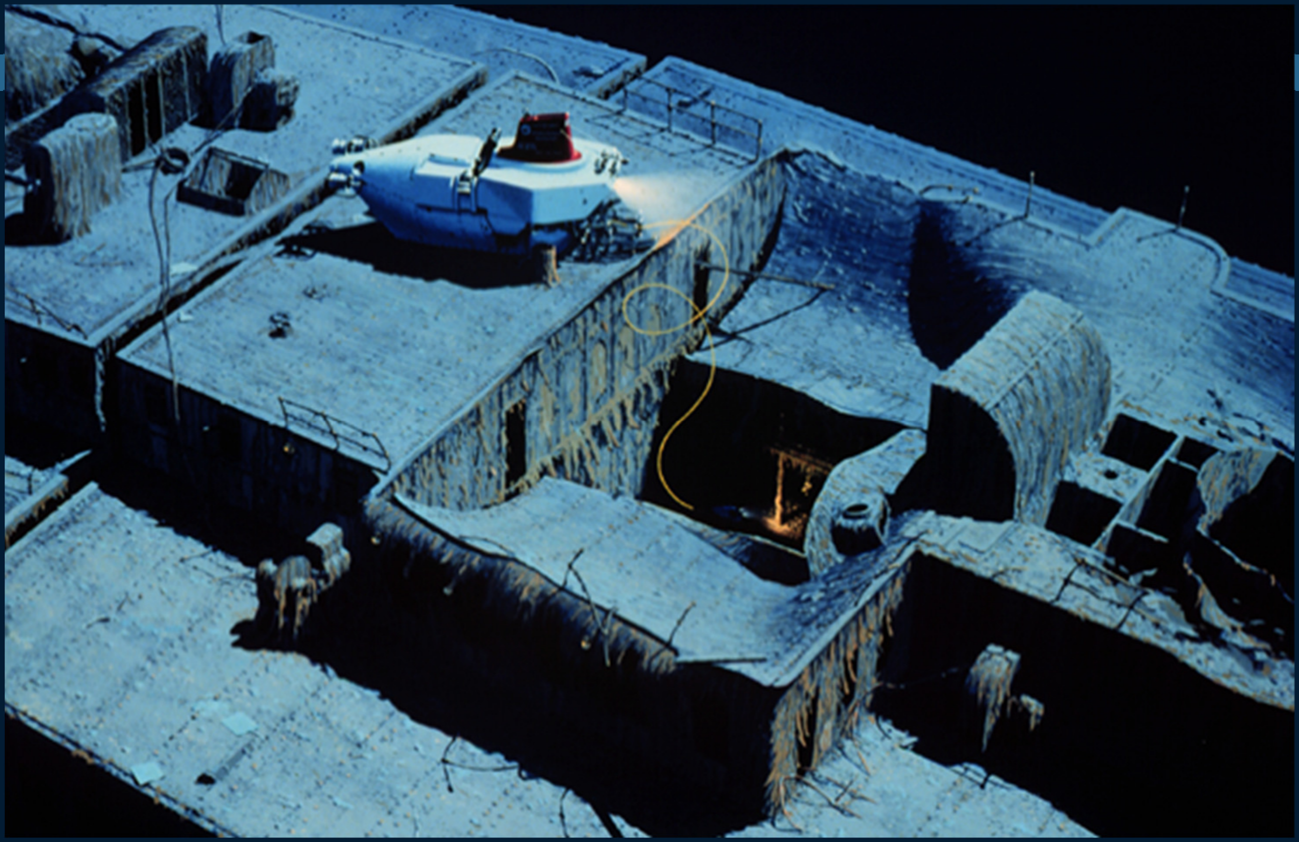
Exploring Titanic



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