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Capping a Subsea Blowout Is Not Rocket Science – Or Is It?

Andy Cuthbert

HALLIBURTON
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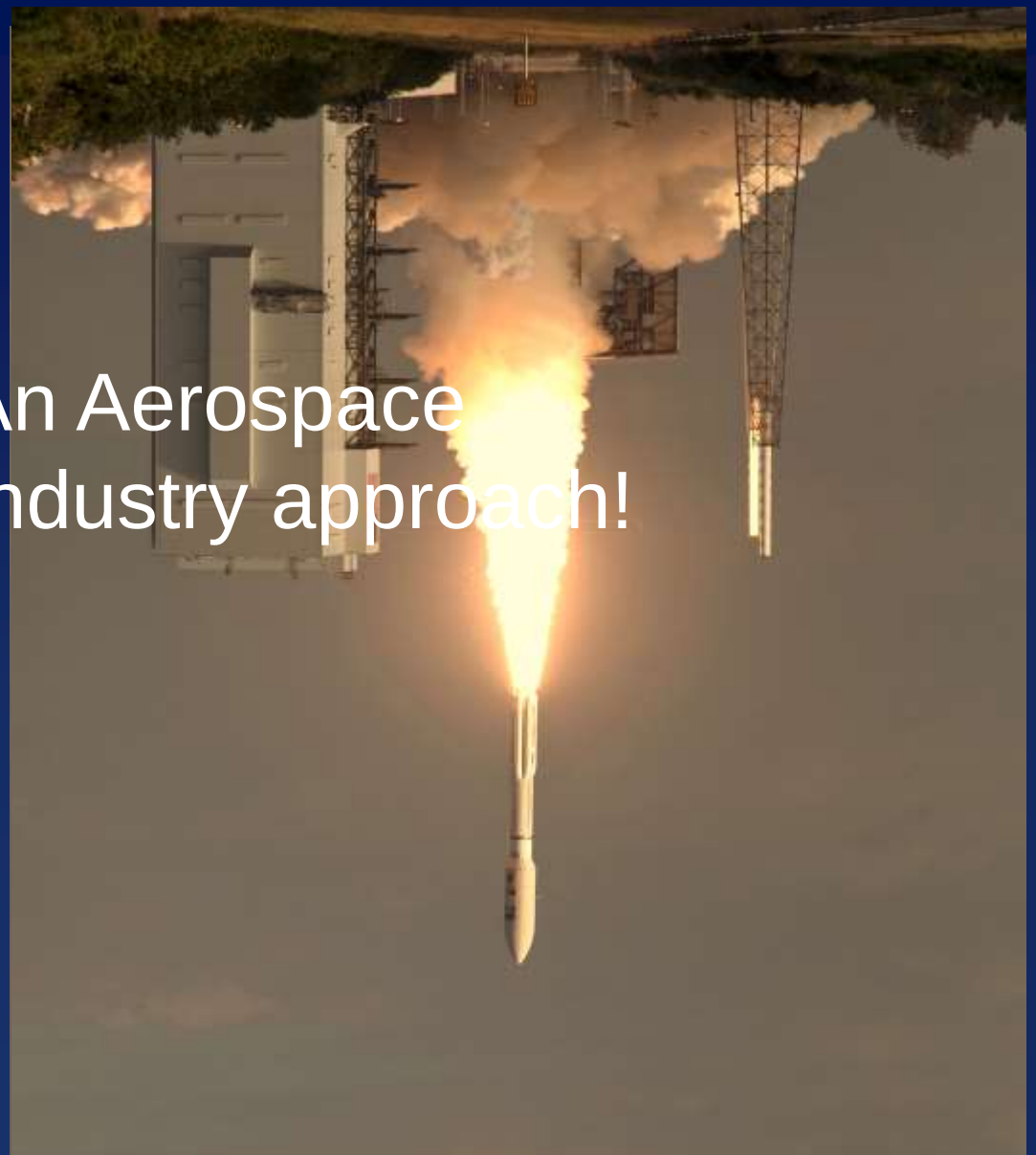
Seeking a Solution



An Aerospace Industry approach!

Plume Characteristic Modeling

Plume simulation based on actual field evidence and footage

Selection and design of operational capping concept for location and blowout specifics

Surface resource deployment operations for capping stackn

- Examination of actual field data.
- Use of computational fluid dynamics based on exit conditions.
- Simulated plume characteristics.

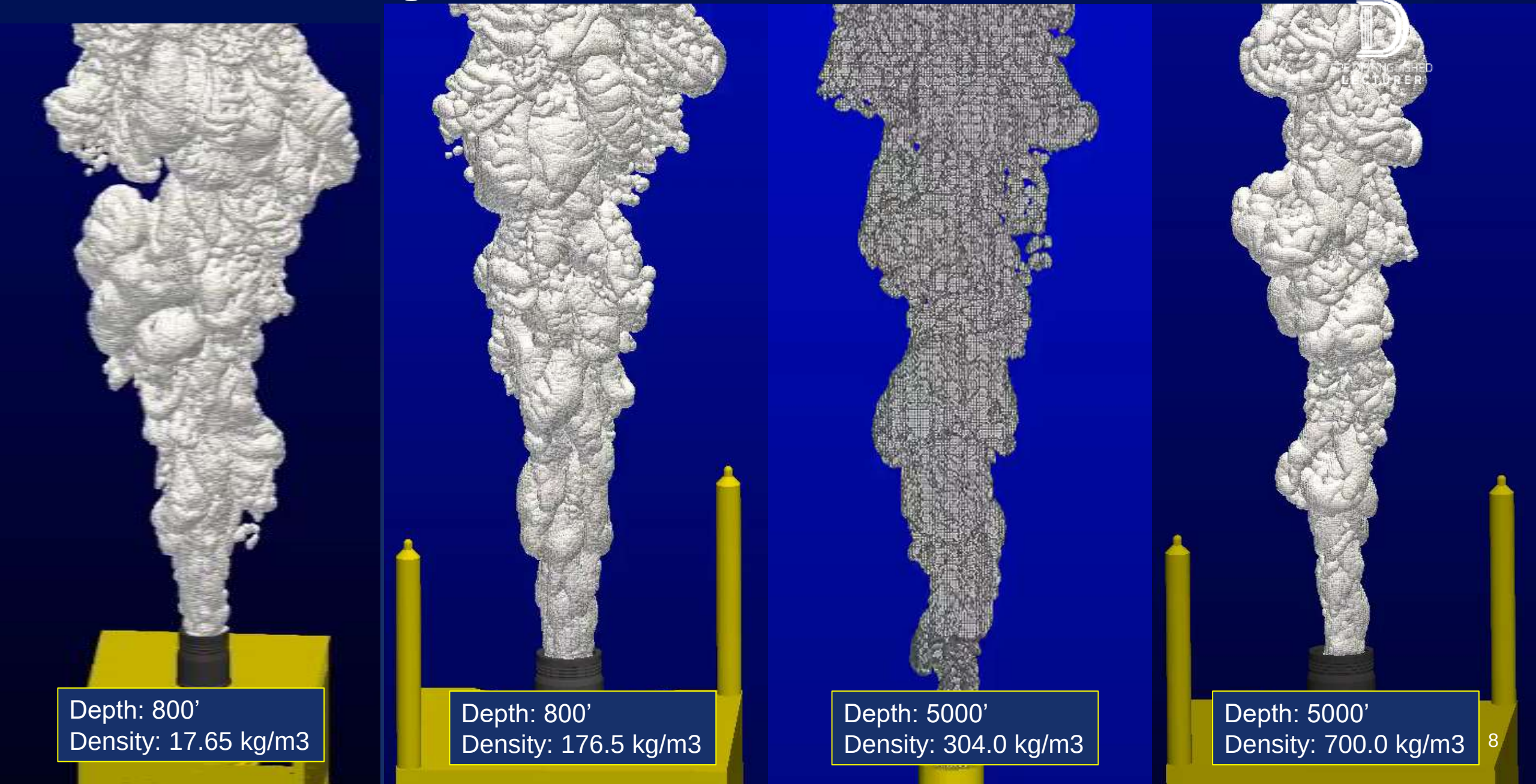
Shallow Water High GOR Blowout Simulation

ROV Footage

300MM scfd Simulation

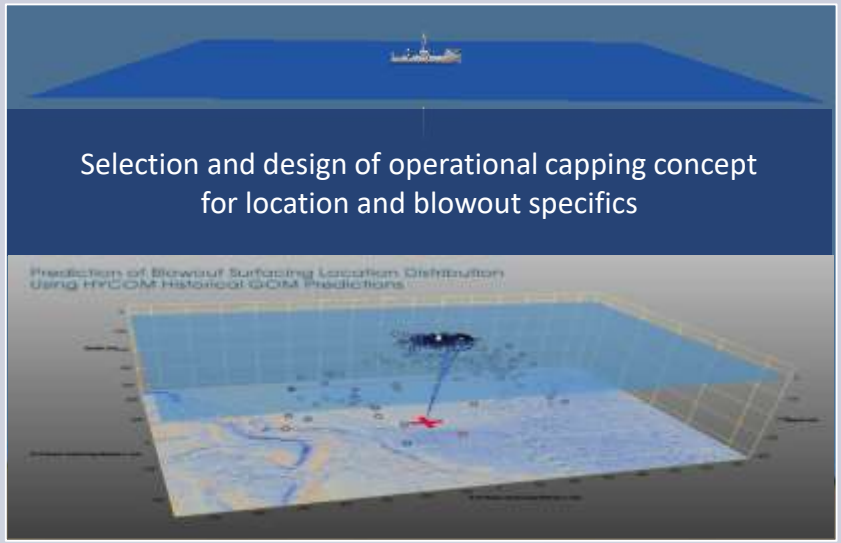
Deepwater Oil Blowout Simulation

Simulate Full Range GOR on Plume



Deployment Considerations

Plume simulation based on actual field evidence and footage



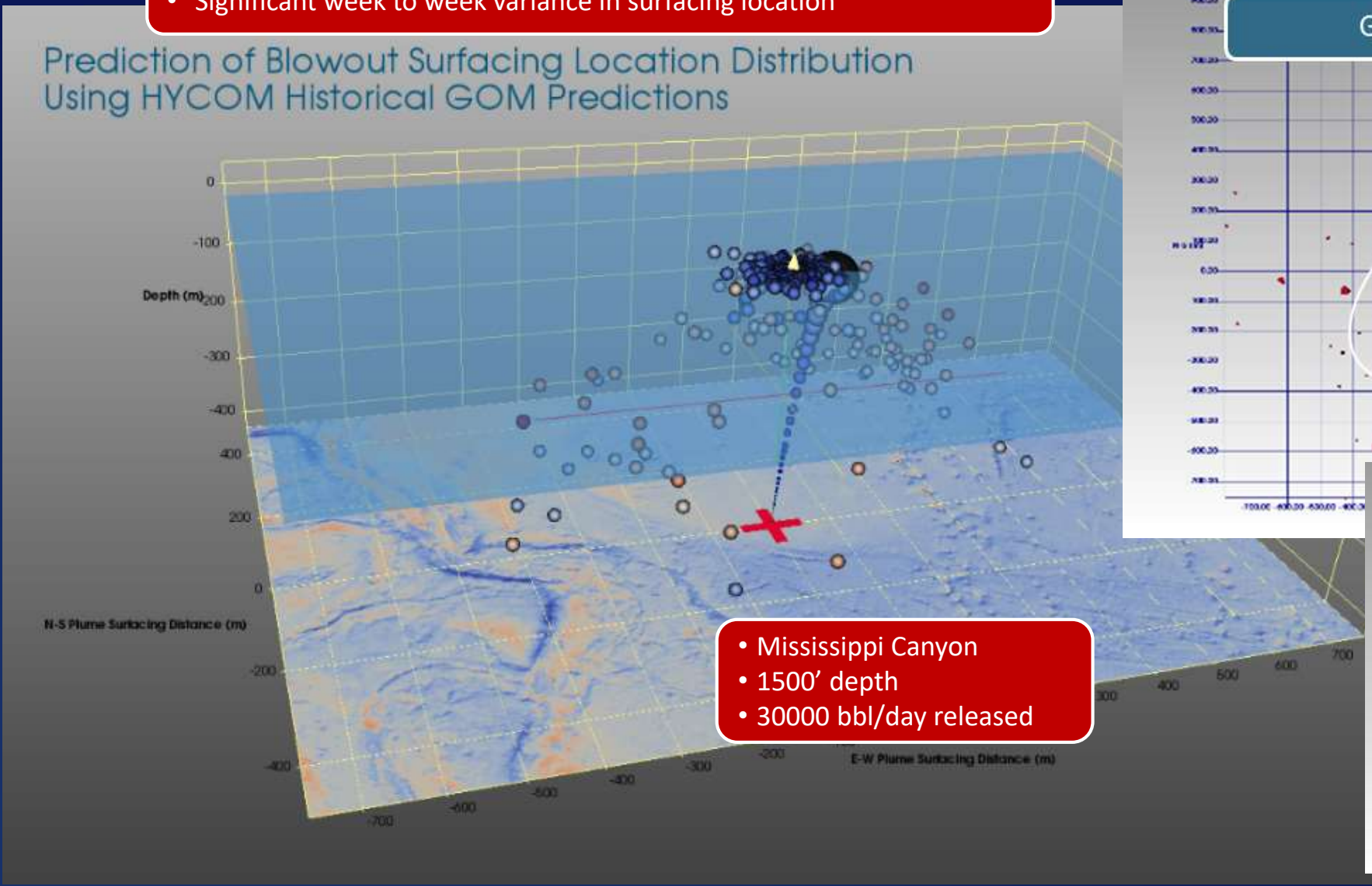
Selection and design of operational capping concept for location and blowout specifics

Surface resource deployment operations for capping stack

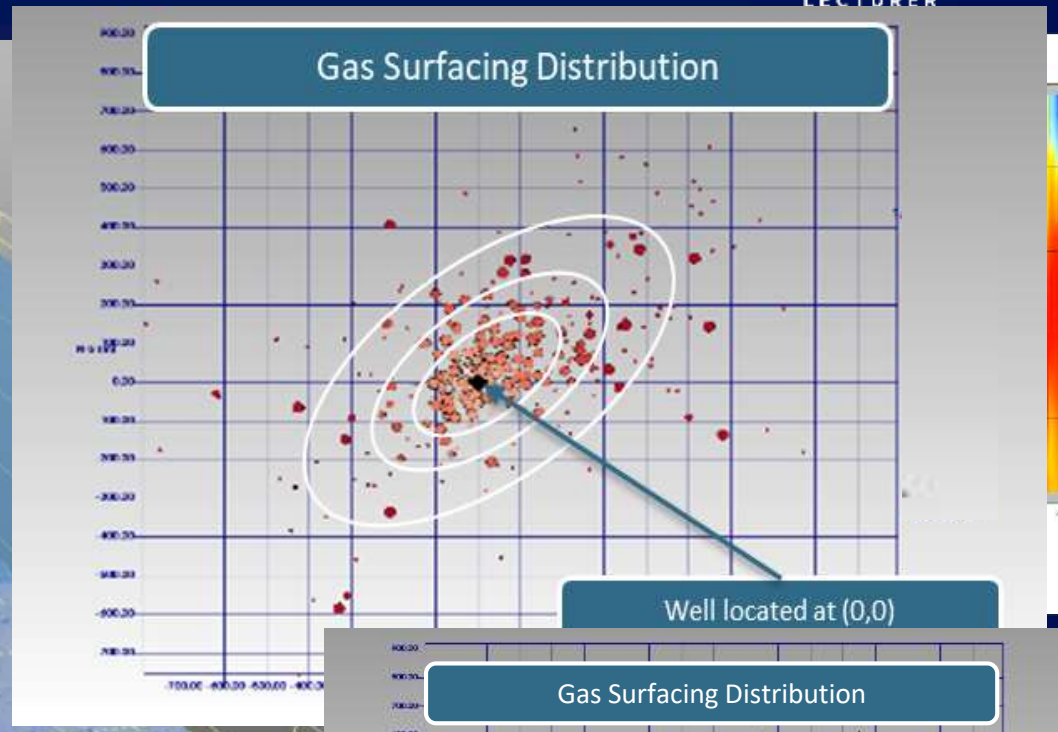
- Defining capping concept based on blowout specifics.
- Analyzing geographical metocean conditions.
- Seasonal / diurnal considerations.

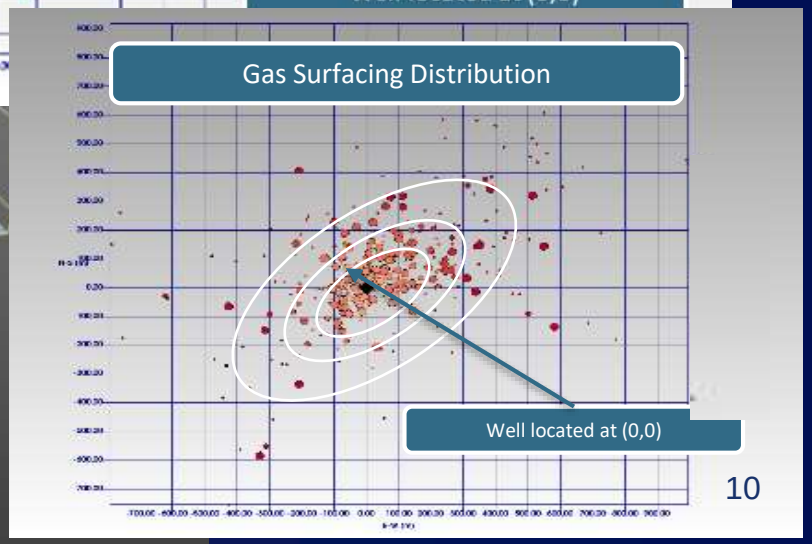
Effect of Metocean Conditions

- Simulations from 4/01/2009 to 9/1/2014
- Significant week to week variance in surfacing location



- Mississippi Canyon
- 1500' depth
- 30000 bbl/day released

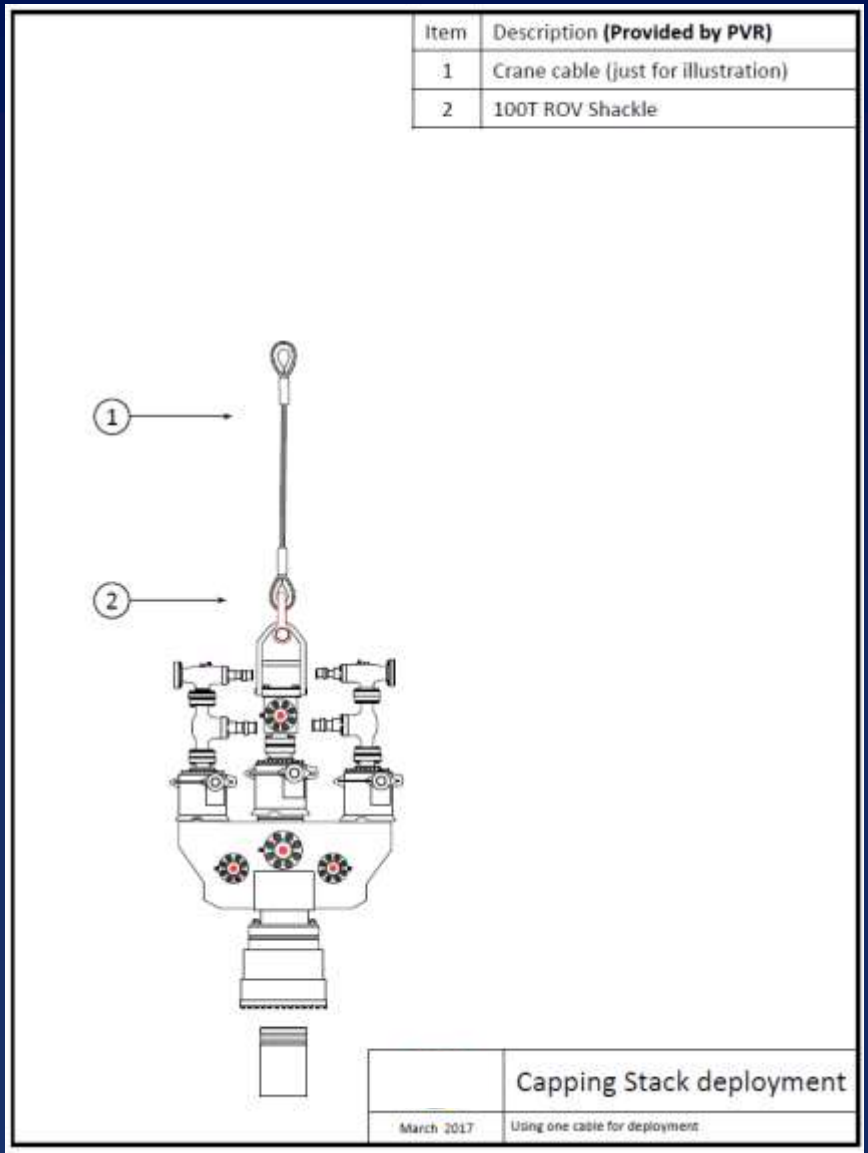




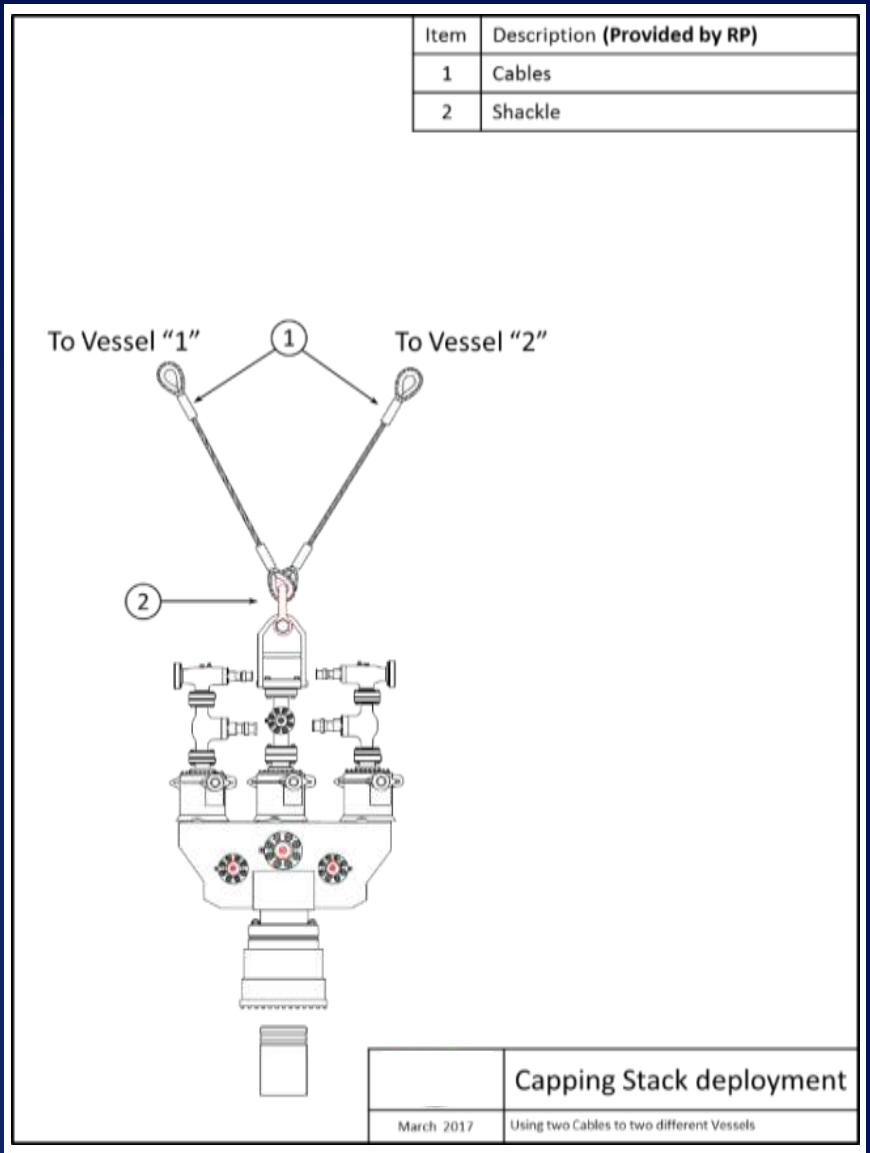
Deployment Vessel Operations

- Impact of metocean conditions transmitted across hull geometry.
- Reaction of heave compensation to blowout induced loading on capping stack.
- Reaction of deployment cable to fluctuating stack loading.
- Combined cross-current dynamic loading of surface vessel and plume.
- Remotely Operated Vehicle (ROV) multi-body interaction with capping stack in plume.

Deployment Methods



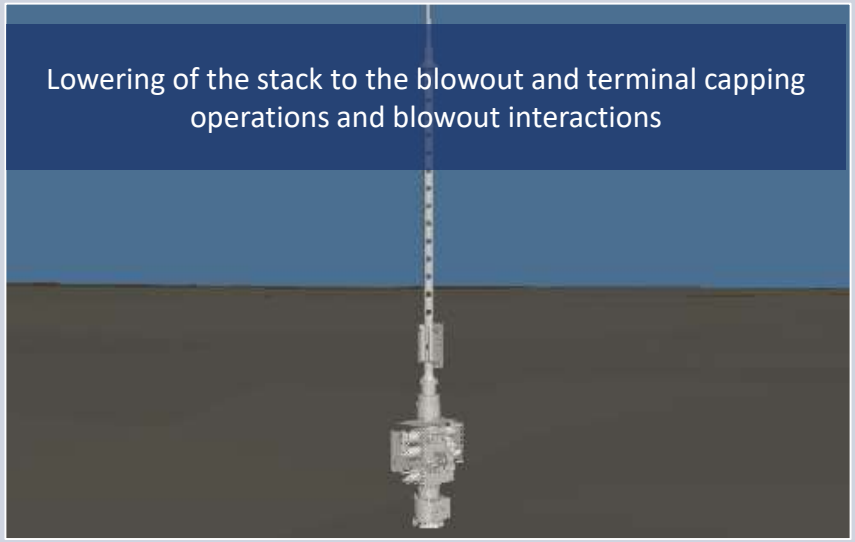
Vertical Cable Deployment



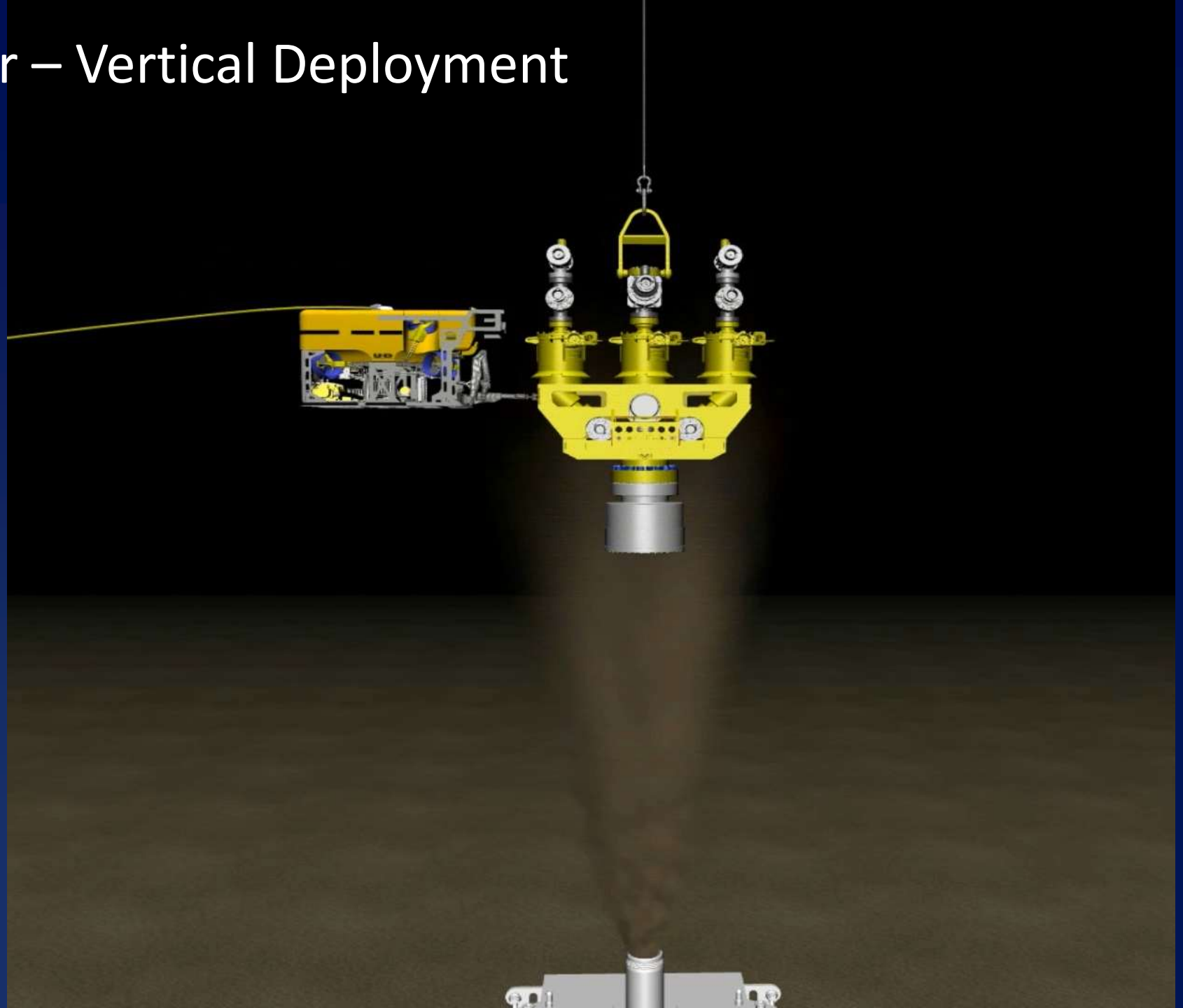
Offset Cable Deployment

Suspension System Dynamics

- Prediction of stack loading as a function of depth, flow rate, GOR, and stack specifics.
- Fully coupled system dynamics and specific risks.
- ROV interactions in near-jet operations and subsea current.
- Combined dynamics of the system, movement tolerances.



Deepwater – Vertical Deployment



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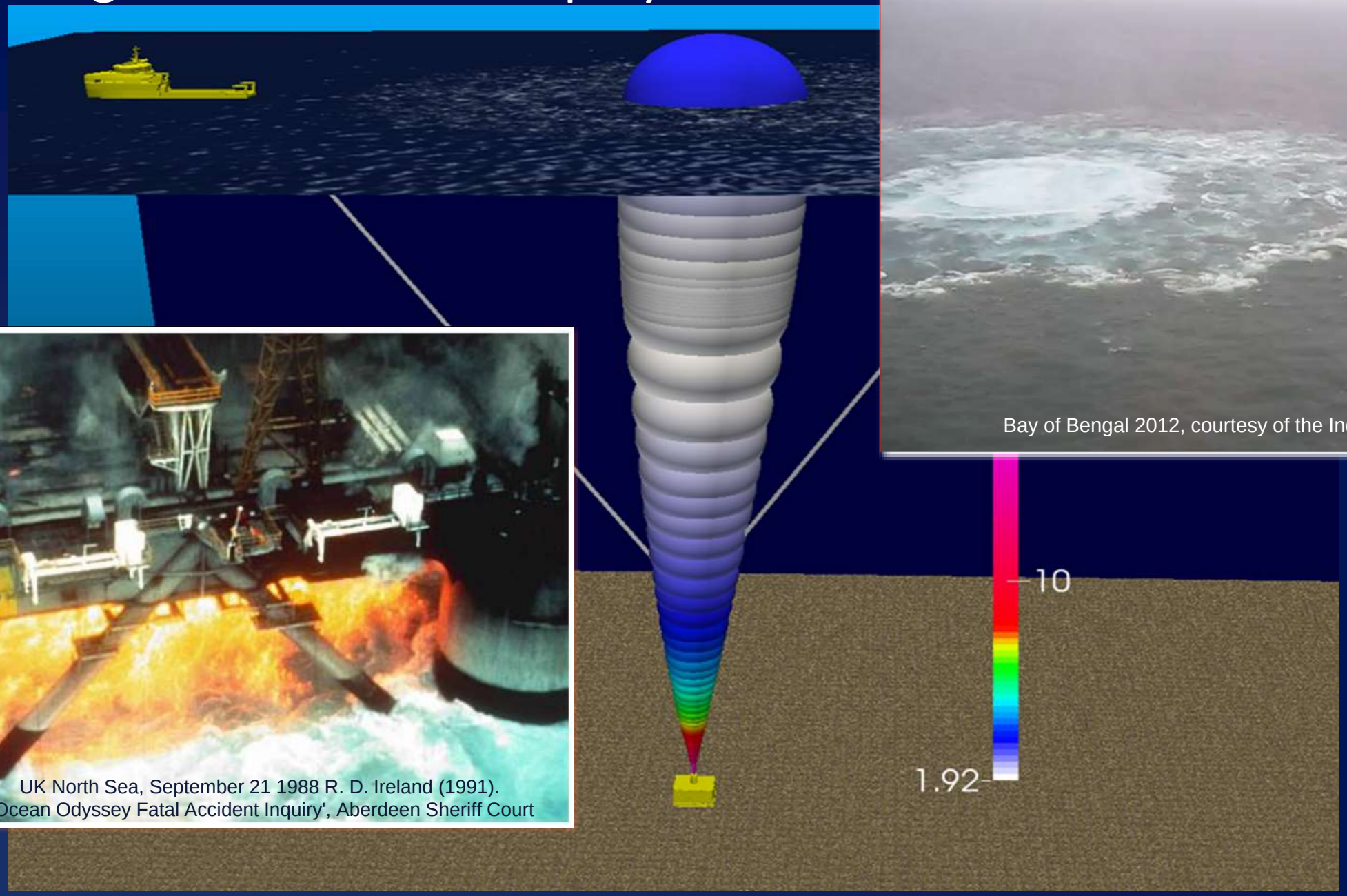
Surfacing Plume – Offset Deployment



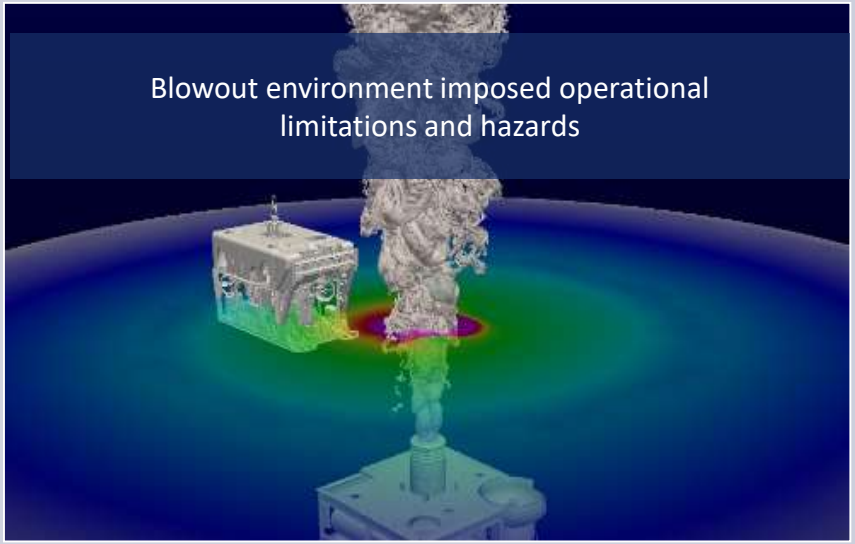
Bay of Bengal 2012, courtesy of the Indian Air Force,

UK North Sea, September 21 1988 R. D. Ireland (1991).
'Ocean Odyssey Fatal Accident Inquiry', Aberdeen Sheriff Court

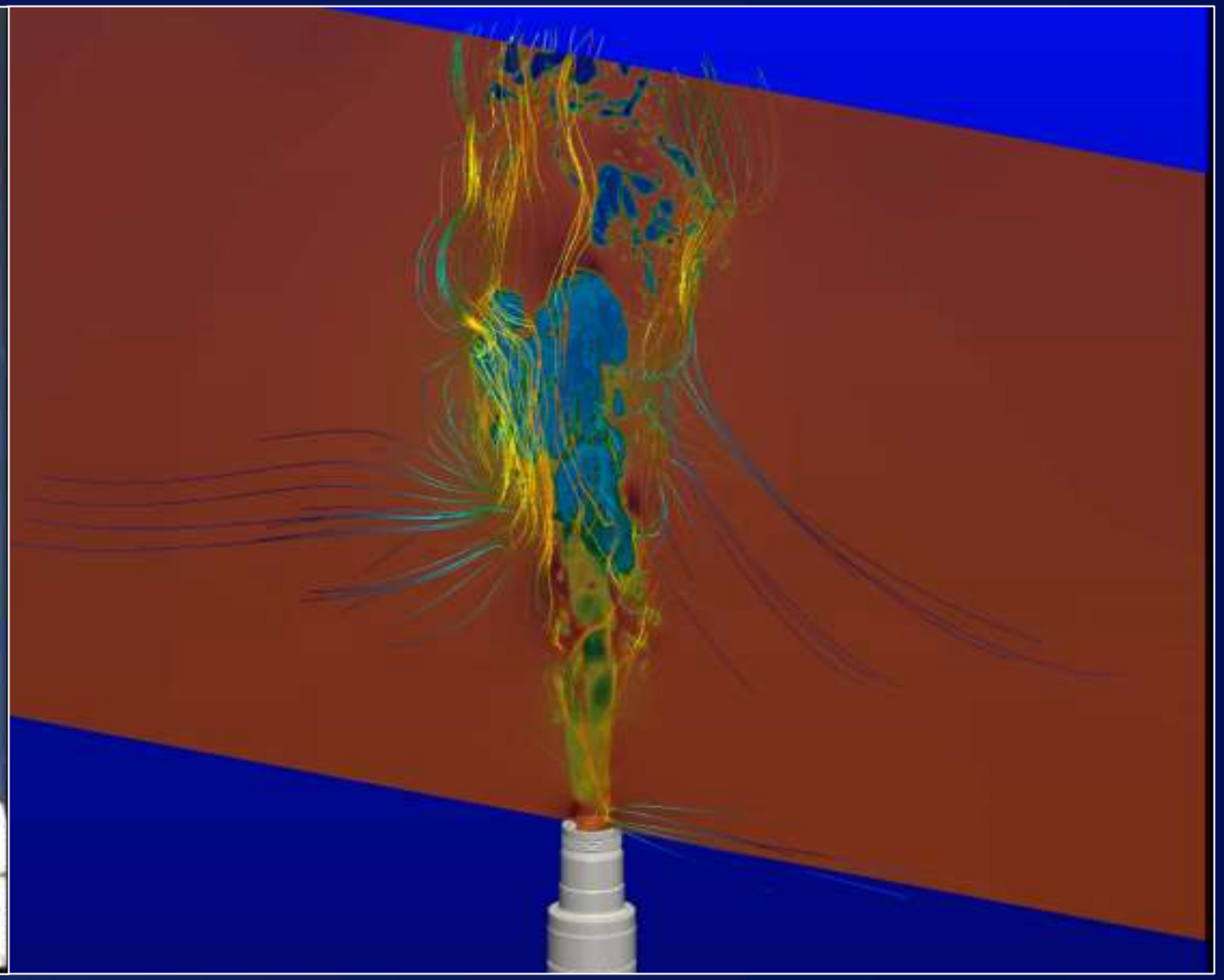
Surfacing Plume – Offset Deployment

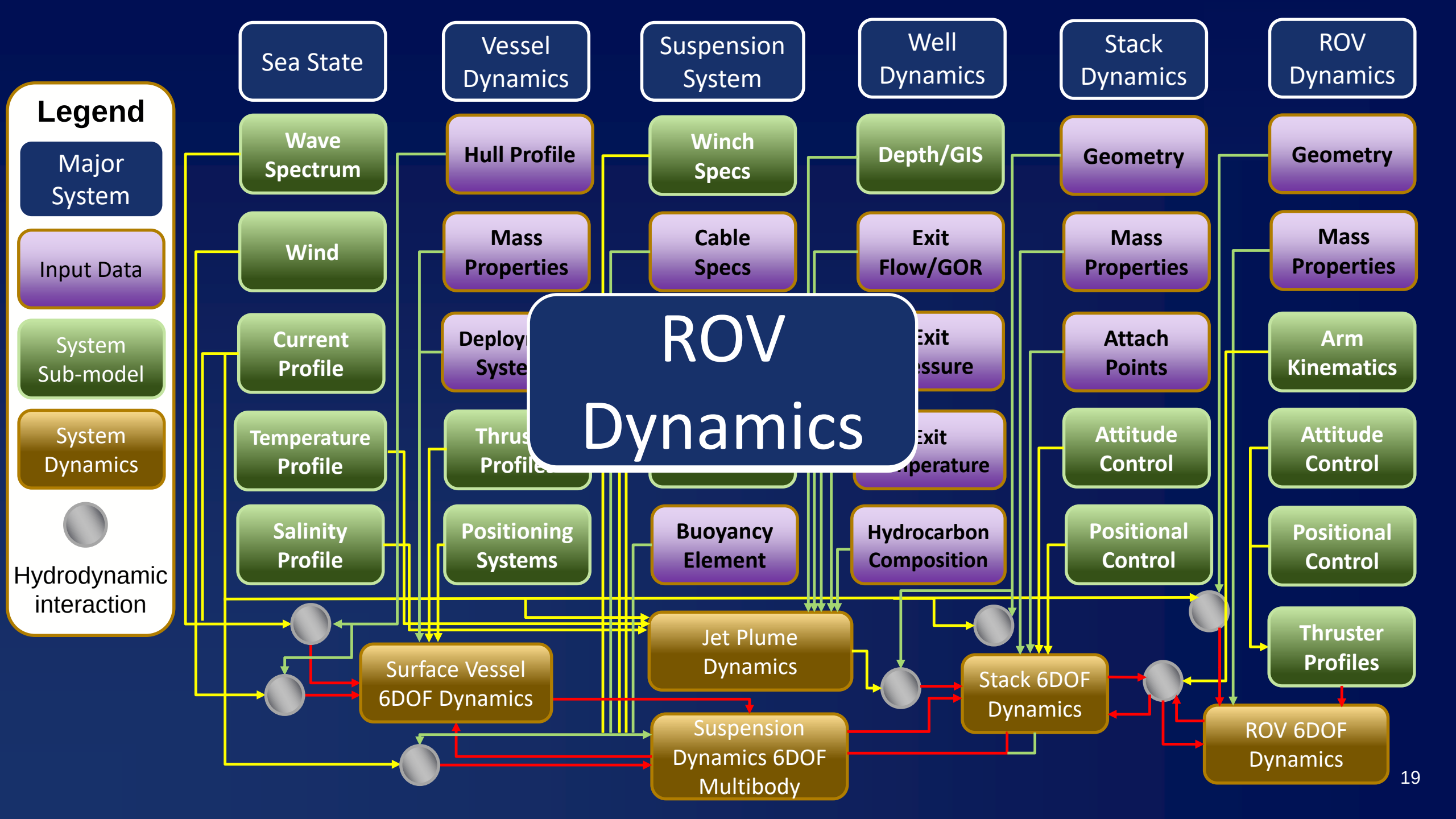
Flowfield Operations

- Reaction of control systems as the stack enters the plume.
- Blowout flowfield induced operational limits.
- Additional blowout hazards to successful capping operations.

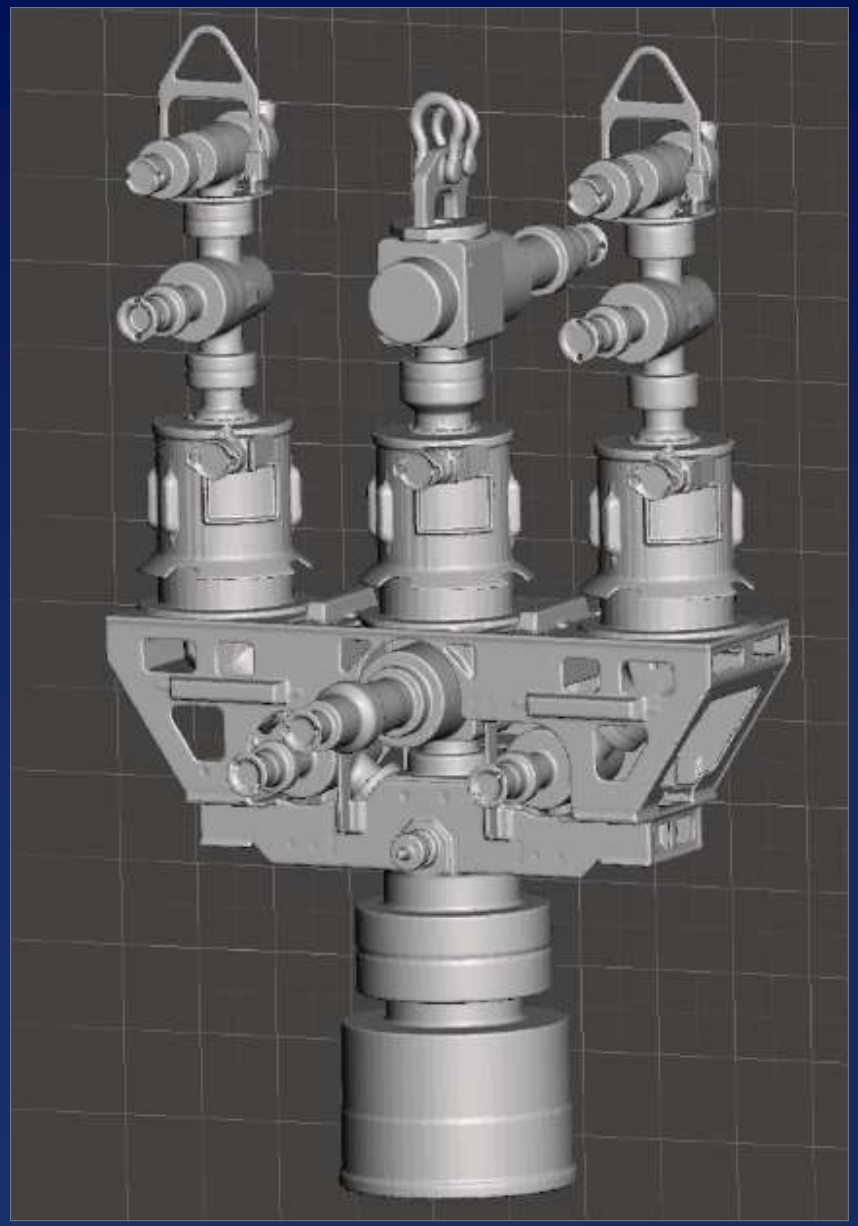


Operational Awareness

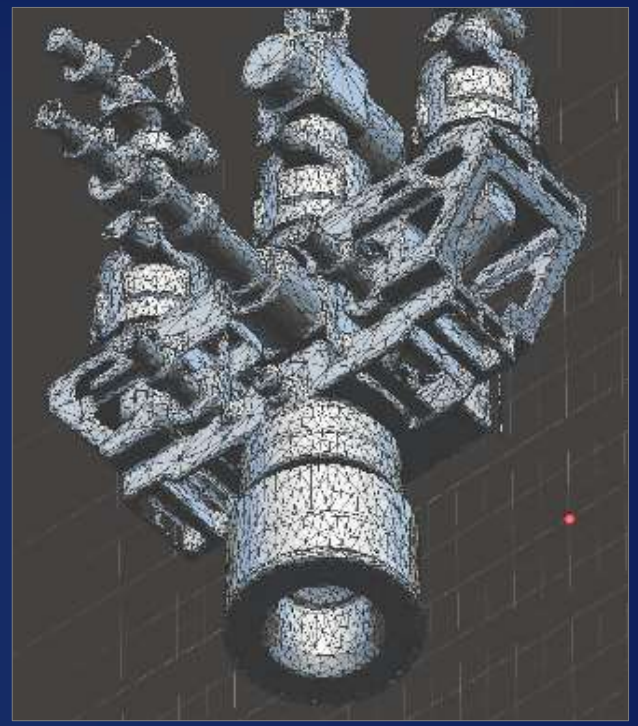


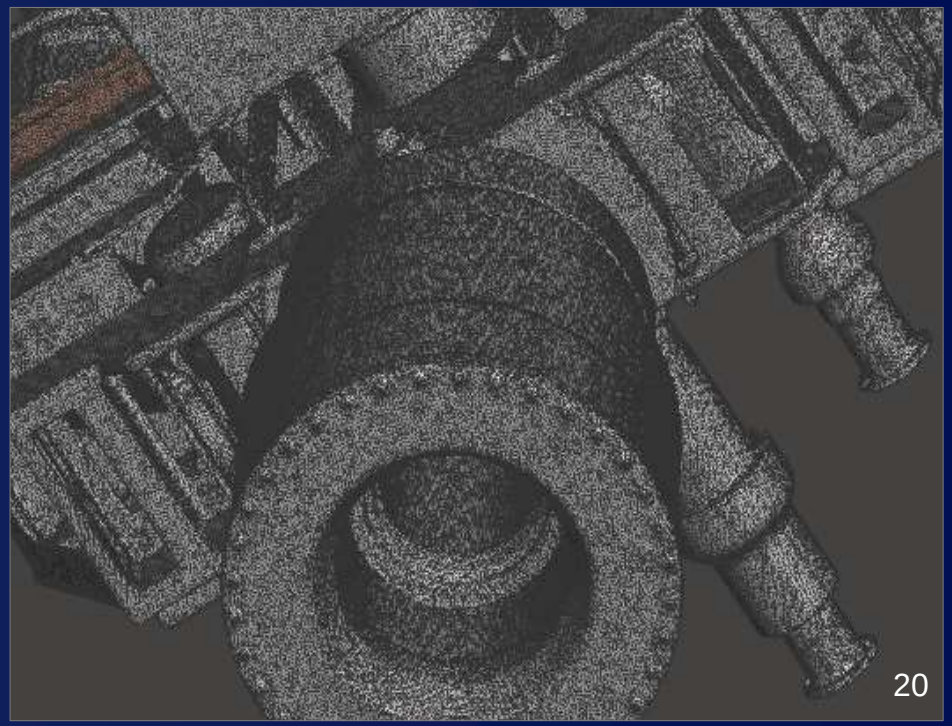

Legend
Major System
Input Data
System Sub-model
System Dynamics
Hydrodynamic interaction
Sea State
Vessel Dynamics
Suspension System
Well Dynamics
Stack Dynamics
ROV Dynamics
Wave Spectrum
Wind
Current Profile
Temperature Profile
Salinity Profile
Hull Profile
Mass Properties
Positioning Systems
Winch Specs
Cable Specs
Buoyancy Element
Depth/GIS
Exit Flow/GOR
Hydrocarbon Composition
Geometry
Mass Properties
Attach Points
Attitude Control
Positional Control
Geometry
Mass Properties
Arm Kinematics
Attitude Control
Positional Control
Thruster Profiles
ROV Dynamics
Surface Vessel 6DOF Dynamics
Jet Plume Dynamics
Suspension Dynamics 6DOF Multibody
Stack 6DOF Dynamics
ROV 6DOF Dynamics

Rigid Body Modeling



- Overset grid methodology.
- OpenFLOW CFD derivative - Caelus.
- Coupled Caelus flow solver with Chrono dynamics.
- Simulation time-step to avoid anomalies.

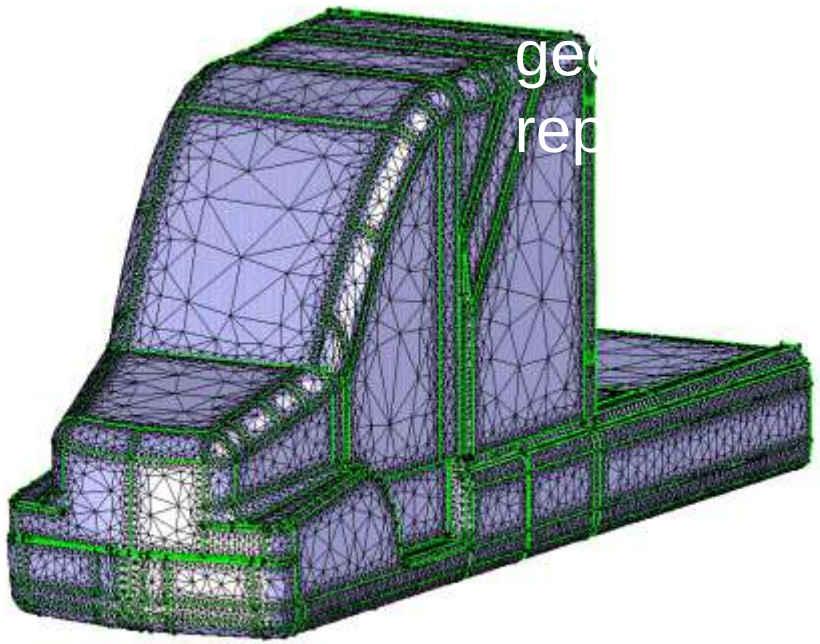




Overset Grid & Caelus Flow Solver

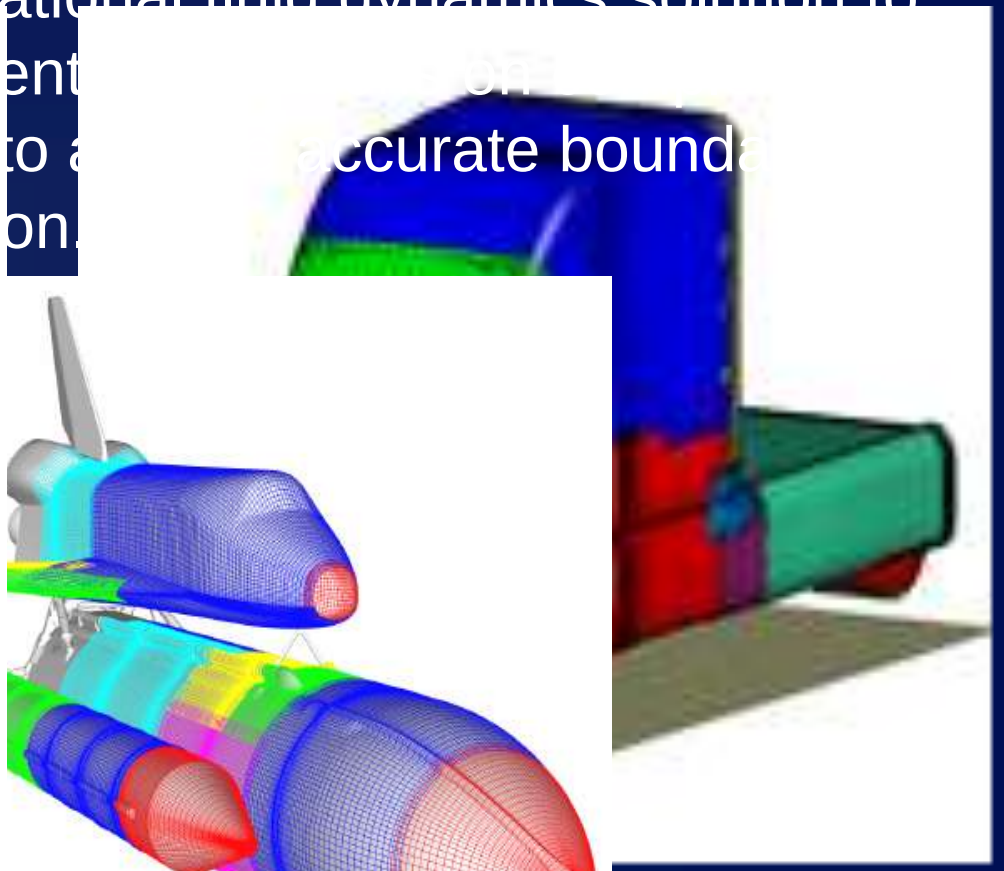
Overset grids provide high quality, fast moving grid generation, using rapid and memory efficient algorithms.

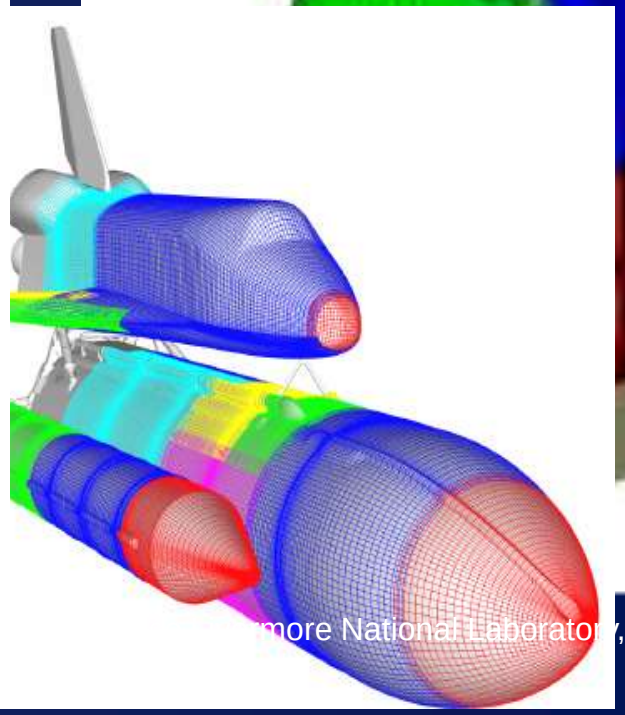
Global Triangulation



Caelus: computational continuum mechanics and computational fluid dynamics solution to

Overlapping Grid





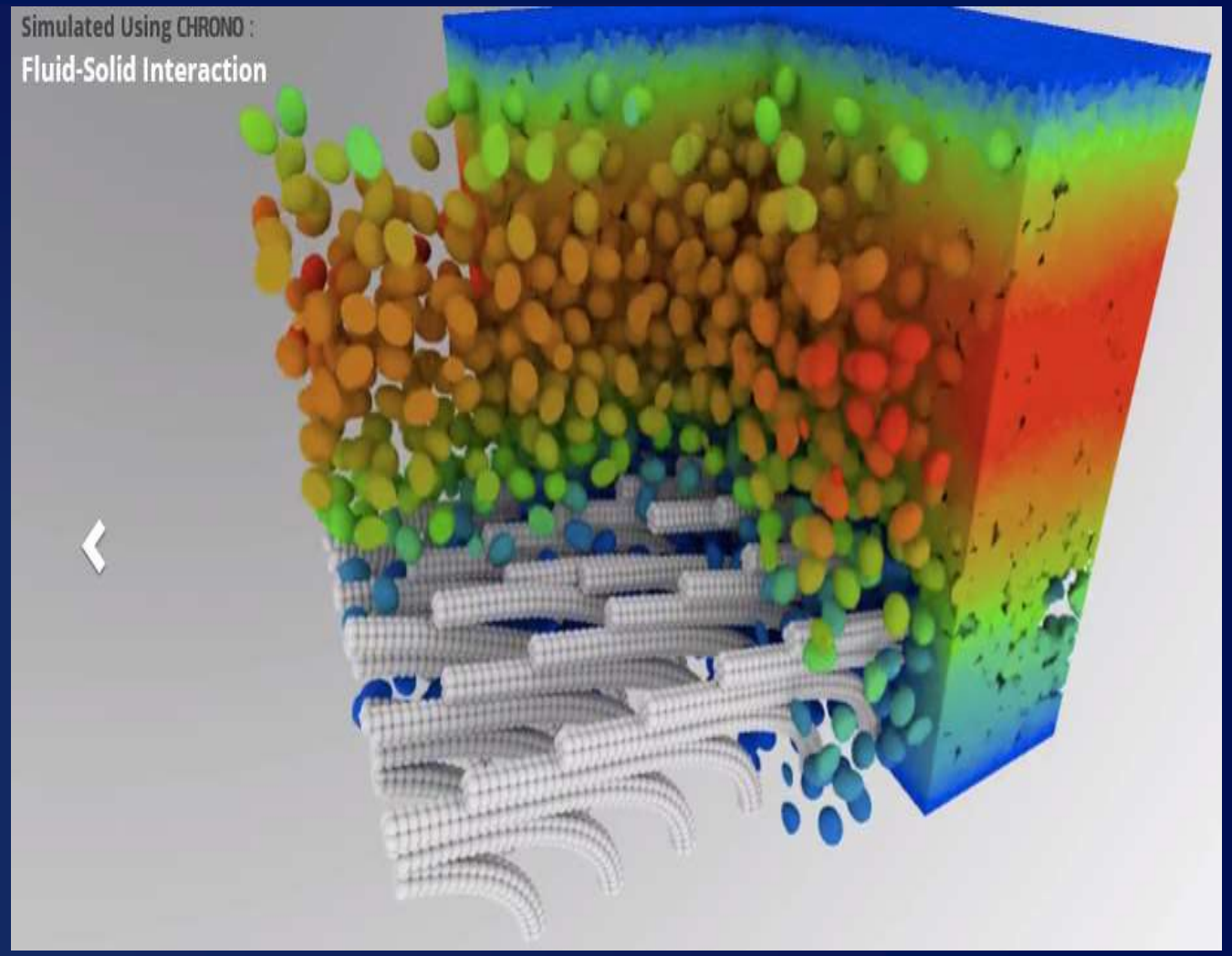
Courtesy of Bill Henshaw, Center for Applied Scientific

more National Laboratory, CA

Space shuttle images courtesy of William Chan, NASA Ames Research Center and Reynaldo Gomez, NASA Johnson Space Center

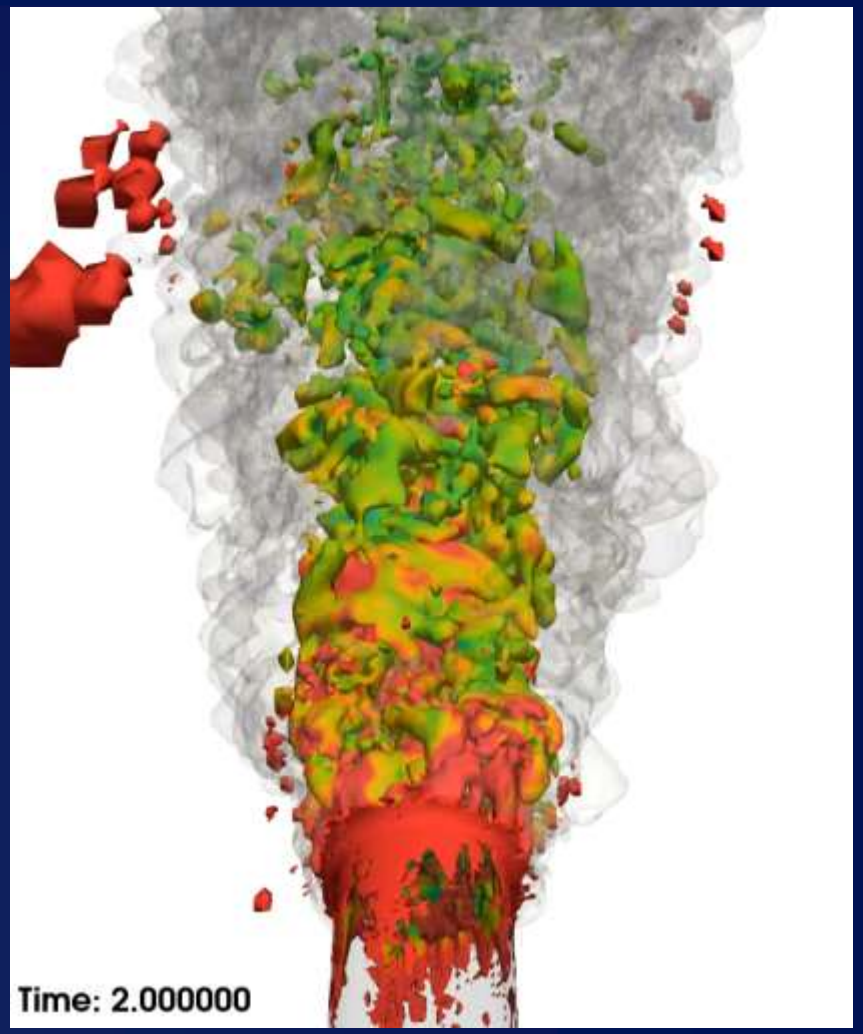
Chrono Dynamics Software

Chrono Dynamics: multibody simulation tool, supports rigid and soft body dynamics, finite element analysis (FEA) and collision detection (FSI) dynamics.

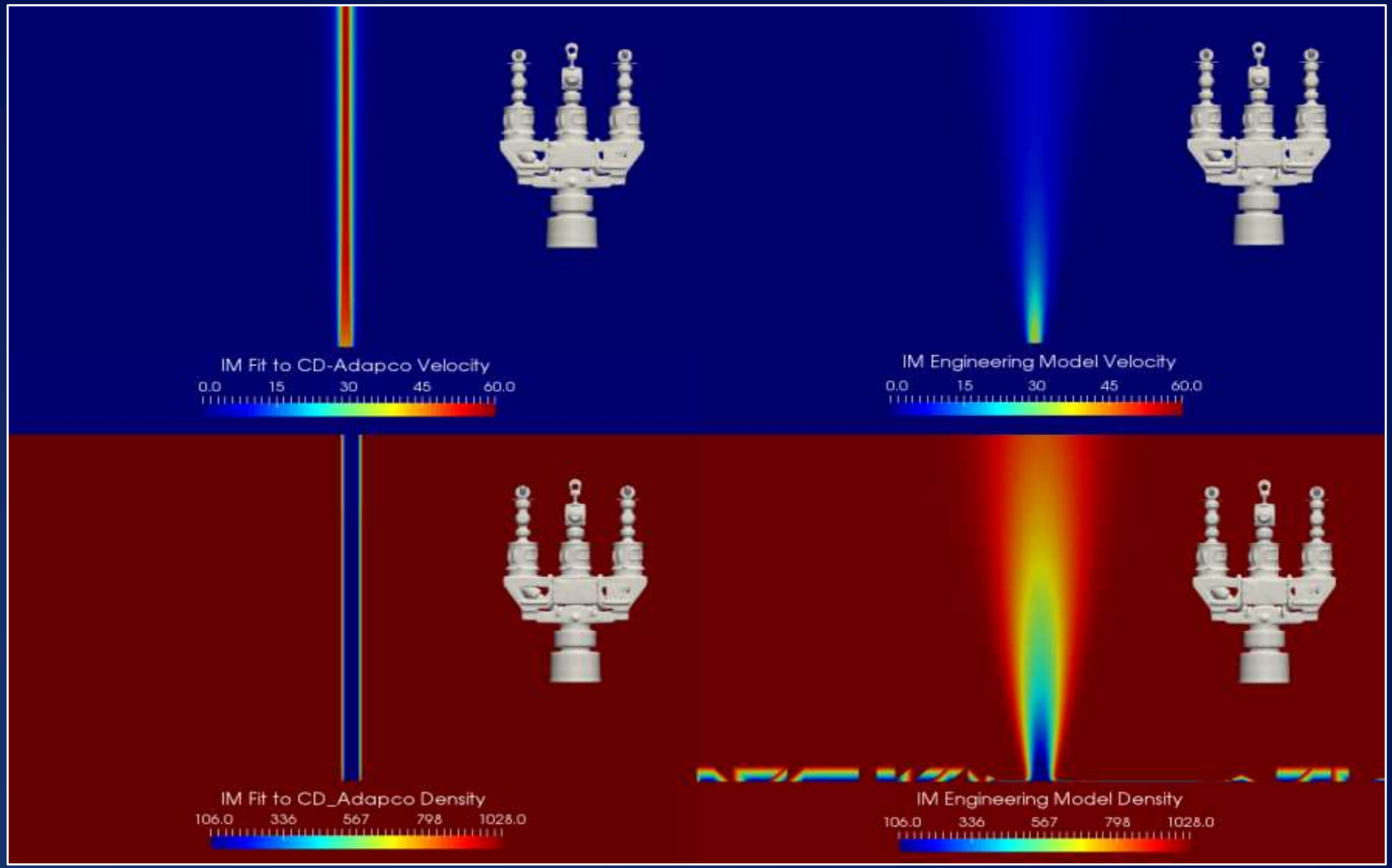


Case Study 1

- Use “as-built” geometry
- Perform stack flowfield analysis with fully coupled CFD/Dynamics solver
- Perform simulation at “Worst Case” flow conditions:
  - 5000ft. water depth
  - 3.25 Bscf/day
  - Release density of 130kg/m^3
  - Turbulent flow release (Re > 2300)
- Evaluate and reproduce industry accepted flowfield analysis capability



Comparison with Existing Landing CFD



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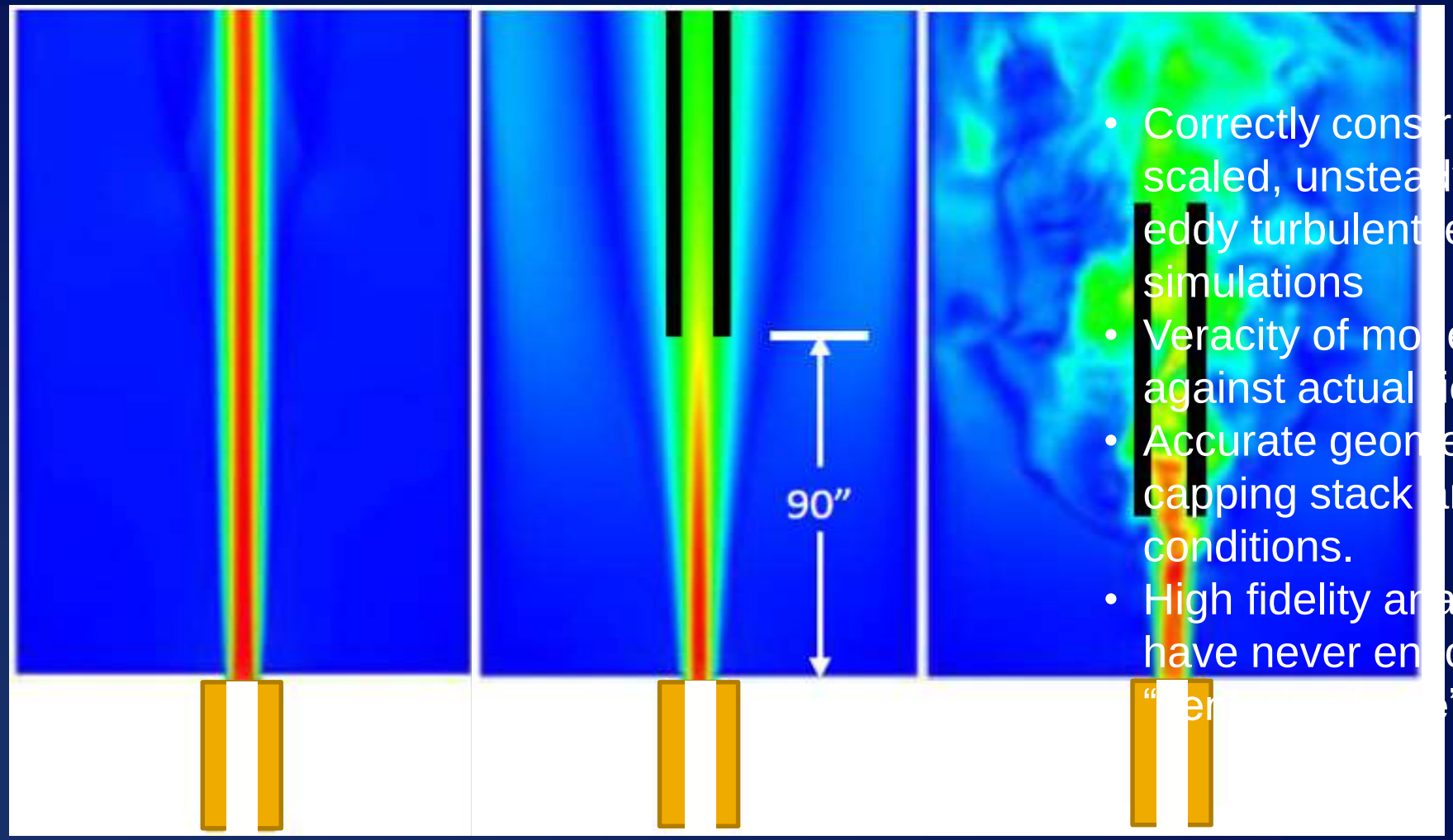
Myths & Legends – "Centering Force"

- Red area represents "core flow"
  - High momentum
  - Stable flow
  - Strong gradients
  - Core flow ends 5 – 7 exit diameters downstream
- Exit velocity drops at $1/D_{exit}$

Industry "Standard" (Centering Force)	Engineering Model (Analytical Average)	OpenFOAM Turbulence Model



- Correctly constructed, scaled, unsteady, large eddy turbulent jet simulations
- Veracity of modeling against actual field data
- Accurate geometries, capping stack and exit conditions.
- High fidelity analyses have never encountered "[illegible]"

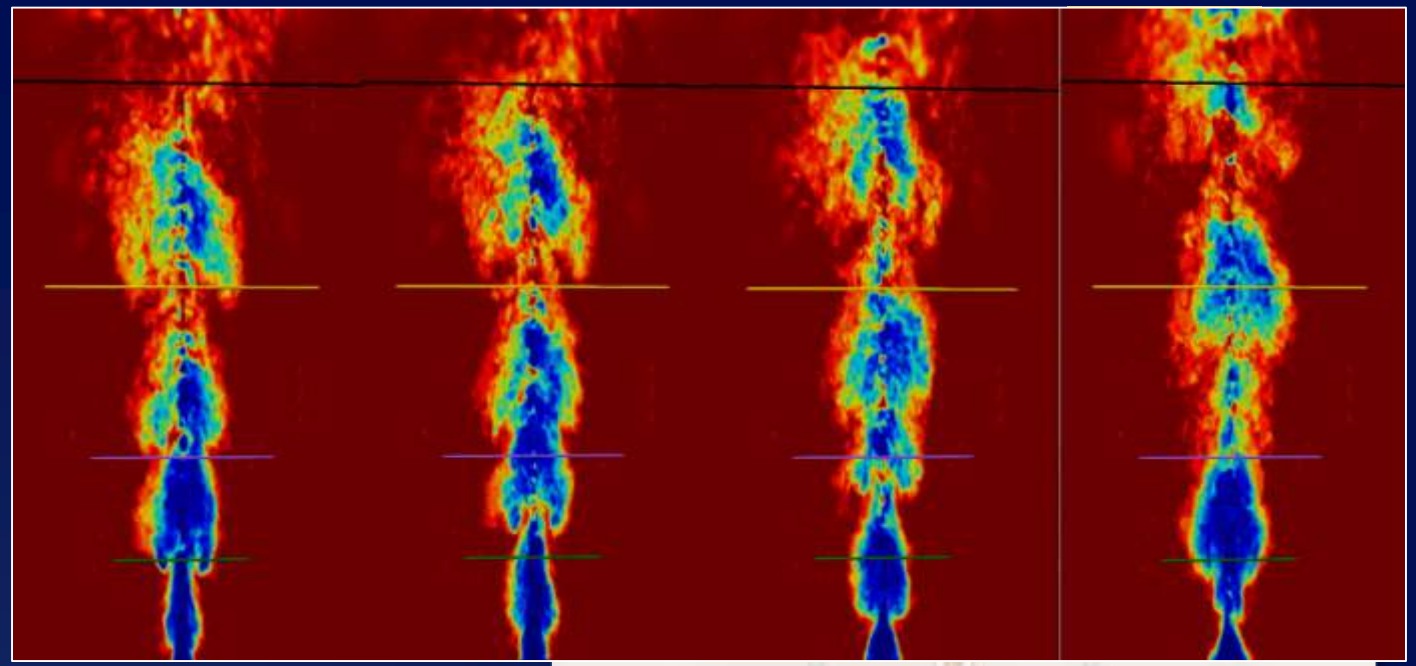
18 3/4-in. Mandrel Exit Geometry

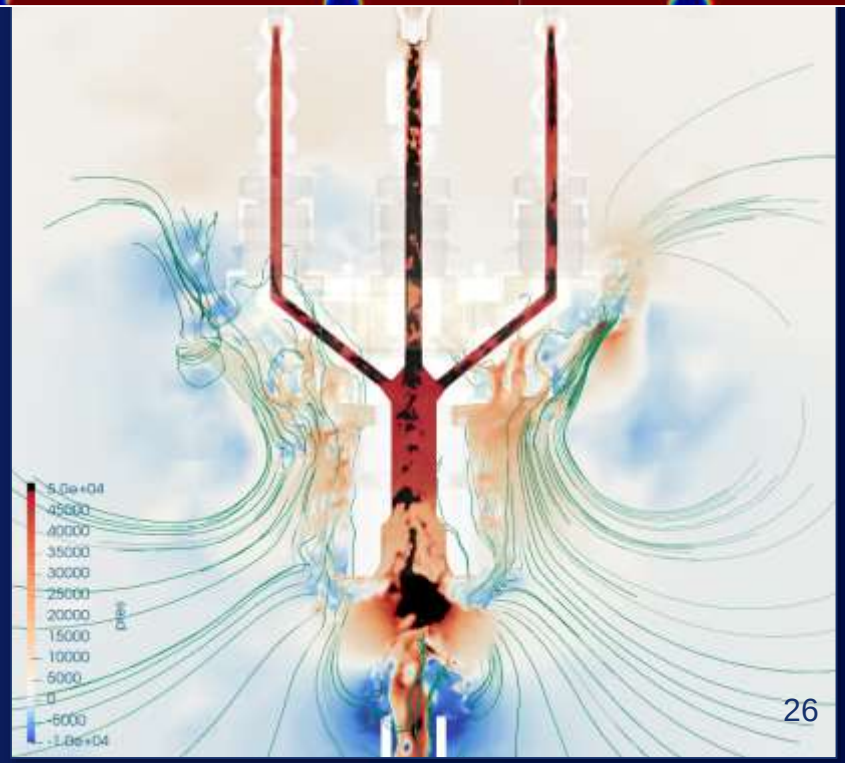
Same flow, three different turbulence assumptions

Case Study 2

Water depth: 282 ft.
Casing diameter: 13-3/8"
Release temp: 84° F
Release rate: 8,255 BOPD
Oil API: 41°
GOR: 621

Release mass flow rate: 61.47 kg/sec
Release density: 6.53 kg/m^3
Release mean velocity: 103.9 m/s

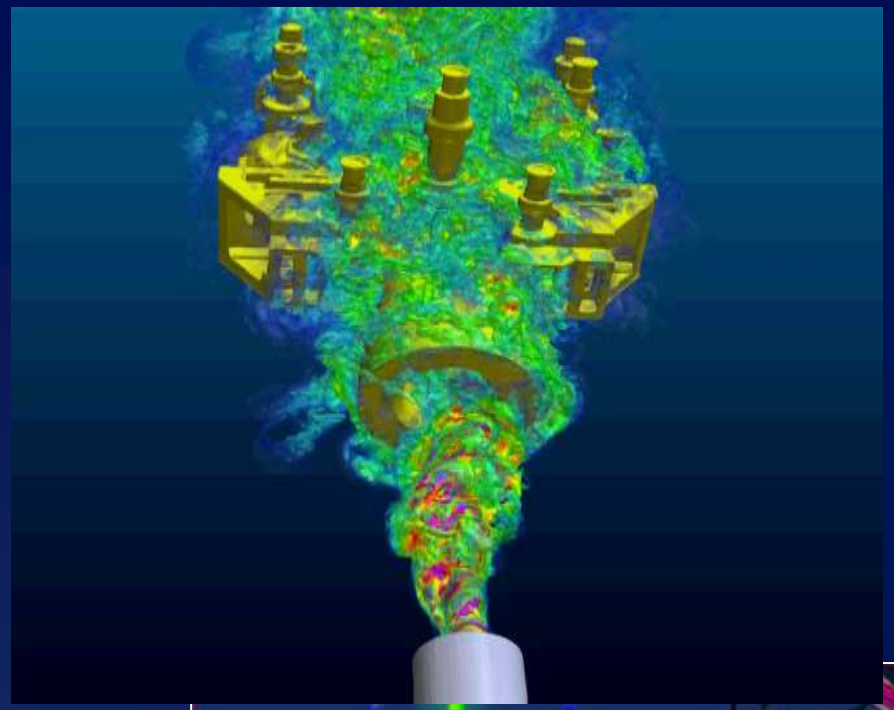




- Combined liftoff forces < 16% of the weight of the stack.
- Lateral plume forces remain within capabilities of work class ROVs.

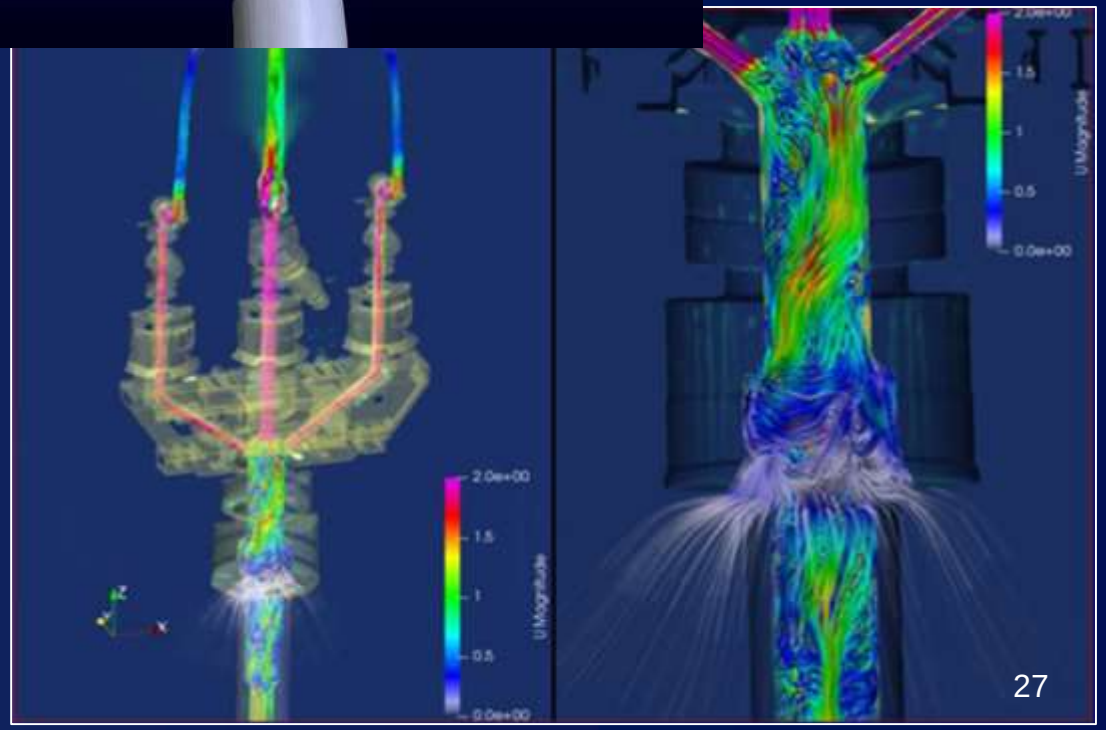
Case Study 3

Water depth: 5,426 ft.
Casing diameter: 13-5/8"
Release temp: 190° F
Release rate: 58,500 BOPD
Oil API: 30°
GOR: 586

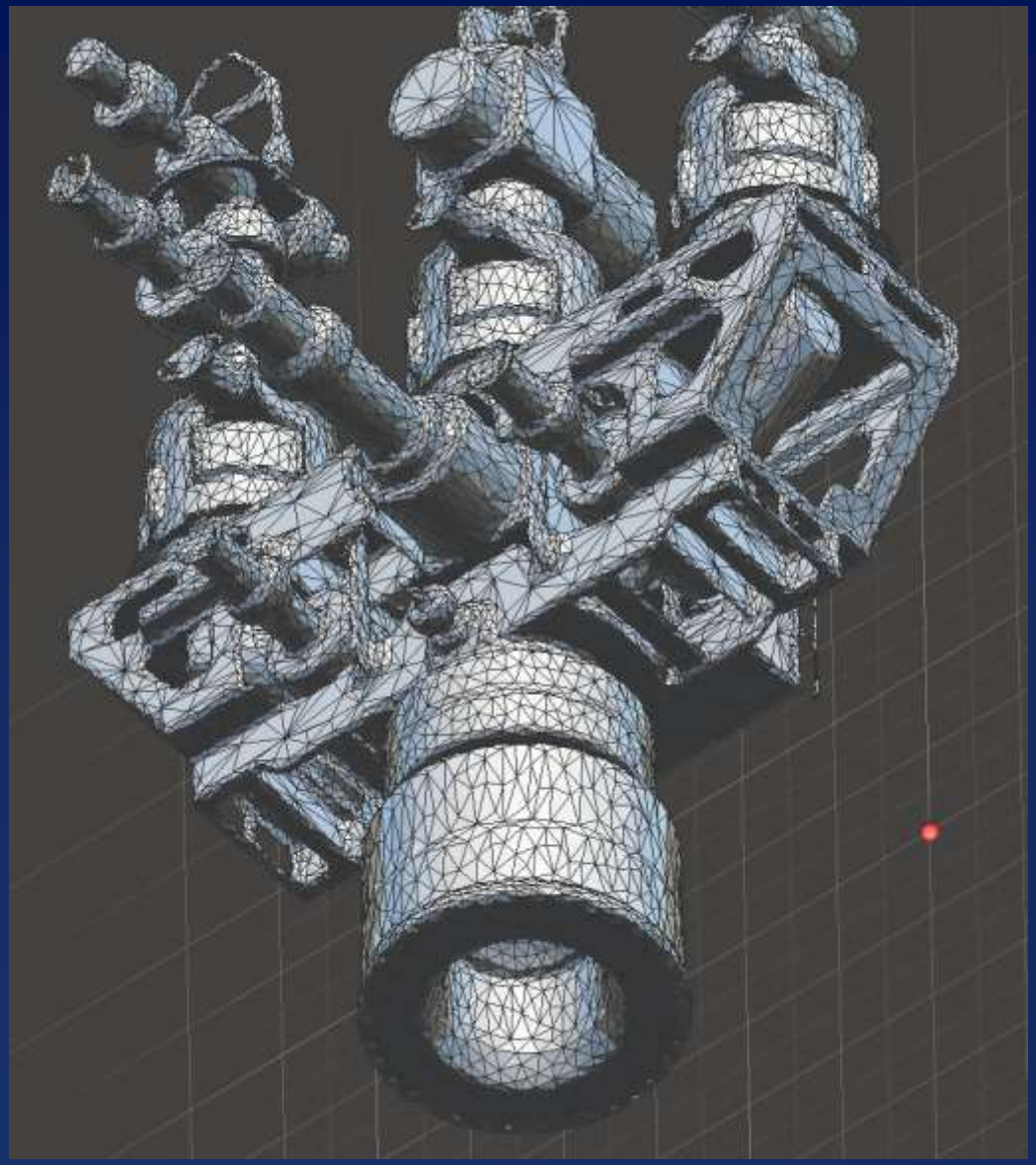


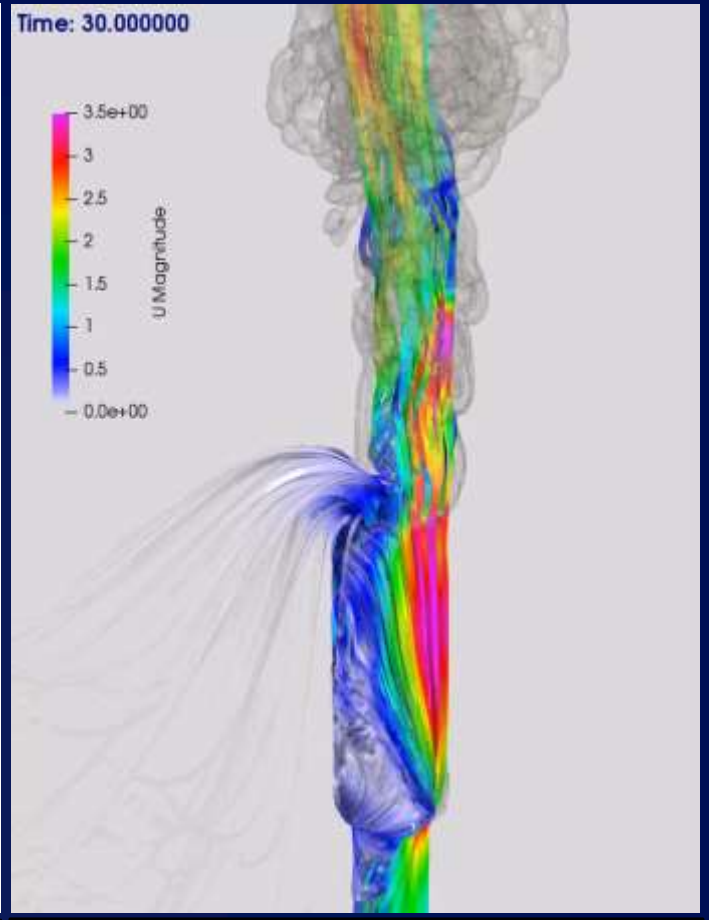
Release mass flow rate: 71.42 kg/sec
Release density: 663.1 kg/m^3
Release mean velocity: 1.38 m/s

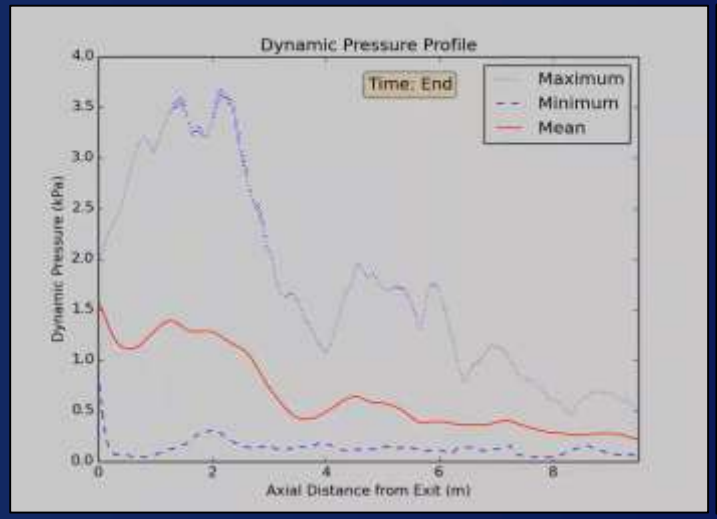
- ROV interventions, in the order of 100 pounds laterally, will keep stack on centerline.

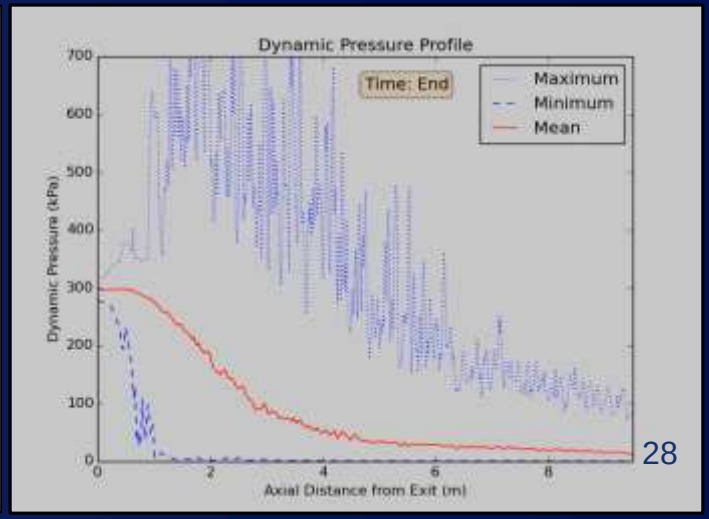


Ongoing Studies:
Wave Period & Frequency









Study Conclusions

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- Applied aerospace domain expertise to turbulent plume-force dynamics with high speed jet velocities, “rocket science”.
- NASA methodology for examining jet induced uplift forces.
- Accurate modelling and veracity of simulations based on actual data, combined a fully coupled system algorithm.
- Challenged industry accepted modeling results.

Salient lessons from aerospace engineering assisting the oil industry in knowing what it doesn’t know!

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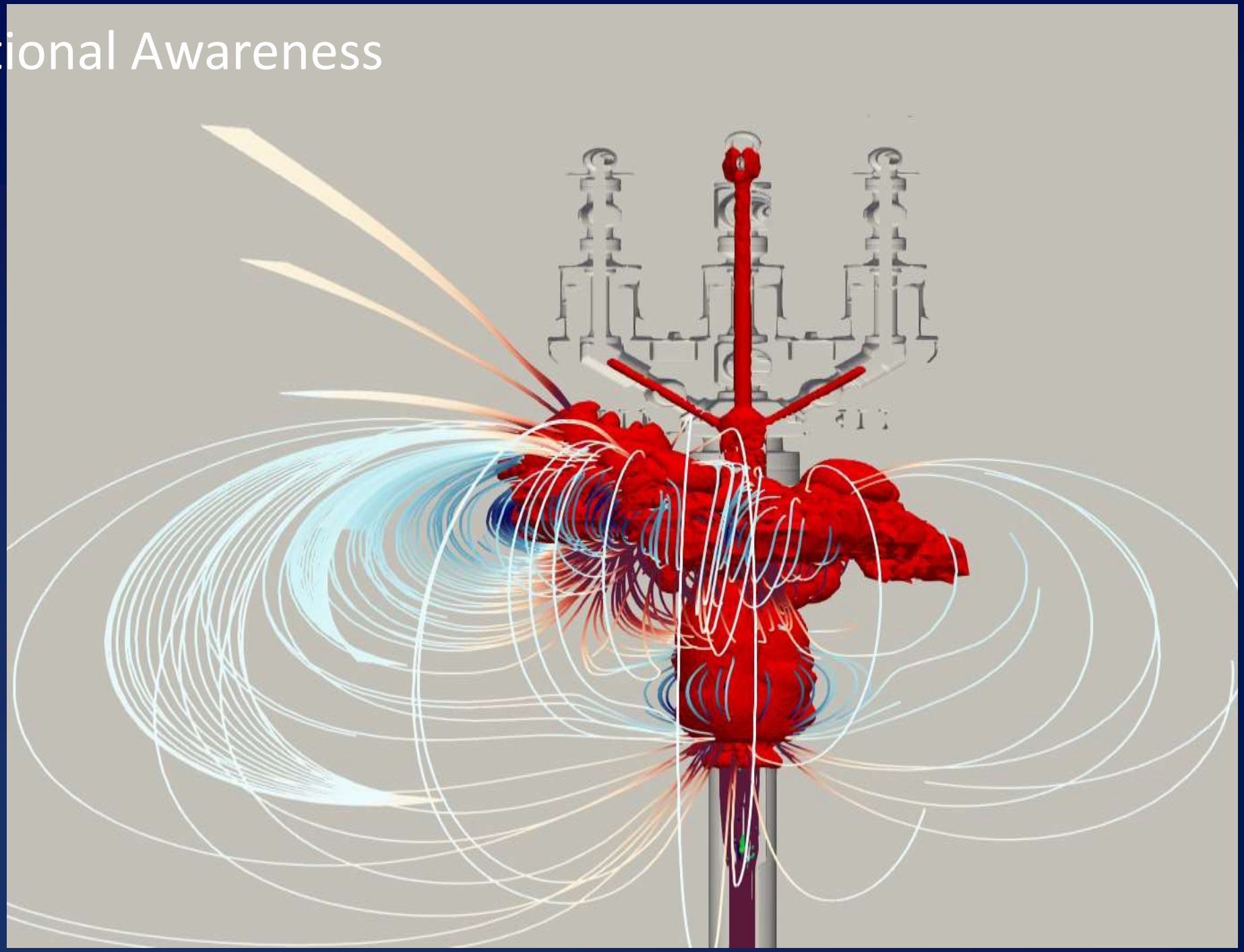
Operational Awareness



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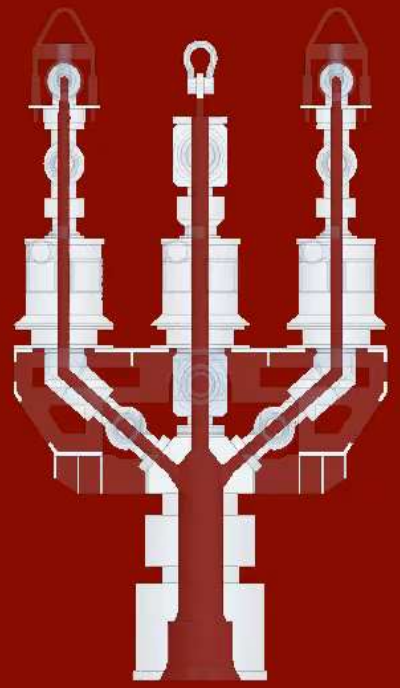
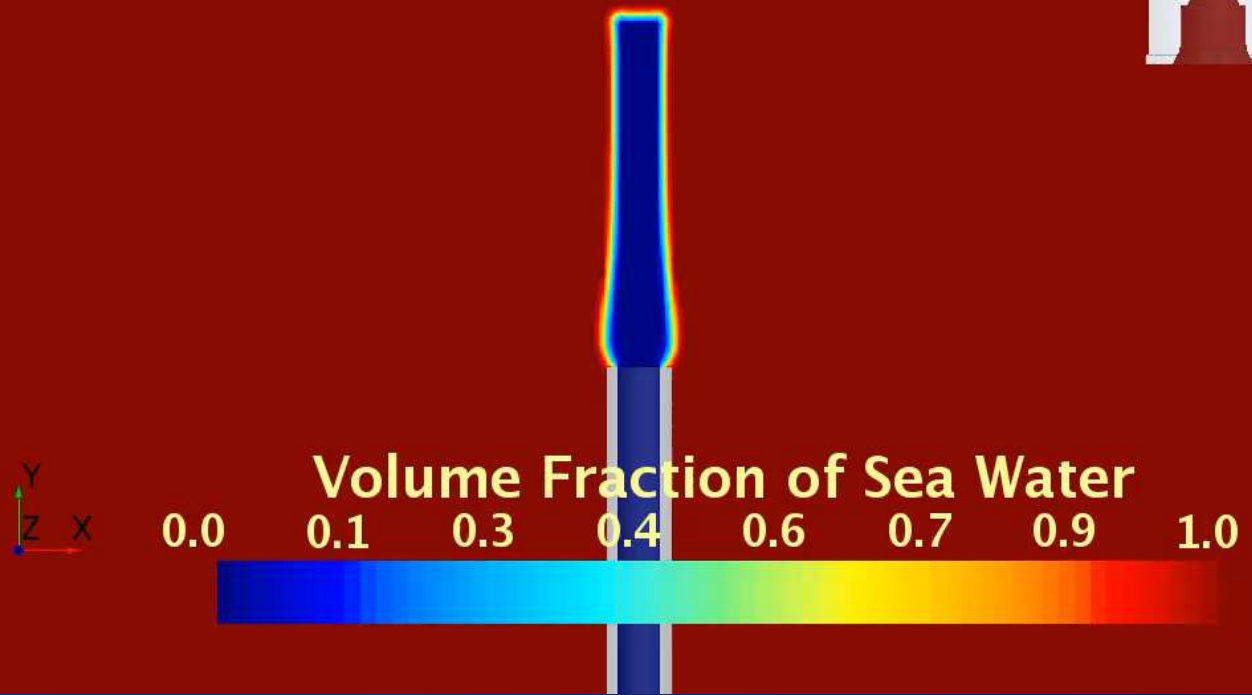
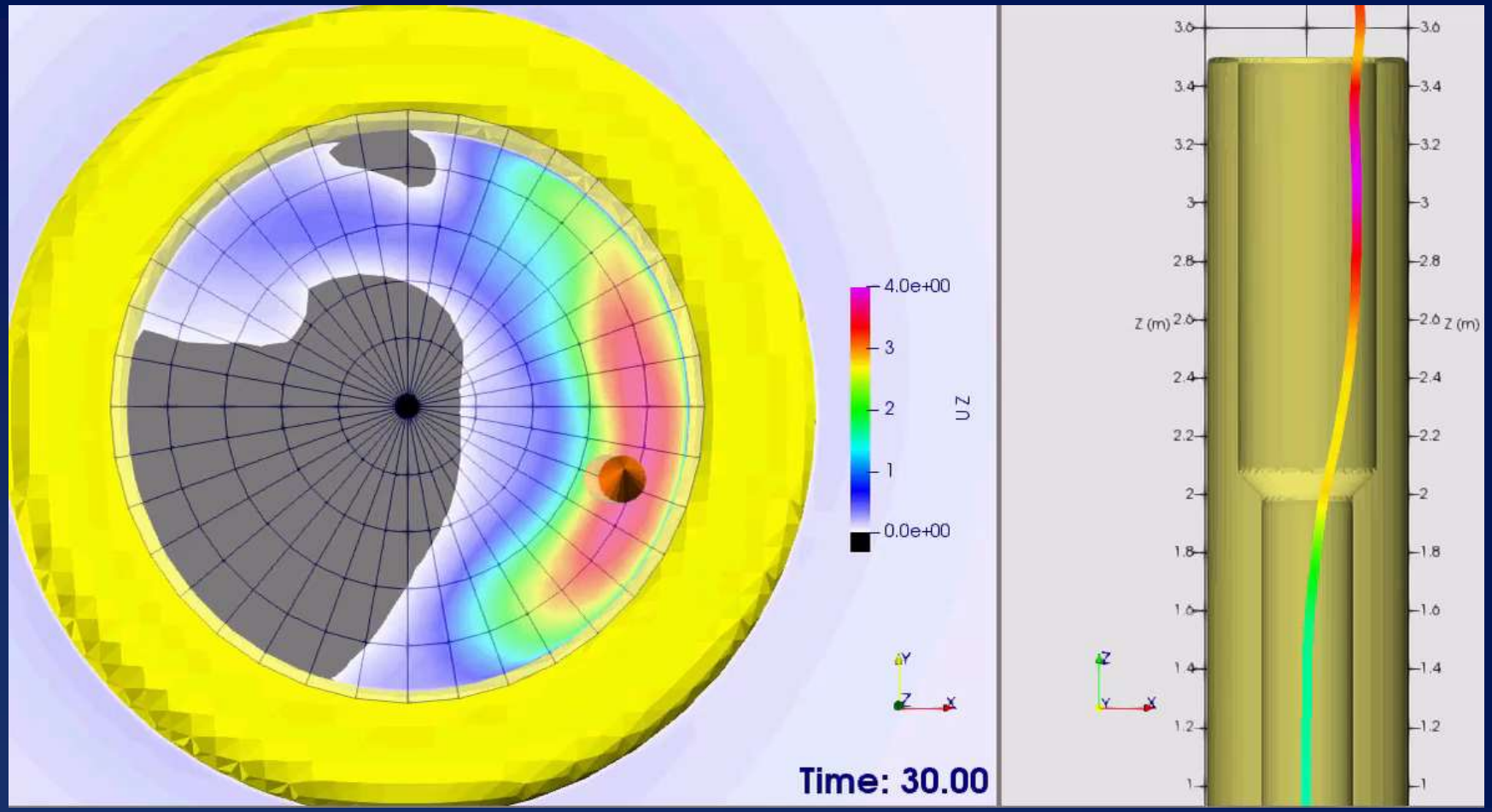
Capping Stack – Landing Sequence

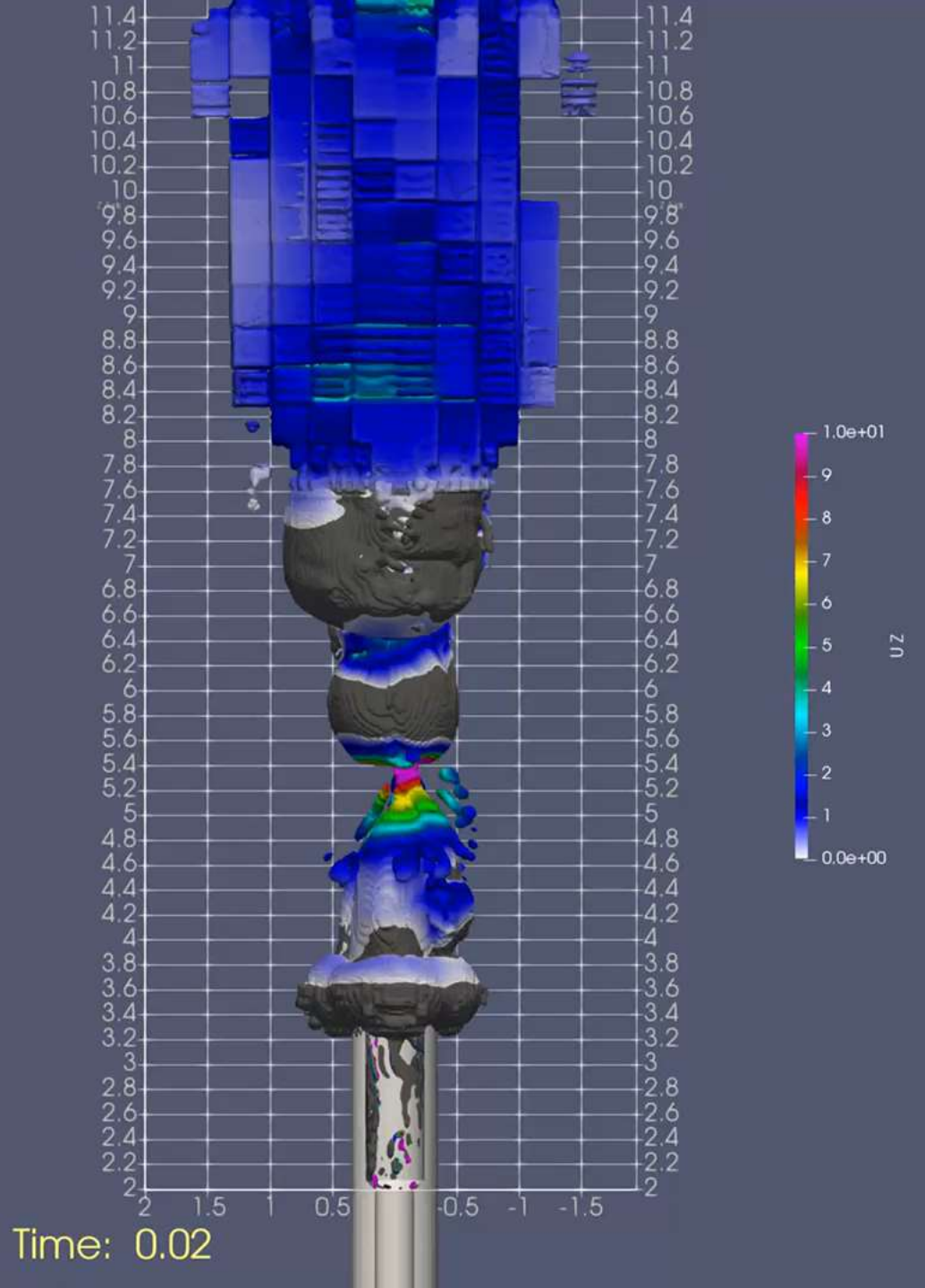




Mandrel Exit Pressure Differential



Initial Exit Conditions



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