Malaysia Airlines Flight MH370: Water Entry of an Airliner

Goong Chen[1], Cong Gu[2], Philip J. Morris[3], Eric G. Paterson[4], Alexey Sergeev[5], Yi-Ching Wang[2] and Tomasz Wierzbicki[6]

Introduction: MH370

On March 8, 2014 Malaysia Airlines Flight MH370 disappeared less than an hour after take-off on a flight from Kuala Lumpur to Beijing. The Boeing 777-200ER carried 12 crew members and 227 passengers.

"It is therefore with deep sadness and regret that I must inform you that ... Flight MH370 ended in the Southern Indian Ocean."

— Malaysia Prime Minister Perdana Menteri

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Introduction: An Interdisciplinary Perspective

Research on this air incident requires interdisciplinary perspective.
Computational mathematics and mechanics can help us:

- understand the physical nature of an aircraft emergency water landing
- model and compute this problem
- use this knowledge to help safe civil aviation and other aerospace related undertakings

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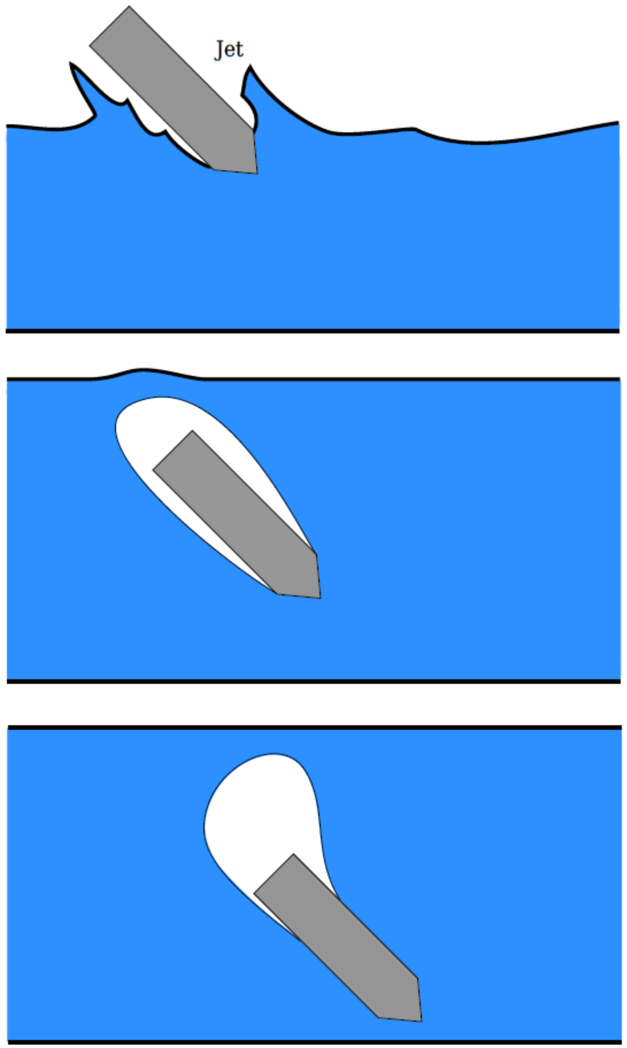
Challenges for Classical Methods

Sub-models and corrections are needed for various complicating factors

- trapped air cavitation
- water compressibility and acoustic effects
- complex, real-world geometries
- ...



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Approach and Objective

Flight MH370:

- If fight MH370 did not have a mid-air explosion, then all available signs indicate that it crashed somewhere in the Indian Ocean. This is an aircraft water-entry problem.

Approach:

- Instead of the classical methods introduced above, we utilize Computation Fluid Dynamics (CFD) that can resolve local details and take factors like trapped air, water compressibility, and the real-world geometry (Boeing 777) into account.

Objective:

- Numerically simulate and analyze several hypothetical scenarios.

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OpenFOAM: Software Platform

OpenFOAM (Open Source Field Operation and Manipulation) is an free and open-source C++ toolbox for the development of customized numerical solvers, and pre-/post-processing utilities for the solution of continuum mechanics problems, including CFD.

There are three steps to run OpenFOAM

- generate polyhedral mesh
- execute a numerical solver for the given differential equation
- display and analyze the results

OpenFOAM

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Aircraft Water Entry

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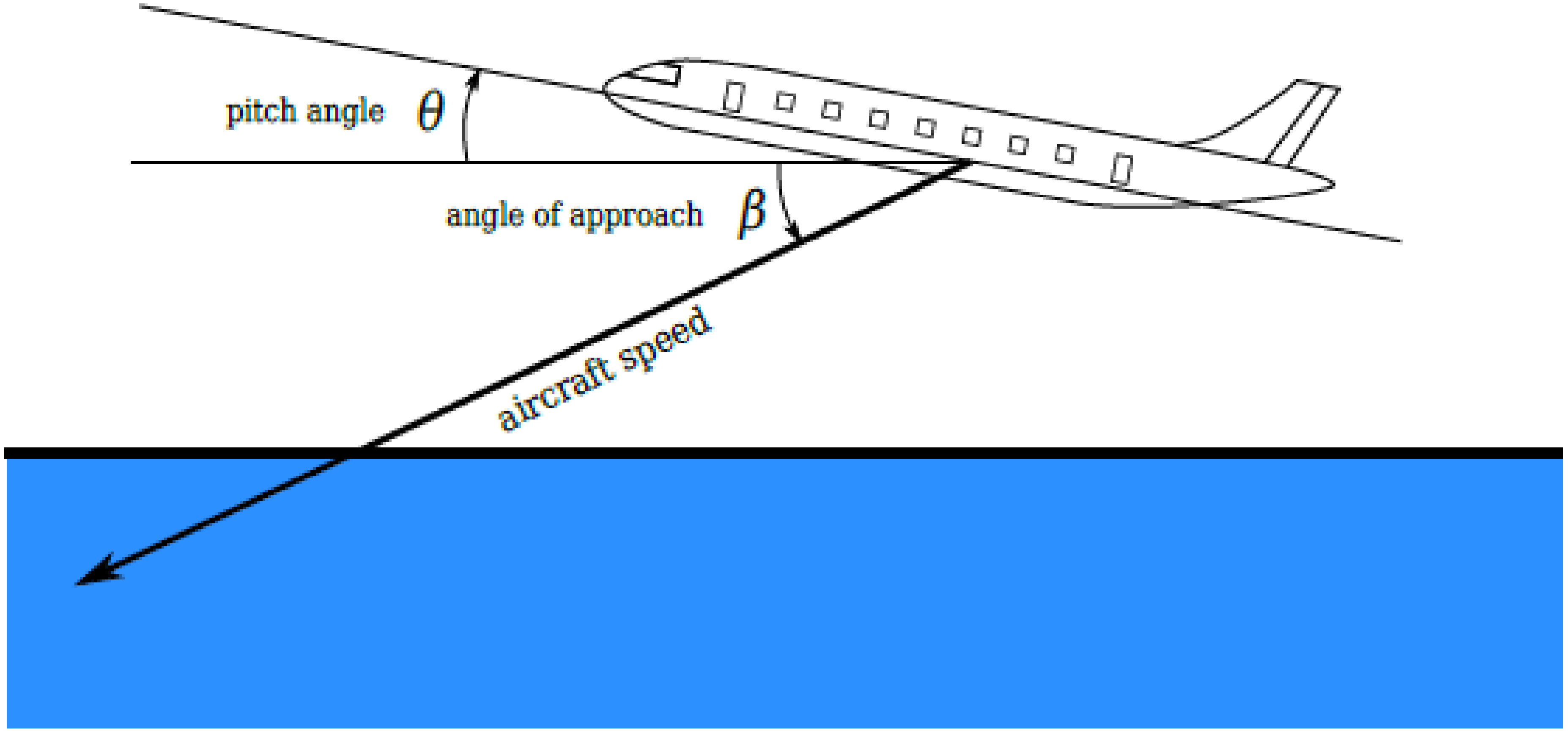

θ = pitch angle

β = angle of approach

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Governing Equations I

- (Conservation of phase mass)

$$\frac{\partial(\rho_i \alpha_i)}{\partial t} + \nabla \cdot (\rho_i \alpha_i \boldsymbol{u}) = 0.$$

α_i = volume fraction of phase i, and $\alpha_1 + \alpha_2 = 1.$

- (Conservation of momentum)

$$\frac{\partial(\rho \boldsymbol{u})}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}\boldsymbol{u}) = -\nabla_p + \nabla \cdot T + \rho g + f_{surf},$$

$$T = \mu\,(\nabla \boldsymbol{u} + \nabla\,\boldsymbol{u}^T) - \frac{2}{3}\mu\,(\nabla \cdot \boldsymbol{u})\,I,$$

ρ = mixture density = $\rho_1 \alpha_1 + \rho_2 \alpha_2$,

μ = mixture viscosity.

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Governing Equations II

- (Continuum surface force)

  $$\boldsymbol{f}_{surf} = \gamma K \nabla \alpha_1,$$

  K = interface curvature = $-\nabla \cdot \left(\frac{\nabla \alpha_1}{|\nabla \alpha_1|}\right)$,

  γ = surface tension.

- (Material equation of state)

  ρ_1 = water density = $\rho_0 + \varphi_1 \rho$,

  ρ_2 = air density = $\varphi_2 \rho$.

- (Six degrees of freedom of motion)

  $\sigma = -\rho \boldsymbol{I} + \boldsymbol{T}$,

  $F(t)$ = force on object = $\int_{\partial\Omega(t)} \boldsymbol{\sigma} \hat{\boldsymbol{n}} \, dS$,

  $\tau(t)$ = torque on object = $\int_{\partial\Omega(t)} \boldsymbol{r} \times \boldsymbol{\sigma} \hat{\boldsymbol{n}} \, dS$.

  $\Longrightarrow$ Resulting velocity on object skin $\boldsymbol{V}(x, t)$ for $x \in \partial\Omega(t)$

- (Moving boundary condition on object skin)

  $$\mathbf{u}|_{\partial\Omega(t)} = \boldsymbol{V}(x, t)$$

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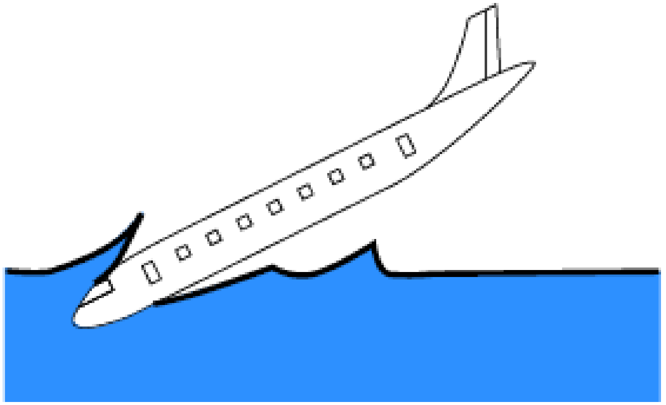
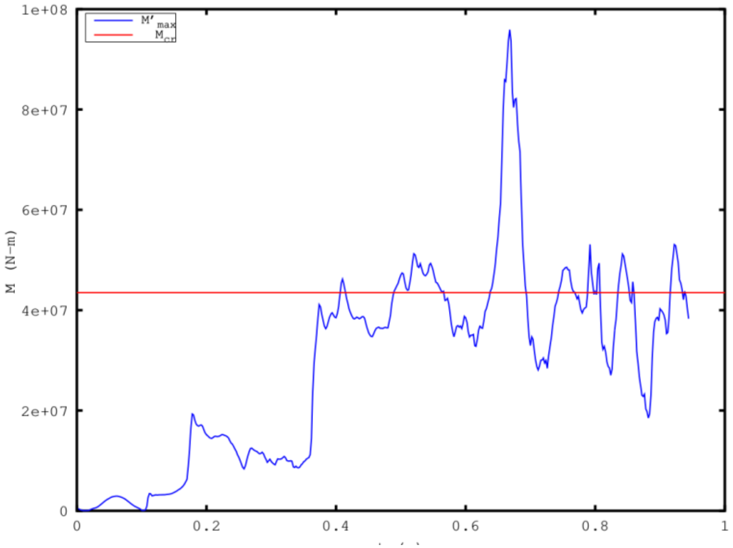
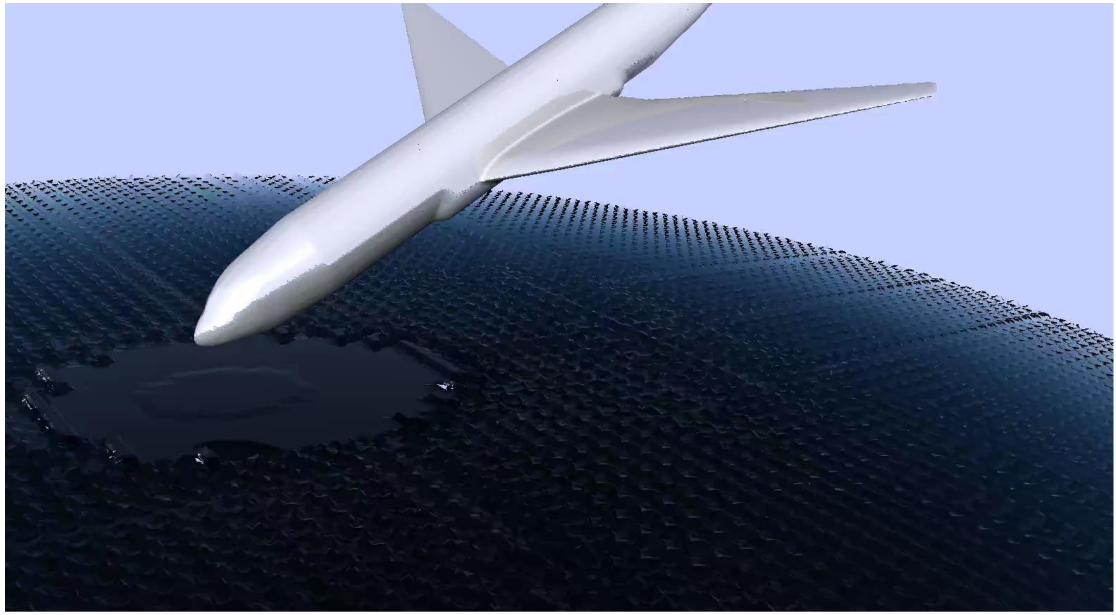
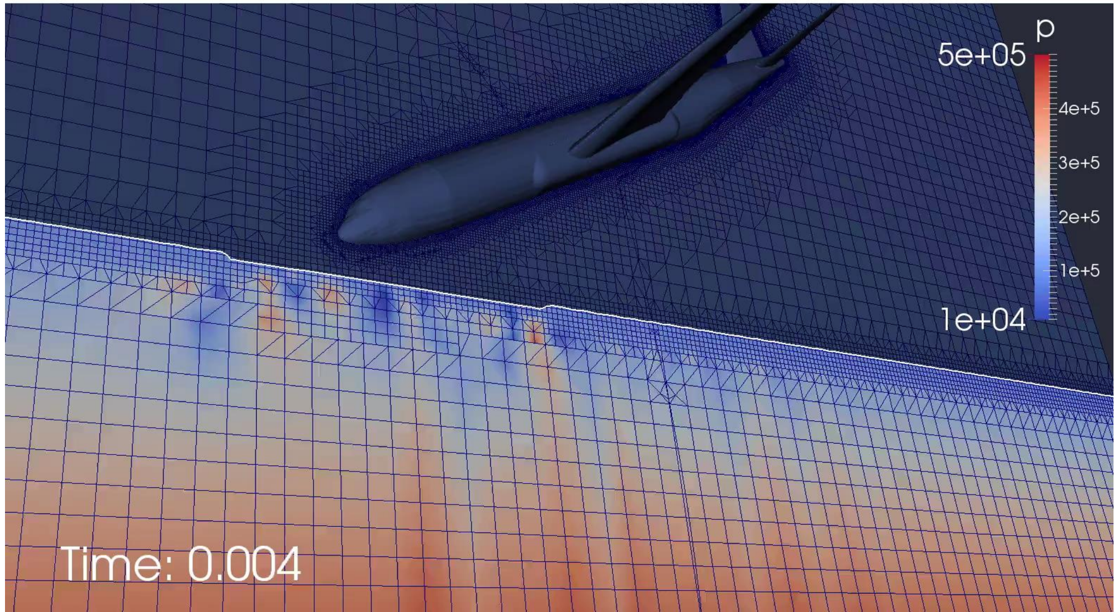
Scenario with 30°-Diving (θ = -30°, β = 30°)





Bending Moment





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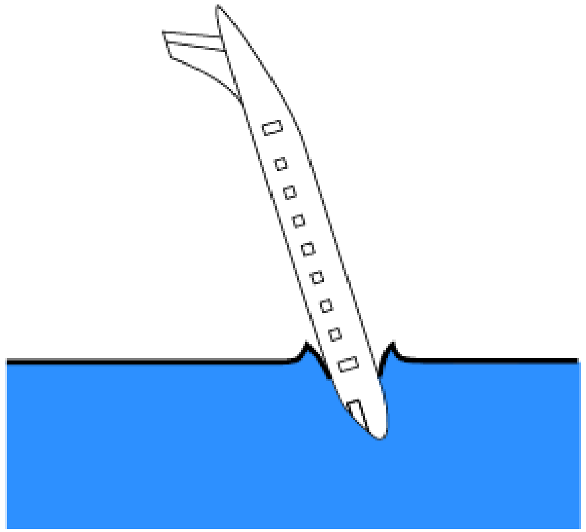
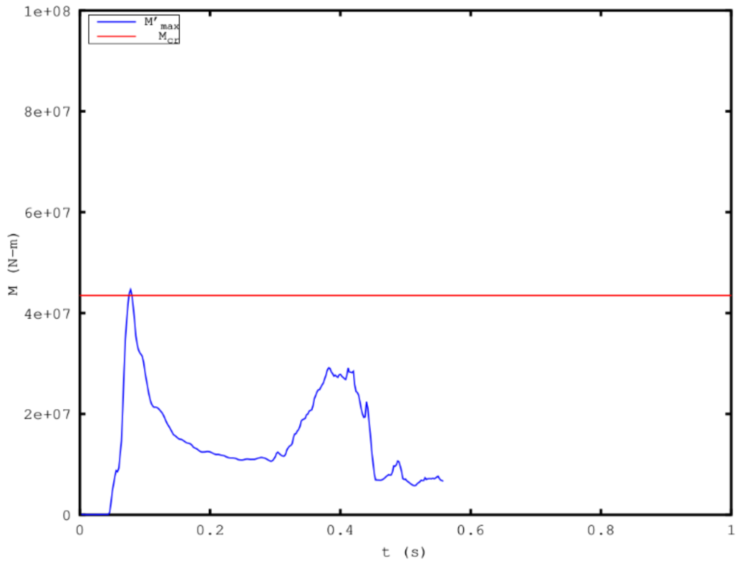
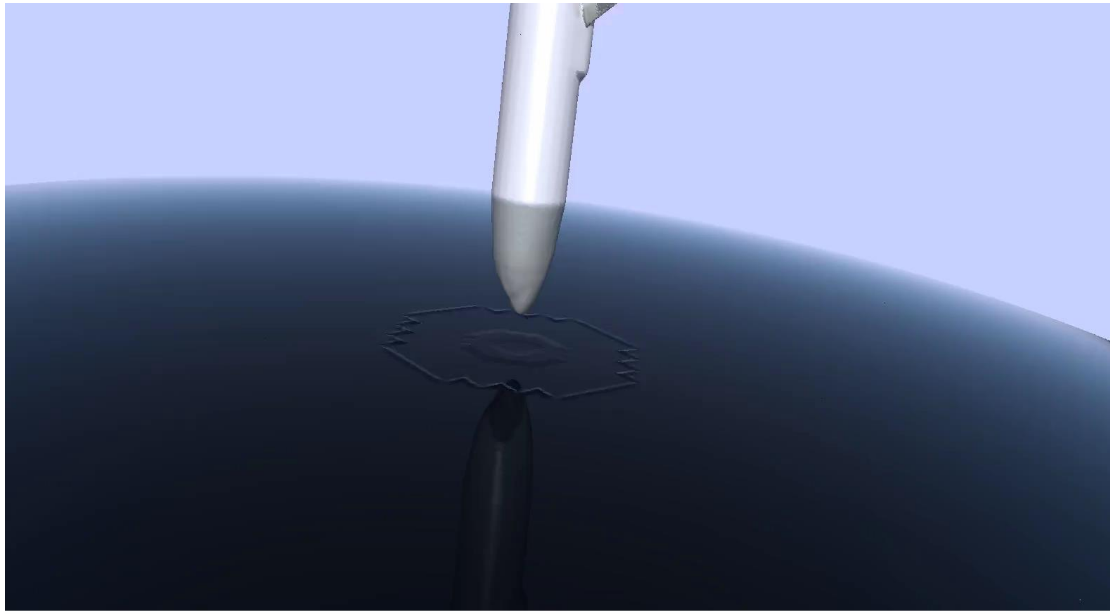
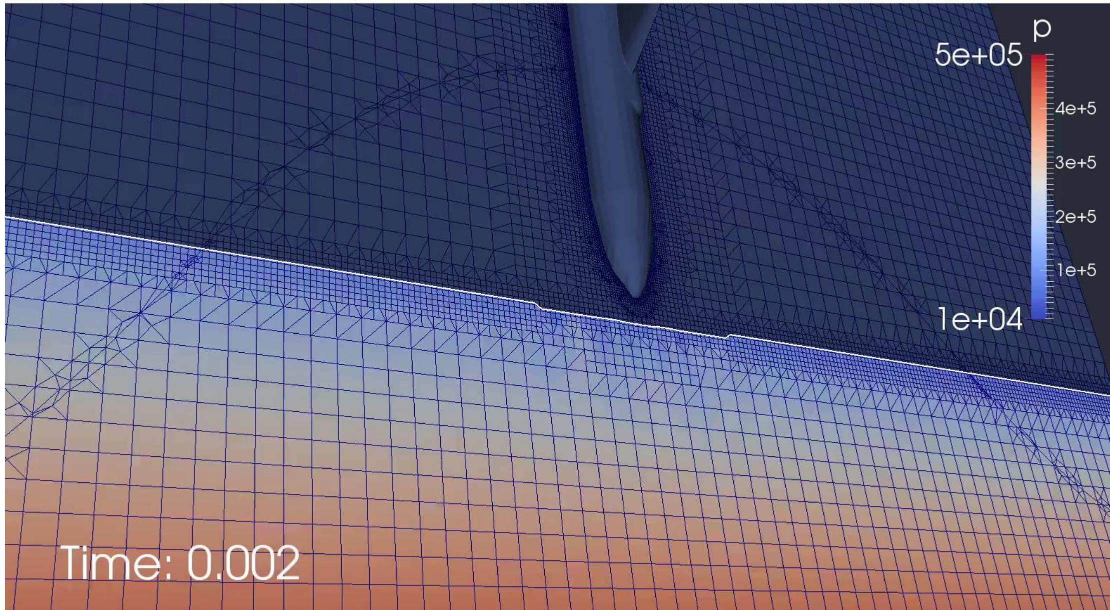
Scenario with Nose-Diving (θ = -90°, β = 93°)





Bending Moment





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