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Rocket Flight Loads Determination

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Motivation

- From project requirements:
  - “Defiance shall have a FOS of 2 during the point of maximum aerodynamic loading (max Q).”
- Defiance has a very high fineness ratio (FR)
  - Length to width ratio
- The higher the FR
  - The lower the drag, UP TO A POINT
  - The higher the effect of bending loads on a rocket, specially in high speed upper atmosphere winds

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Does this really matter? I mean, what is the worst thing that could happen?

Source: https://www.youtube.com/watch?v=lNxxyp_2fNI&t=15s

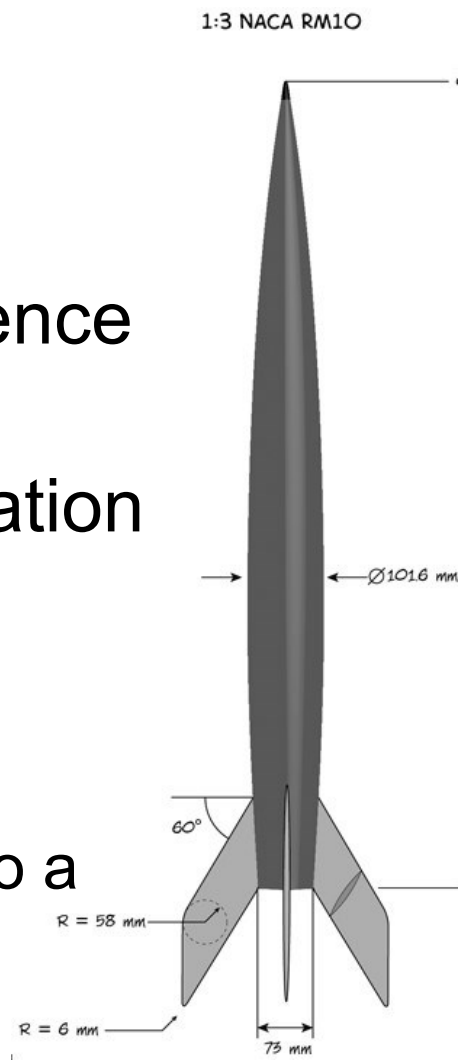
Approach

- We evaluated three methods for calculating flight loads and opted to proceed with the two in **bold**, which together offer a balance of simplicity and accuracy
  - PANAIR
    - Expected to give a semi-representative solution
    - Limited to AoA less than 2° and Mach numbers less than 3
  - **Euler-Bernoulli beam theory**
    - Simple method
    - Computationally cheap
  - **Computational Fluid Dynamics (CFD)**
    - Complex method
    - Computationally expensive
    - Not limited by angle of attack or Mach number

Computational Fluid Dynamics (CFD) Approach

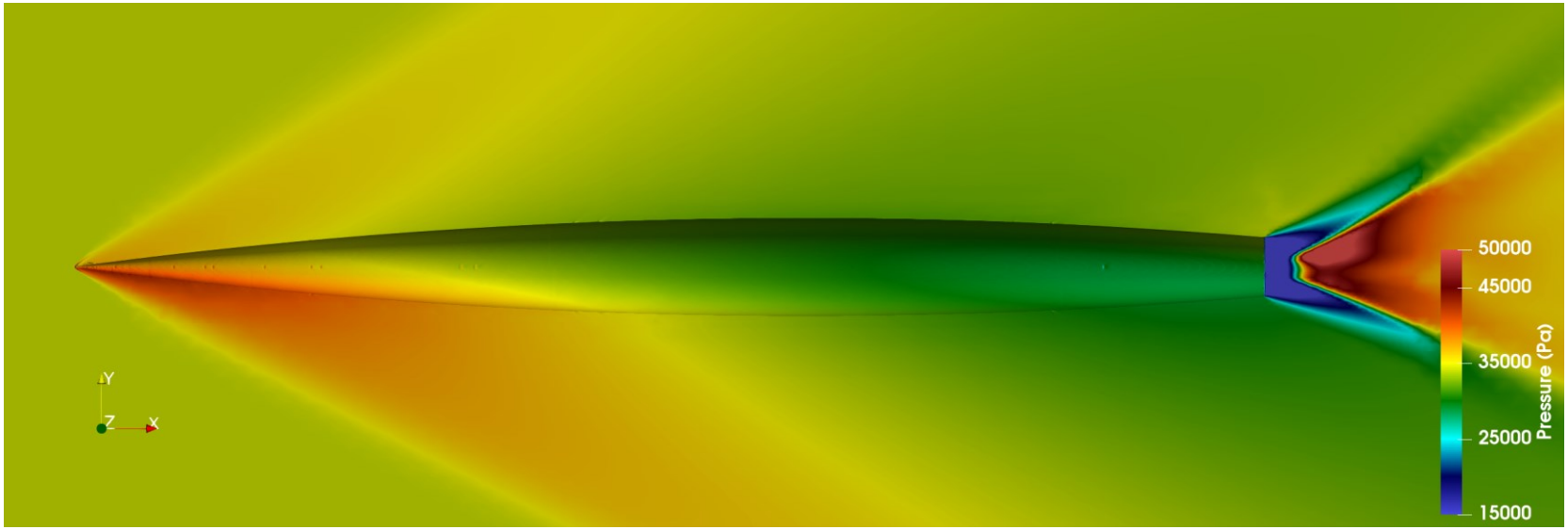
Validation

- In order to use any sort of numerical analysis we should have some confidence that the results are meaningful
- If not, we could end up in a GIGO situation
  - Garbage in, garbage out
- Validation case is NACA RM-10
  - Validation geometry from the 1950's
  - Chosen because of its similar geometry to a rocket and similar flight conditions to Defiance at max-Q



Validation Results

- RM-10 CFD results at Mach = 1.98, AoA = 4°



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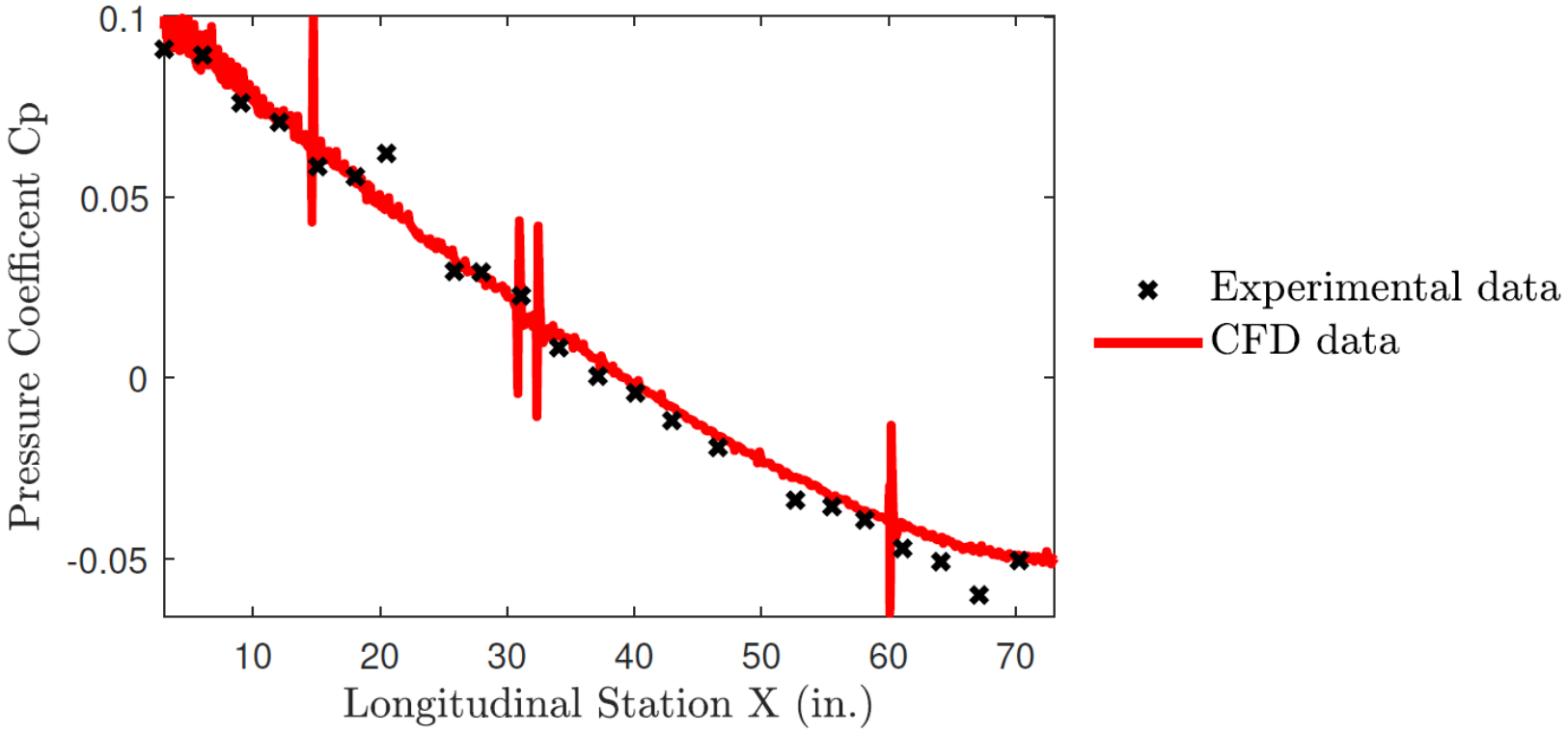

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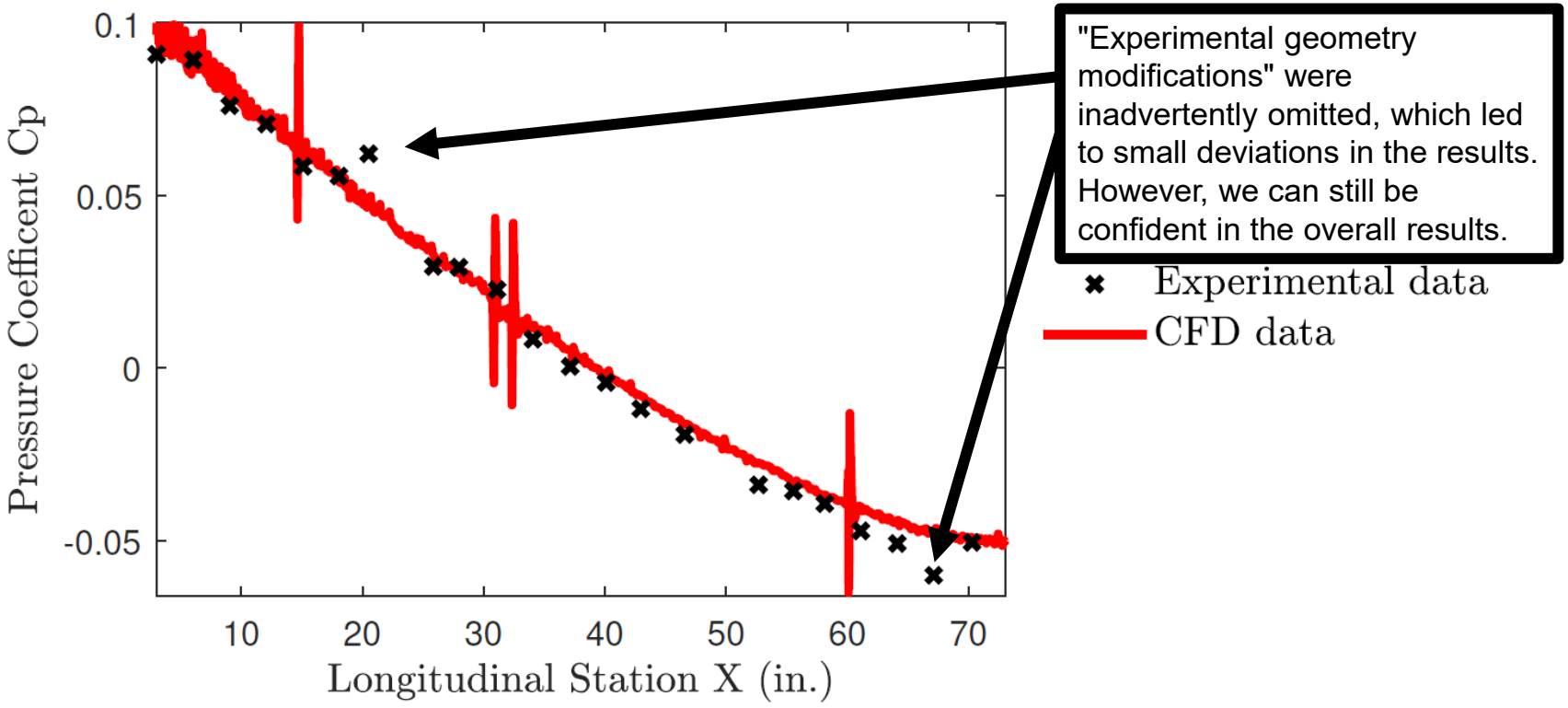

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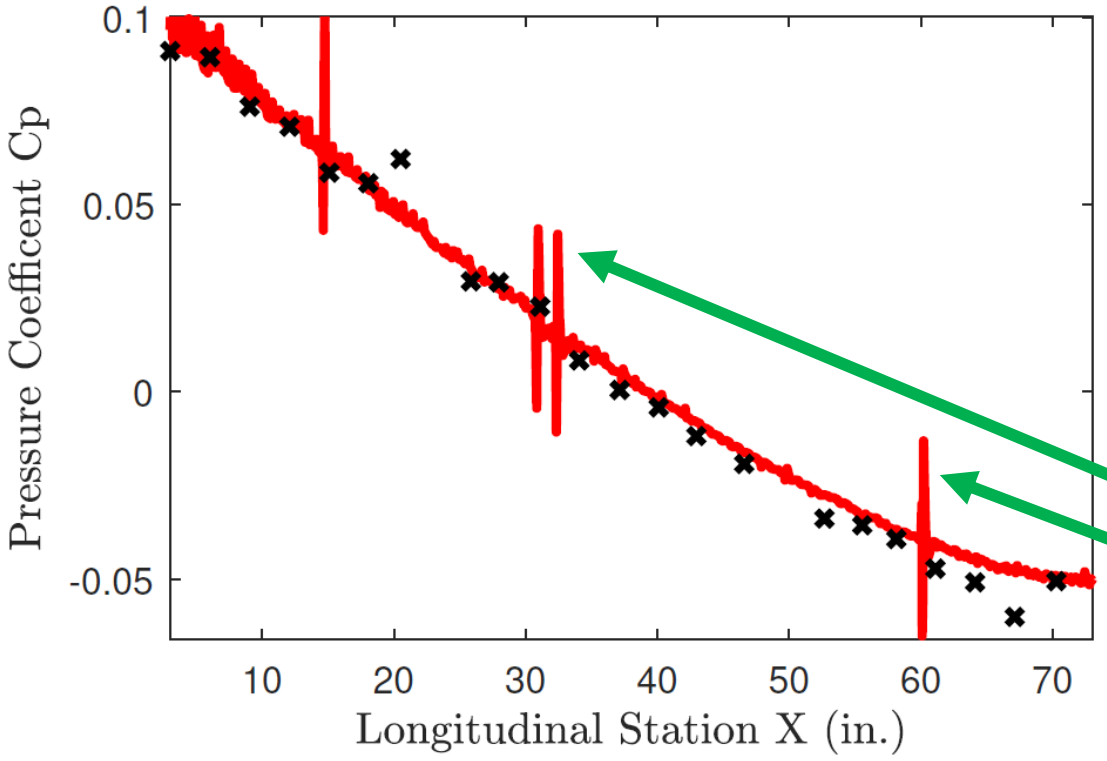


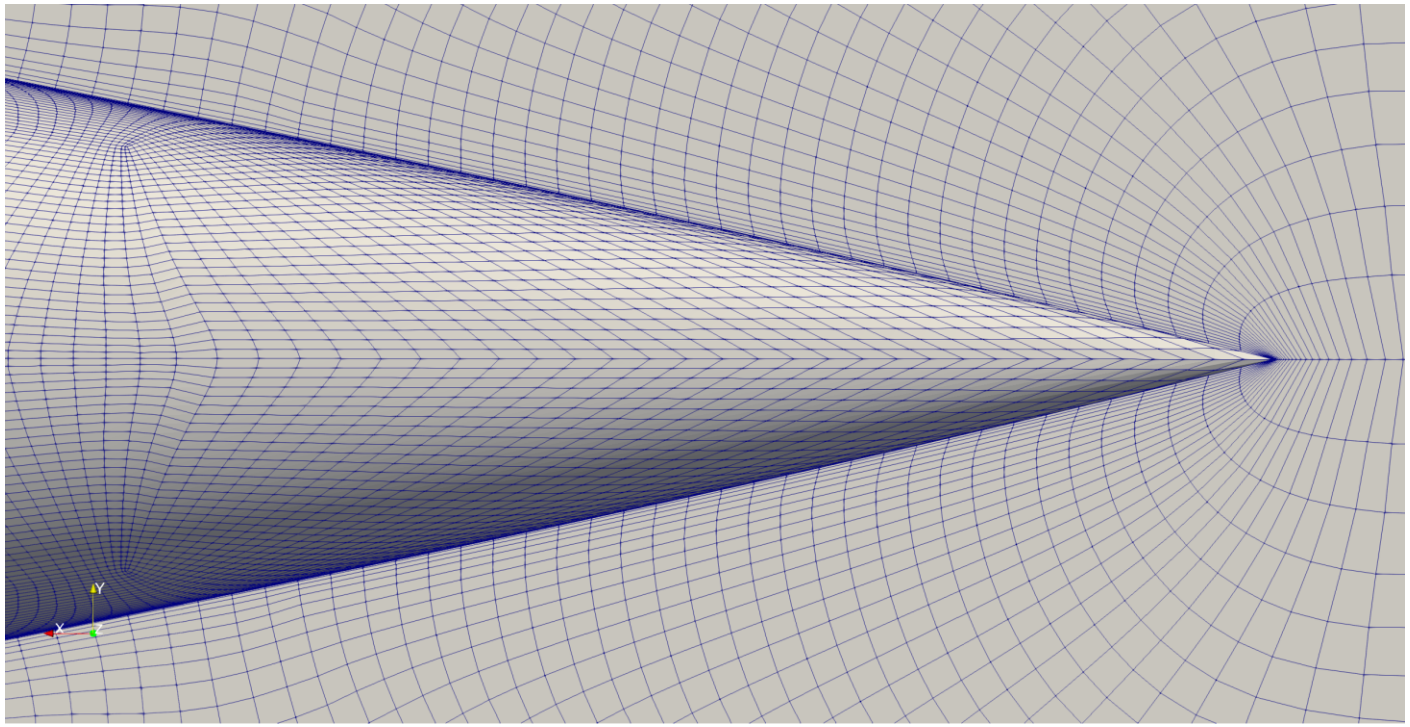
First meshing method utilized a cut-cell approach which was suboptimal and caused the sharp discontinuities

Defiance CFD

- Two step process
  - 1. Finless version of Defiance (thus simpler mesh)
  - 2. Finned version of Defiance
- Using hybrid mesh generator Pointwise
- Using open-source CFD platform OpenFOAM
  - Using inviscid, compressible solver
- Run in parallel using 320 to 480 processors on Canada's fastest supercomputer, Niagara
  - Thank you to Prof. Groth and Mohamed Khalil

Finless Defiance CFD Mesh

- Total number of elements: ~ 7 million



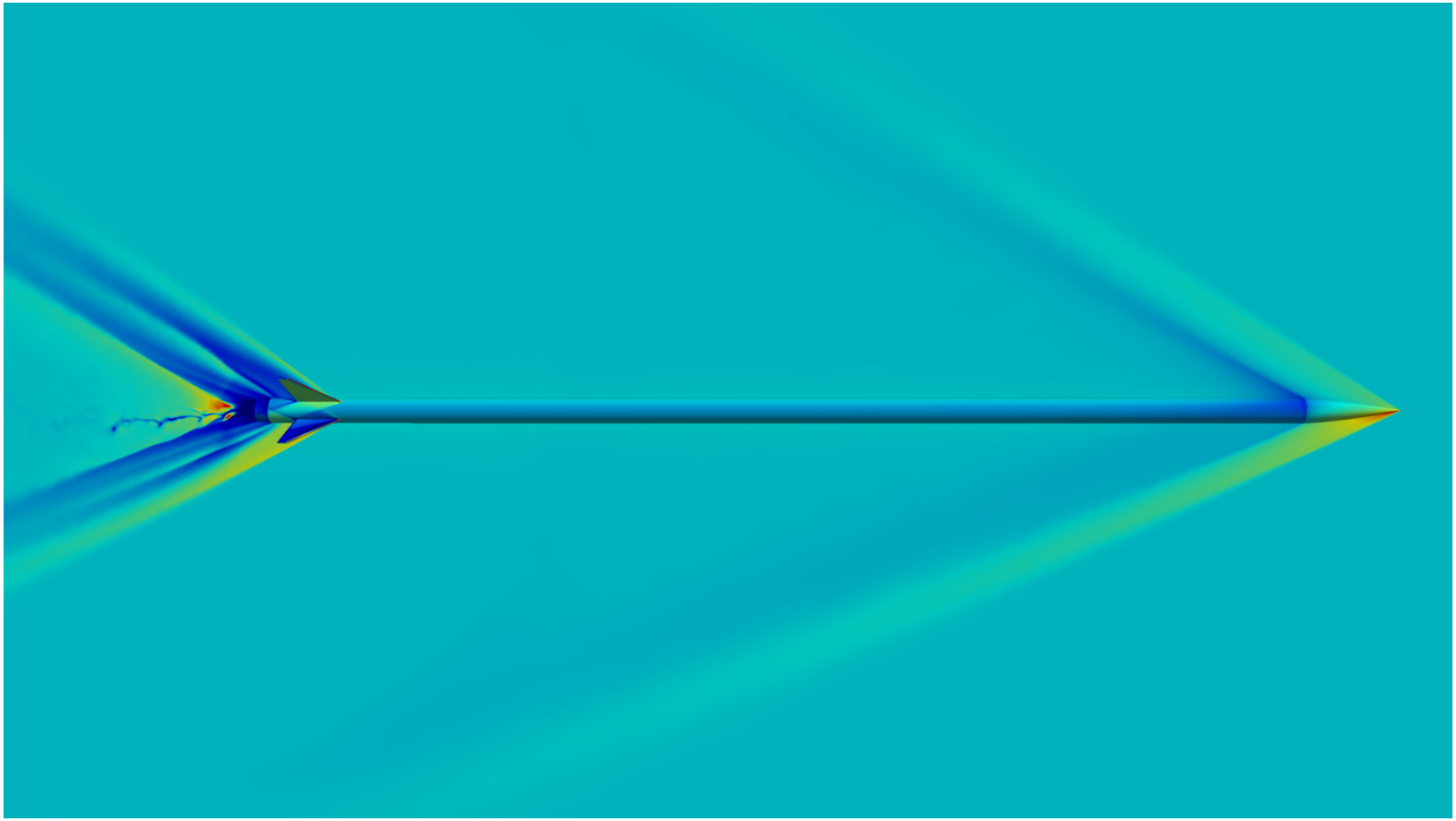
Finless Defiance CFD Results

- CFD results at Mach = 2.24, AoA = 5°

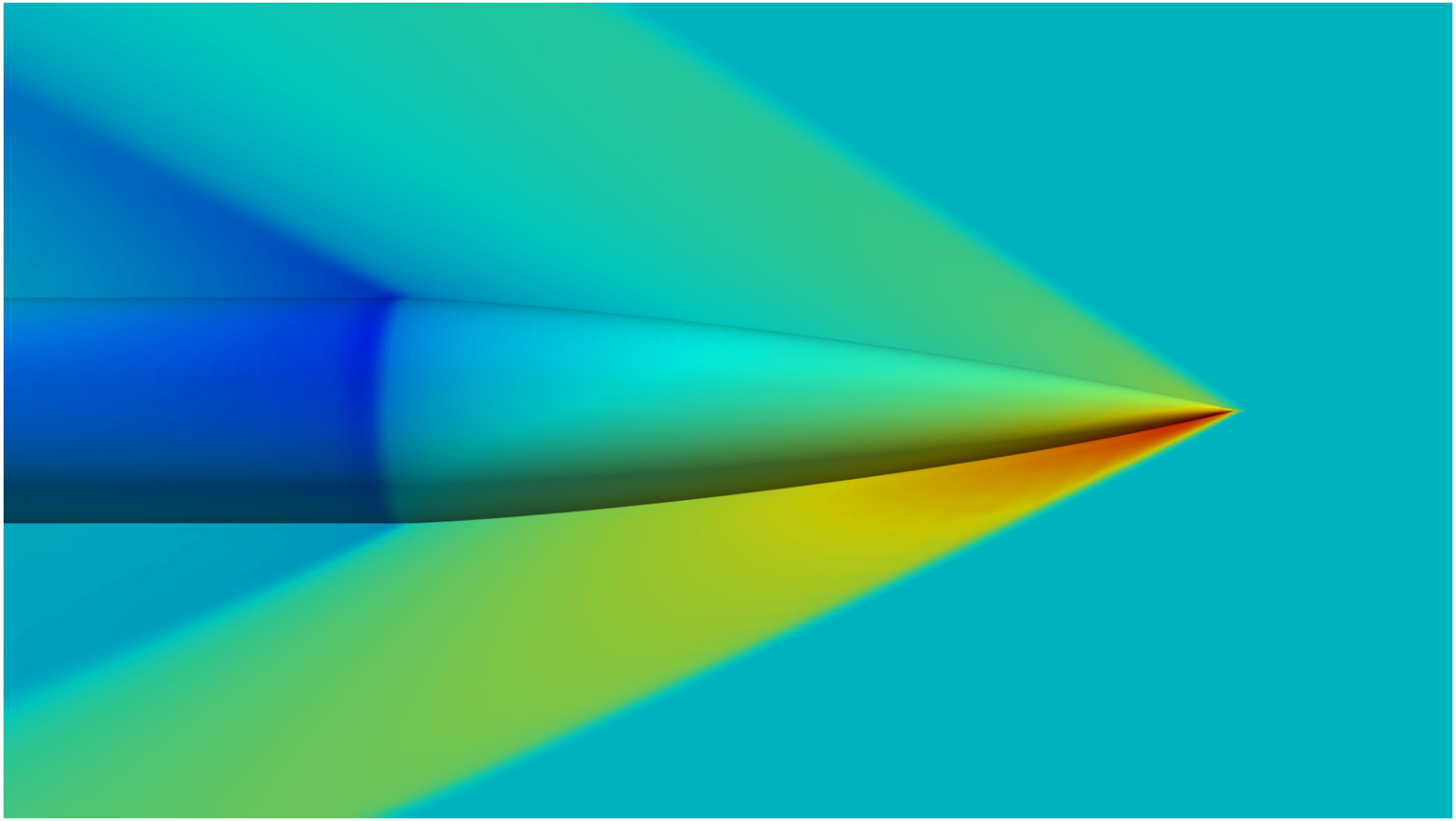
Next Steps

- We need to re-run the RM-10 case, using the updated numerical methods and meshing approach
  - This will give us confidence in the current workflow which has changed a lot since the previous validation
- Post-process and extract the results from the Finned Defiance model

Finned Defiance CFD Results



Finned Defiance CFD Results



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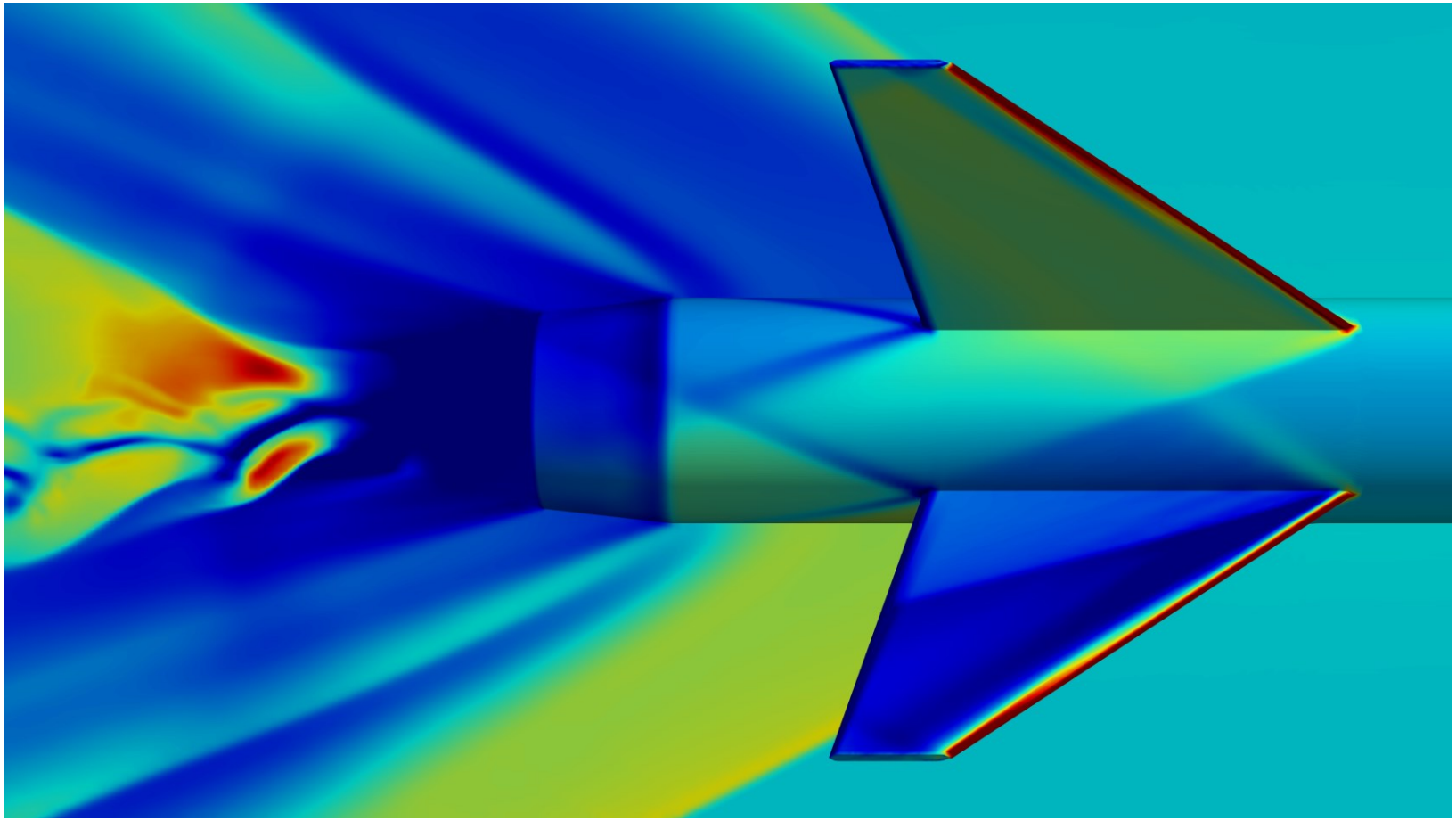


Euler-Bernoulli Beam Theory Approach

Overview

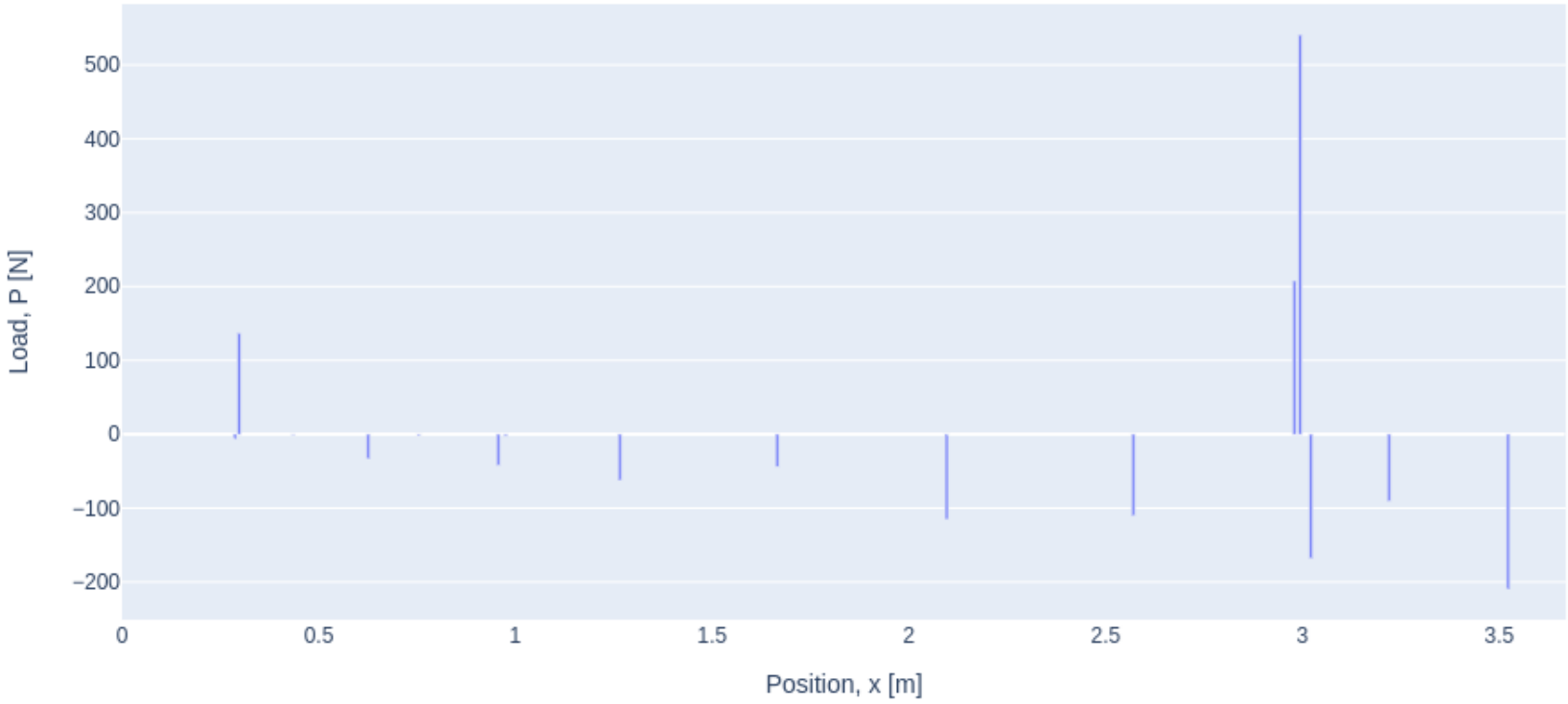
- Rocket is treated as a free-free beam subject to
  - Normal aerodynamic lift forces
  - Inertial loads
- Apply Euler-Bernoulli beam theory
  - Integrate loads to get shears
  - Integrate shears to get moments
- Based on procedure by Aspirepace
- Aerodynamic coefficients found using AeroLab
- A 5.77° angle of attack was calculated assuming a 25 m/s wind gust at max Q

Parameters

- Aerodynamic coefficients found using AeroLab
- 5.77° AoA calculated assuming 25 m/s wind gust at max Q

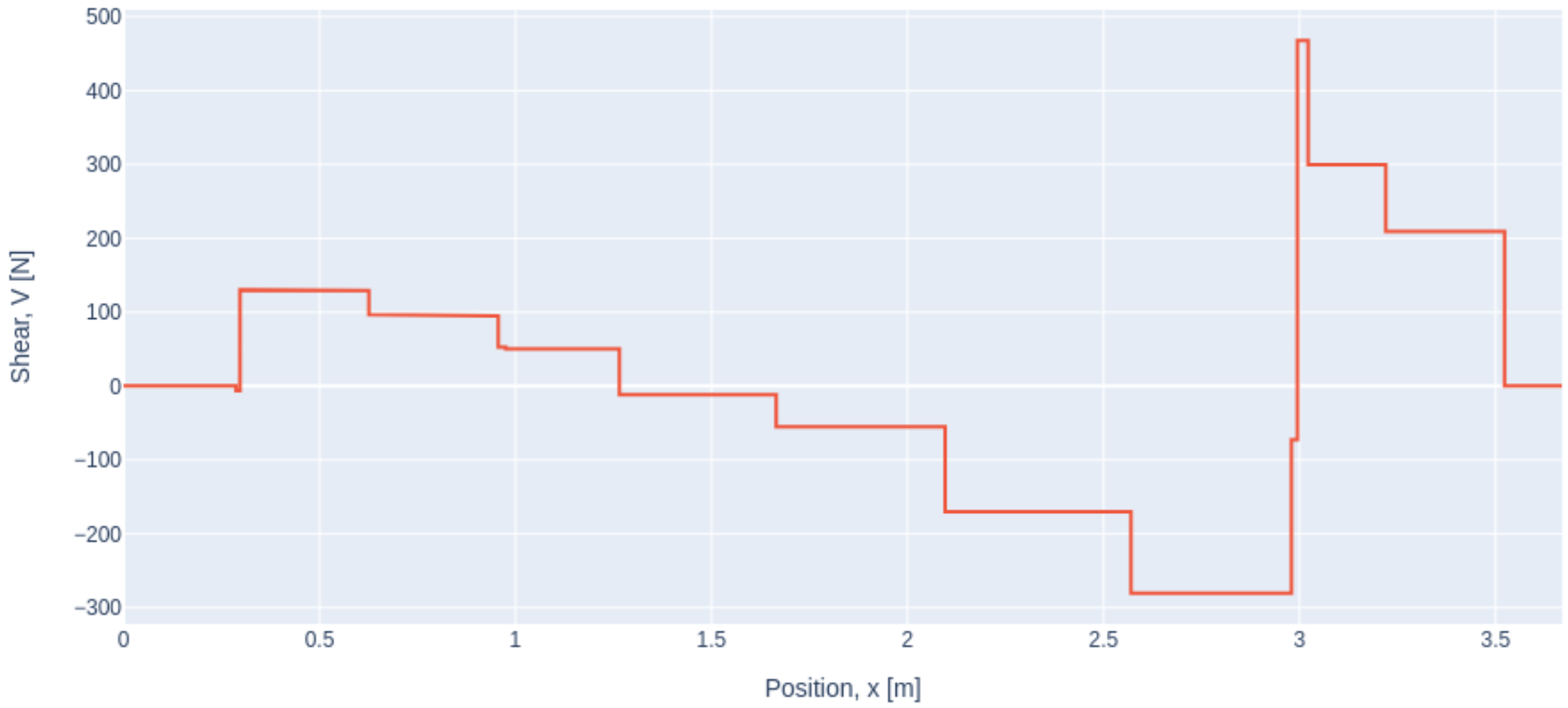
Angle of attack (AoA)	5.77°
Wind gust (assumed)	25 m/s
Total lift	885 N
Total mass	43.919 kg
Lateral acceleration	20.151 m/s^2
Total moment from lift	587 N m
Total moment of inertia	52.418 kg m^2
Rotational acceleration	11.191 rad/s^2
$\lvert M_{max} \rvert$	136 N m at body-wing

Transverse Loading Analysis Results



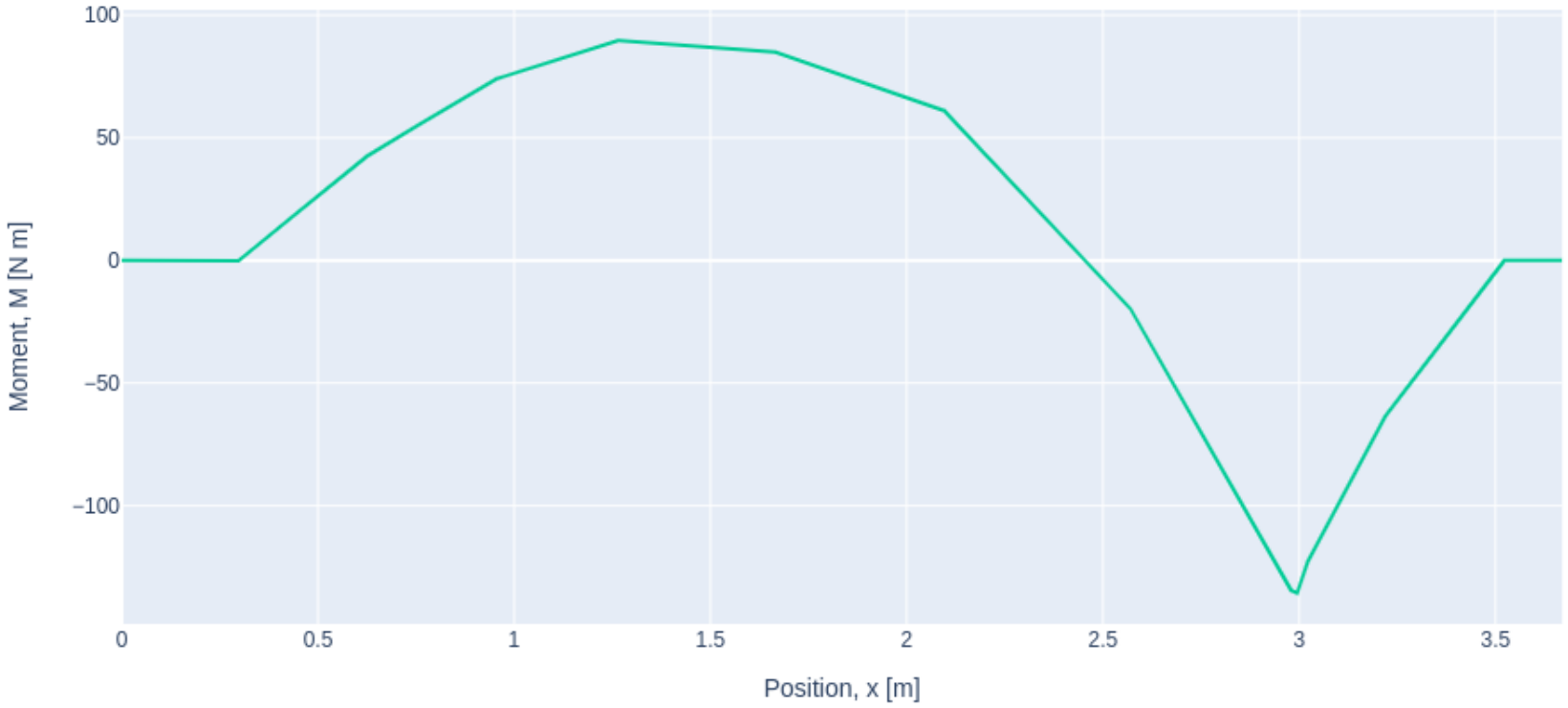
Point force diagram

Transverse Loading Analysis Results



Shear force diagram

Transverse Loading Analysis Results



Bending moment diagram

Thank you!

Questions?