# Maneuver Loads Analysis using CFD Methods of a Fighter Aircraft

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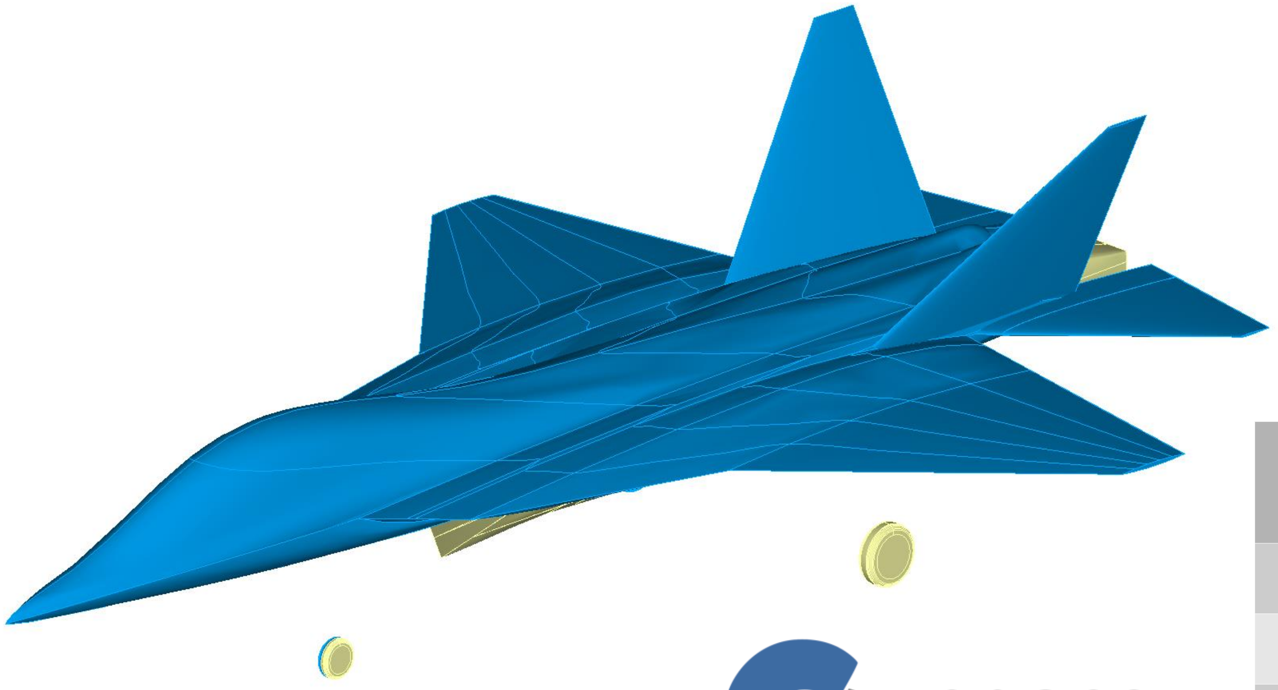
# The DLR Future Fighter Demonstrator (FFD)



- Conceptual Design performed by DLR Institute of System Architectures in Aeronautics
- More detailed aerodynamic shape by the DLR Institute of Aerodynamics and Flow Technology

| | |
|---|---|
| Maximum speed | VC = Ma 2.0 at 36,000 - 50,000 ft<br>VD = Ma 2.3 at 36,000 - 50,000 ft |
| Maximum altitude | 50,000 ft |
| Mission radius | 550 - 700 NM |
| Mass | 30.0 – 36.0 t MTOM |
| Payload | air 2 air mission: 1820 kg (internal)<br>optional: 8000 kg (internal + external) |
| Agility | Load factor Nz = -3.0 … +9.0 with BFDM |
| Longitudinal Stability | Subsonic: unstable, supersonic: stable |
| Control surfaces | All-movable HTP, VTP with rudder, ailerons along trailing edge |

cpacs
A Common Language for Aircraft Design

- Data exchange via Common Parametric Aircraft Configuration Schema (CPACS)

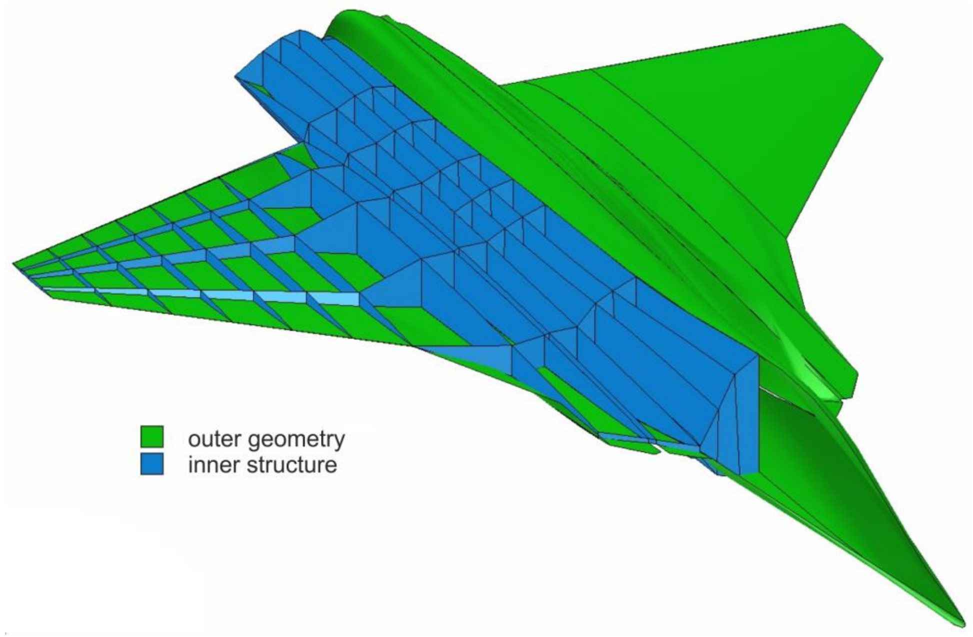
# Overview

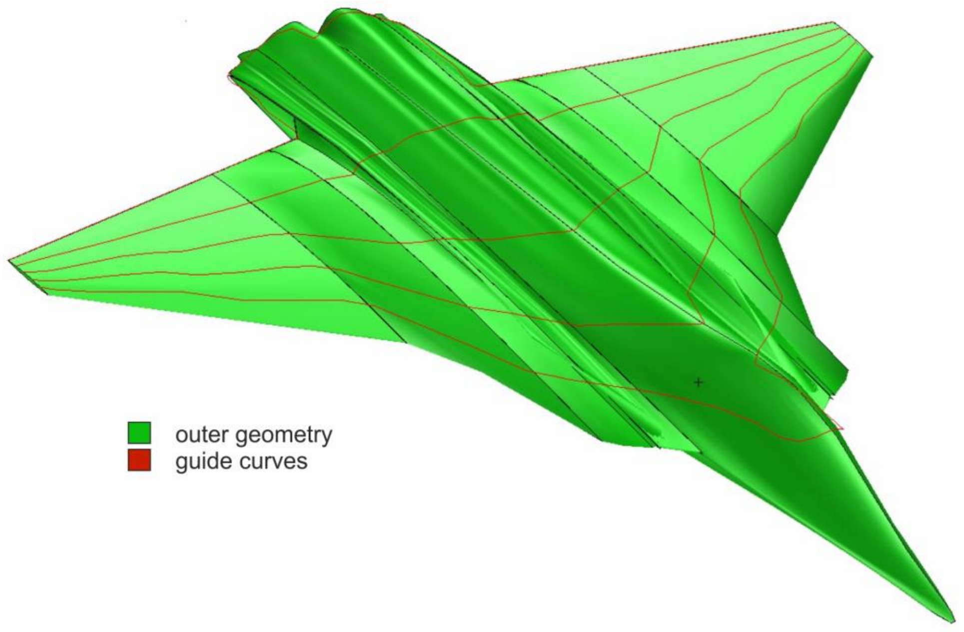
- Motivation & Introduction

- Set-up of Aeroelastic Modeling
- Comparison of CFD with Panel Aerodynamics
- Maneuver Loads Analysis across the Flight Envelope

- Conclusions and Outlook

# Parametric Geometrical Modeling with ModGen

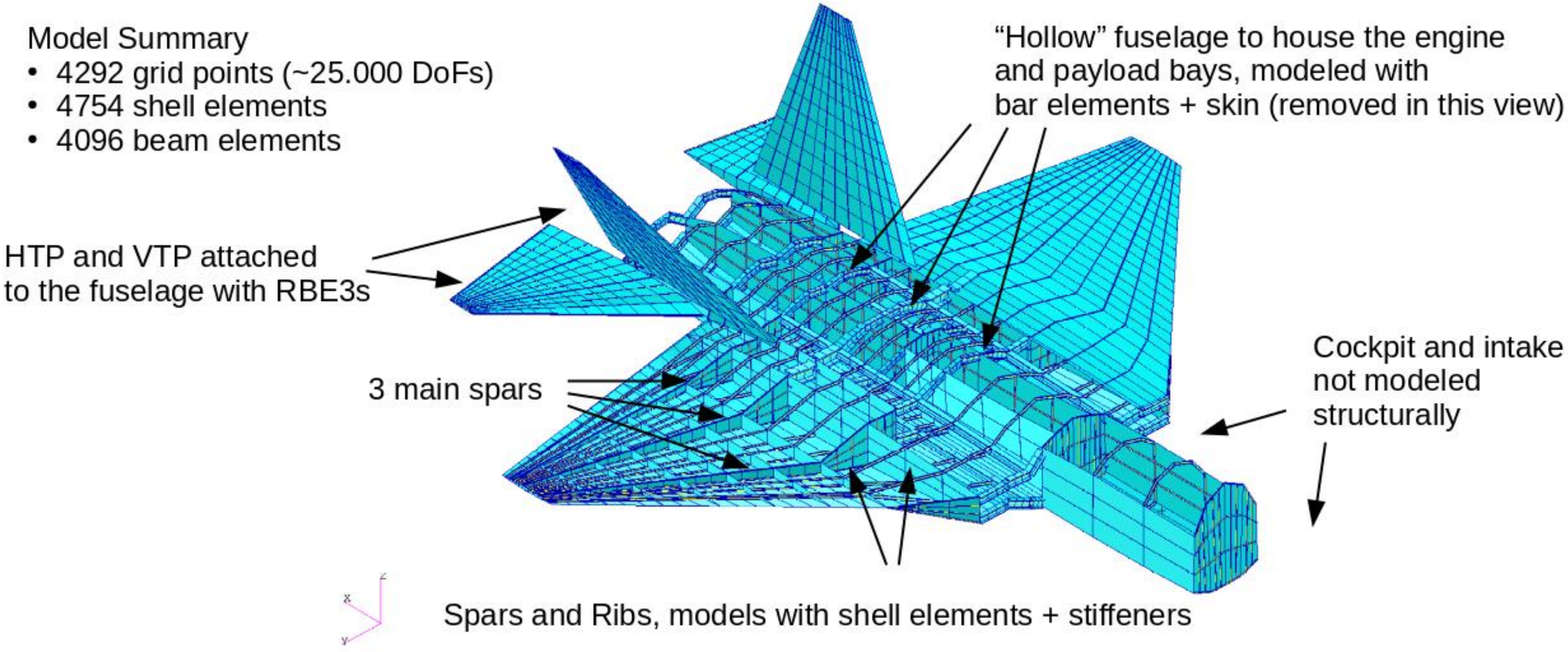



- Geometry defined in cpacs is processed in ModGen (inhouse tool)
  a) Geometry models for the primary structure parts like spars and ribs
  b) Outer hull for CFD mesh generation

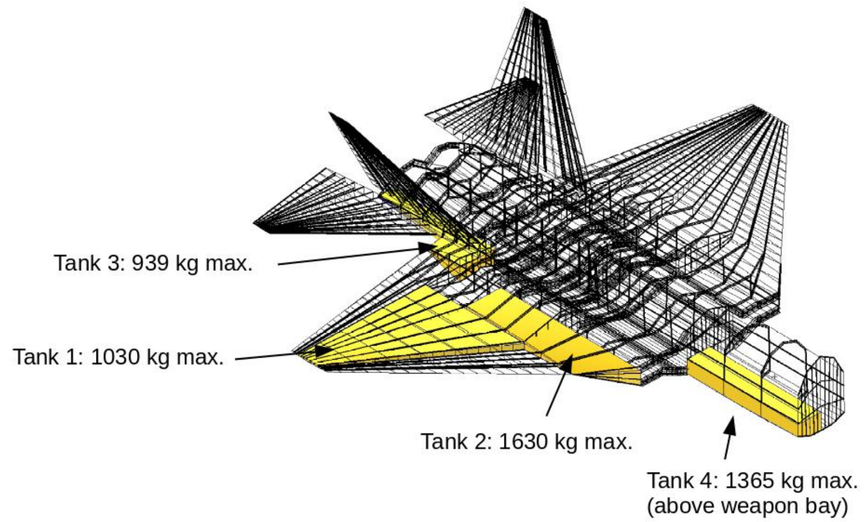
# Structural Modeling

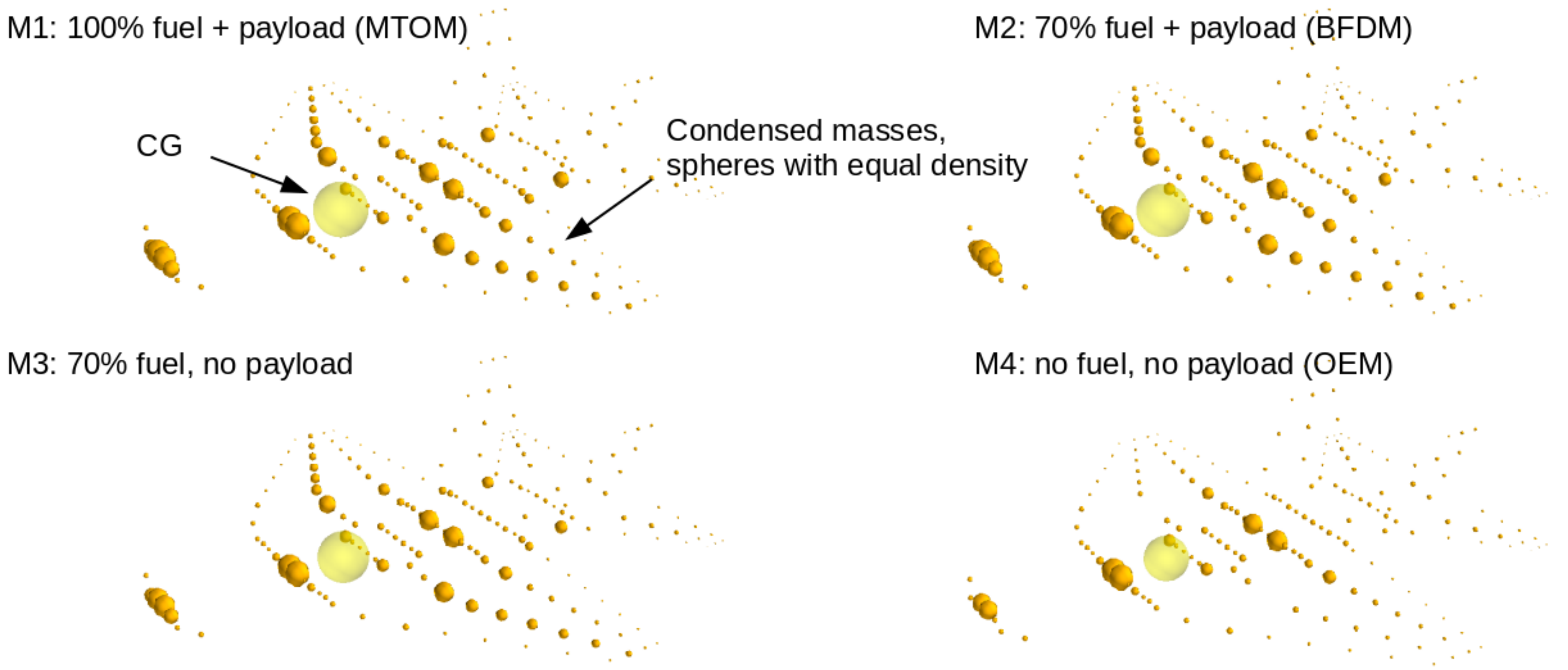
- Global structural dynamic characteristics
- Deformations for Fluid-Structure-Interaction



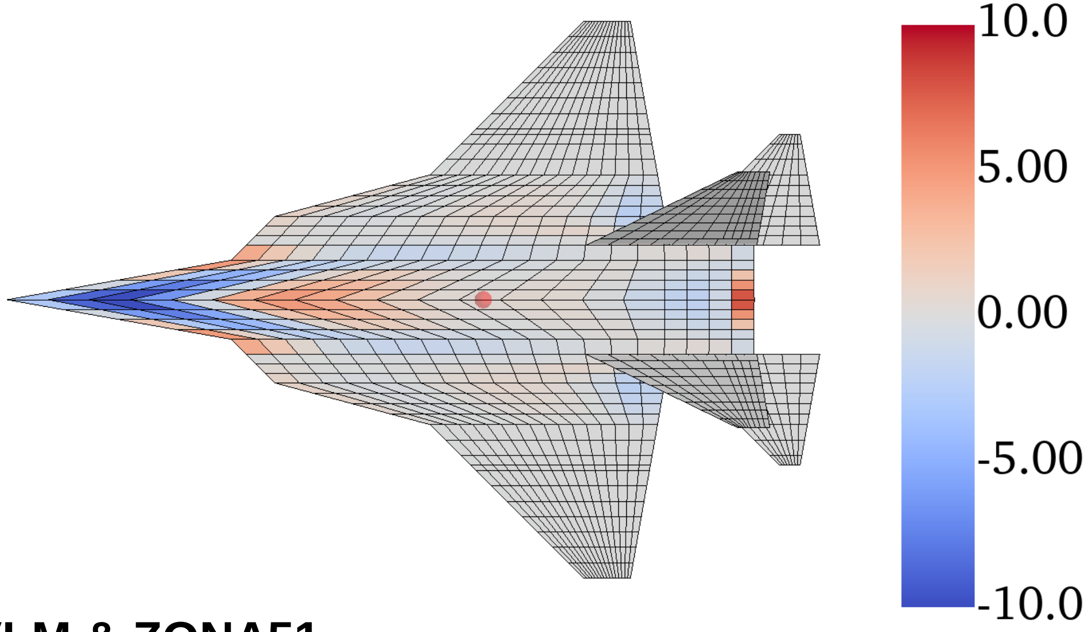
# Mass Modeling

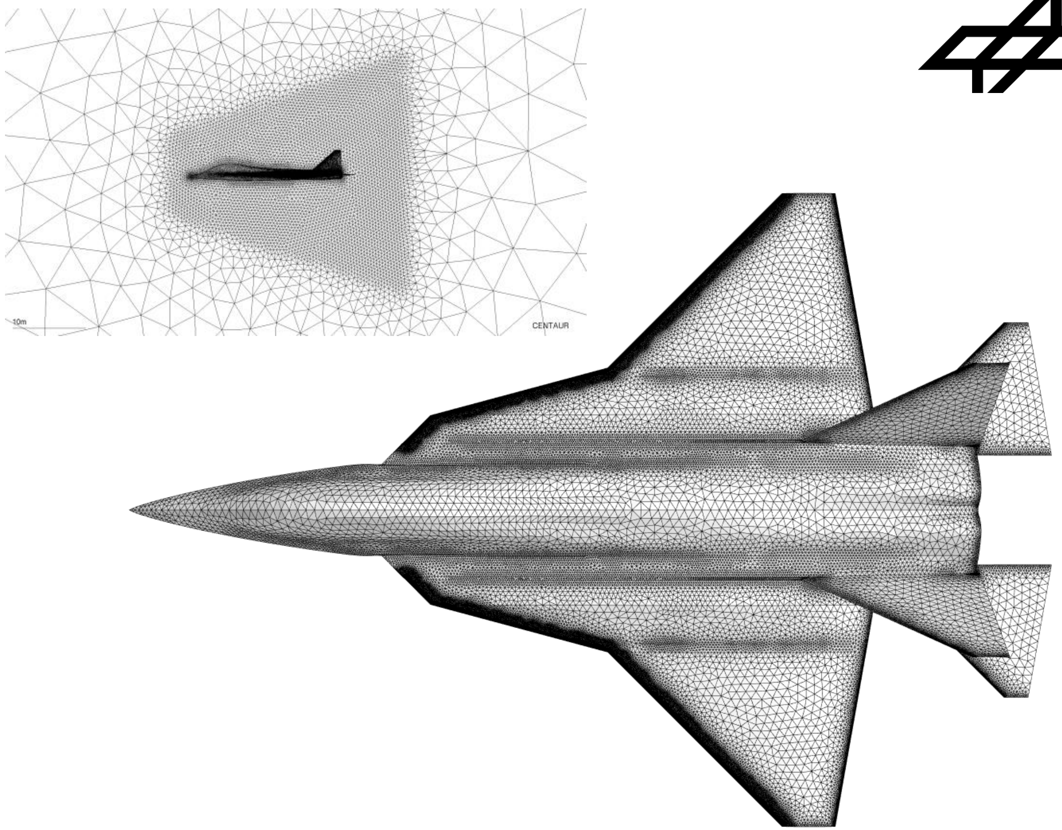
- Volumetric fuel modeling → mass and inertia properties per section
- Estimates for system masses, primary structural mass from material density
- Four mass configurations representing different phases during flight



# Aerodynamic Modeling



**VLM & ZONA51**

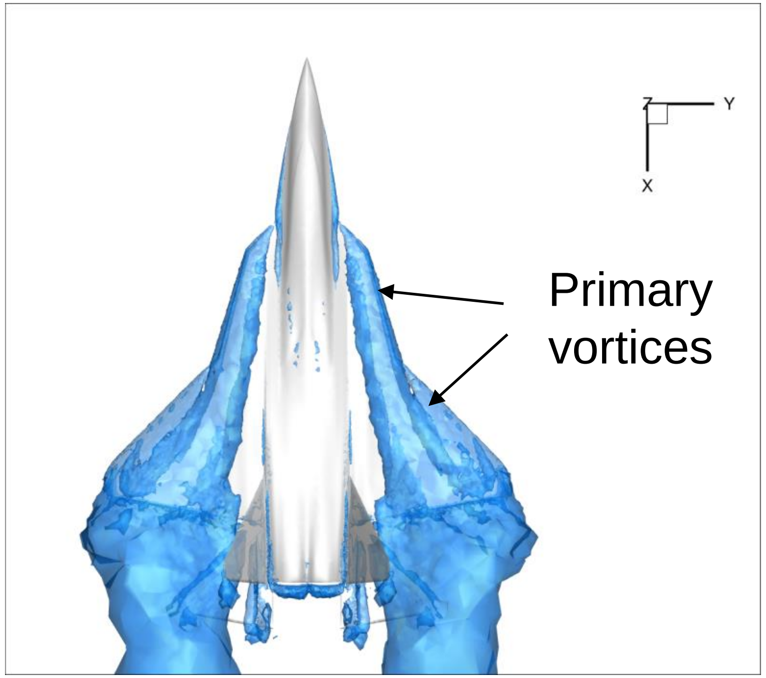
- CAERO cards
- 1112 panels
- Correction for camber and twist (indicated by color)

**DLR TAU-Code & SU2 Euler**

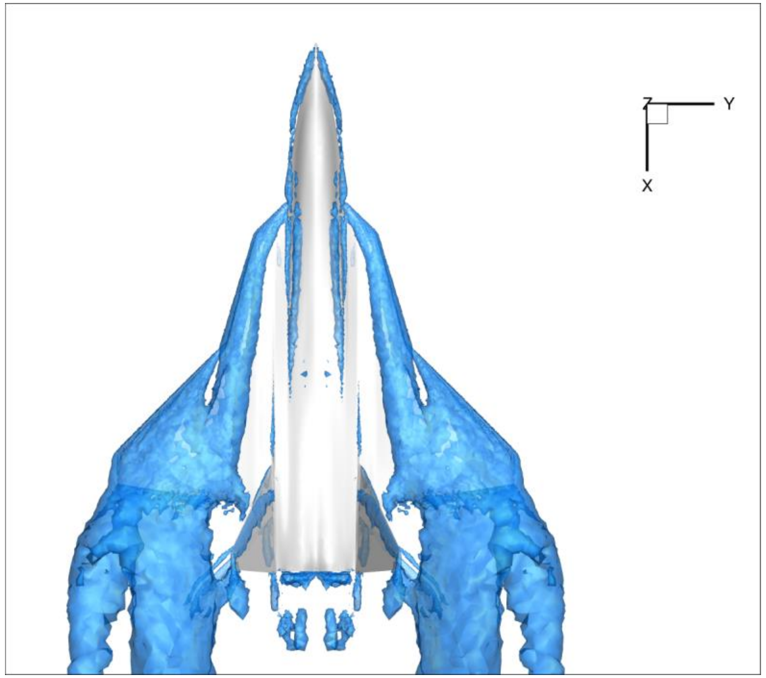
- ModGen geometry based on CPACS file
- Centaur
- 206k surface triangles
- 4.4M volume cells / 0.8M volume points
- Refined, cylindrical area to better resolve vortices

# The Vortex-Dominated Flow in CFD: Q-Criterion

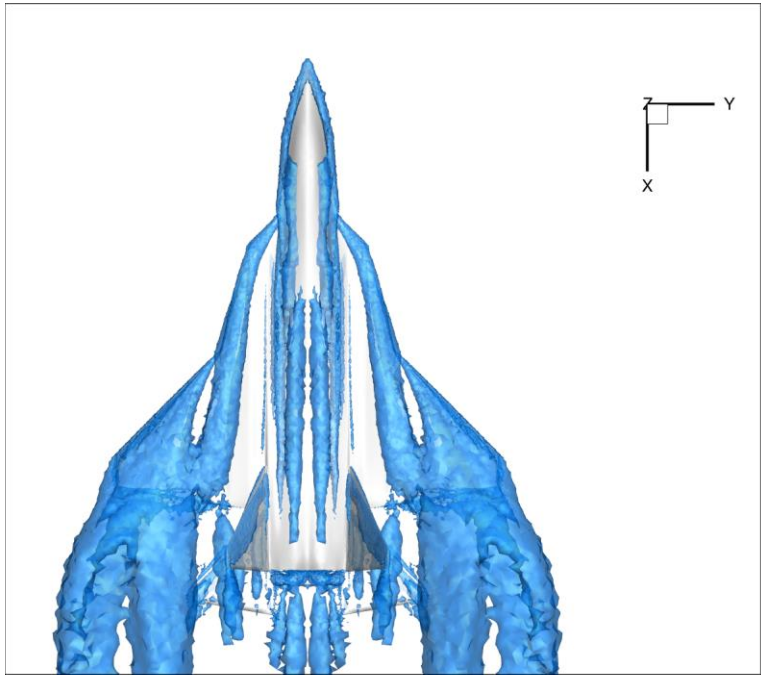
Ma=0.4, alpha=15.0°, Tau RANS (DLR Institute of Aerodynamics and Flow Technology)




Ma=0.4, alpha=15.0°, Tau Euler



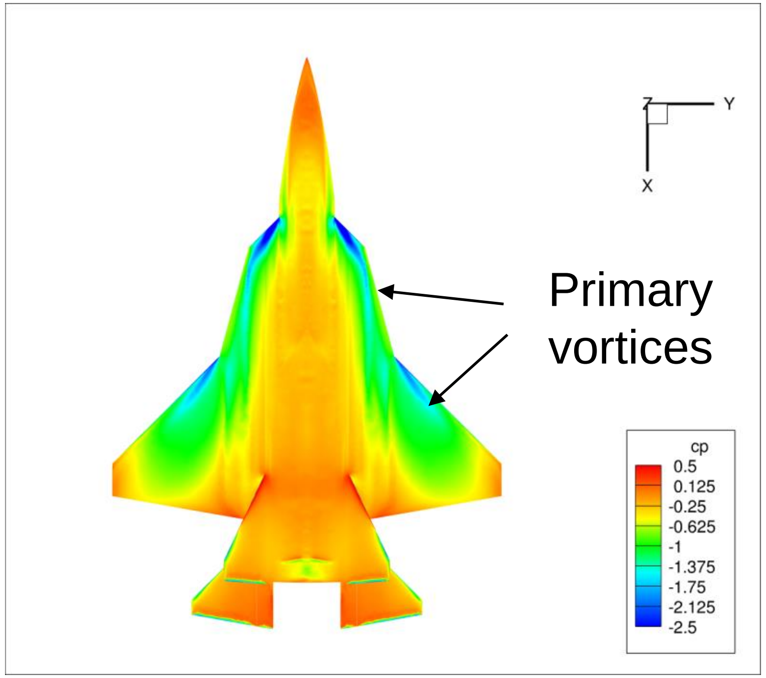

Ma=0.4, alpha=15.0°, SU2 Euler



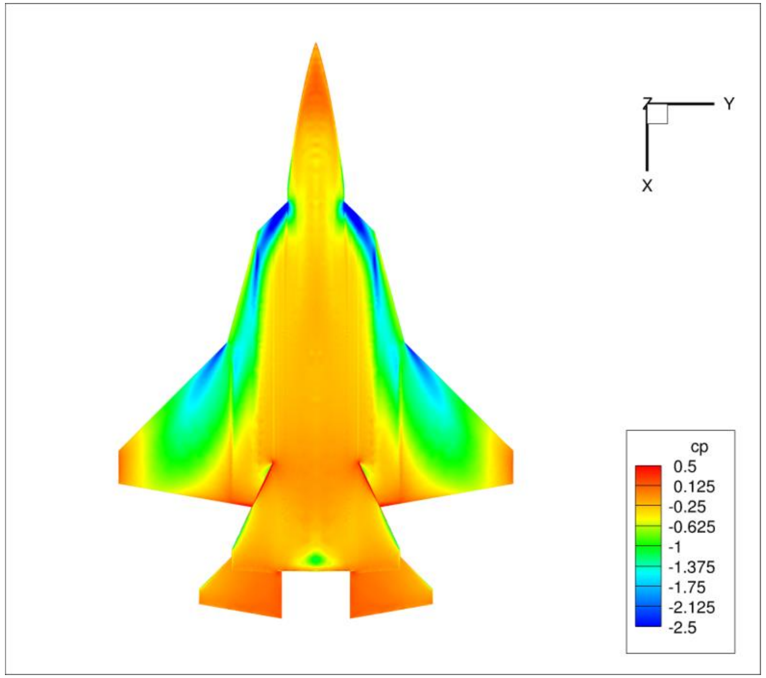

- Iso-surfaces at Q=50 identify two primary vortices in all three solutions
- Vortices slightly stronger the two Euler, as expected due to the missing viscous dissipation

# The Vortex-Dominated Flow in CFD: Cp

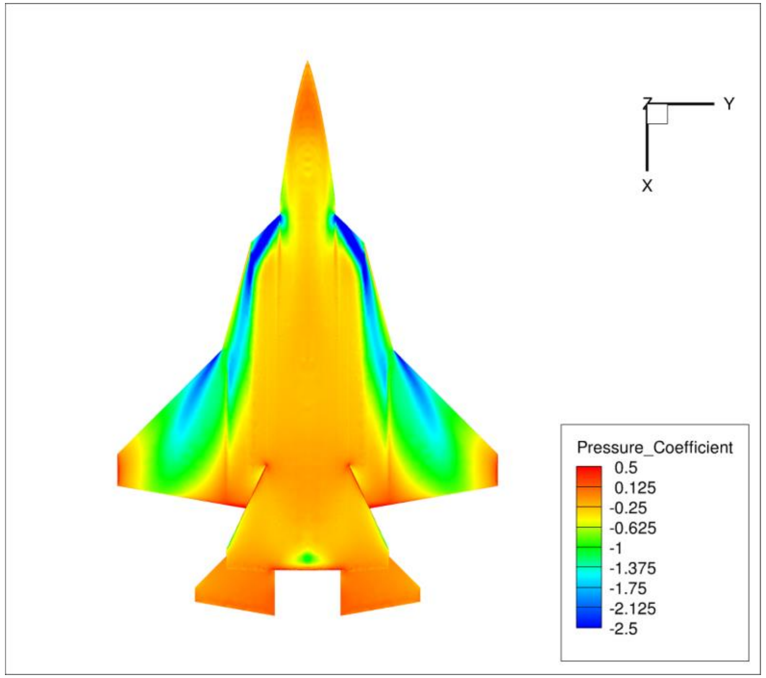
Ma=0.4, alpha=15.0°, Tau RANS (DLR Institute of Aerodynamics and Flow Technology)




Ma=0.4, alpha=15.0°, Tau Euler




Ma=0.4, alpha=15.0°, SU2 Euler

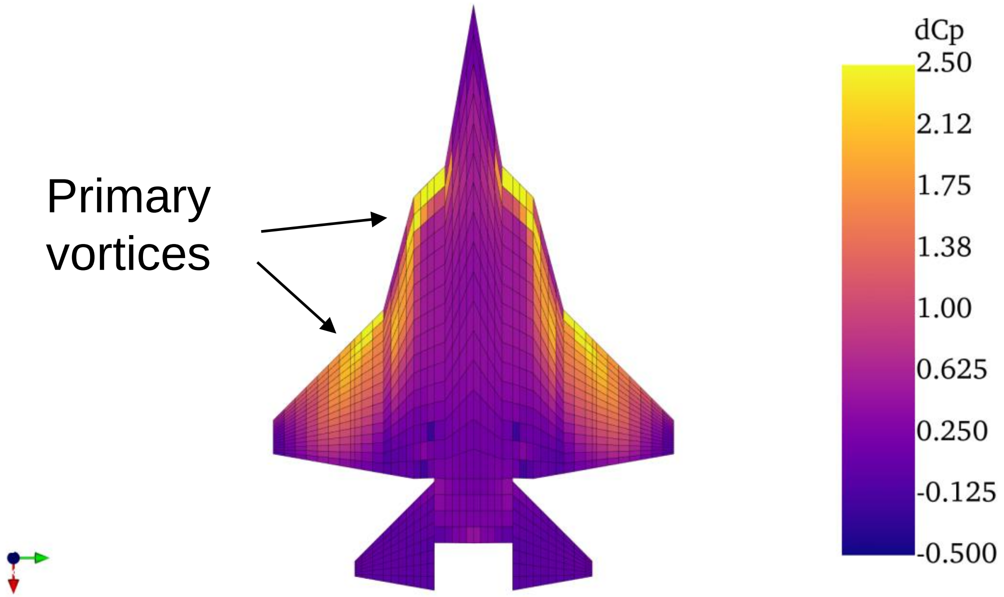



- Surface pressure distributions very similar in all three solutions
- “Footprints” of the vortices visible as suction peaks in green to blue colors

# CFD vs. Panel Methods: dCp

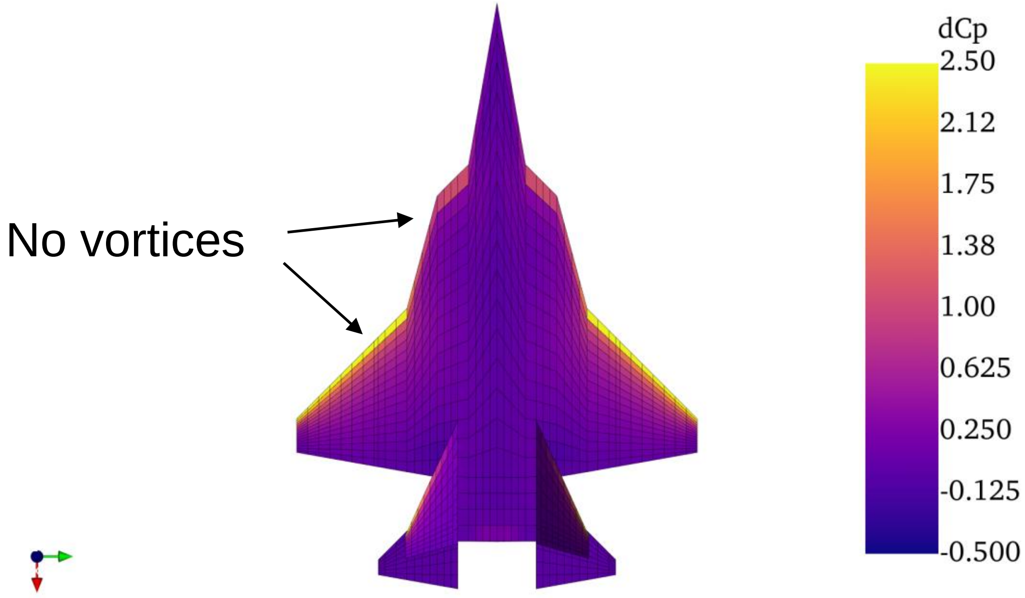
Ma=0.4, alpha=15.0°, SU2 Euler

$$\mathbf{\Delta c}_p^{\text{CFD, interp}} = \mathbf{c}_{p,\text{lower}}^{\text{CFD, interp}} - \mathbf{c}_{p,\text{upper}}^{\text{CFD, interp}}$$




Ma=0.4, alpha=15.0°, VLM

$$\mathbf{\Delta c}_p^{\text{AIC}} = \mathbf{AIC} \cdot \mathbf{w}_j$$




- Vortex-dominated flow is not captured properly by VLM

# Intermediate Conclusions

### CFD vs. Panel Methods

- Vortices are not captured properly
- *ZONA51 provides a reasonable solution in supersonic regime (not only for academic cases but for complex configurations)*

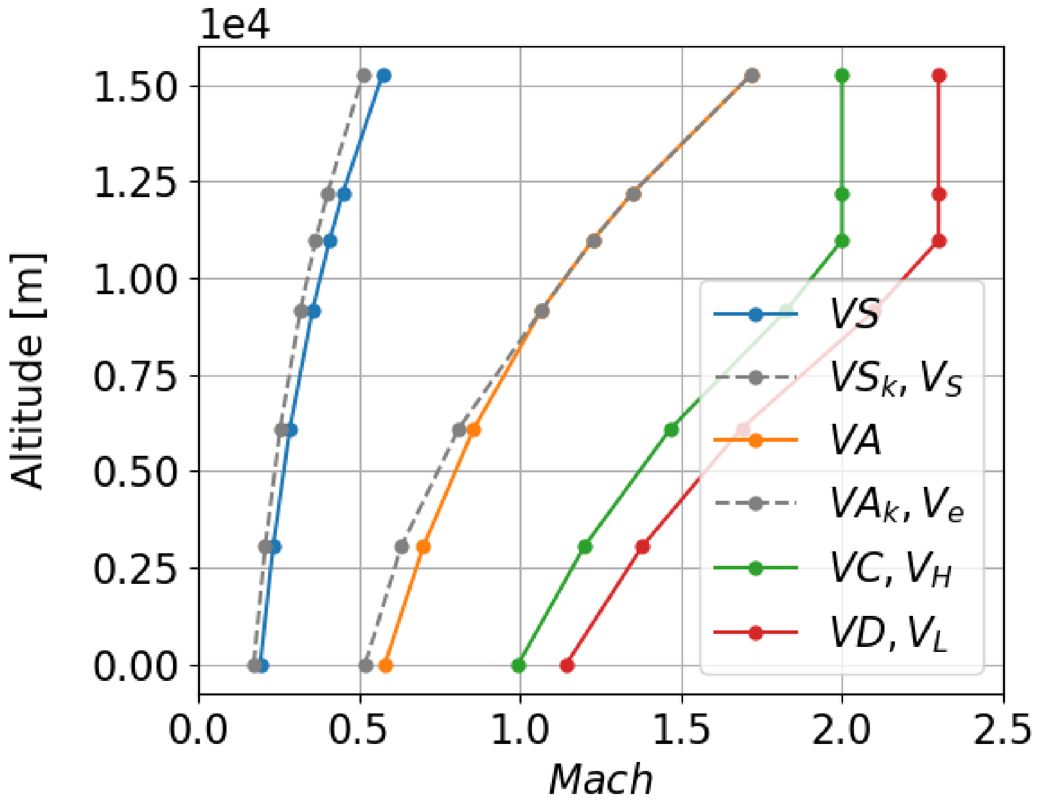
### Tau RANS vs. Tau Euler vs. SU2 Euler

- Euler is a reasonable choice for loads analysis, especially w.r.t. maturity of aircraft design
- RANS has its place and purpose!
- *Difficulties with other CFD solvers in supersonic regime, SU2 very robust*

### What does this mean for maneuver loads?

- <u>Panel methods are at their physical limit</u> → for fighter aircraft, we should use CFD !
- CFD maneuver loads are very labor intensive (trimmed aircraft, fully coupled with FEM, incl. control surface deflections, for all 688 load cases, in all areas of the flight envelope)

# Design Flight Speeds & Load Case Selection




**Overview on maneuver load parameters**

- Load factor $N_z = -3.0 \ldots 9.0$
- Roll rate $p = \pm 20°/s \cdots \pm 220°/s$
- Roll acceleration $\dot{p} = 20°/s^2 \ldots 550°/s^2$
- Elevator deflection $\eta_{\min,\max} = \pm 15°$

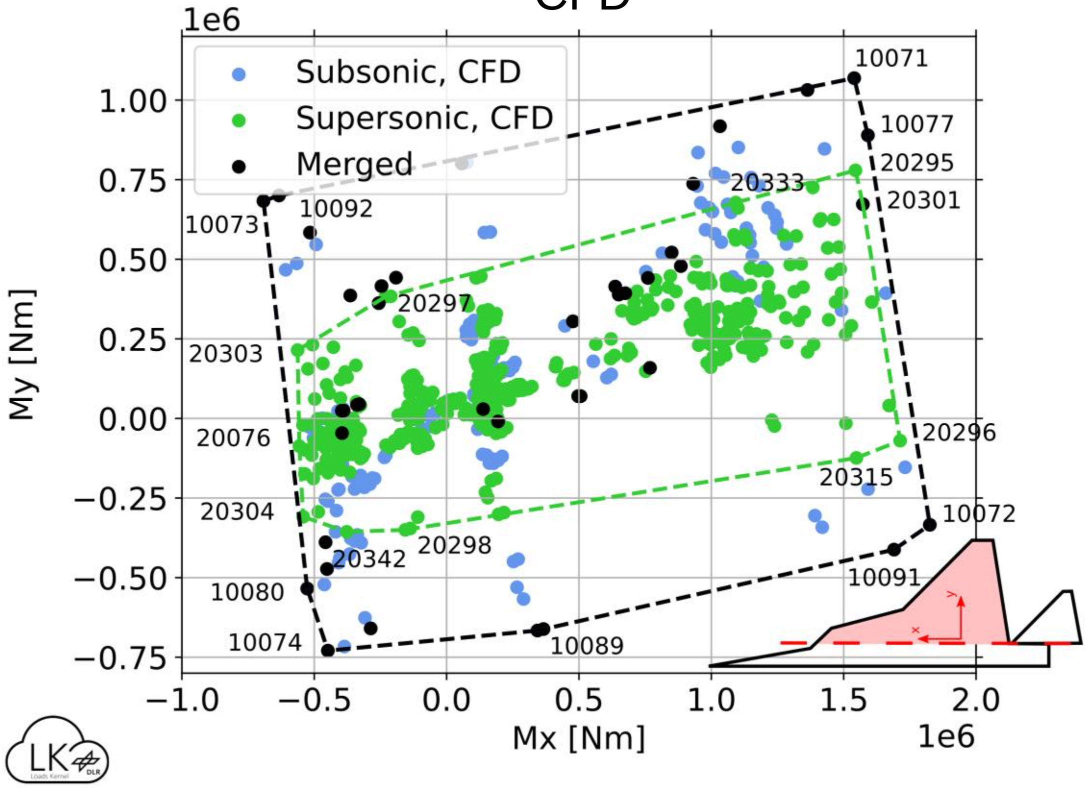
**Total of 688 maneuver load cases**

- For all flight speeds, at seven different altitudes, with four mass cases
- 175 subsonic and 513 supersonic load cases

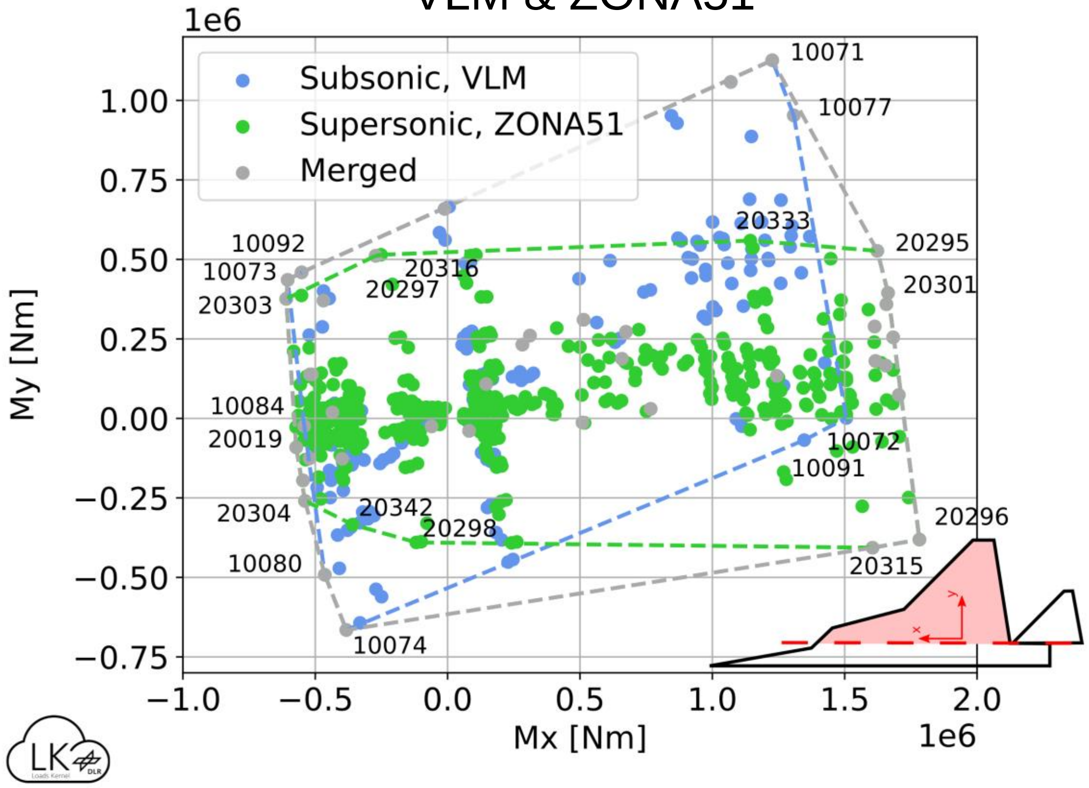
# CFD Maneuver Loads

- First interpretation: loads are similar, but different.
- Some details: magnitudes of Mx and My, upper right corner, lower right corner, no clock-wise rotation, envelopes defined by (mostly) the same load cases

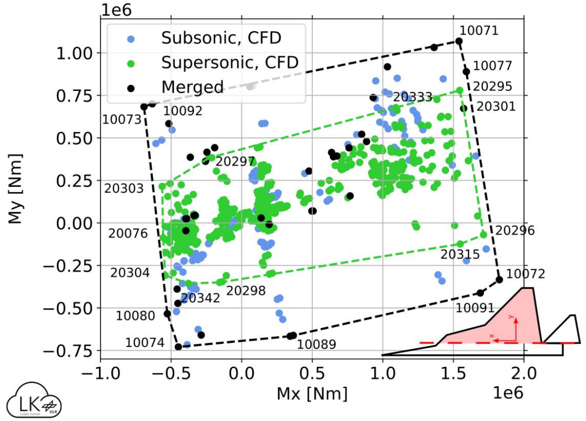
CFD

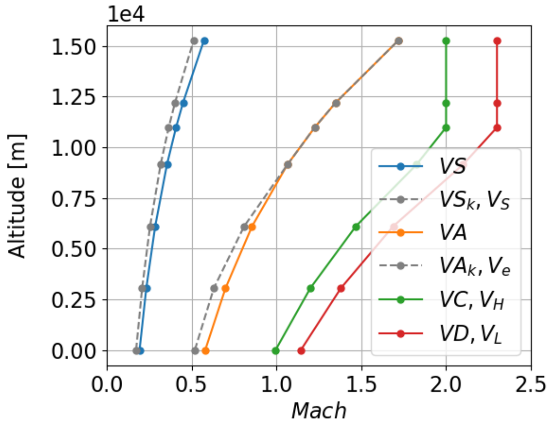



VLM & ZONA51



# Requirements on CFD Solver




**Robustness**

- Many load cases → many single simulations
    - Per load case: typically 1-3 h on one node with 128 CPUs
    - High degree of automation, no room for user-interaction
- Reliable solution for "numerically difficult" flow conditions on the edge of the envelope and beyond
- Imperfect modeling, e.g. surface geometry not perfect due to preliminary design stage

**Python interface**

- Input: surface deformations, set onflow condition
- Run solver
- Output: force vector

Coupled simulation via Python interface

LK Loads Kernel DLR ↔ SU2 The Open-Source CFD Code

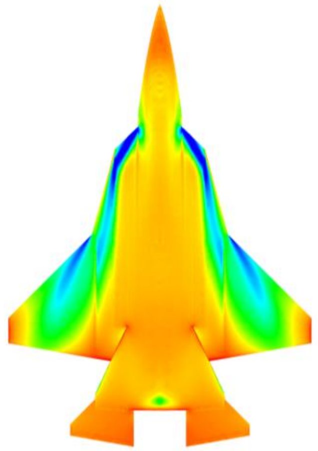
Loads Kernel Software available here:
[https://github.com/DLR-AE/LoadsKernel](https://github.com/DLR-AE/LoadsKernel)

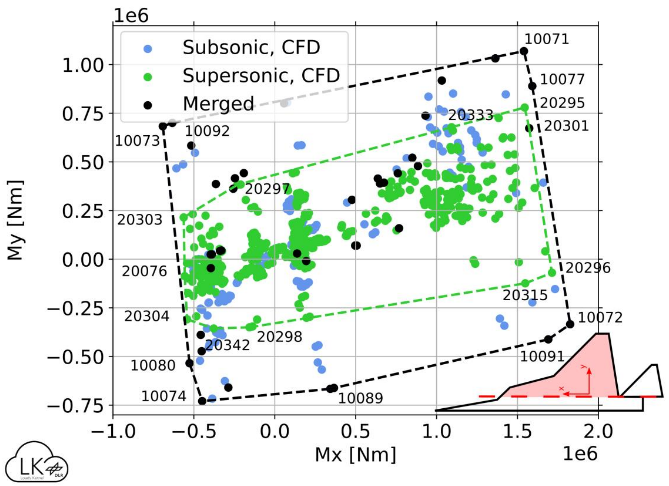
# Conclusions

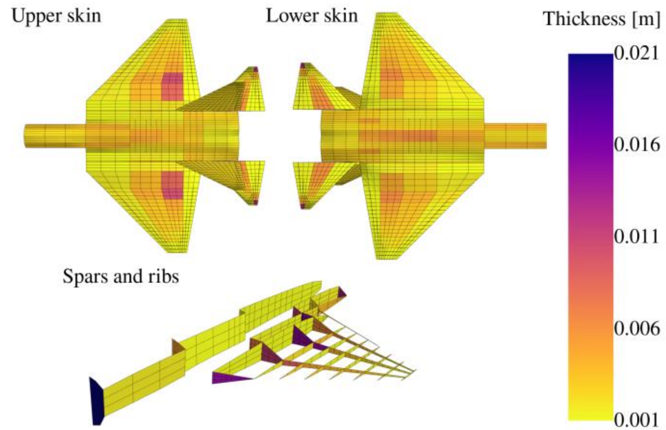
- Comprehensive maneuver loads analysis covering the whole flight envelope is performed with CFD.
- VLM and ZONA51 fail because the magnitude of the section loads is unreliable.
- Necessity of a maneuver loads analysis using CFD for fighter configurations is shown.
- Work published at ICAS (2022) and in AST Journal (2023, open access)
- My most important requirements on the CFD solver:
  Robustness, Python interface
  + support from developers


Aerospace Science and Technology
Parametric aeroelastic modeling, maneuver loads analysis using CFD methods and structural design of a fighter aircraft
A. Voß, T. Klimmek

Fully coupled maneuver loads analysis with CFD + structural sizing





# Next Step: Gust Encounter