Advanced Modeling & Simulation Seminar Series
NASA Ames Research Center
March 29, 2016

Maneuvering Rotorcraft Simulations using HPCMP CREATE™ - AV Helios

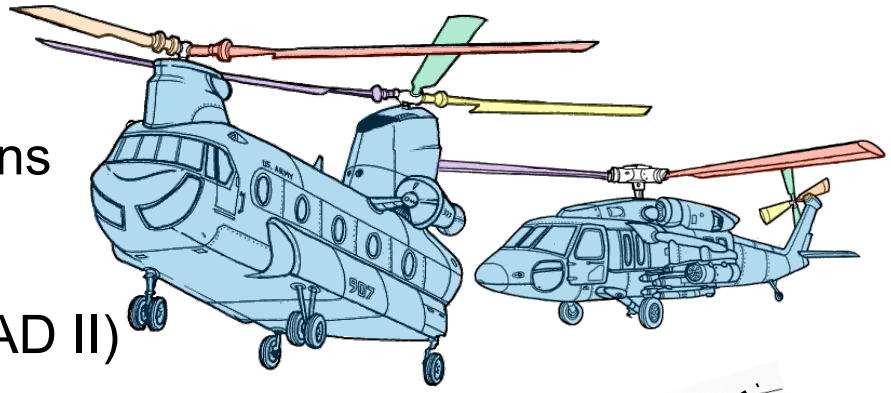
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Beatrice Roget Science and Technology Corporation
Jay Sitaraman Parallel Geometric Algorithms, LLC
Andy Wissink U.S. Army Aviation Development Directorate
Hossein Saberi and Weibin Chen Advanced Rotorcraft Technology, Inc.

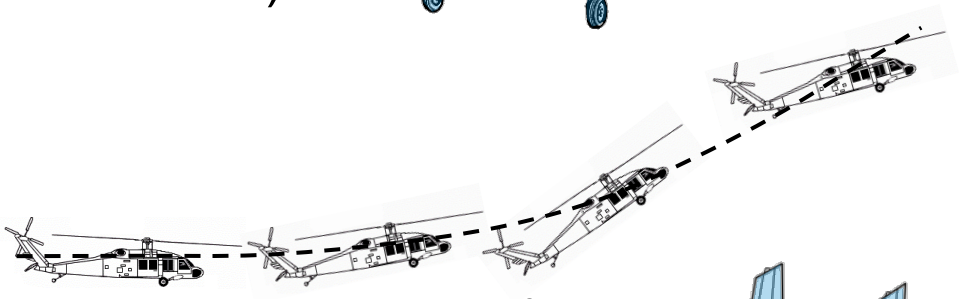
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Review completed by the AMRDEC Public Affairs Office (PR1830, 08 Dec 2015)

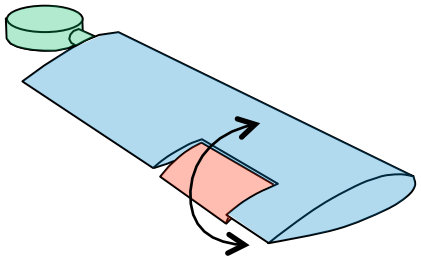
Introduction

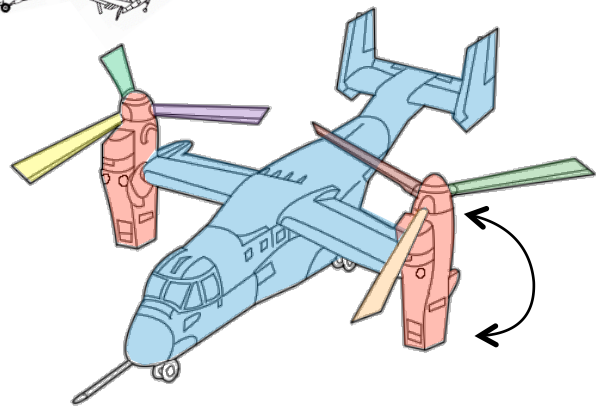
- **Previous Helios capabilities:**
  - Conventional rotorcraft configurations only (fixed fuselage/multi-rotor)
  - CFD/CSD coupling (RCAS, CAMRAD II)
  - Steady flight conditions only



- **Configurations of interest:**
  - Maneuvering rotorcraft
  - Tilt-rotor with flexible wings & blades
  - Moving control surfaces
  - Slung loads
  - Store separation …



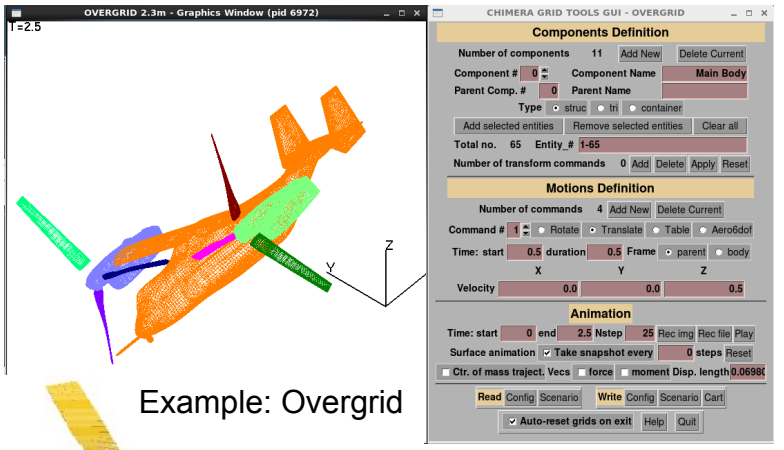




→ Need generic flexible multi-body CFD/CSD tool

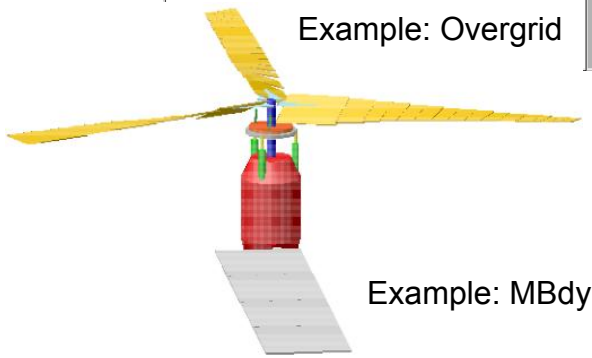
Introduction

- Several CFD codes already have some body hierarchy capability (CREATE™ - AV Kestrel, OVERFLOW, FUN3D)… Limitations on type of configurations allowed



Example: Overgrid

- CSD codes are much more general –for example structural multi-body codes (DYMORE, MBdyn) or Comprehensive Analysis (CAMRADII, RCAS…)

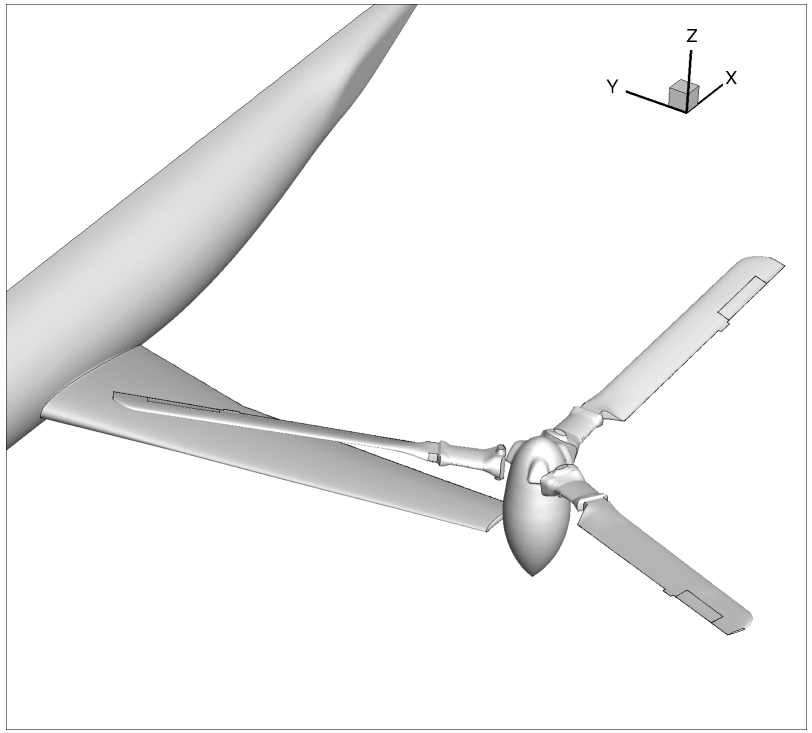


Example: MBdyn

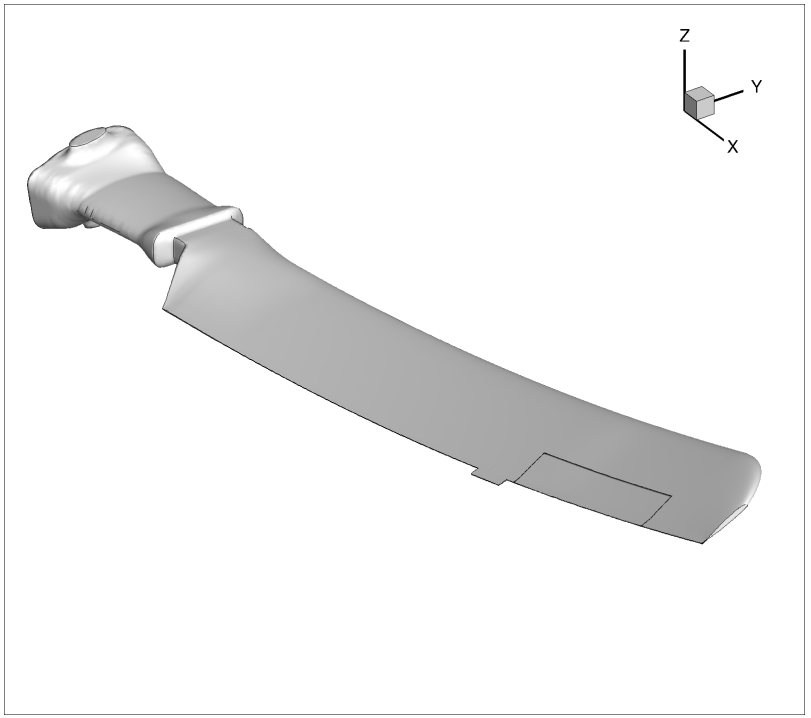
- Helios focus on rotorcraft – flexibility is crucial, specialized CFD/CSD exchange for trimmed periodic response.
- Goal: develop hierarchical flexible multi-body representation capable of
  - modeling complex configurations similar to CSD modules
  - support CFD/CSD analysis for rotorcraft systems.

Example of complex case

Maneuvering tilt-rotor with flexible wing, nacelle tilt, flexible rotating blades with active flaps …



Nacelle+rotor attached to tip of elastic wing



Elastic flap moving within elastic blade

Flexible structure connected to another flexible structure

... Not currently possible with any existing CFD code

Objectives

New Helios module Melodi :

(**Me**sh Motion, **Lo**ading, and **D**eformation **I**nterface):

uses a hierarchical flexible multi-body model description

- Apply rigid-body motions
- Apply mesh deformations

} prescribed or from CSD

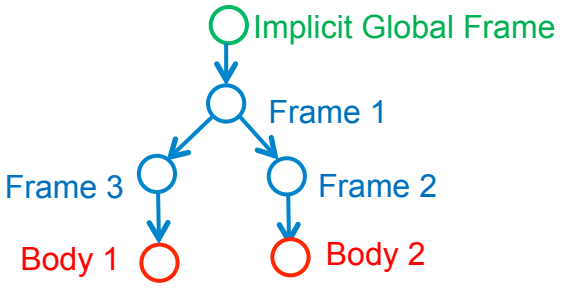
- Compute reduced airloads on structure → CSD

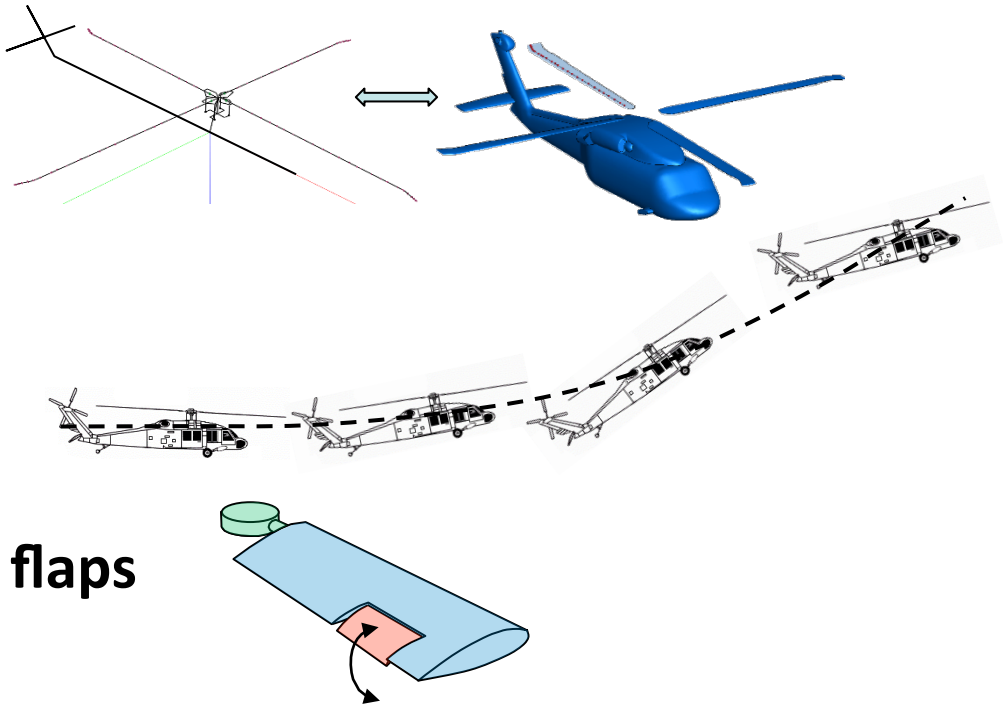
MELODI design objectives:

- **Generality**: provide a hierarchical representation for flexible multi-body systems of arbitrary complexity
- **Simplicity** : interface should be user-friendly, requesting as few as possible user inputs in an intuitive manner.
- **Modularity** : able to interface with different CSD/CA modules ; easy to add new motion/deformation methods.

Outline

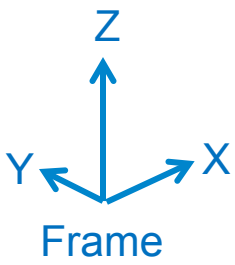
- Methodology
  - Body Hierarchy
  - Fluid-Structure Interface
- Results
  - UH-60 pull-up maneuver
  - SMART rotor with active flaps
- Conclusions





Body Hierarchy Primitives

2 basic primitives: Frames and Bodies

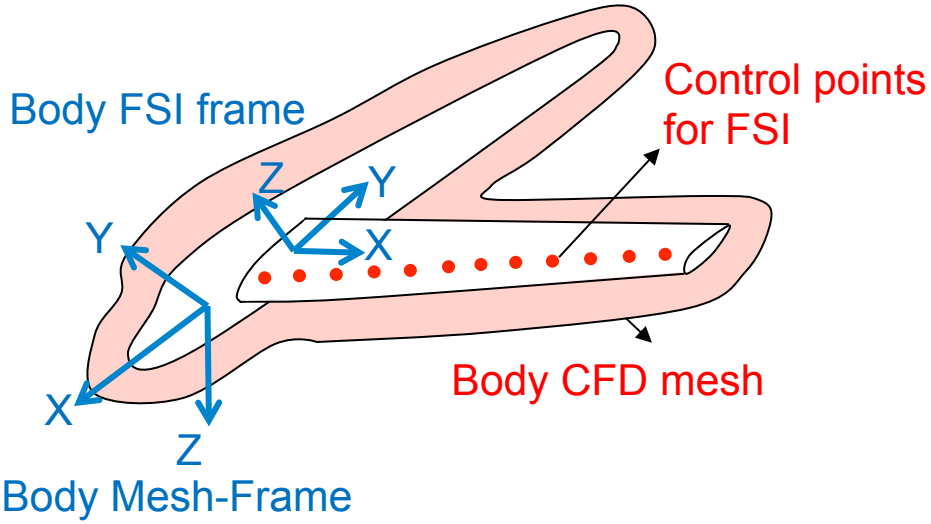


FRAME (→ MOTIONS)

- right-hand-rule orthonormal coordinate system (origin/orientation in another frame).
- used as a tool to position and move bodies in space.

BODY (→ DEFORMATIONS)

- surface-conforming CFD mesh, can be deformed
- coordinates of mesh points expressed in a Body Mesh Frame
- deformation applied in FSI frame



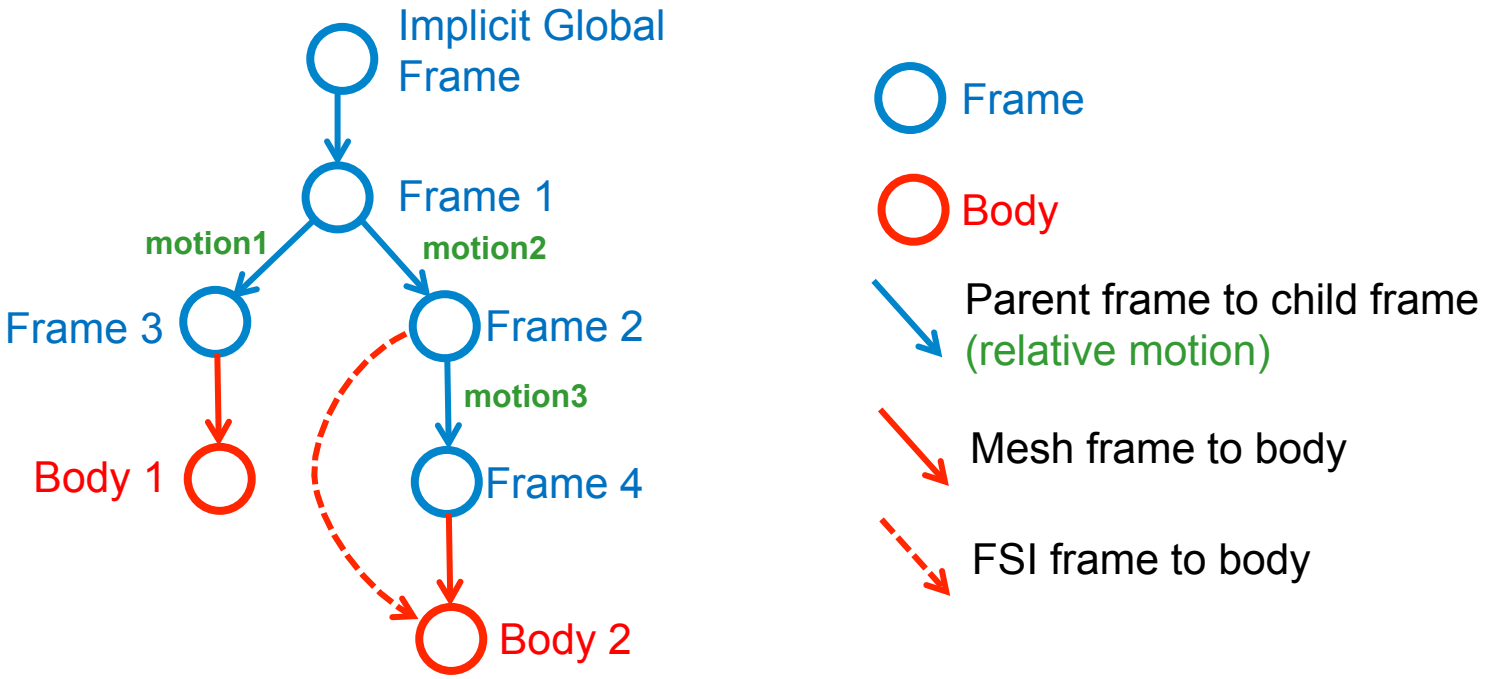
Motions can be specified in several ways:

- Prescribed rotation or translation
- Fixed rate rotation or translation
- Frame rigidly attached to flexible body
- Inherited directly from CSD

Deformations can be:

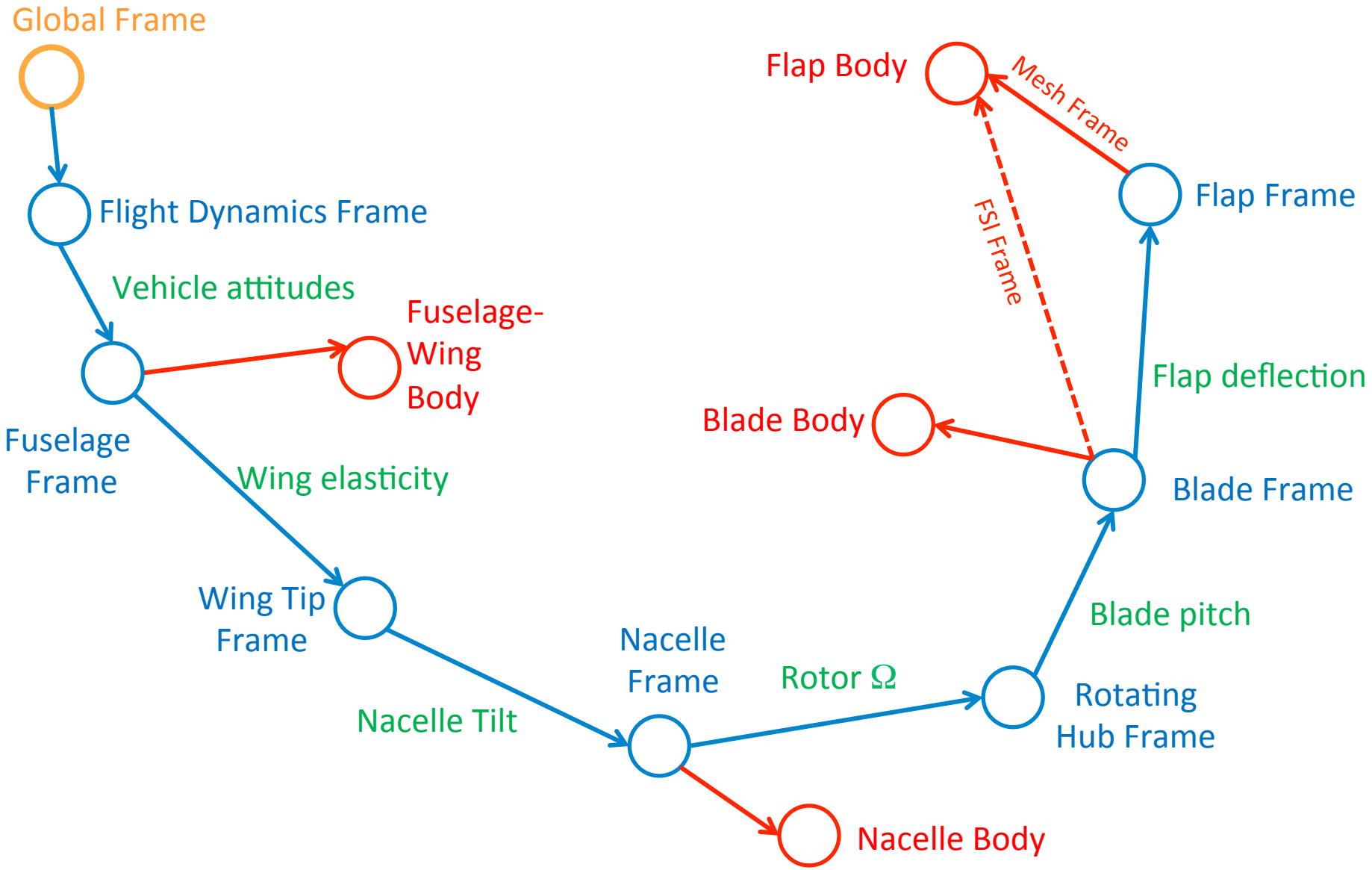
- Prescribed
- Inherited directly from CSD

Body Hierarchy Tree

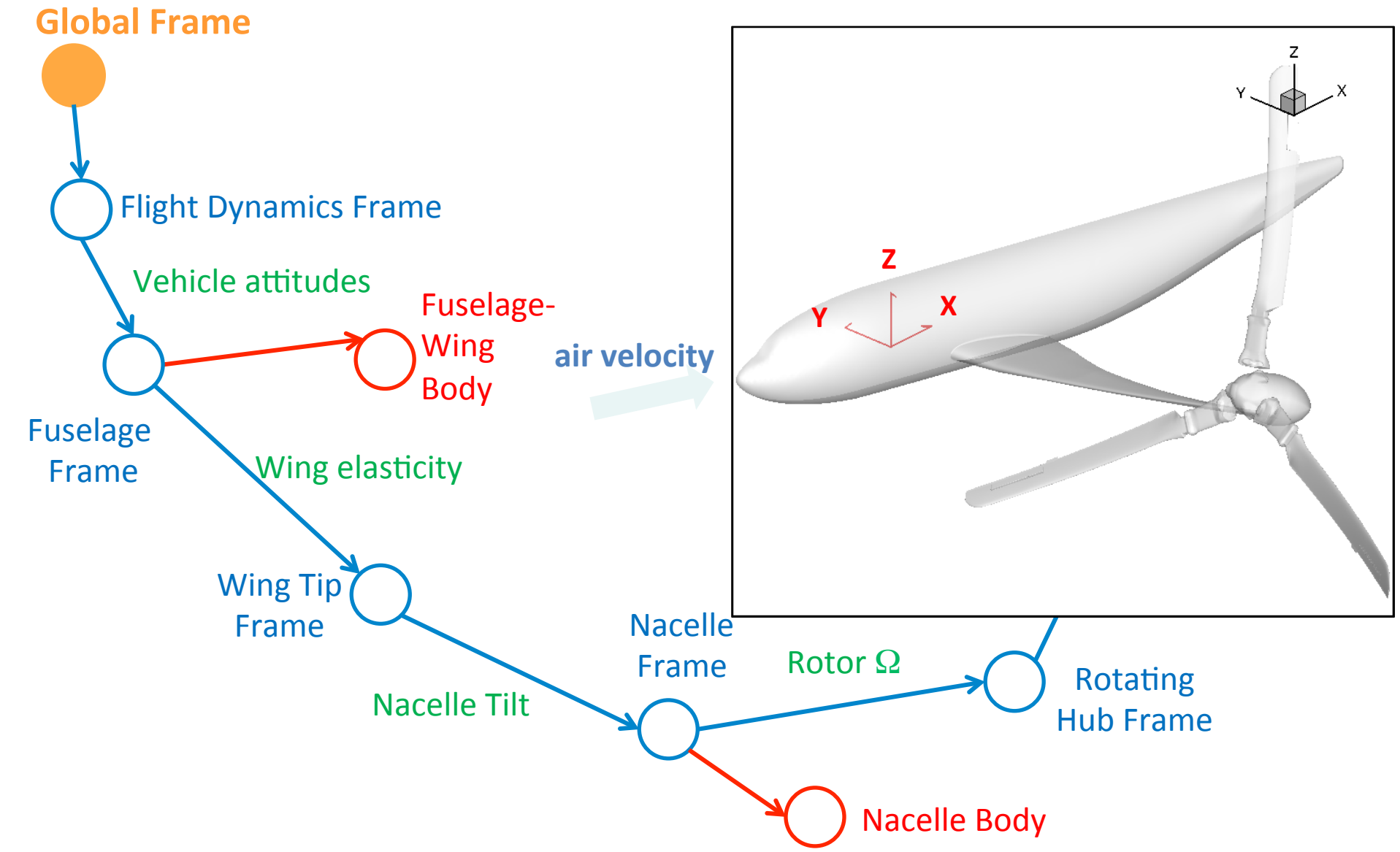


- Frames and Bodies nodes successively added
- Top node = implicit global frame
- Only Frames have children (Body = leaf node)
- Parent for Frames = relative frame for motion
- Parent for Bodies = mesh-frame
- Bodies can also have FSI frame for deformations

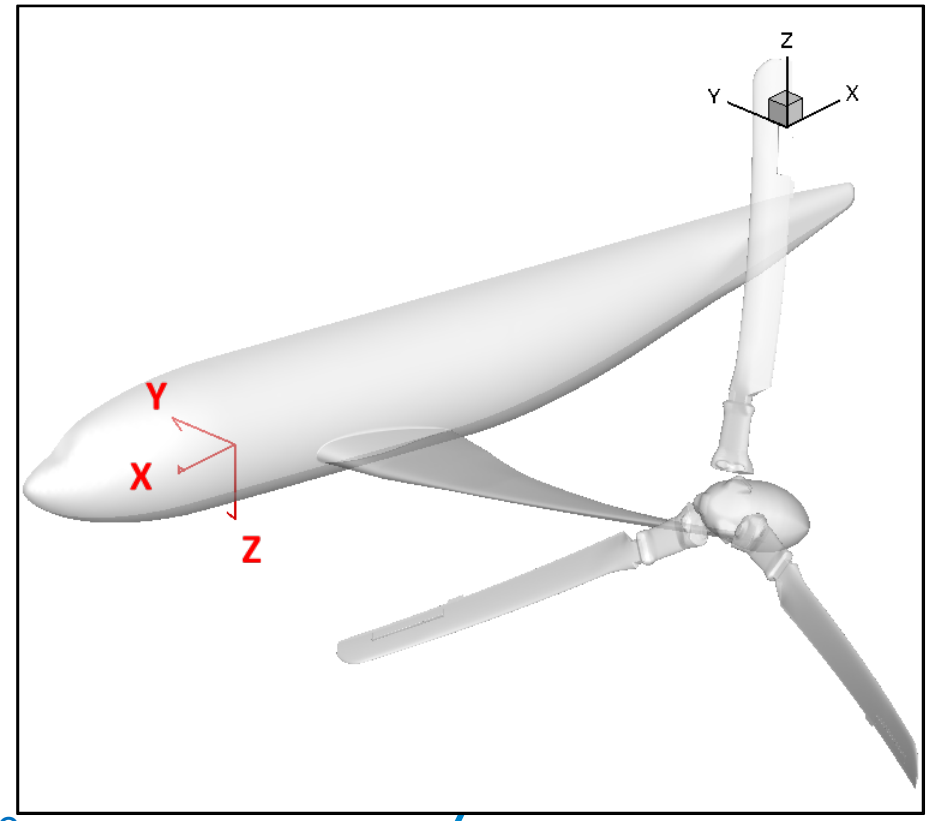
Example: Tilt-Rotor with TE flaps



Example: Tilt-Rotor with TE flaps



Example: Tilt-Rotor with TE flaps



Global Frame

Flight Dynamics Frame

Vehicle attitudes

Fuselage-Wing Body

Fuselage Frame

Wing elasticity

Wing Tip Frame

Nacelle Tilt

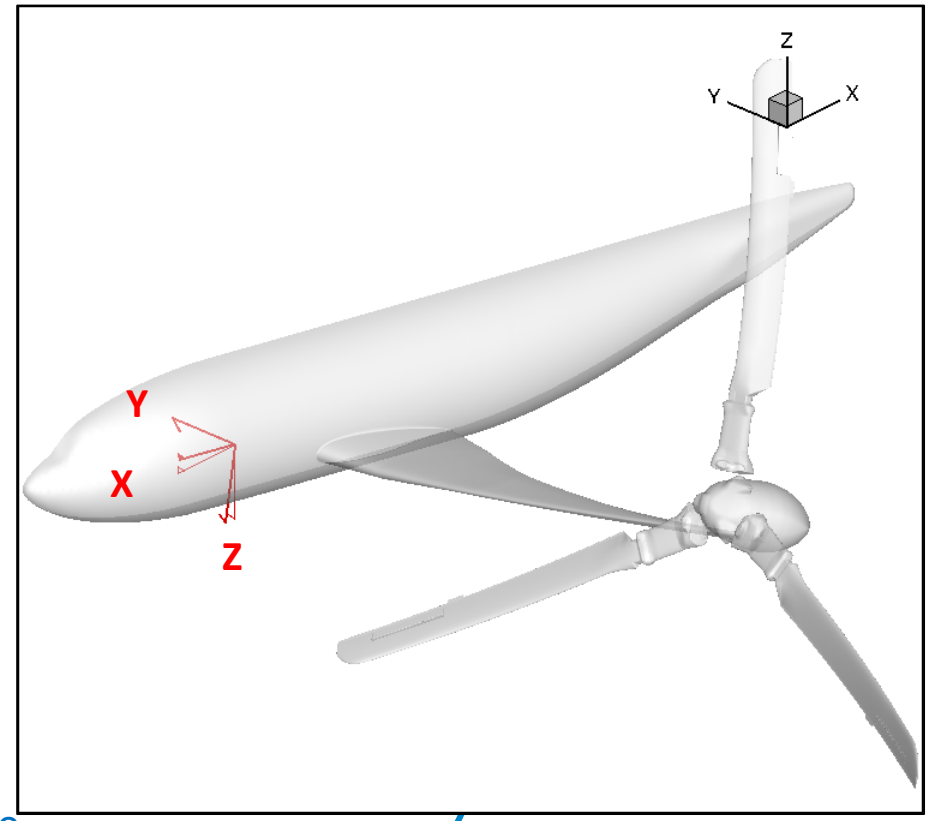
Nacelle Frame

Rotor Ω

Rotating Hub Frame

Nacelle Body

Example: Tilt-Rotor with TE flaps



Global Frame

Flight Dynamics Frame

Vehicle attitudes

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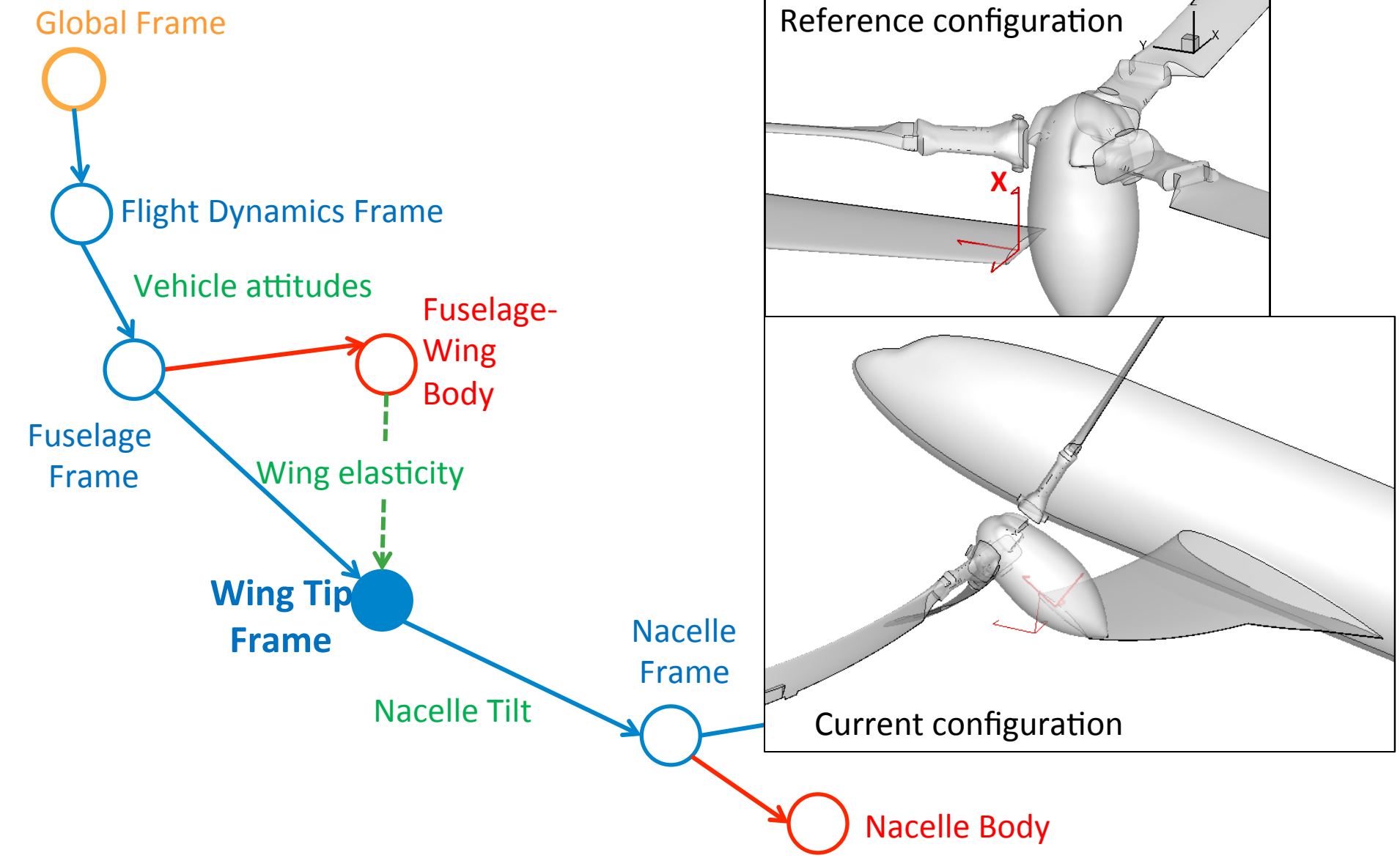
Nacelle Frame

Rotor Ω

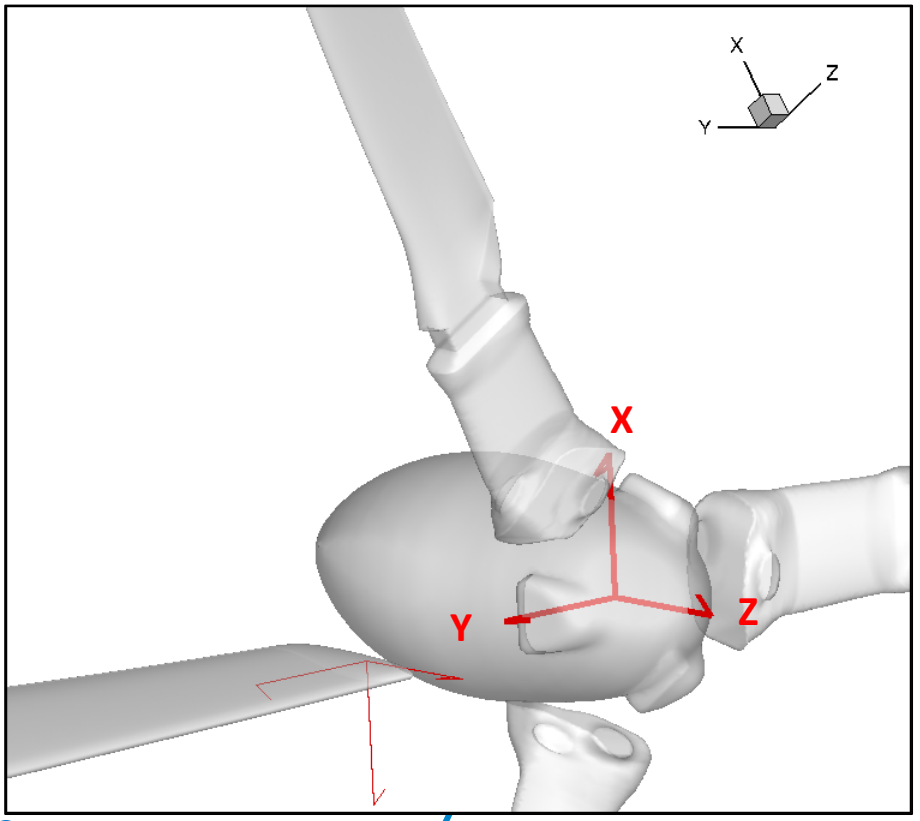
Rotating Hub Frame

Nacelle Body

Example: Tilt-Rotor with TE flaps



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Global Frame

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Vehicle attitudes

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Nacelle Tilt

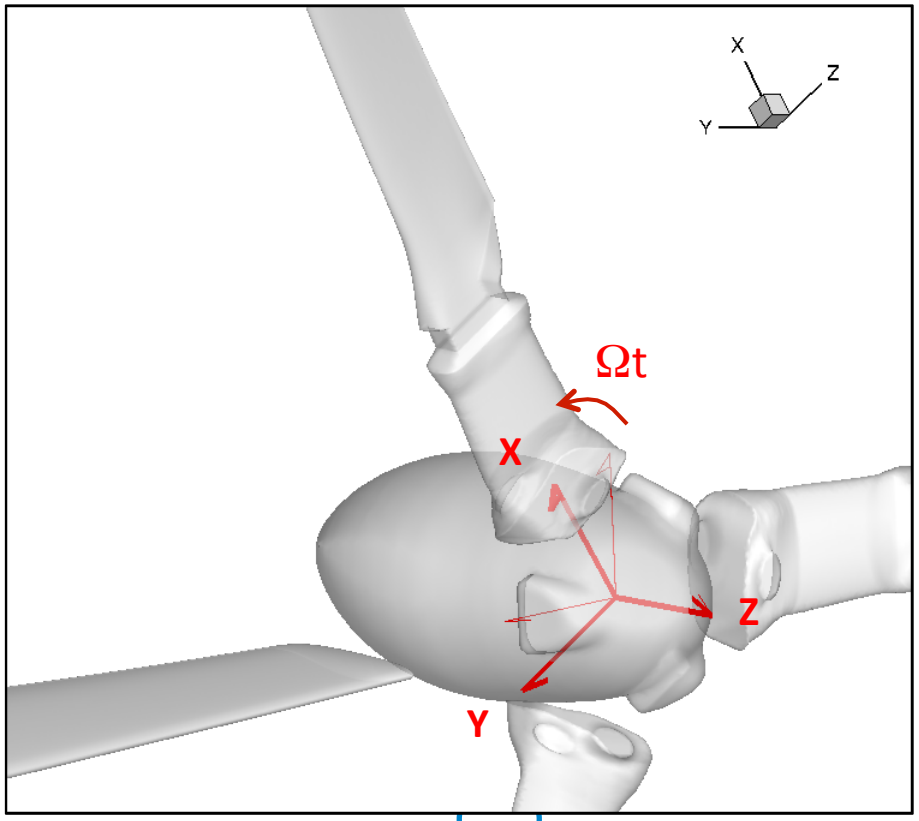
Nacelle Frame

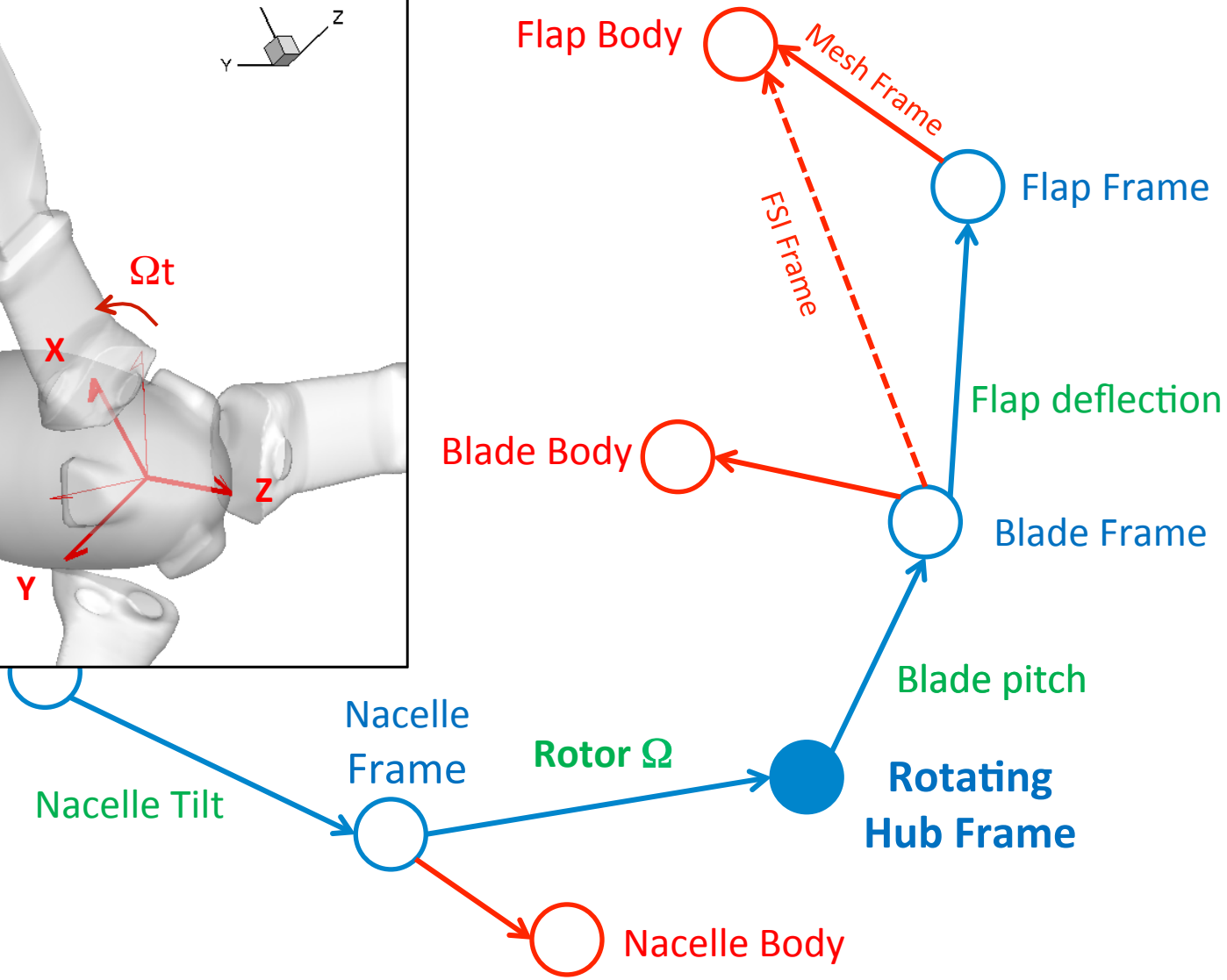
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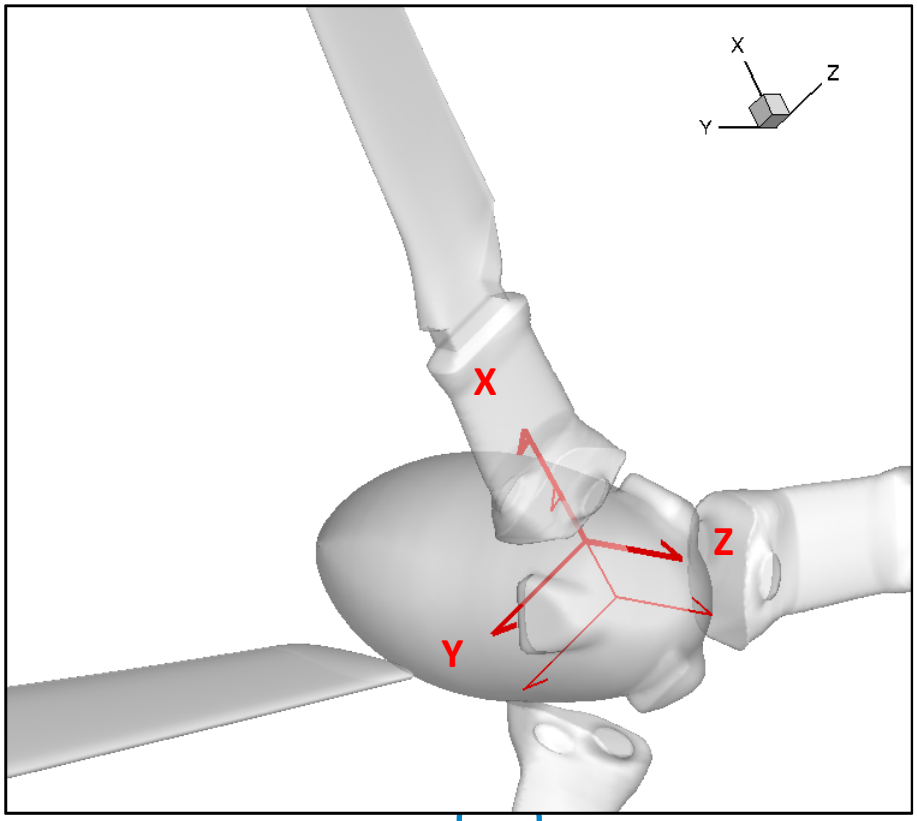
Nacelle Body

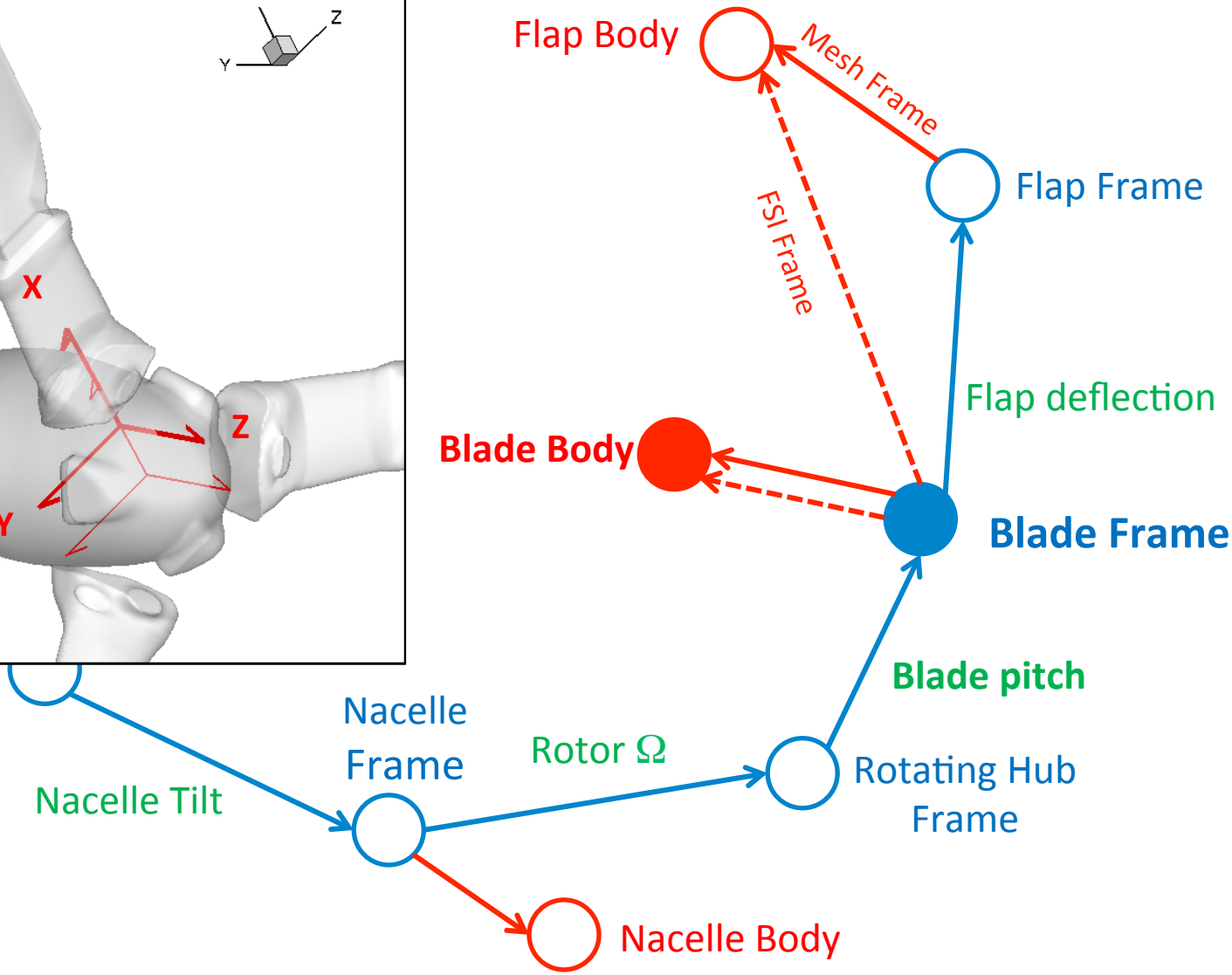
Example: Tilt-Rotor with TE flaps



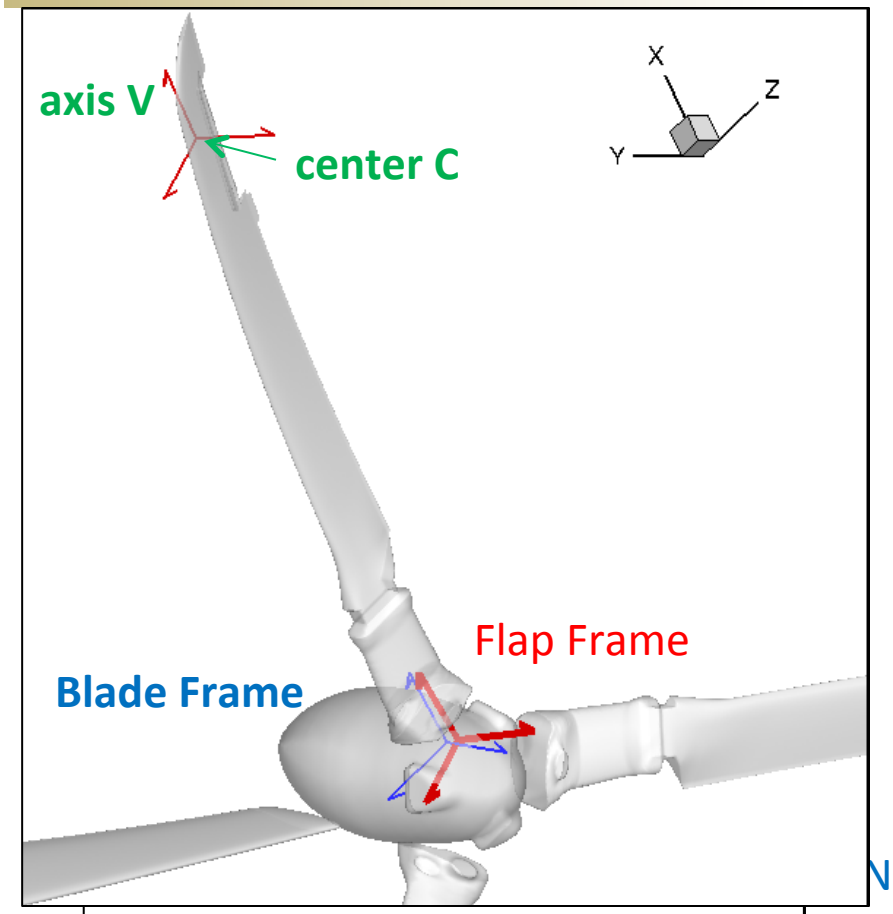


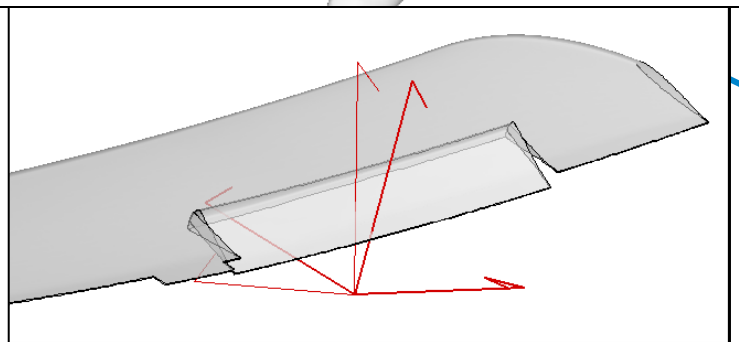
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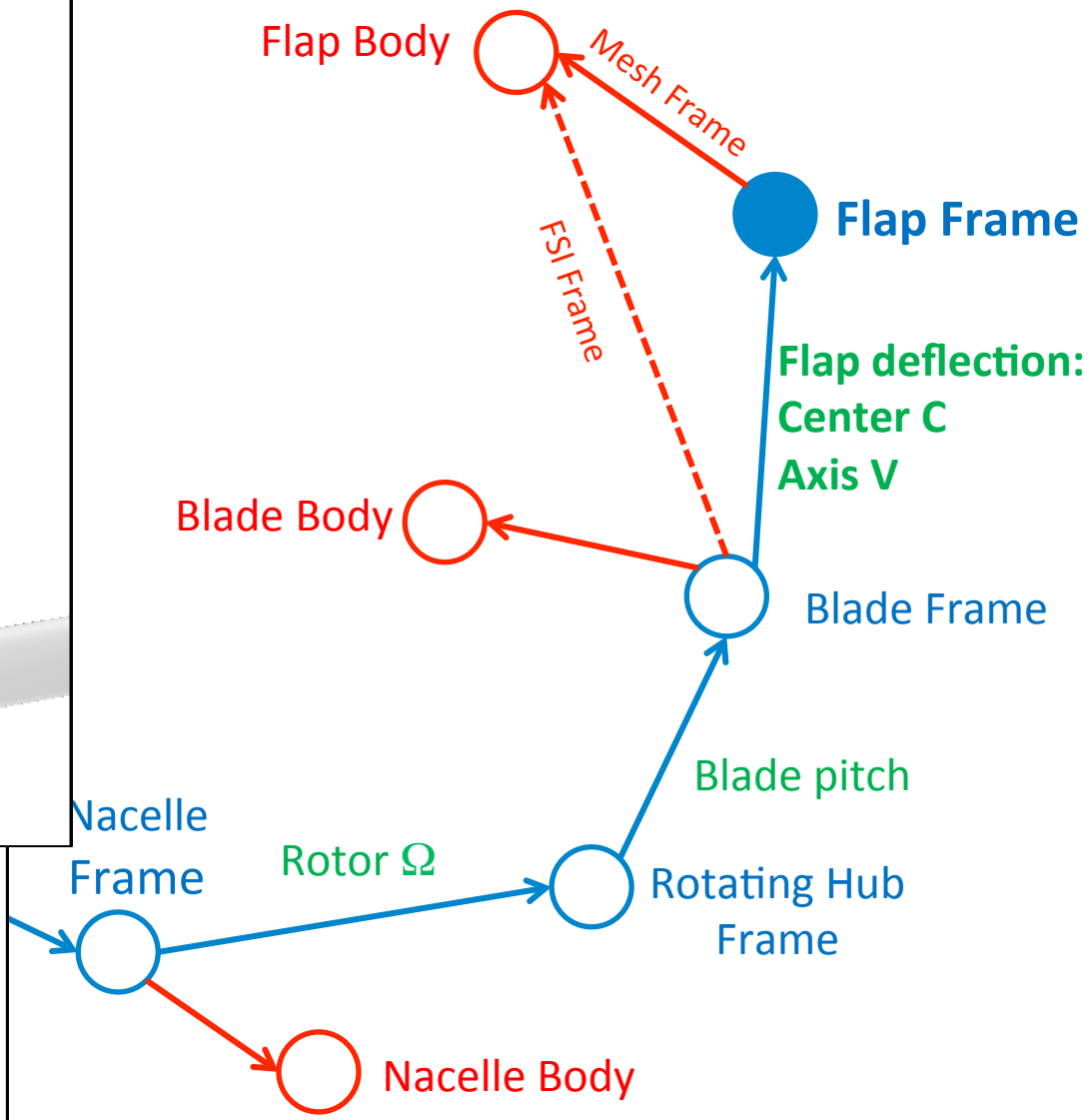




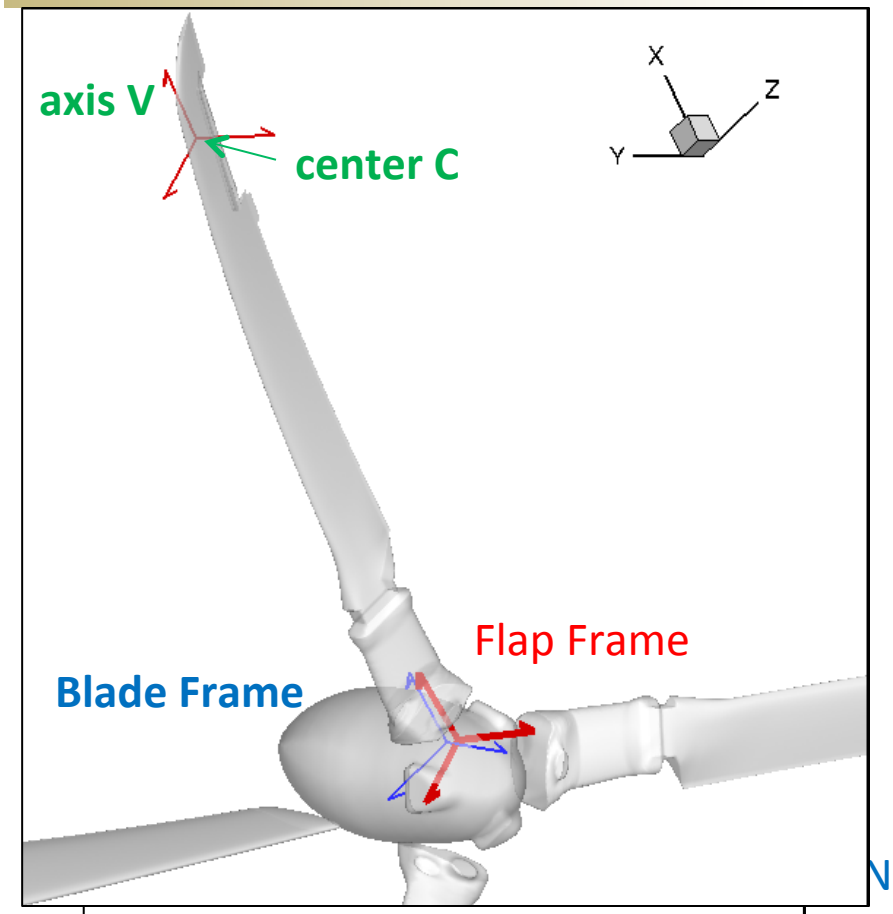
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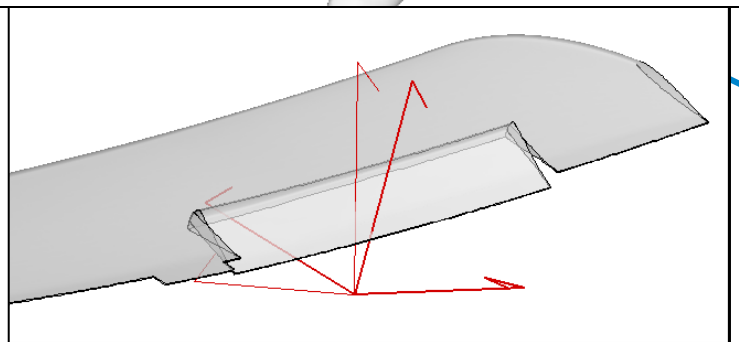


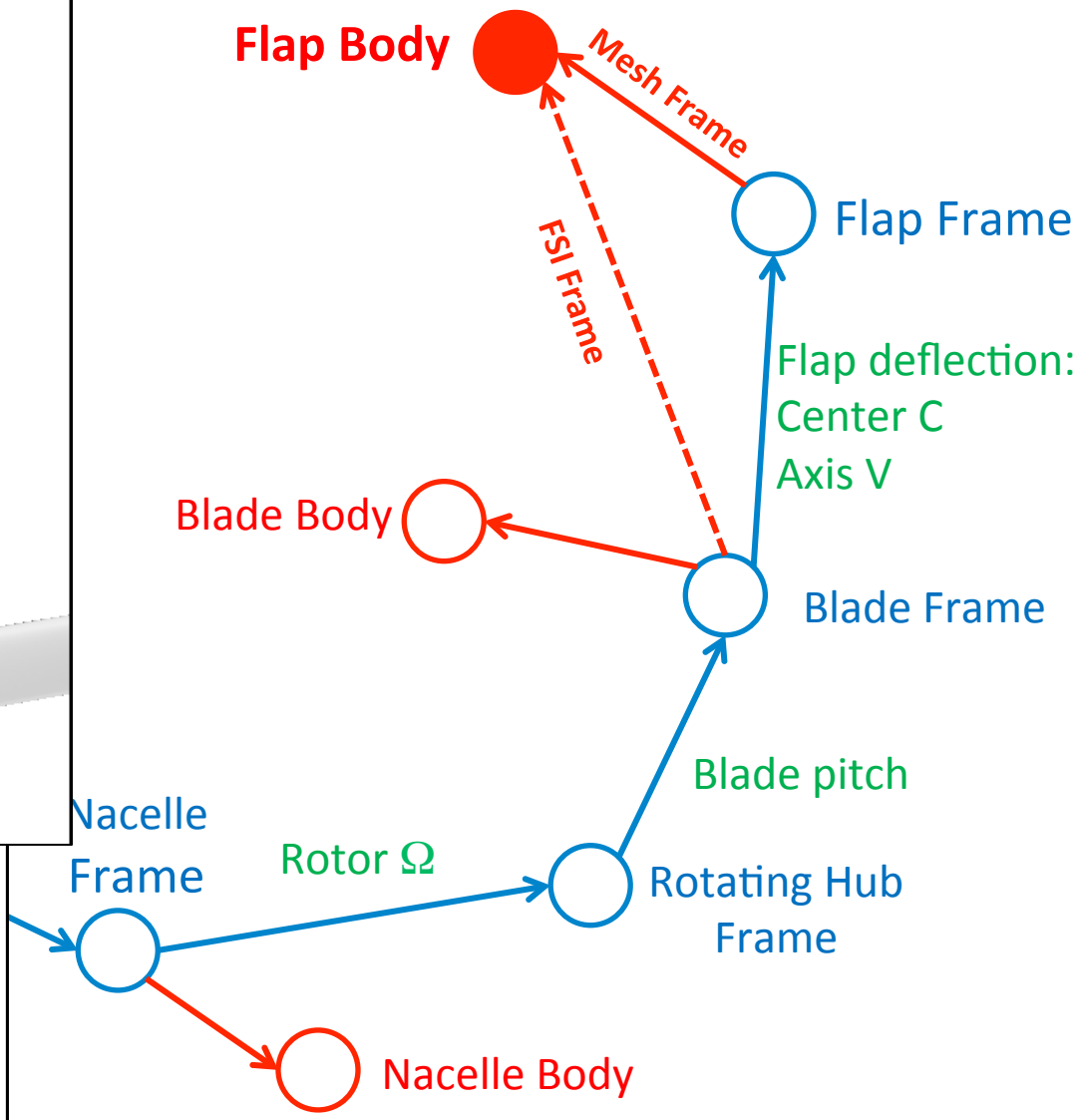




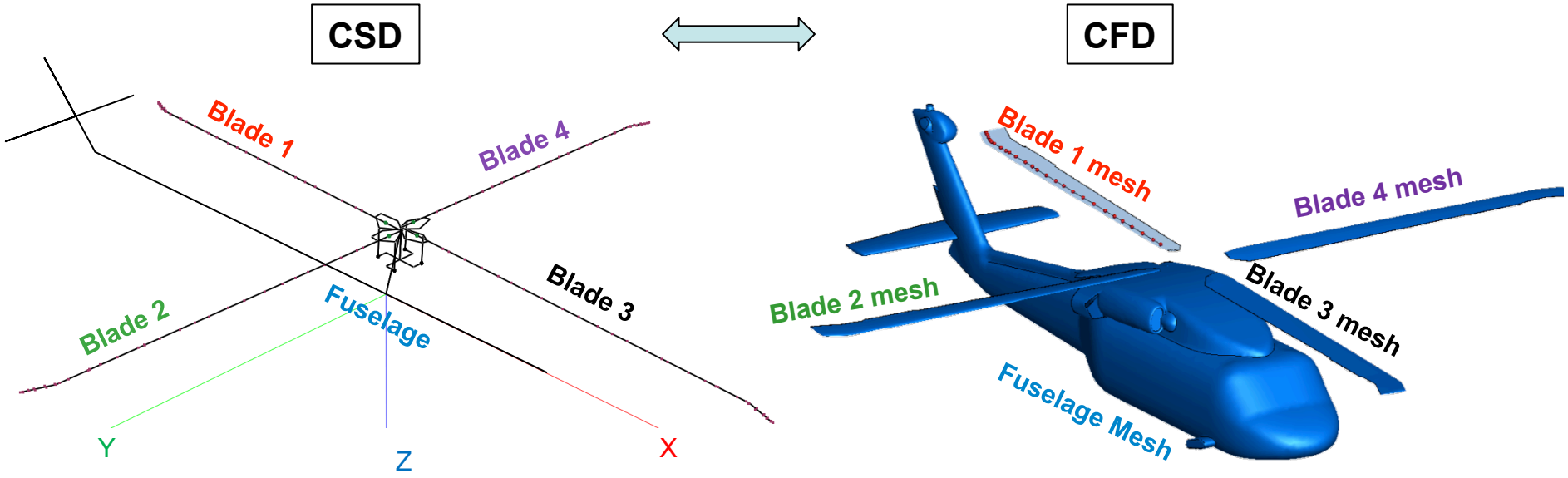
Example: Tilt-Rotor with TE flaps







Comprehensive Analysis Interface



- One-to-one match between CSD components and CFD meshes.

  e.g. RCAS → Component Frame, Control Points, and Deformations in that frame.

- MELODI can also inherit directly frame motions from CSD

  → simplifies model set-up (no body hierarchy duplication)

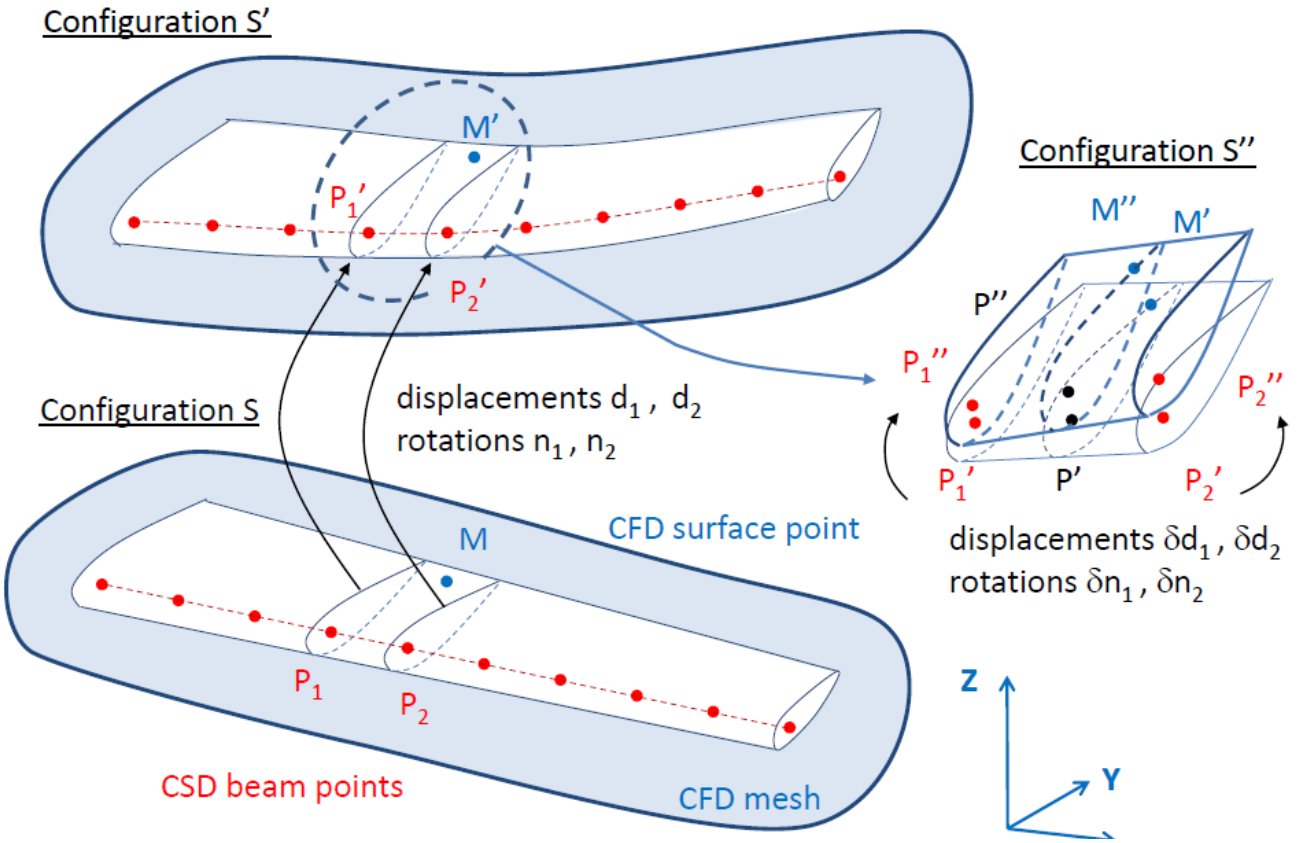
  → ensures automatic model consistency on CFD side & CSD side

Mesh deformation / Load reduction

- Assumes deformation and loading provided/computed at same location
  → energy conservative load reduction scheme

$$\delta W_{CFD} = \delta W_{CSD}$$

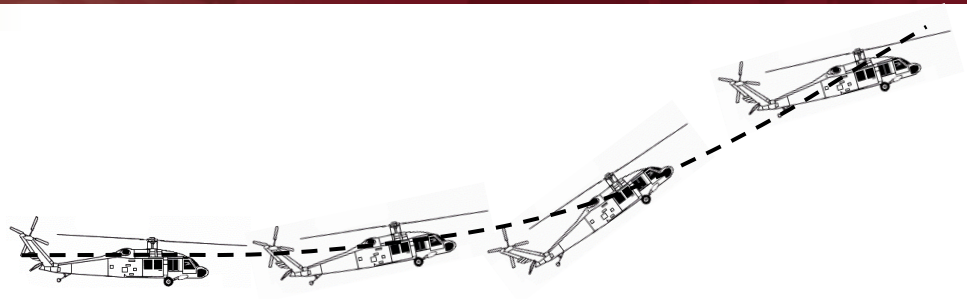
- Deformations provided as disp + Euler angles in 1-2-3 sequence (extrinsic)
- Linearly interpolated along beam axis
- Airloads reduced from CFD by enforcing conservation of virtual work (2nd order error)



Results

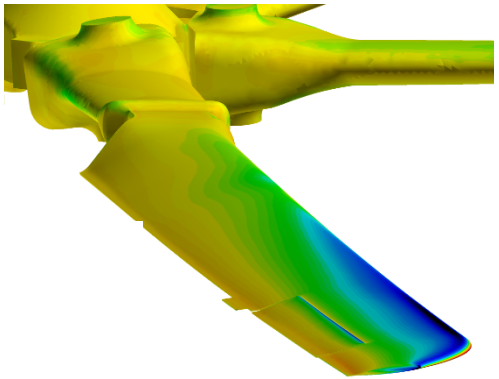
- UH60 pull-up maneuver

  Body hierarchy inherited from CSD



- SMART rotor with active trailing-edge flaps

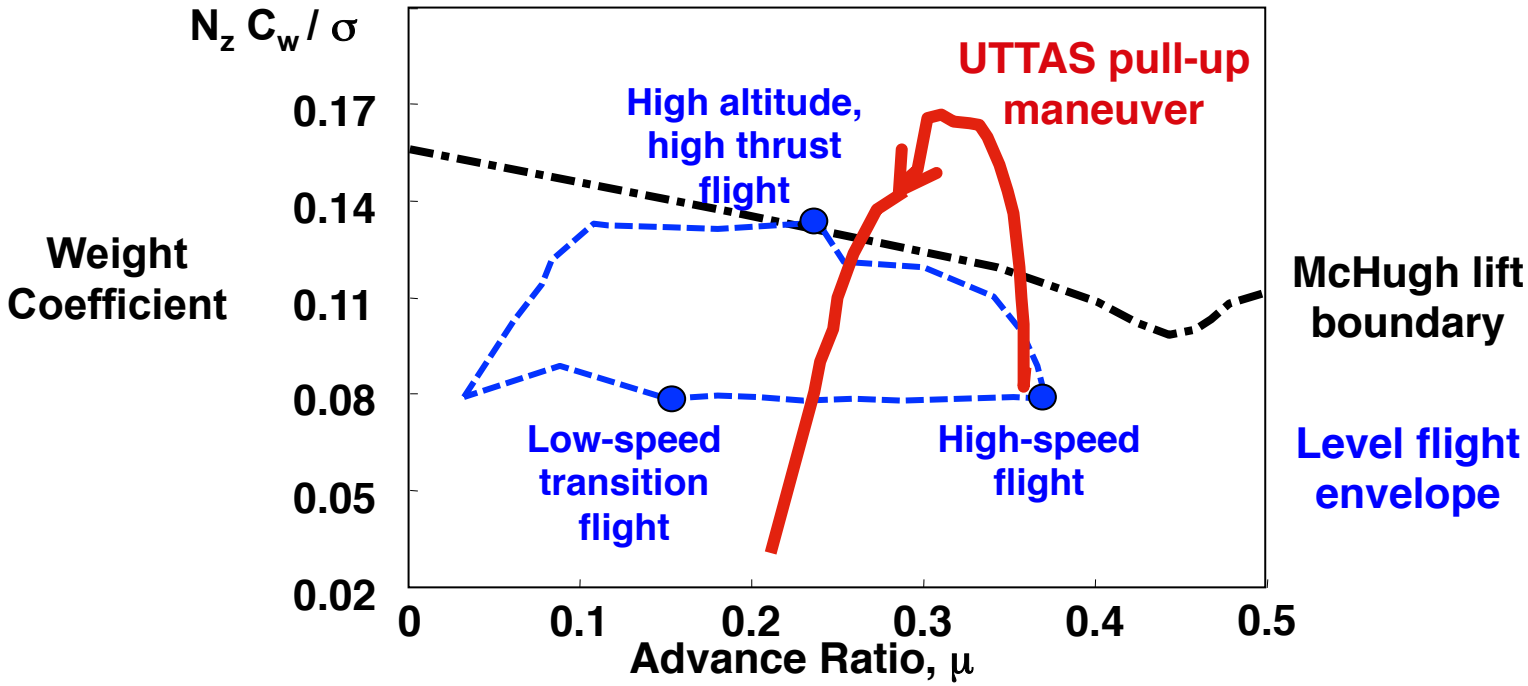
  Body hierarchy defined in Melodi



All results use:

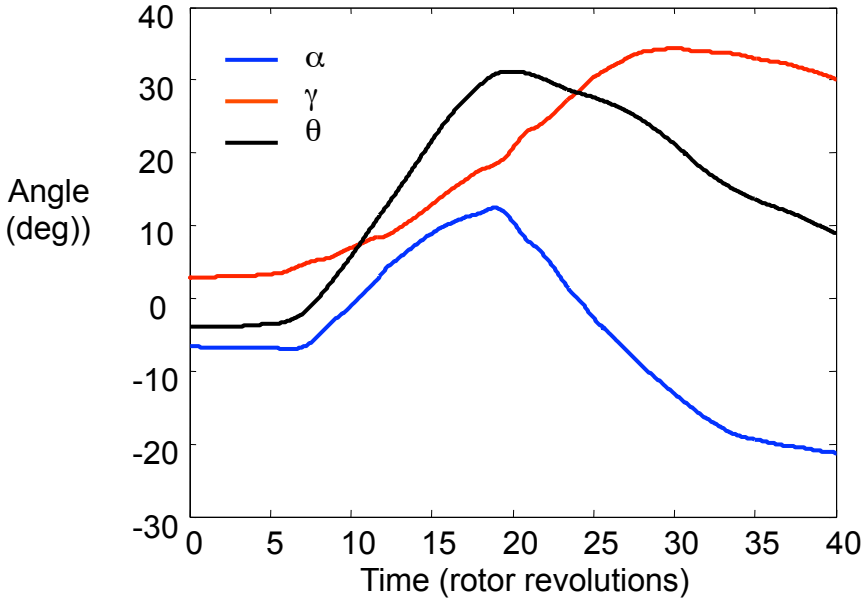
- Helios V6
- Unstructured near-body meshes (near body solver: NSU3D)
- Cartesian background mesh (SAMCART implicit solver, with RANS/DES)
- Domain connectivity (PUNDIT) with load balancing
- UH60 simulation run on 3600 cores (3hr/rev for 40 revs → 5 days)
- SMART rotor : 1920 cores (8hr/rev for 3 revs → 1 day)

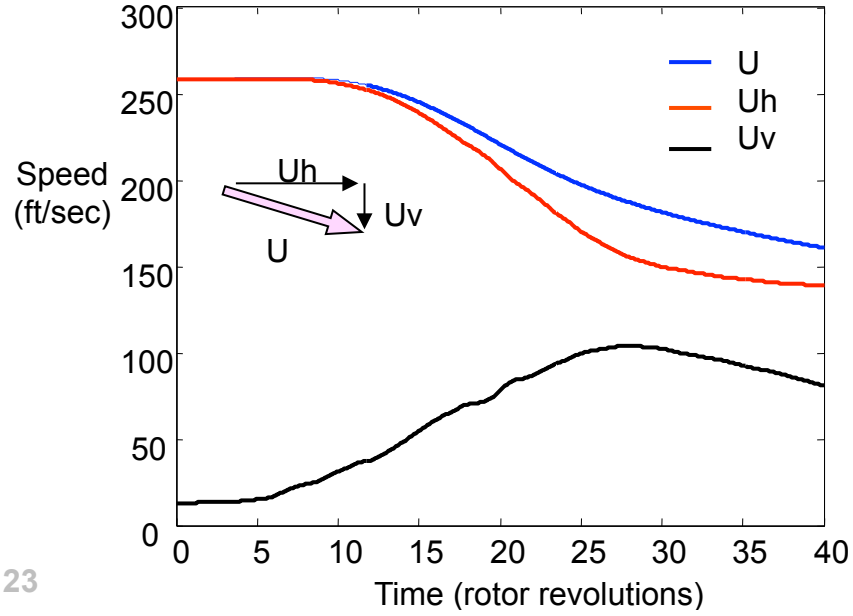
UH60 pull-up maneuver

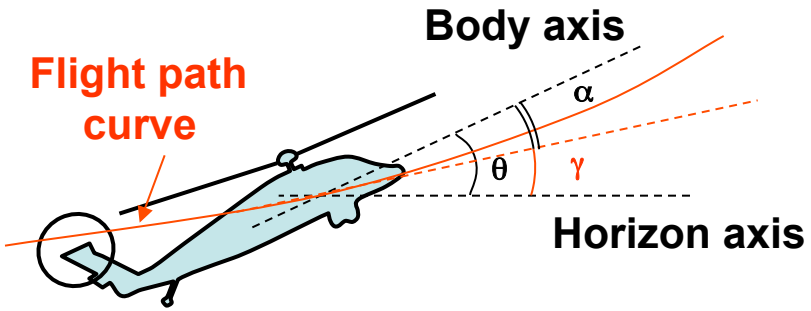


- UTTAS pull-up maneuver: challenging flight condition, peak load factor 2.1 g
- Start near maximum level flight speed, rapid climb and deceleration
- Previous CFD/CSD studies : Bhagwat et al.(2007), Silbaugh and Baeder (2008), Abhishek and Chopra (2008), Sitaraman et al. (2008) – Research efforts requiring large set-up time and user expertise.

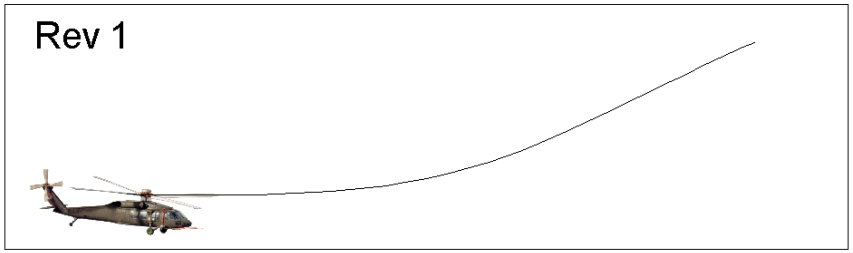
UH60 pull-up maneuver



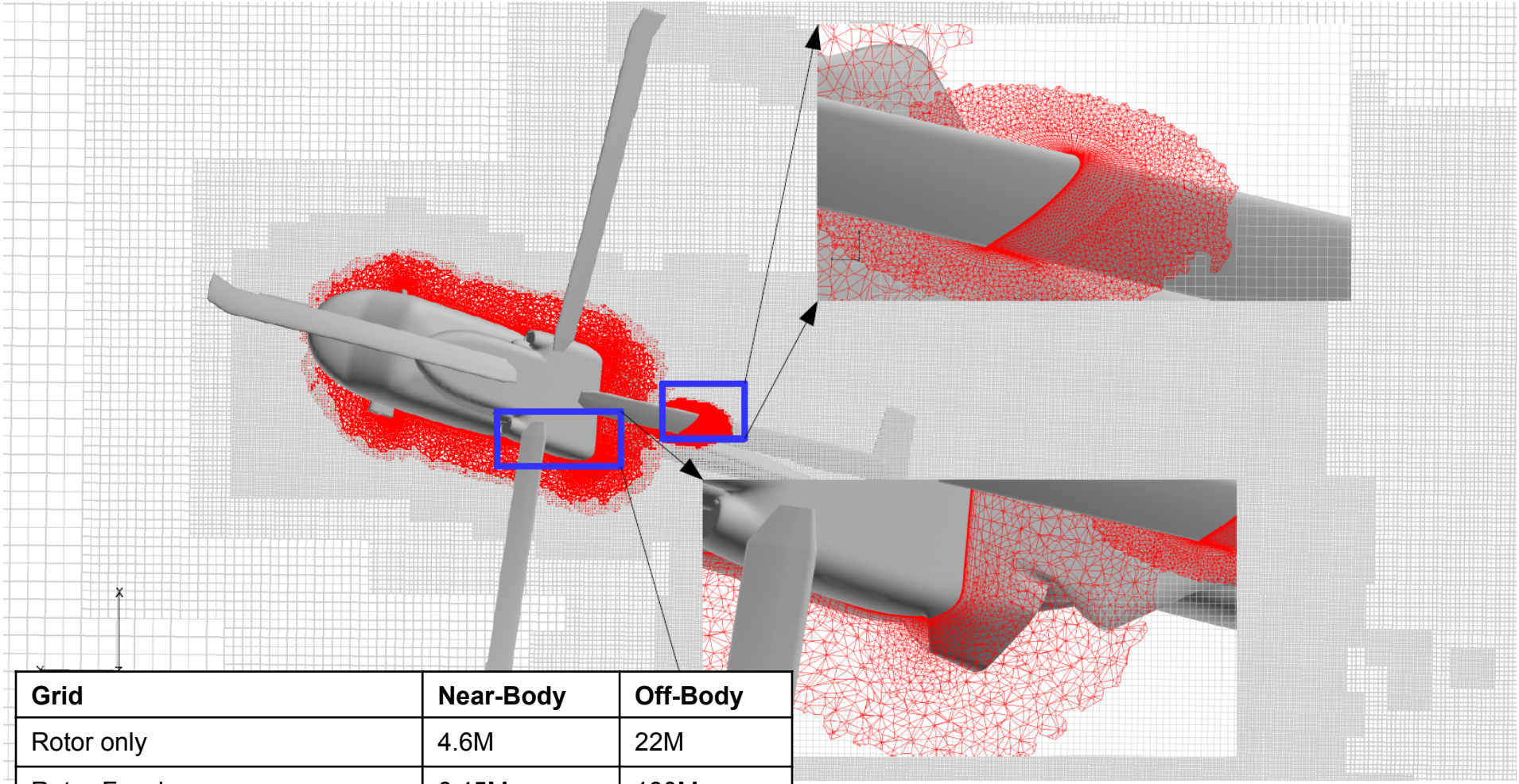




- **Prescribed vehicle pitch, roll, yaw**
- **Prescribed pilot inputs with offset to match RCAS trim values**
- **3 revolutions of loose coupling (5 coupling cycles) followed by 40 rev of tight coupling (about 9 seconds, 0.25 deg time step)**

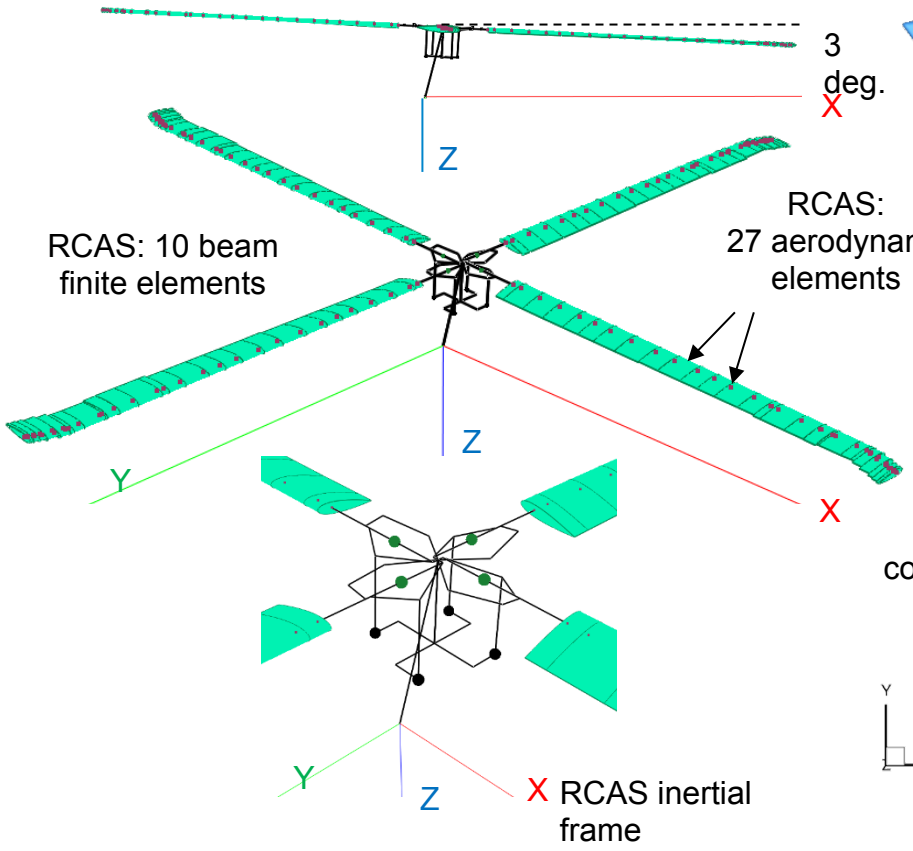


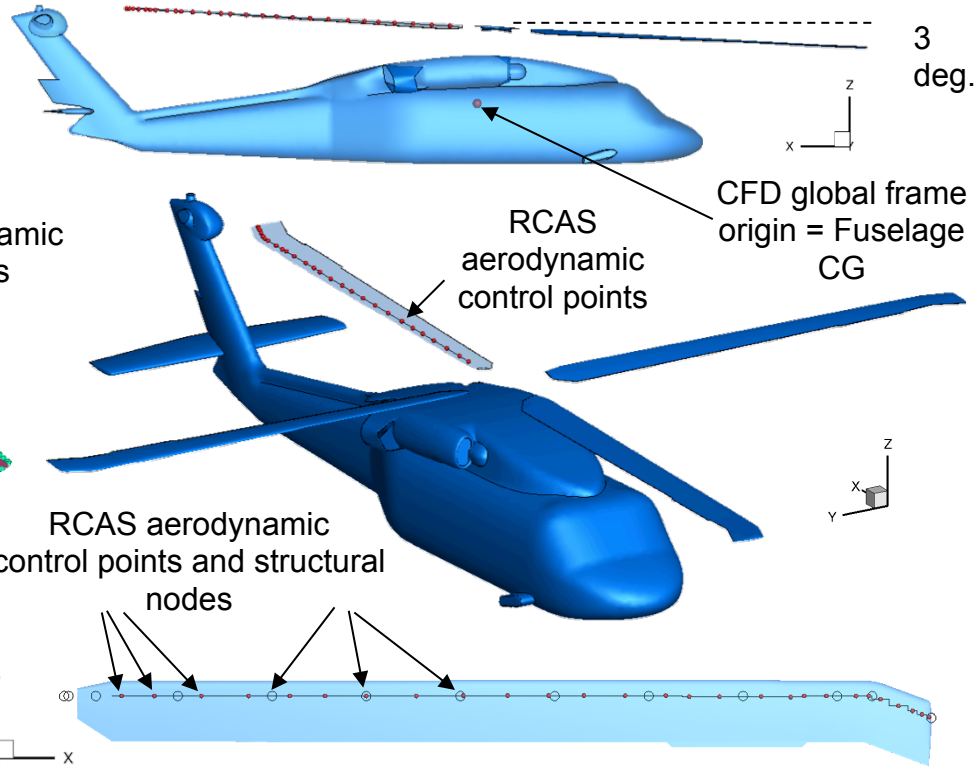
UH60 CFD MODEL



Grid	Near-Body	Off-Body
Rotor only	4.6M	22M
Rotor-Fuselage, coarse	6.45M	130M
Rotor-Fuselage, fine	17.5M	155M
Rotor-fuselage, fine, AMR	17.5M	30-180M

CFD/CSD reference configurations

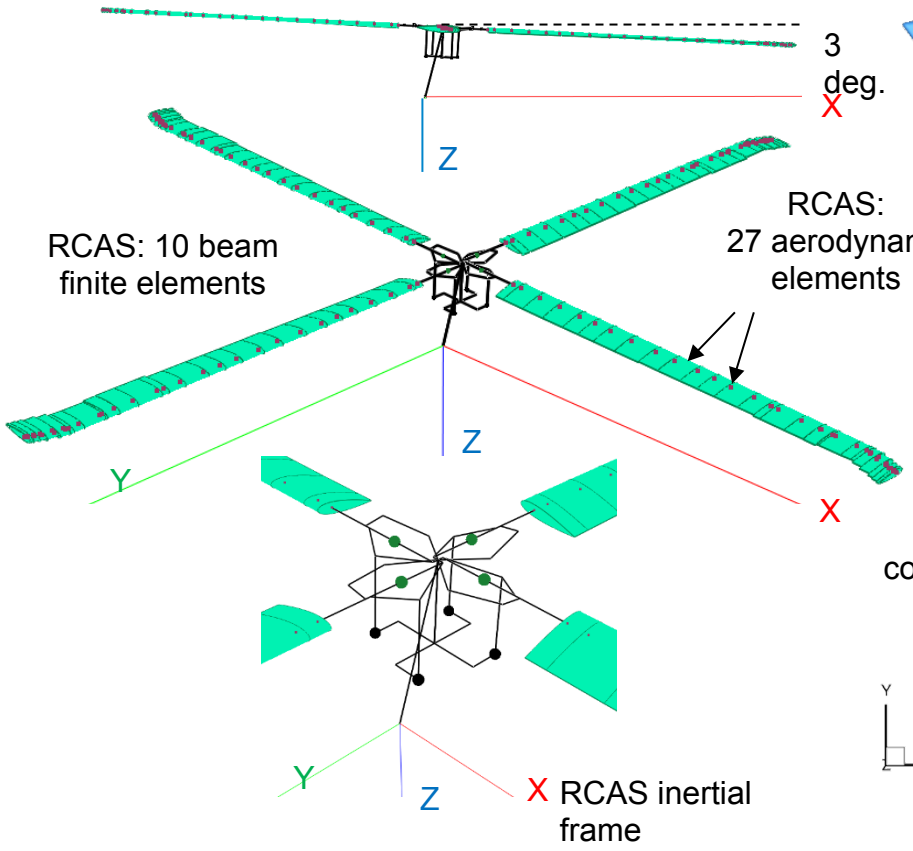


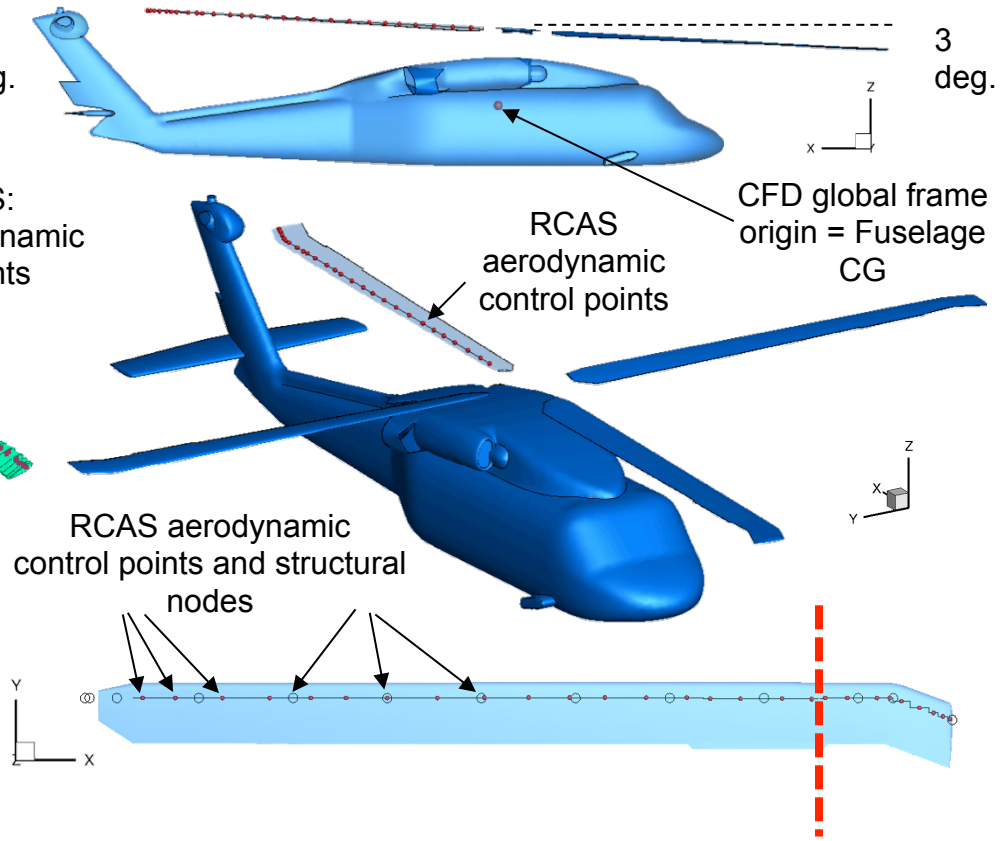


CFD and CSD models ensured to match in reference configuration:

- Fuselage CG at origin
- Rotor plane tilted forward by 3 degrees
- Blade 1 at azimuth 0

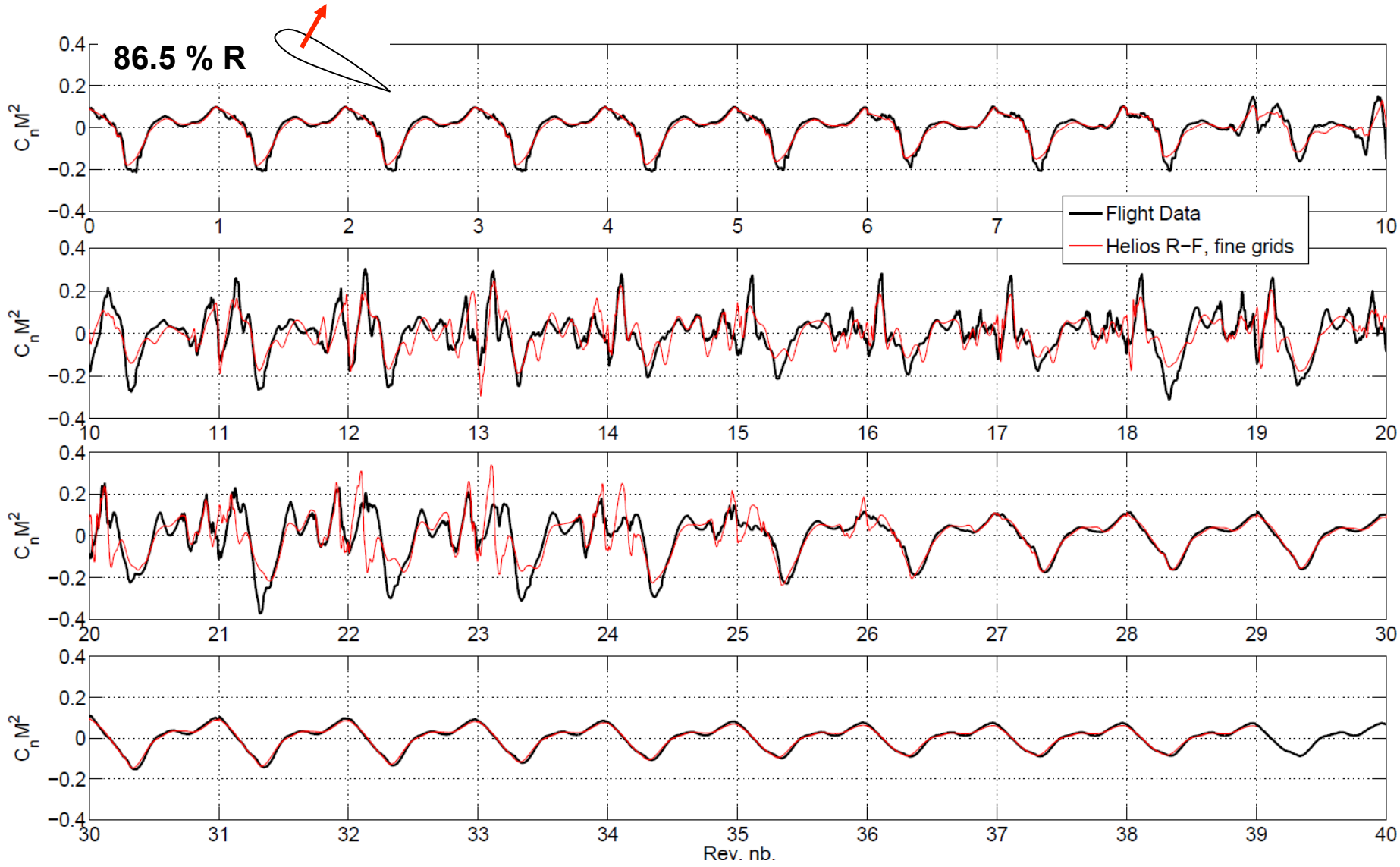
CFD/CSD reference configurations





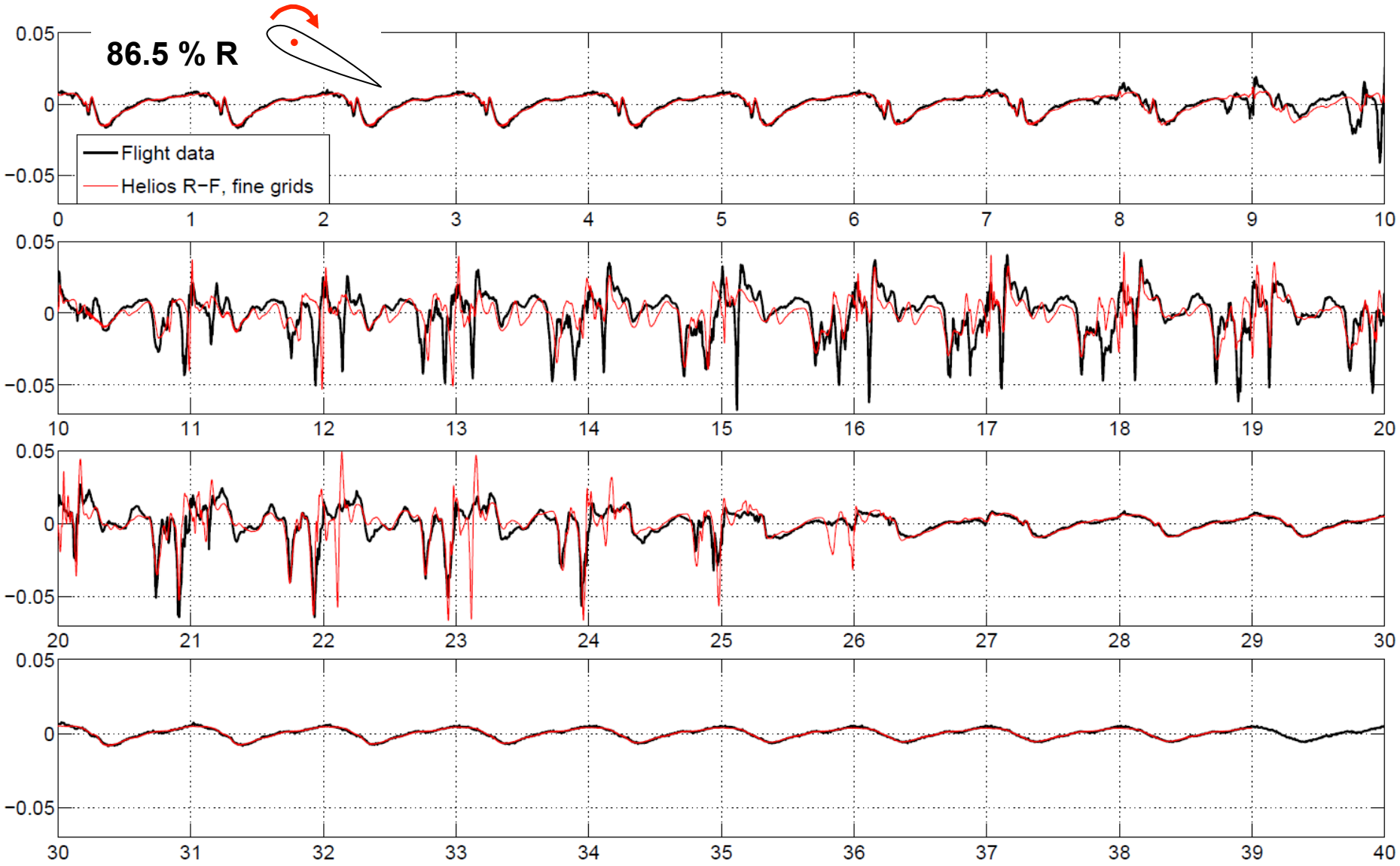
Results shown at 86.5 % station

Section Normal Force $C_n M^2$



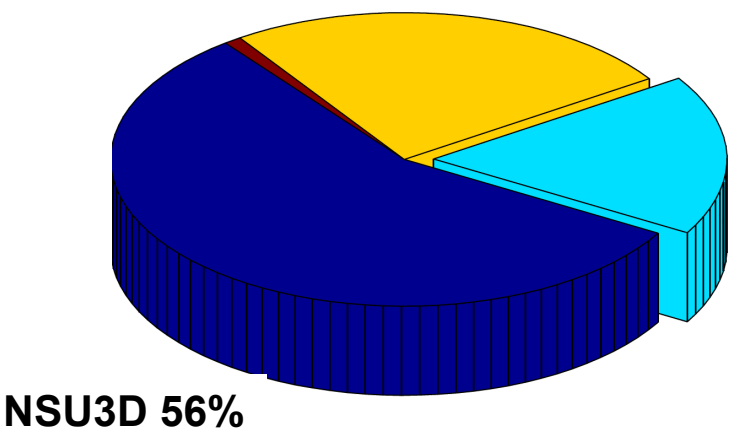
Mean removed

Section Pitching Moment C_m M^2



Mean removed

UH60 maneuver simulation



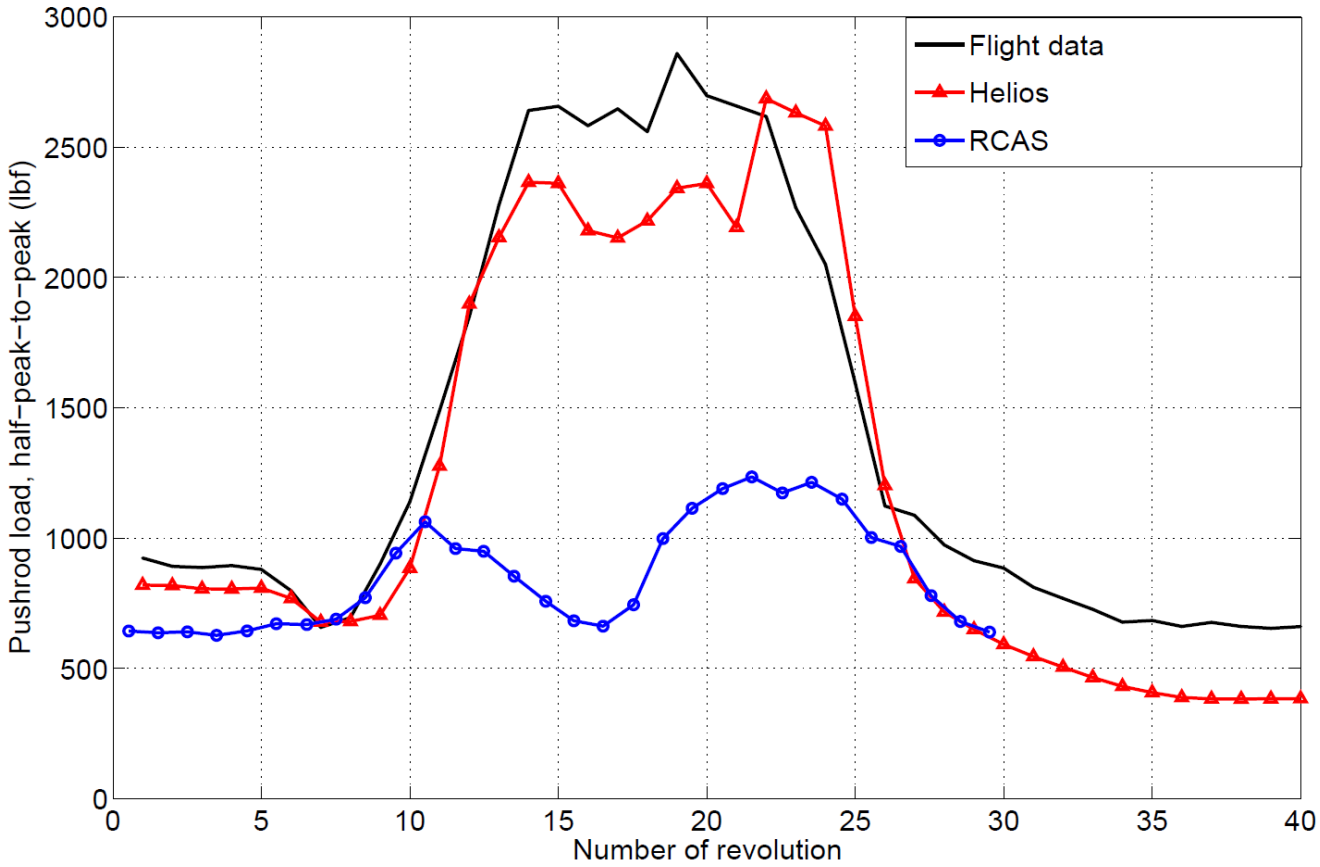
PUNDIT time (s)

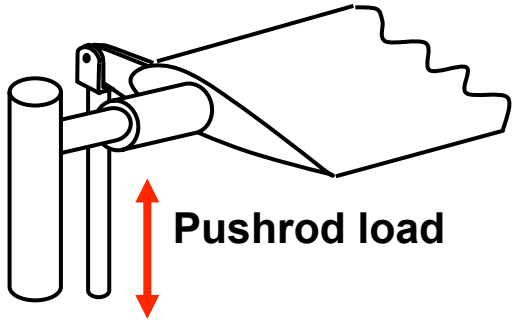
The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

Effect of Load Balancing in Domain Connectivity:
11s → 1s

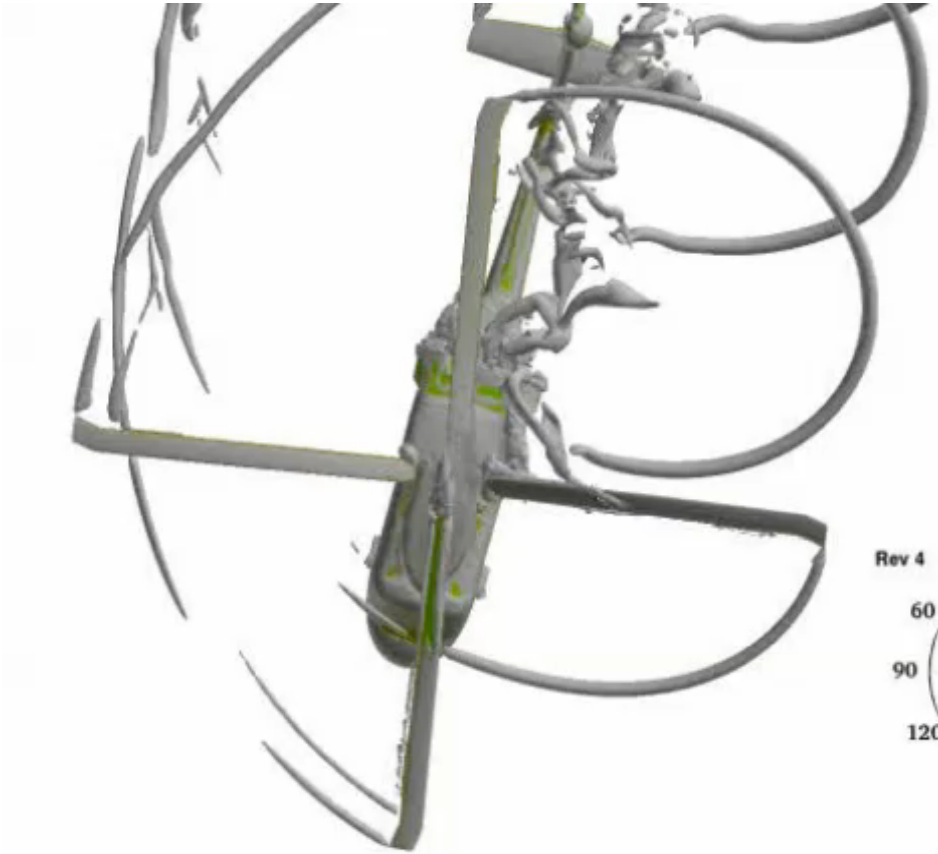
Grid	Near-body	Off-body	NPROC	Time per revolution
Rotor-only	4.6M (1.15M/blade)	22 M	1440	1.12 hrs/rev, $\Delta\Psi = 0.25^o$
Rotor-fuselage-fine	17.5M (3.9M/blade)	155 M	3600	2.8 hrs/rev, $\Delta\Psi = 0.25^o$
Rotor-fuselage-fine-AMR	17.5M (3.9M/blade)	30-180 M	3600	2.4-3.3 hrs/rev, $\Delta\Psi = 0.25^o$
Rotor-fuselage-coarse	6.45M (1.15M/blade)	130 M	1440	2.28 hrs/rev, $\Delta\Psi = 0.25^o$

UH60 maneuver : Pushrod loads

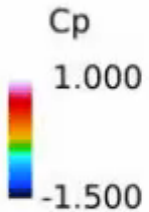


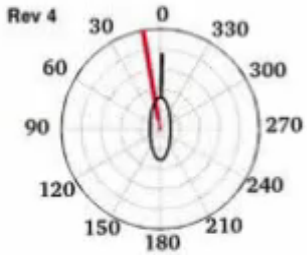


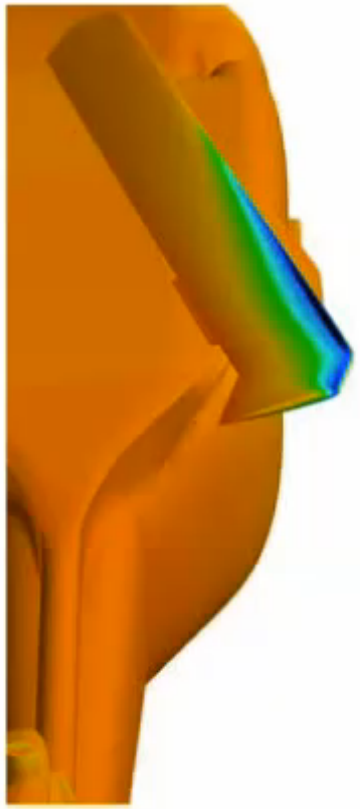
- **Dramatic improvement in peak-to-peak load prediction compared to RCAS alone**
- **Significant under-prediction at maneuver end**

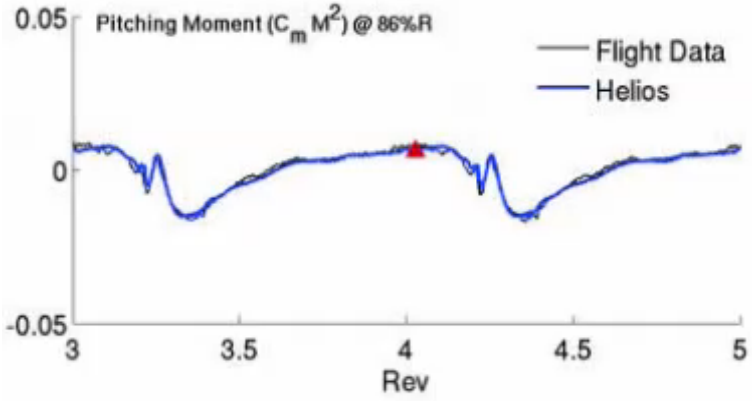


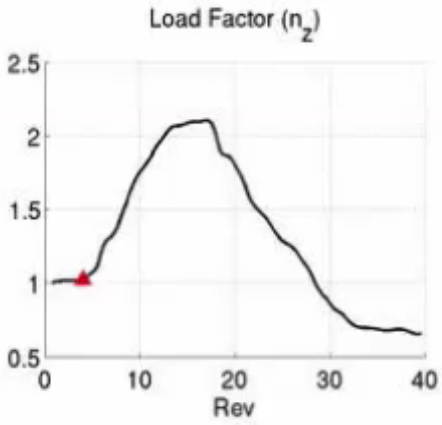



Cp
1.000
-1.500


Rev 4
0
30
60
90
120
150
180
210
240
270
300
330




Pitching Moment ($C_m M^2$) @ 86%R
Flight Data
Helios
0.05
0
-0.05
3
3.5
4
4.5
5
Rev


Load Factor (n_z)
2.5
2
1.5
1
0.5
0
10
20
30
40
Rev

SMART rotor

- Boeing Smart Material Actuated Rotor Technology (SMART)
- 5 bladed full-scale MD 900 rotor piezoelectric trailing-edge flaps at 83%R (18%R, 35% chord)
- Tested in 2008 in 40 by 80 ft NFAC wind tunnel for vibration and noise reduction

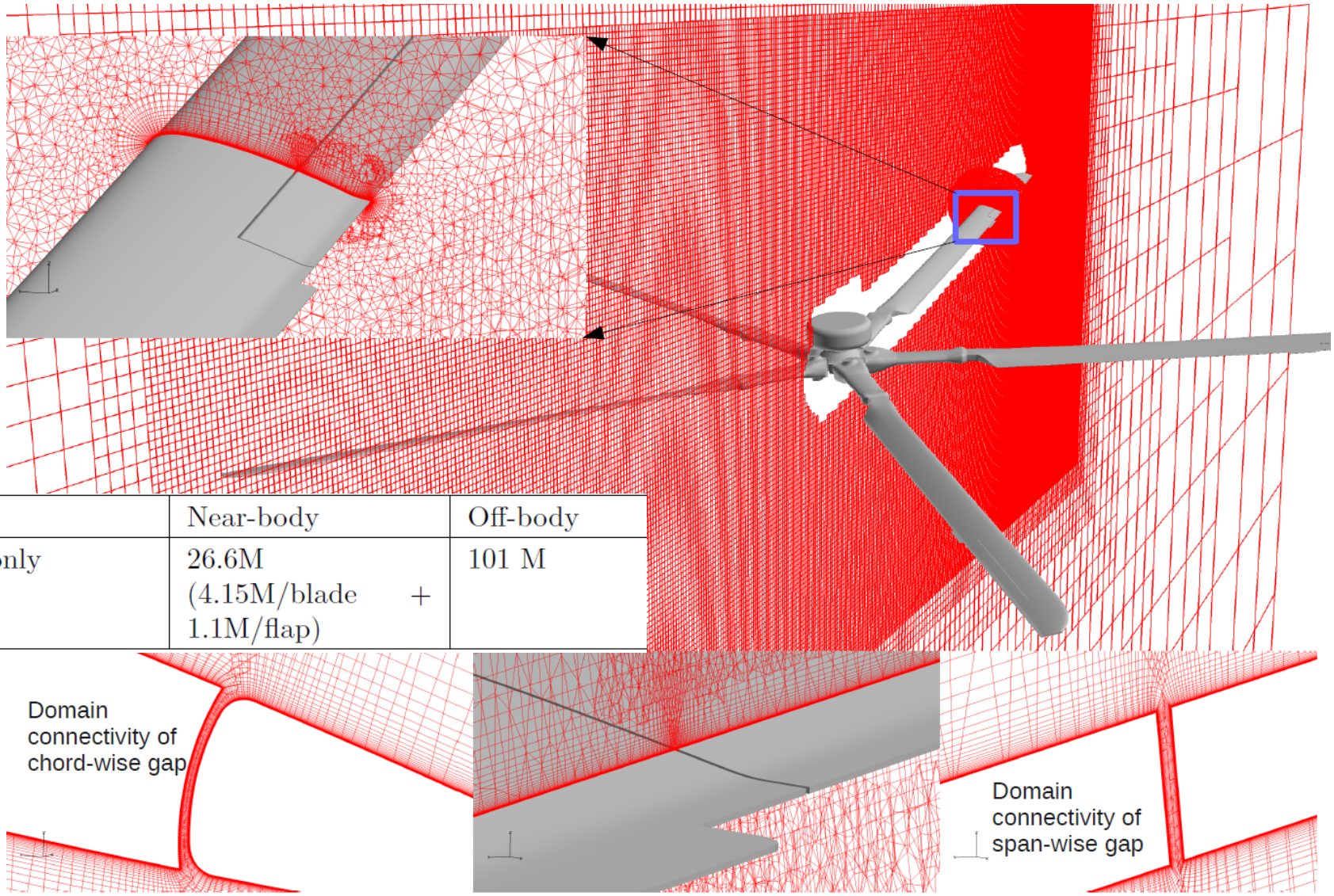
Simulation settings (CFD only):

- Prescribed blade motions and deformations from Potsdam et al. OVERFLOW/CAMRAD II 2010 study
- Advance ratio 0.3, 9.1 deg nose down rotor tilt.
- Flap deflection: 2/rev and 5/rev up to +/- 3 deg
- Flap gap very small : about 2mm (rotor radius 5.16 m)
  → Flap mesh deformed together with blade mesh



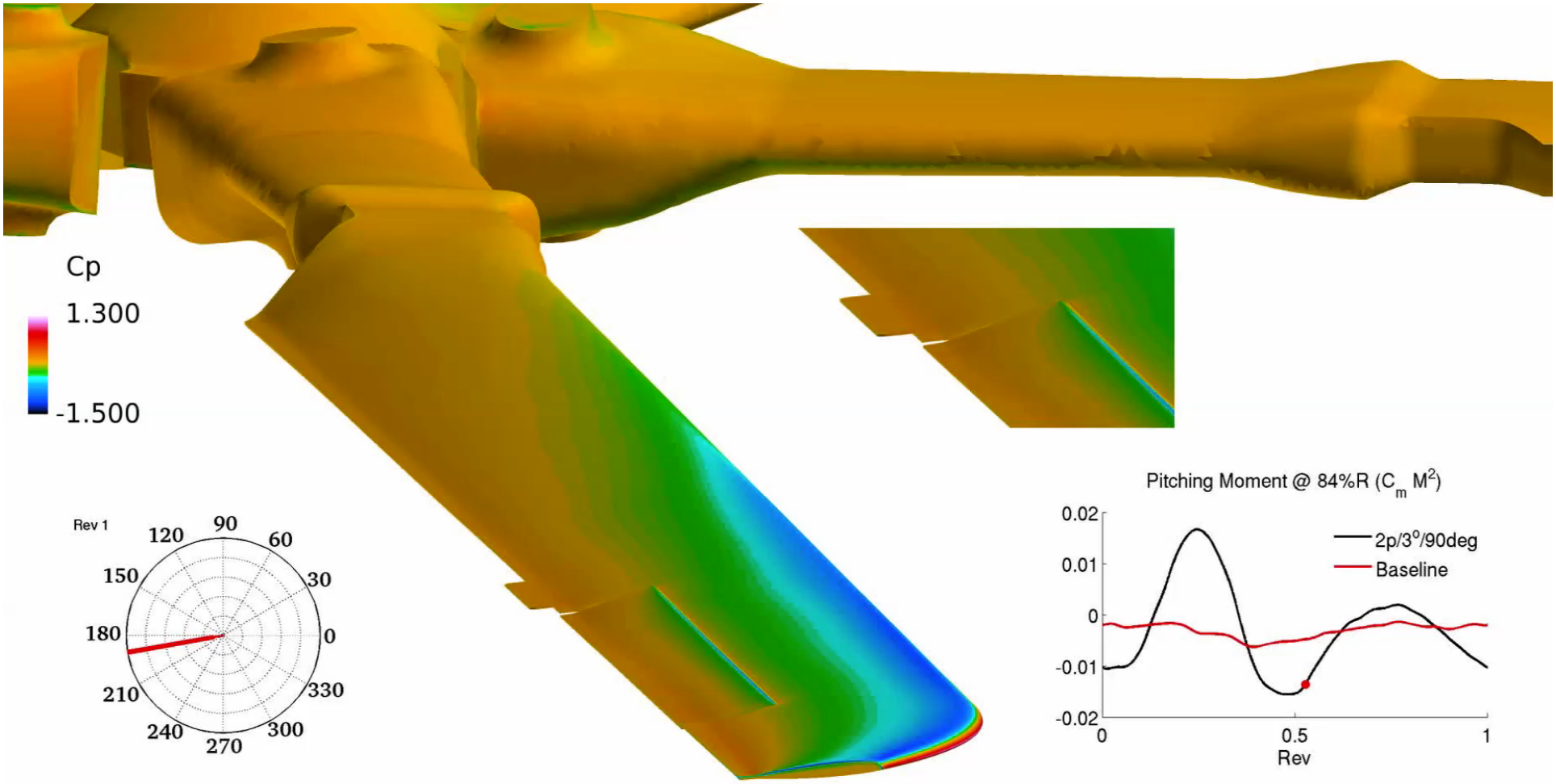
Credit: NASA/Boeing

SMART rotor : CFD model



Grid	Near-body	Off-body
Rotor-only	26.6M (4.15M/blade + 1.1M/flap)	101 M

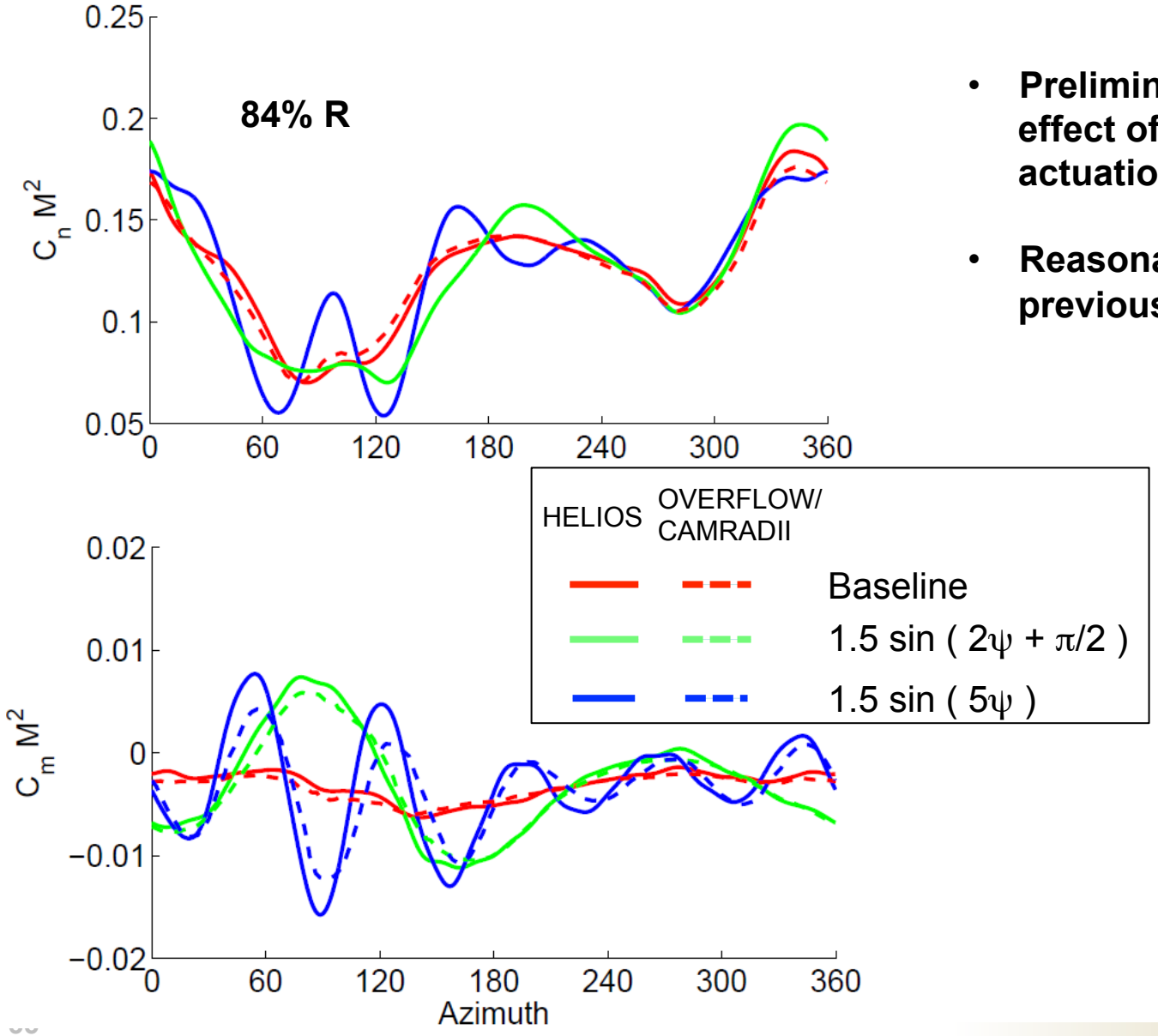
SMART rotor


Cp
1.300
-1.500

Rev 1
90
120
60
150
30
180
0
210
330
240
300
270

Pitching Moment @ 84%R (C_m M^2)
0.02
0.01
0
-0.01
-0.02
0
0.5
1
Rev
2p/3°/90deg
Baseline

SMART rotor : flap effect



- **Preliminary results show effect of 5/rev and 2/rev flap actuation**
- **Reasonable comparison with previous CFD/CSD study**

Conclusions and Future Work

- New Helios module **Melodi** successfully developed and validated - enables general hierarchical flexible multi-body simulations

- Enables basic research on complex configurations such as tilt-rotor transition and whirl flutter

- UH60 maneuver simulation agreement with flight test data on par with earlier CFD/CSD studies
  - significant improvement in pushrod loads compared to RCAS stand-alone

- Future work:
  - Improve GUI to further simplify model set-up
  - Expand new CFD/CSD interface to CAMRAD II
  - Expand motion methods (harmonic input, 6dof)

Acknowledgements

- Support from HPCMP CREATE™ - AV program
- High Performance Computing and Modernization (HPCMO) DSRC computing resources
- Dr. Mahendra Bhagwat (AFDD) and Dr. Robert Ormiston (AFDD) for guidance in maneuver set-up and data analysis
- Mark Potsdam (AFDD) for providing all the unstructured grids and deformation data for the SMART rotor