LUBETA

Modelling and Simulation for Aerial Refueling Automation Research for Manned and Unmanned Aircraft

Nicolas Fezans – DLR, Braunschweig – Inst. of Flight Systems

with contributions from:
T. Jann, T. Gerlach, D. Niedermeier, J. Hettwer, S. Lademann, J. Gotschlich,
S. Schopferer, S. Lorenz, U. Durak, S. Geisbauer (DLR-AS)

DLRK 2016 (Deutscher Luft- und Raumfahrtkongress)
Sept. 15th 2016
Braunschweig, Germany

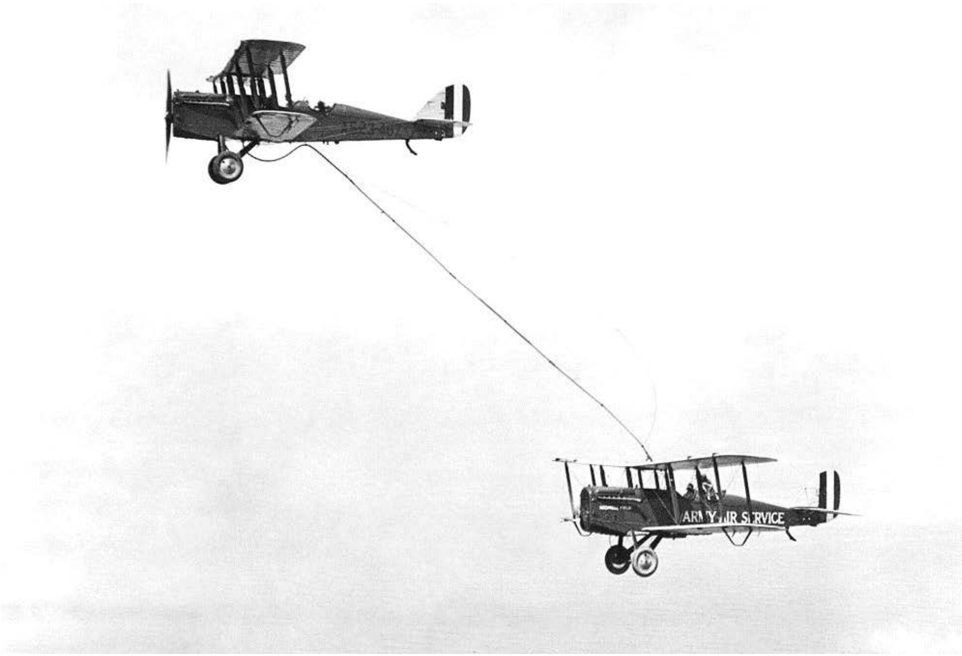
DLR

Outline

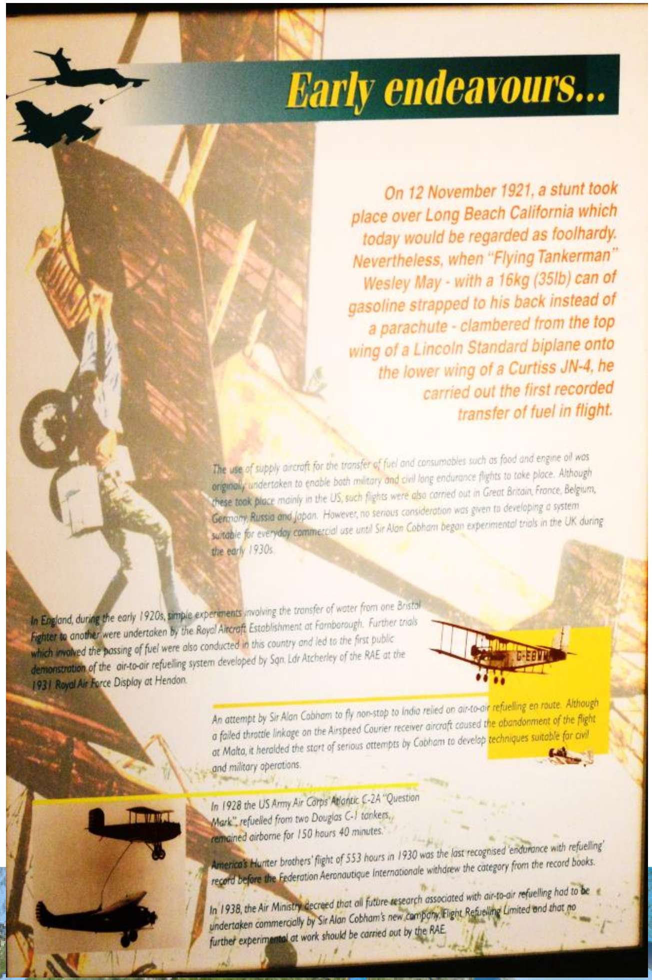
- Introduction on Air-to-Air Refueling
- Overview of on-going DLR research on air-to-air refueling automation
- Modeling activities:
  - Overview Hose-and-Drogue System
  - Aircraft (alone):
    - Future Military Transport Aircraft (FMTA)
    - Future Unmanned Aircraft (FUA)
  - Aerodynamic Interaction
  - Hose-and-Drogue Dynamics
  - Refueling System
- Simulation Infrastructure and Implementation
  - FMTA-FMTA including in the AVES Simulator
  - FMTA-FUA on the desktop
- Summary and Outlook

Air-to-Air Refueling – Overview

First air-to-air refueling above San Diego’s North Island on June, 27th 1923 (“Tangle-and-Grab” method)



RAF Museum (North of London) →



Air-to-Air Refueling – Overview

Probe-and-drogue

Boom-and-receptacle
(view from operator station)

Boom-Drogue
Adapter (BDA)

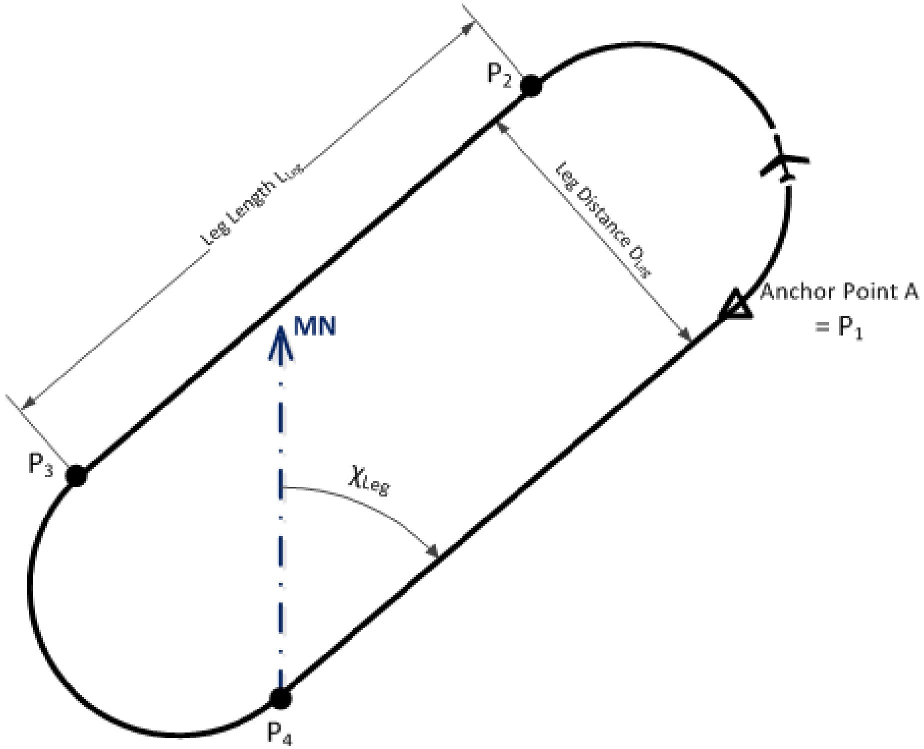
DLR

Air-to-Air Refueling – Procedure

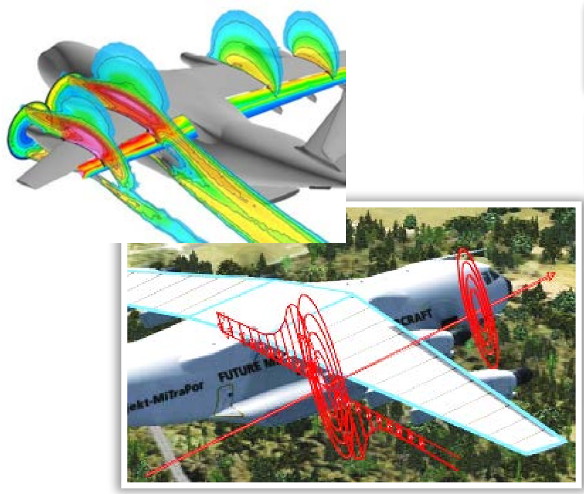
- Various procedures standardized within the NATO
  → NATO Standard ATP-3.3.4.2 Air-to-Air Refueling (ATP56)

- Exact procedure expected to have no / very little influence on the performance evaluations made of the different automation strategies → only the so-called "RendezVous Alpha" is considered

- Flight point:
  FL200, VCAS = 260 kts

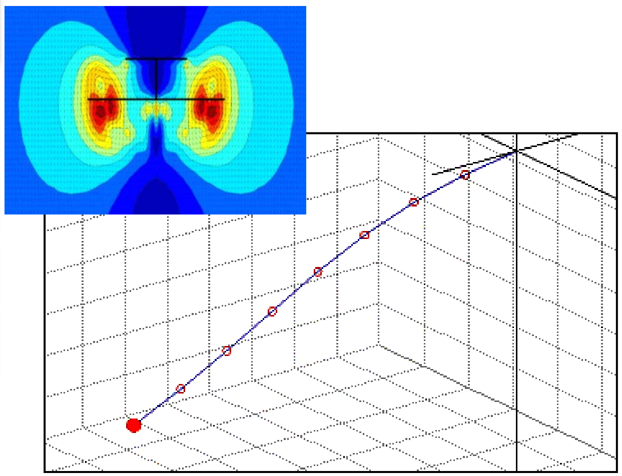


LUBETA: "Automation technologies for aerial refueling"



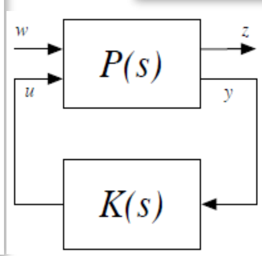
Formation Flight Mechanics

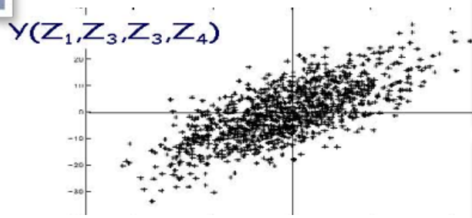
- Flow Field Behind Tanker
- Aerodynamic Interaction
- Hose-and-Drogue Modelling
- Aero-Coupled Formation Model



Manned Aircraft

- AAR Procedure
- Innovative AAR Control Laws and AP Modes
- Validation in Simulator



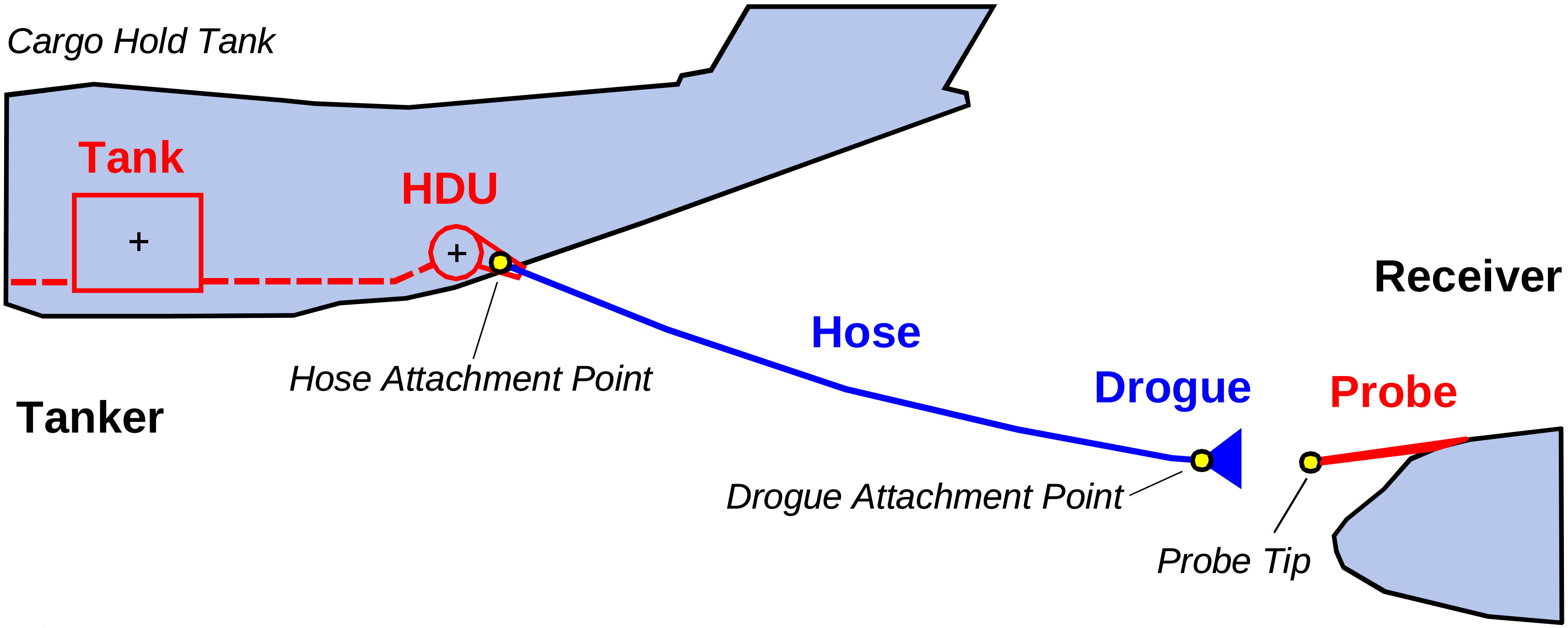


Unmanned Aircraft

- Sensor Modelling
- Fully Automatized Refueling for UAVs
- Simulation & Sensitivity Analysis

Modeling – Overview Hose-and-Drogue System

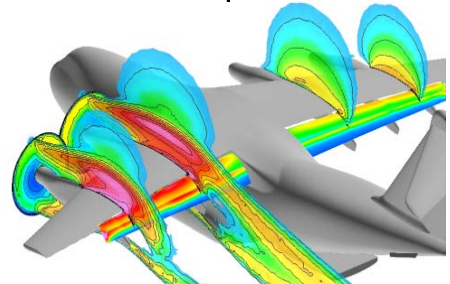
- **Tanker**: always a "Future Military Transport Aircraft" (FMTA) as Tanker
- **Receiver**: either a second FMTA or a "Future Unmanned Aircraft" (FUA)



Modeling – Aircraft – Future Military Transport Aircraft

Extrapolation C-160-Data

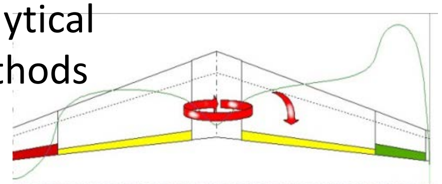
CFD-Computations

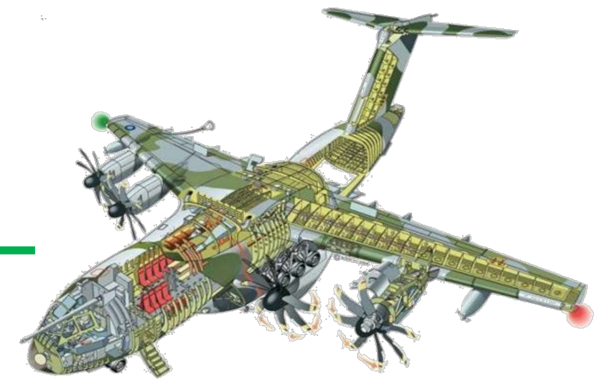


Wind Tunnel Measurement

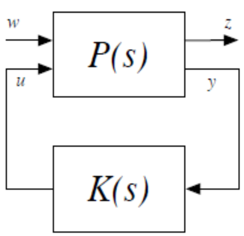
Real-time flight dynamical model of the FMTA

Analytical Methods



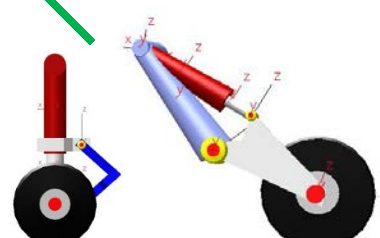


Geometry Data
Technical Specs.



Sidestick, Control Laws,
Autopilot, System Simulation

Actuator Models



Multi-Body
Landing Gear

Huge increase of the number of implemented flight control functions (→ all civil modes)

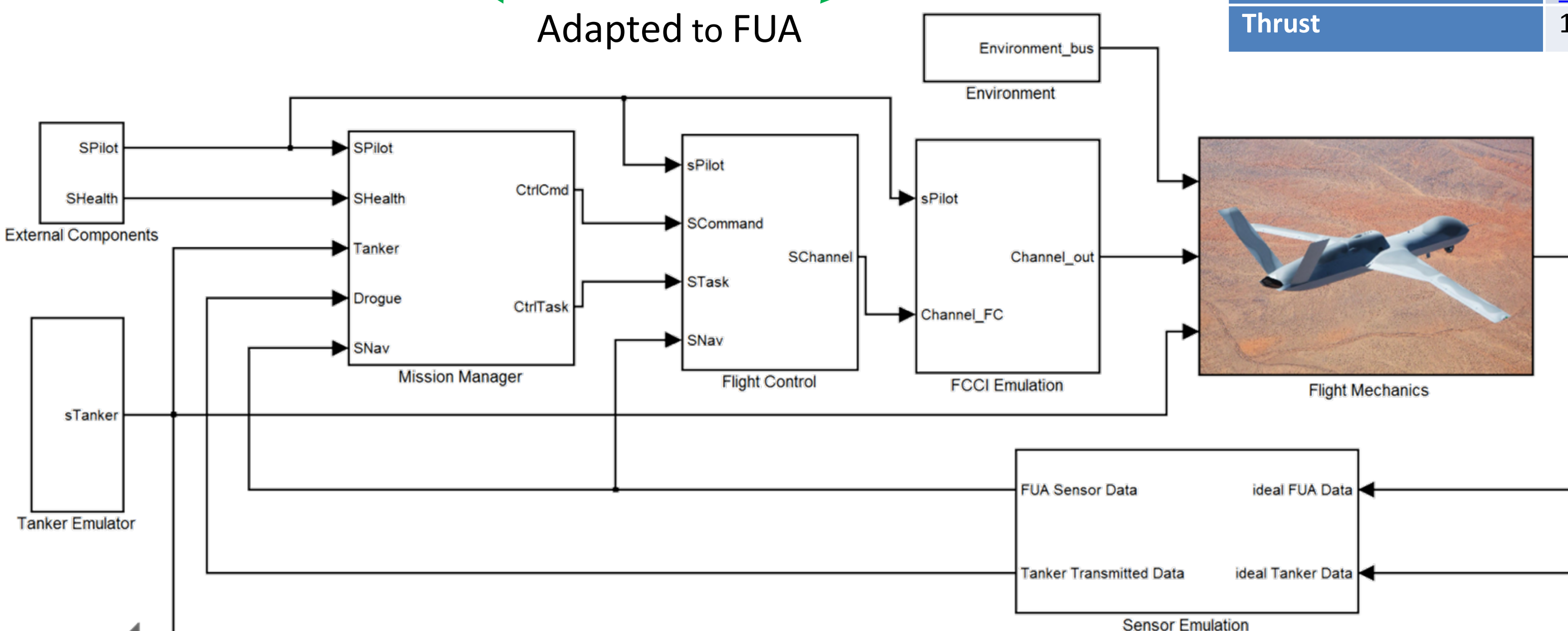
Modeling – Aircraft – Future Unmanned Aircraft

Kenngröße	Daten
Type	Drohne
Length	12.50 m
Wingspan	20.12 m, sweep 17°
Empty weight	N/A
Max Take Off Weight	5 220 kg
Max Speed	740 km/h
Cruise Speed	N/A
Service Ceiling	18 300 m
Propulsion	Pratt & Whitney Canada PW545B-
Thrust	17.7 bis 21.3 kN

Basic Simulation
Aerodynamic coefficients

Geometry Data
Technical Specs.

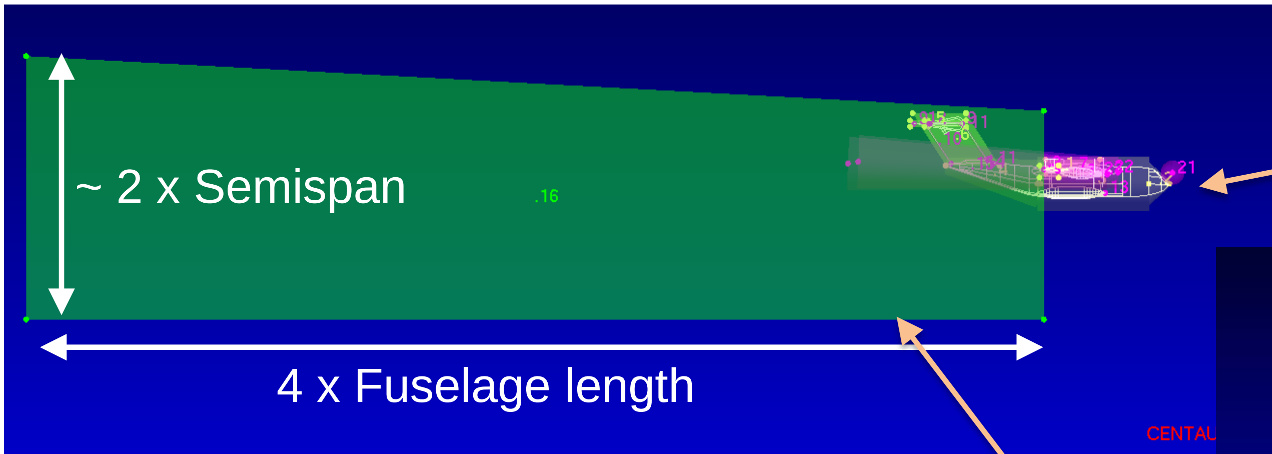
Adapted to FUA

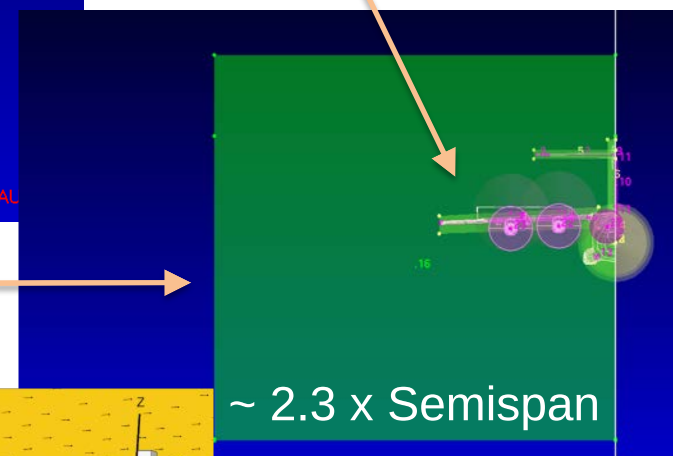


DLR

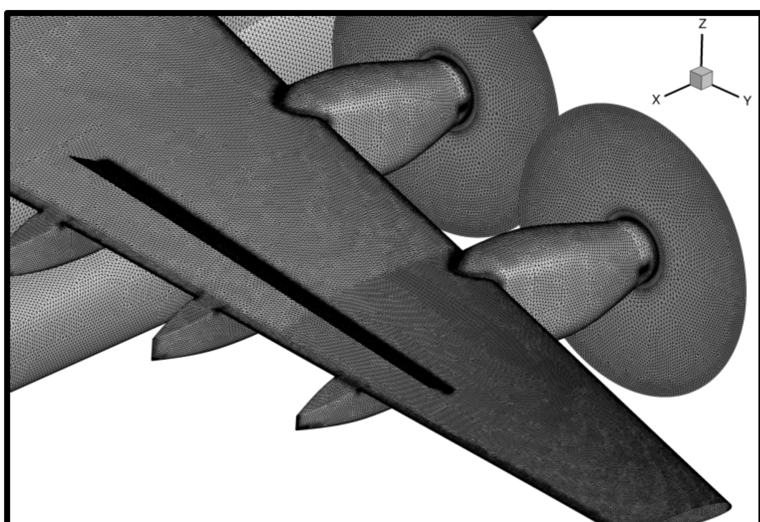
Modeling – Aerodynamic Interaction – Wind Field (1/3)

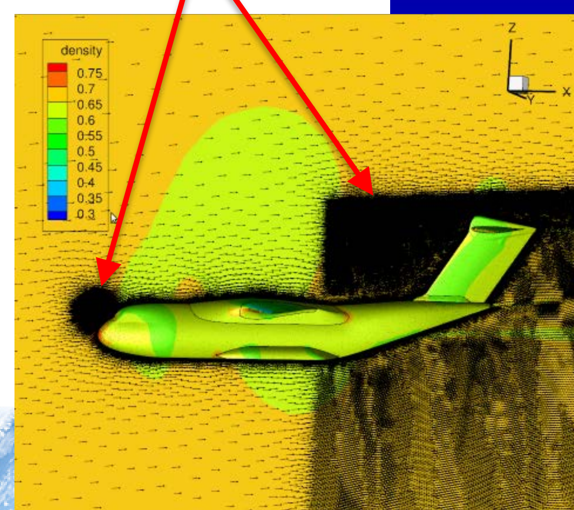
- Box with finer mesh for conservation of the downstream flow characteristics
- Refinements also for bow wave effect





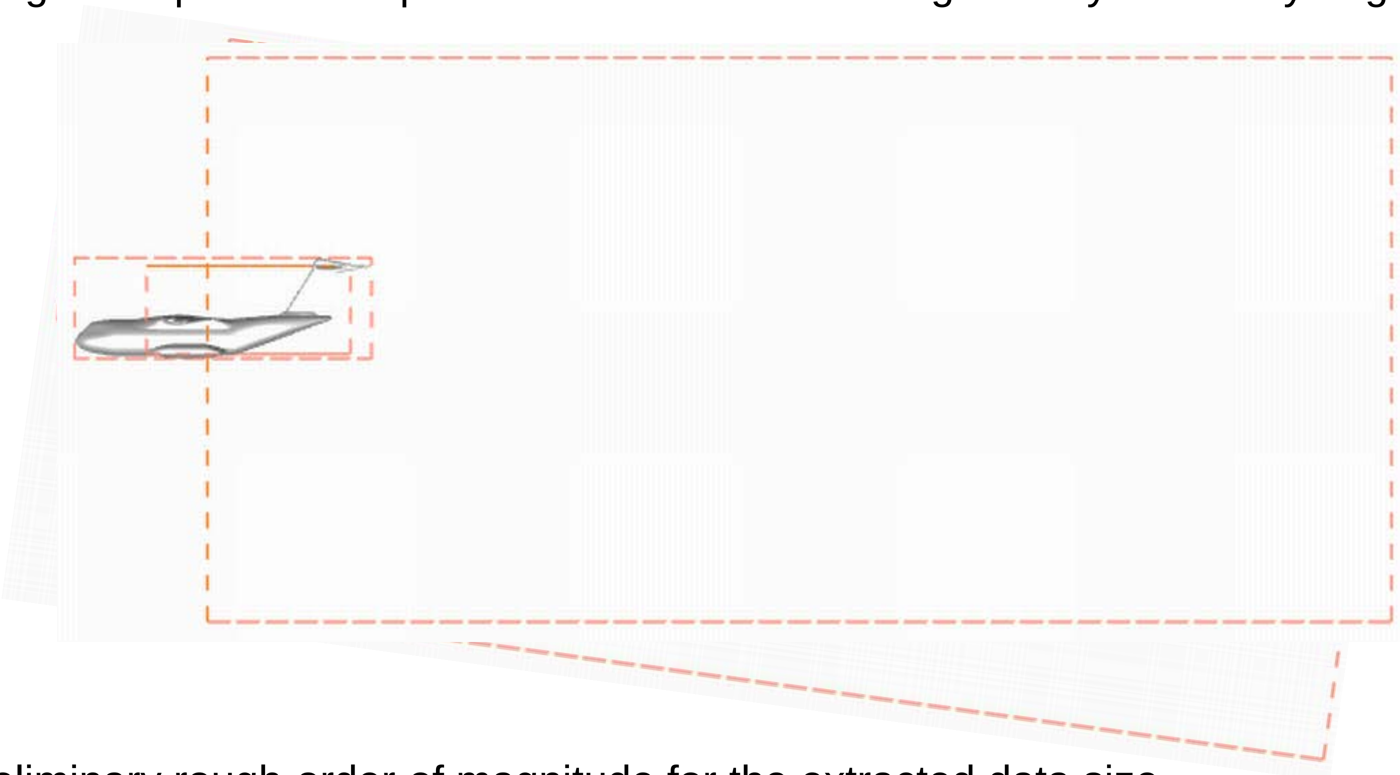
- Spoiler efficiency (various deflections)





Modeling – Aerodynamic Interaction – Wind Field (2/3)

- Flow field directly extracted by the “end-users” from the volume solution
- Different domains and solutions are being tested
  → goal: capture the important effects without having to carry extremely large tables

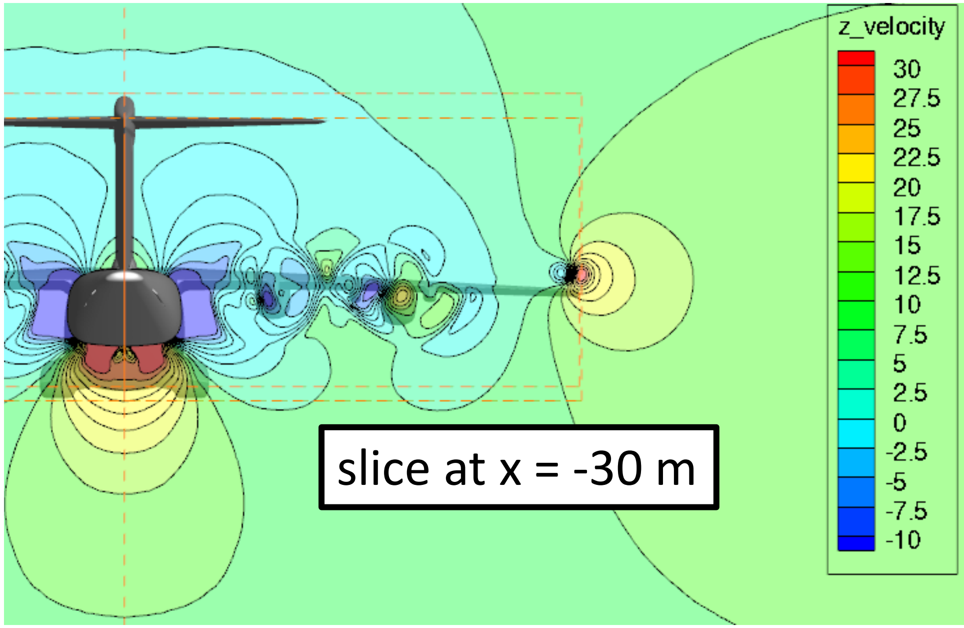


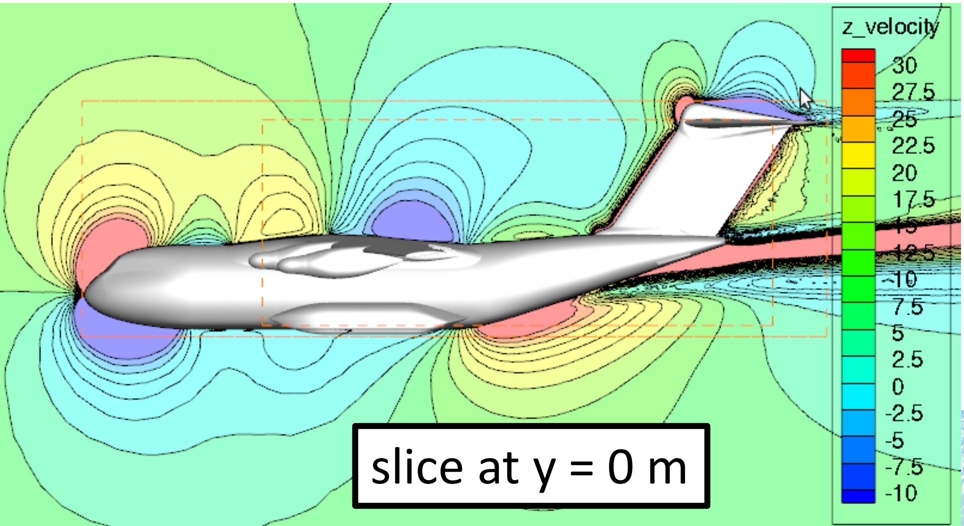
Preliminary rough-order of magnitude for the extracted data size
Domain size: x_b = -200 … 20, y_b = 0 …80, z_b = -40 … 40
Resolution: 2 m in x_b direction; 0,5 m in y_b und z_b direction

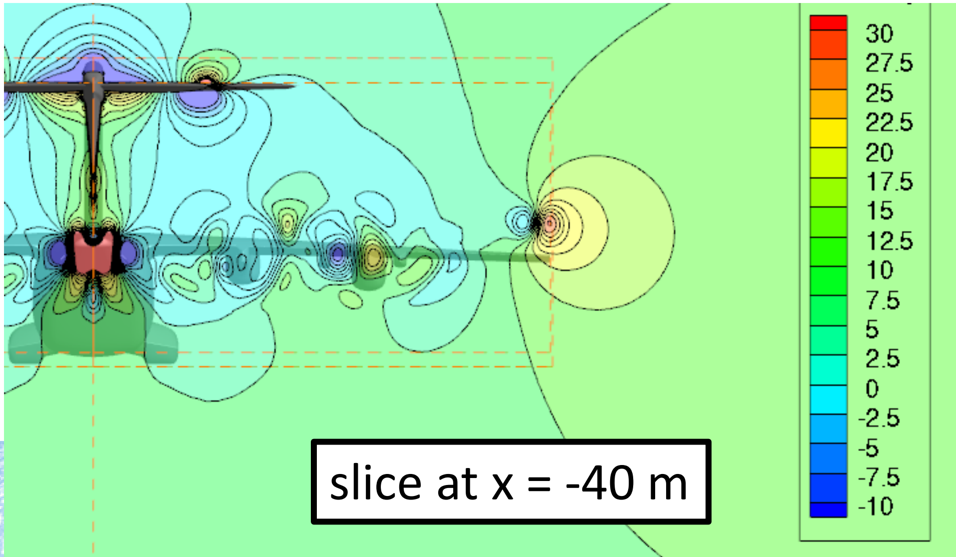
around 2.36 Million points
(file size around 225 MB)

Modeling – Aerodynamic Interaction – Wind Field (3/3)

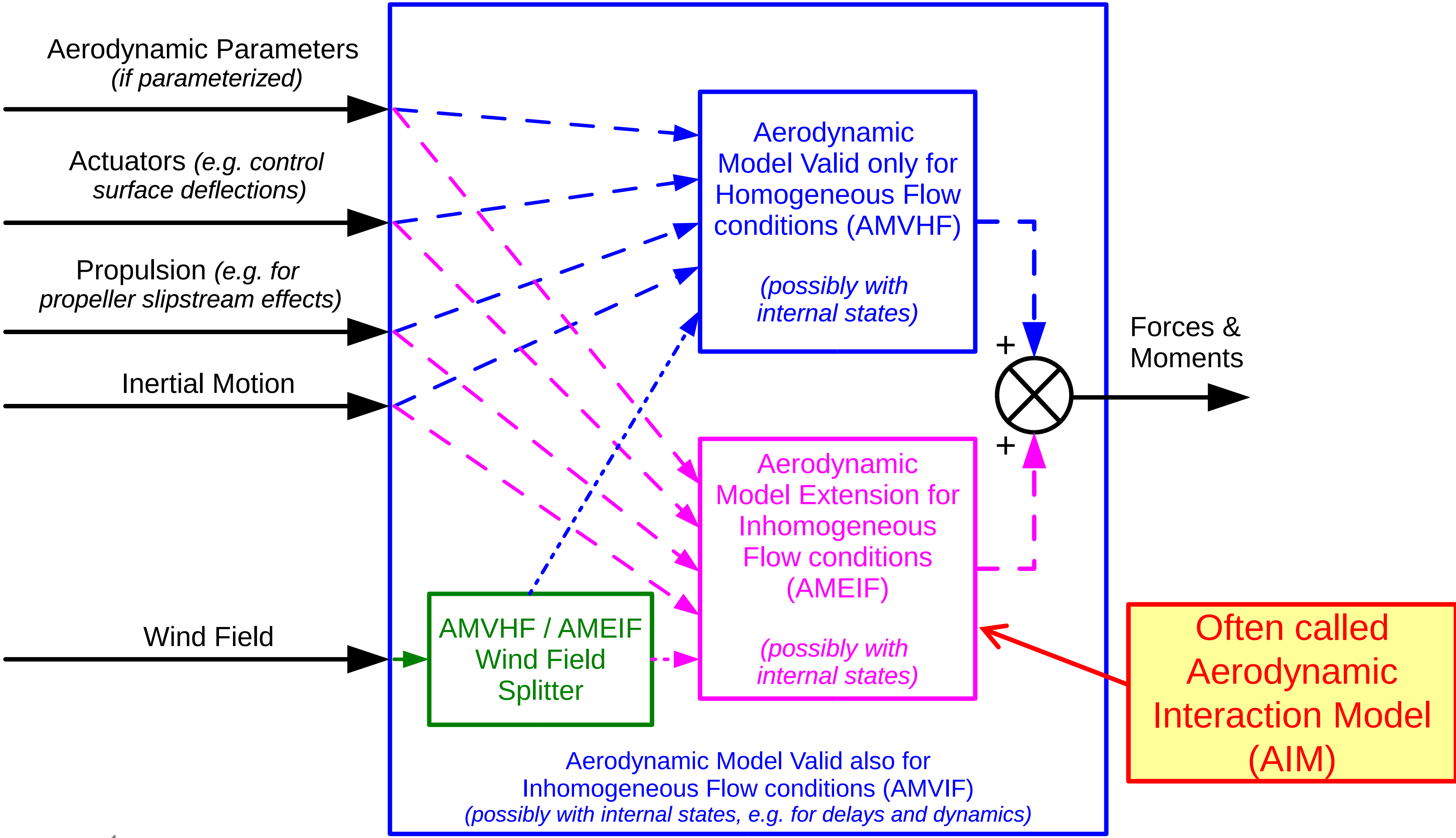
- Significant upwash induced just behind the ramp (first part of the hose)
- Even if the refueling probe is quite long, a quite significant bow wave will affect the drogue (+ strong local gradient)



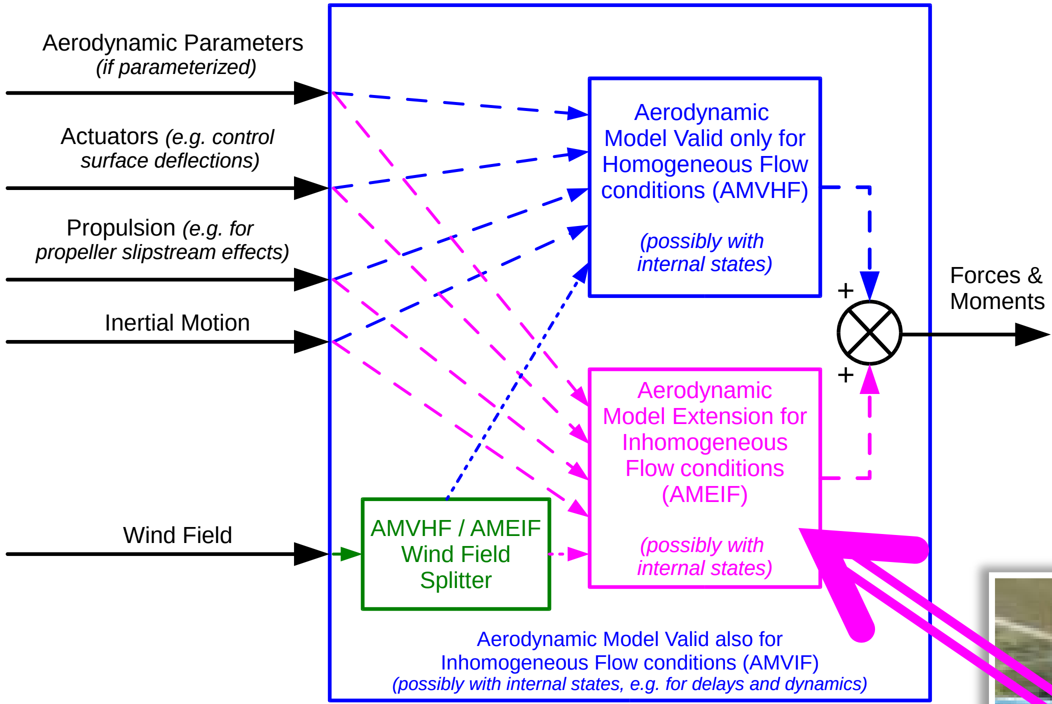




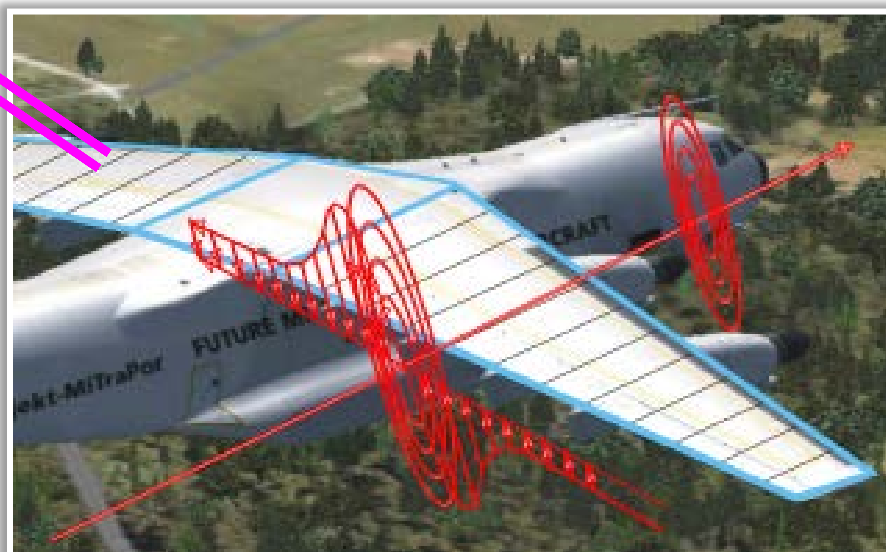
Modeling – Aero. Interaction – Δ Forces and Moments



Modeling – Aero. Interaction – Δ Forces and Moments

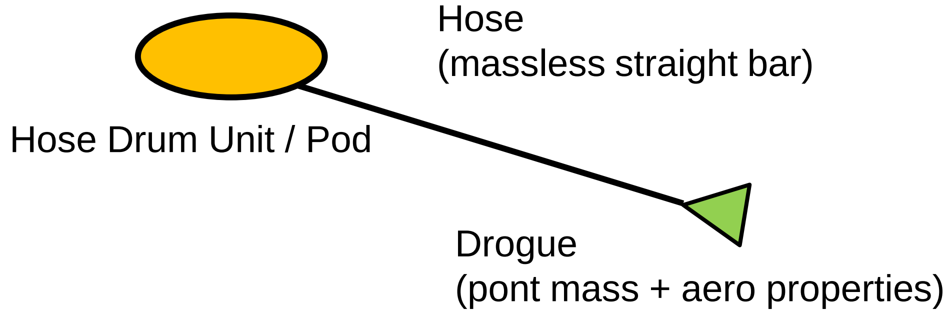


Example of aerodynamic interaction with a wake vortex using a “strip method”

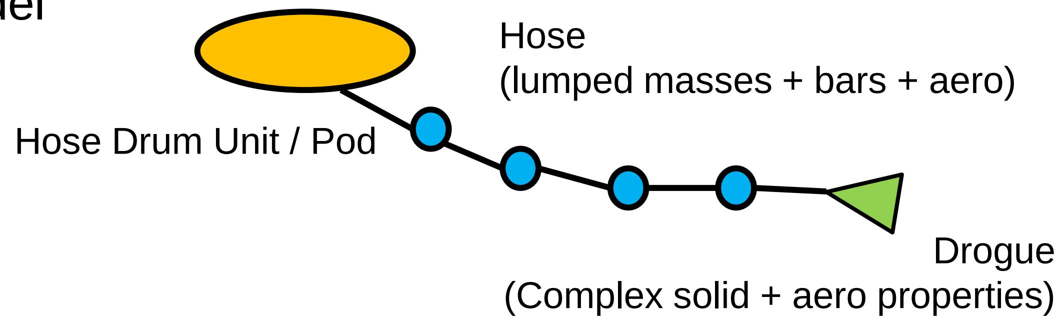


Modeling – Hose-and-Drogue Dynamics (1/2)

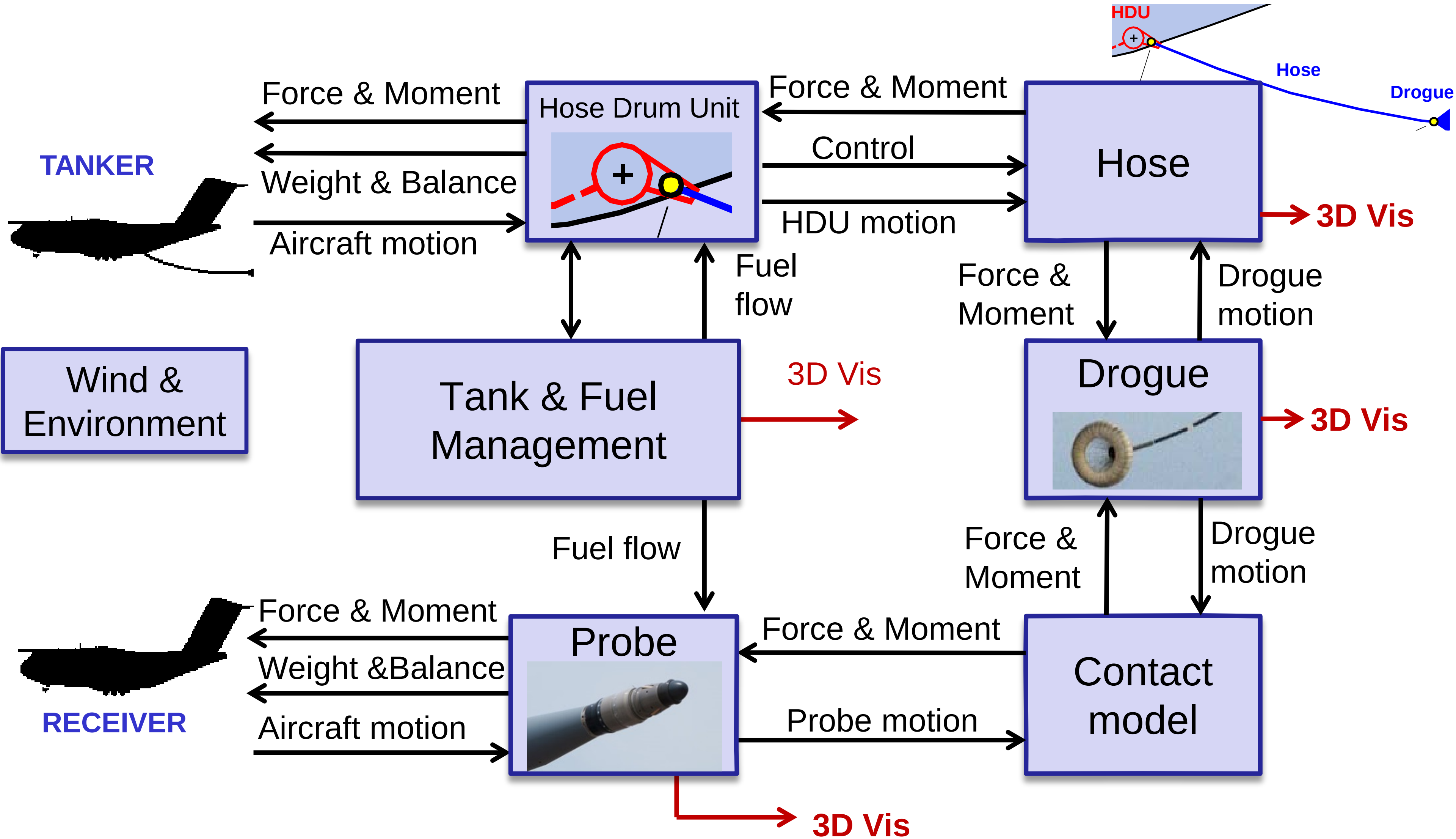
- Models of the hose and drogue dynamic behavior
  - Simple model



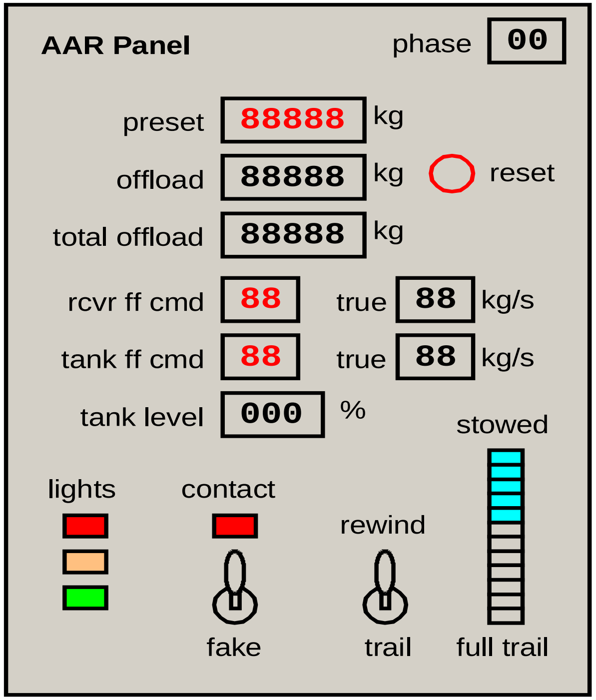
  - Multi-body model

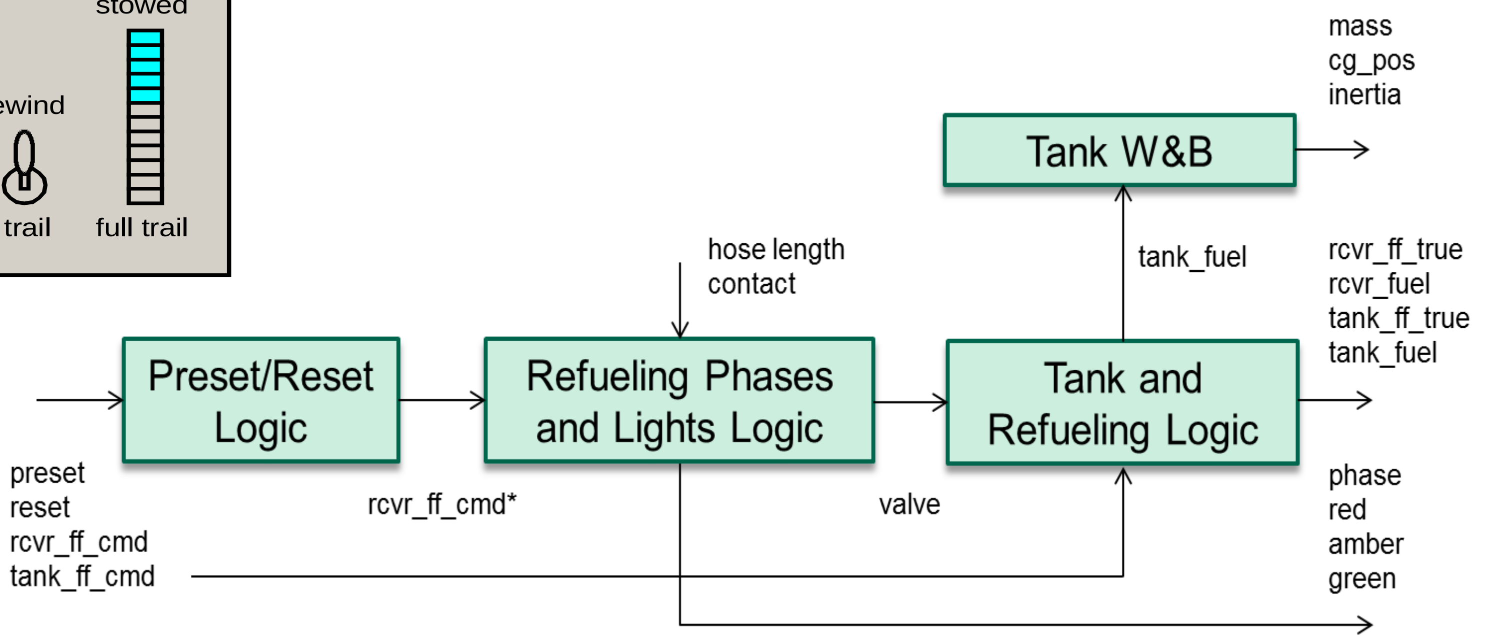


Modeling – Hose-and-Drogue Dynamics (2/2)



Modeling – Refueling System



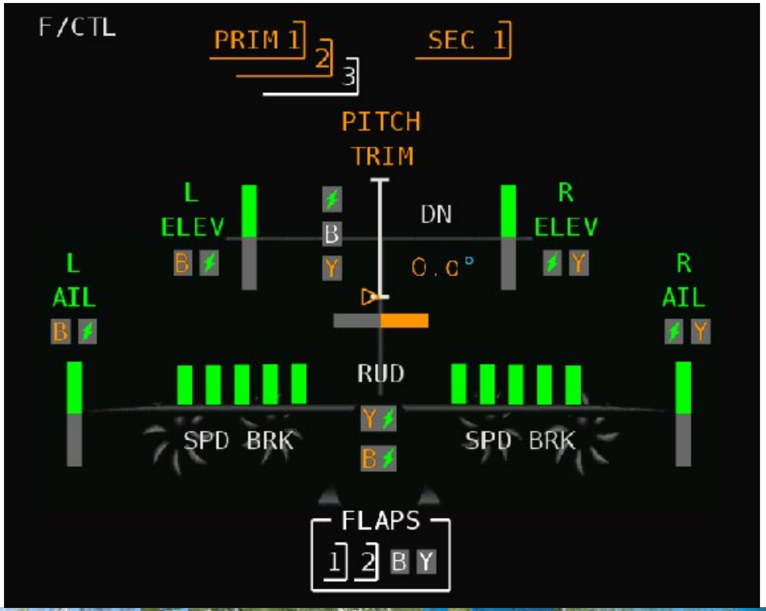


Simulation Infrastructure: FMTA (T) – FMTA (R) (1/2)

- Simulation ported to the DLR AVES Simulator
- A320 cockpit is used for the receiver
- A320 displays are used as they are but with two specialized ECAM pages
    - Engine Monitoring (Upper-ECAM)
    - Flight Controls (Lower-ECAM)
- Logic and protections (stall, overspeed, etc.) are adapted to the FMTA characteristics

Simulation Infrastructure: FMTA (T) – FMTA (R) (1/2)

- Simulation ported to the DLR AVES Simulator
- A320 cockpit is used for the receiver
- A320 displays are used as they are but with two specialized ECAM pages
    - Engine Monitoring (Upper-ECAM)
    - Flight Controls (Lower-ECAM)
- Logic and protections (stall, overspeed, etc.) are adapted to the FMTA characteristics



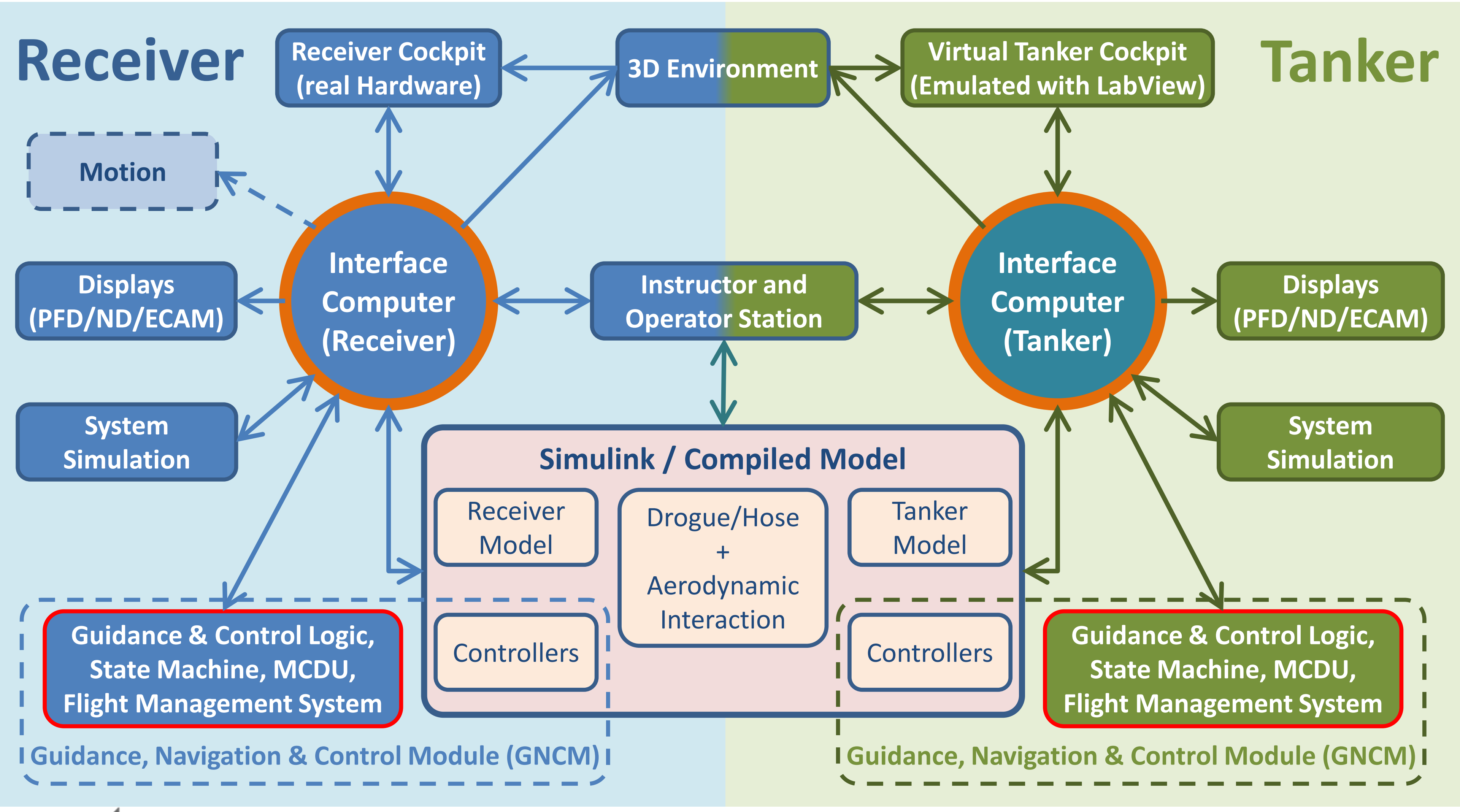
DLR

Simulation Infrastructure: FMTA (T) – FMTA (R) (1/2)

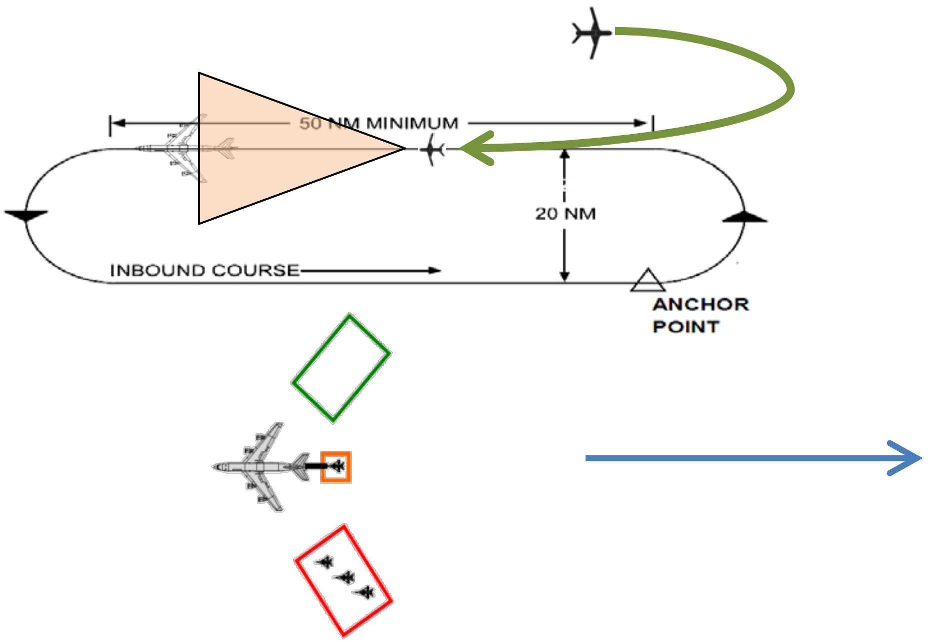
- Simulation ported to the DLR AVES Simulator
- A320 cockpit is used for the receiver
- A320 displays are used as they are but with two specialized ECAM pages
    - Engine Monitoring (Upper-ECAM)
    - Flight Controls (Lower-ECAM)
- Logic and protections (stall, overspeed, etc.) are adapted to the FMTA characteristics

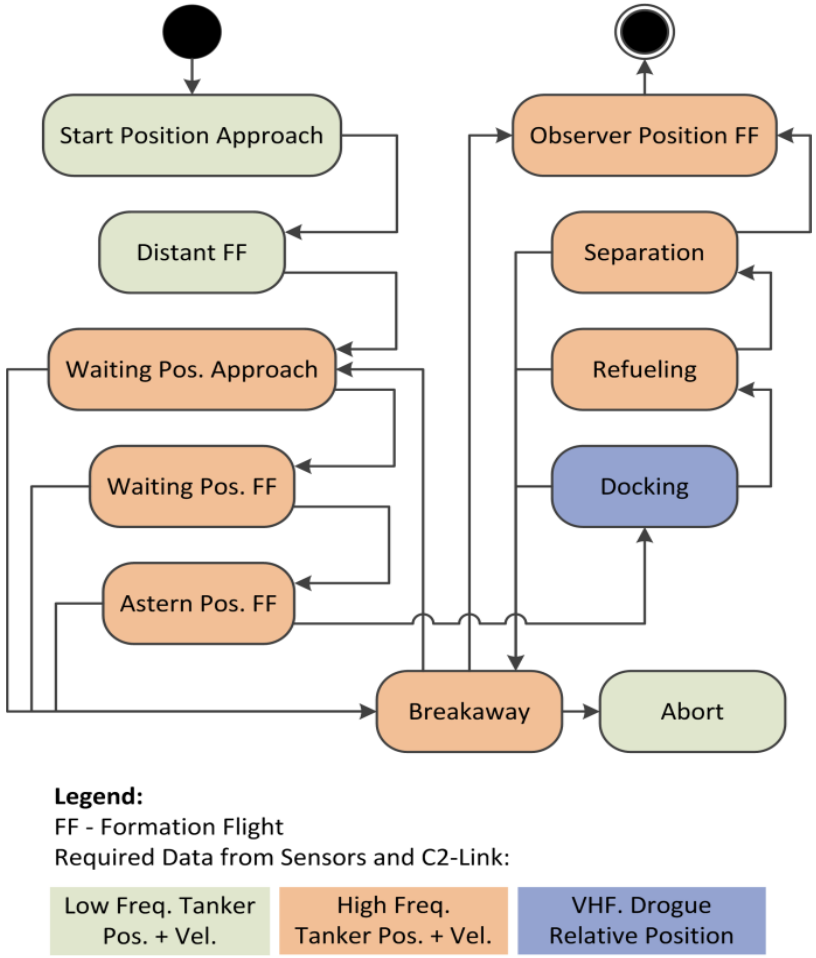
DLR

Simulation Infrastructure: FMTA (T) – FMTA (R) (2/2)



Simulation Infrastructure: FMTA (T) – FUA (R)





- Automated procedure in accordance to manual piloted procedure
- A state machine calls specific controller modes for each phase of the refueling mission
- Phases are defined by entry and exit conditions which ensure a stable flight condition or a fallback solution

Summary and Outlook

- General overview of the modelling and simulation activities performed at DLR for hose-and-drogue AAR research

- First step and enabler for the AAR automation research being performed for manned and unmanned receiver aircraft.

- Probably the most comprehensive effort outside the US:
  - on the modelling and simulation of the air-to-air refueling maneuvers
  - and on the flight control assistance / automation technologies.

A lot more is coming within the next months and years

Thank you for your attention!

Questions?

DLR