



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

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DLRK 2016 (Deutscher Luft- und Raumfahrtkongress)

Sept. 15<sup>th</sup> 2016

Braunschweig, Germany

Knowledge for Tomorrow

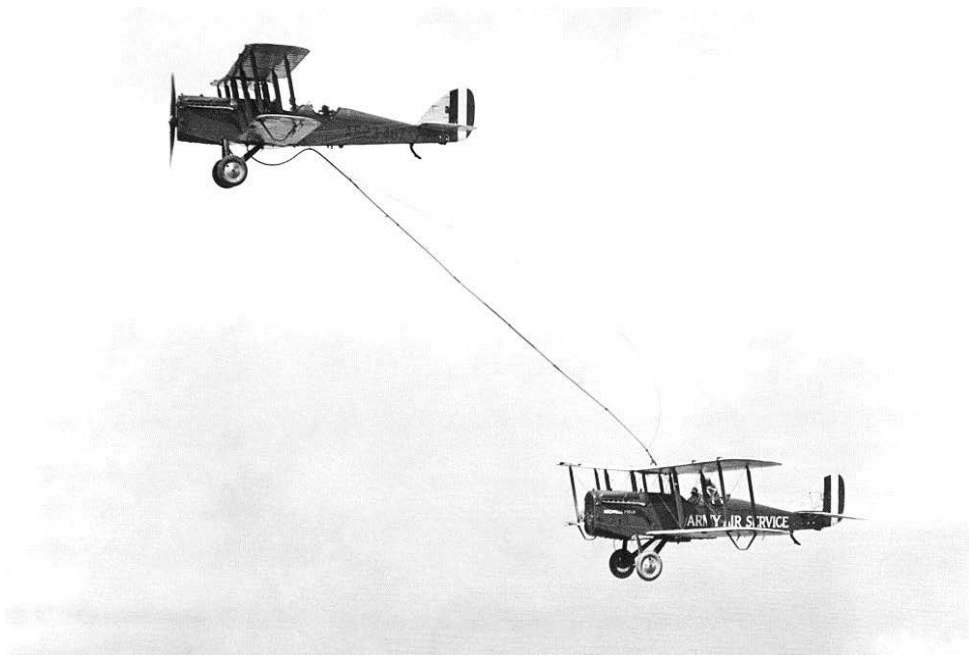
# Outline

- 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, 27<sup>th</sup> 1923  
("Tangle-and-Grab" method)



### Early endeavours...

On 12 November 1921, a stunt took place over Long Beach California which today would be regarded as foolhardy. Nevertheless, when "Flying Tankerman" Wesley May - with a 16kg (35lb) can of gasoline strapped to his back instead of a parachute - clambered from the top wing of a Lincoln Standard biplane onto the lower wing of a Curtiss JN-4, he carried out the first recorded transfer of fuel in flight.

The use of supply aircraft for the transfer of fuel and consumables such as food and engine oil was originally undertaken to enable both military and civil long endurance flights to take place. Although these took place mainly in the US, such flights were also carried out in Great Britain, France, Belgium, Germany, Russia and Japan. However, no serious consideration was given to developing a system suitable for everyday commercial use until Sir Alan Cobham began experimental trials in the UK during the early 1930s.

In England, during the early 1920s, simple experiments involving the transfer of water from one Bristol Fighter to another were undertaken by the Royal Aircraft Establishment at Farnborough. Further trials which involved the passing of fuel were also conducted in this country and led to the first public demonstration of the air-to-air refuelling system developed by Sgt. Ldr Atcherley of the RAE at the 1931 Royal Air Force Display at Hendon.

An attempt by Sir Alan Cobham to fly non-stop to India relied on air-to-air refuelling en route. Although a failed throttle linkage on the Airspeed Courier receiver aircraft caused the abandonment of the flight at Malta, it heralded the start of serious attempts by Cobham to develop techniques suitable for civil and military operations.

In 1928 the US Army Air Corps' Albatross C-2A "Question Mark", refueled from two Douglas C-1 tankers, remained airborne for 150 hours 40 minutes.

America's Hunter brothers flight of 533 hours in 1930 was the last recognised endurance with refuelling record before the Federation Aeronautique Internationale withdrew the category from the record books.

In 1938, the Air Ministry decreed that all future research associated with air-to-air refuelling had to be undertaken commercially by Sir Alan Cobham's new Tanker Flight Refuelling Limited and that no further experimental work should be carried out by the RAE.

RAF Museum (North of London) →





# Air-to-Air Refueling – Overview

Boom-and-receptacle  
(view from operator station)

Probe-and-drogue

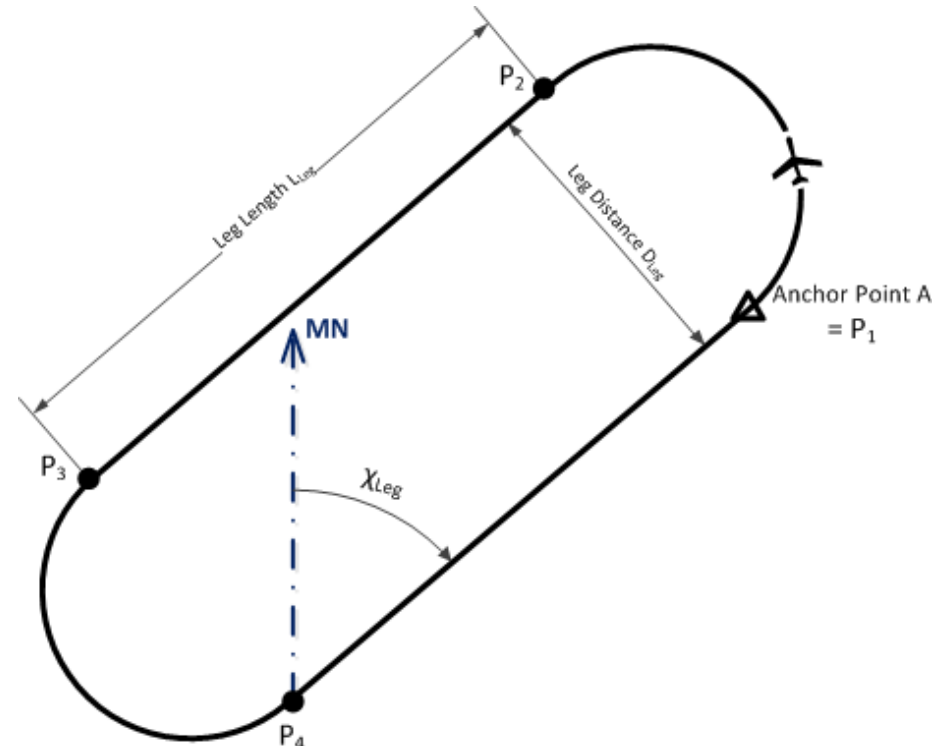


Boom-Drogue  
Adapter (BDA)

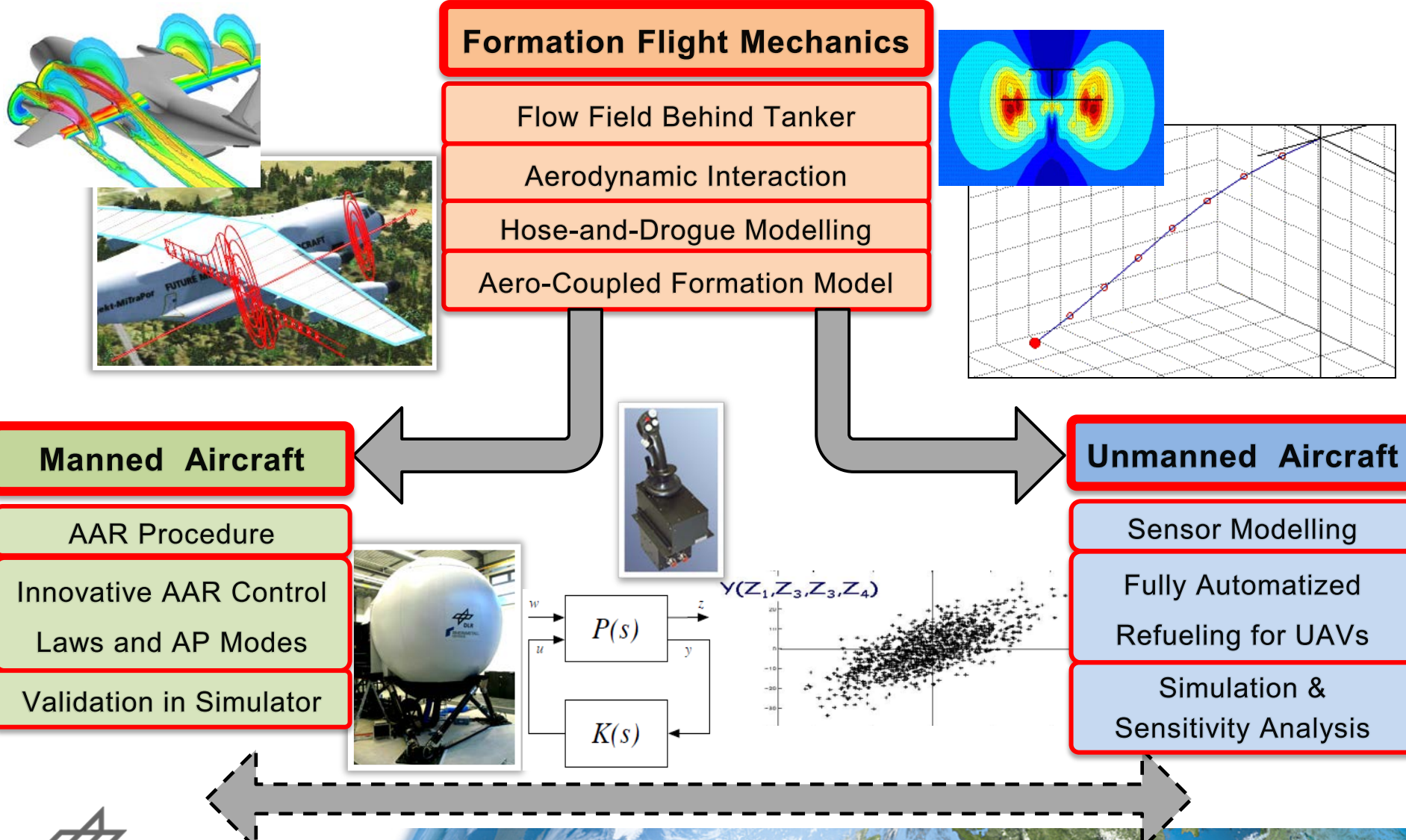


# Air-to-Air Refueling – Procedure

- 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

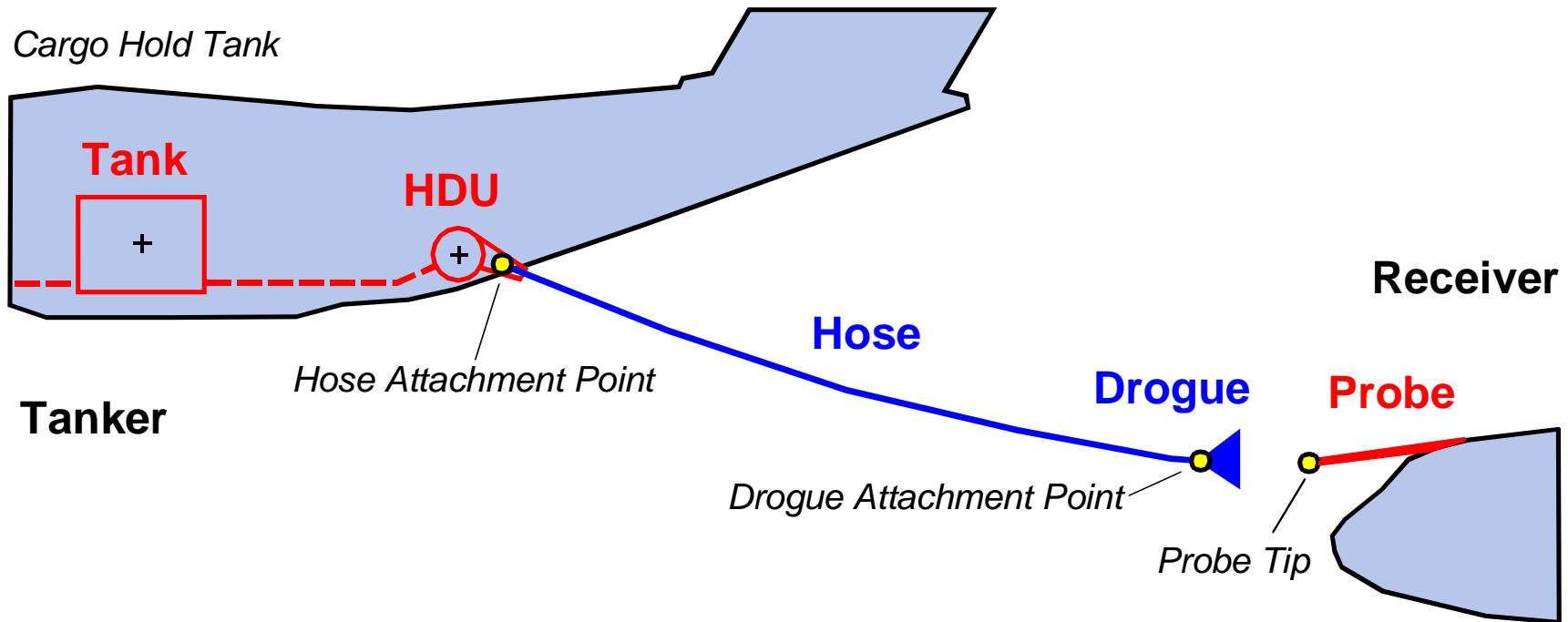


# LUBETA: “Automation technologies for aerial refueling”



# 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)



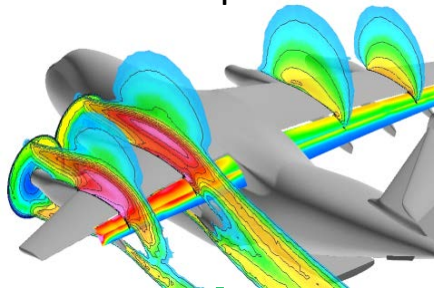


# Modeling – Aircraft – Future Military Transport Aircraft

Extrapolation C-160-Data



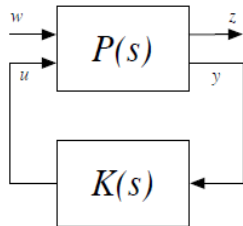
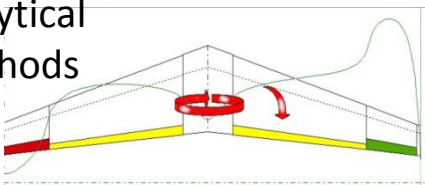
CFD-Computations



Wind Tunnel Measurement

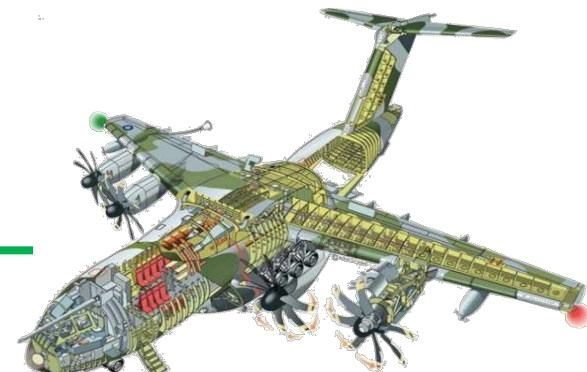


Analytical Methods

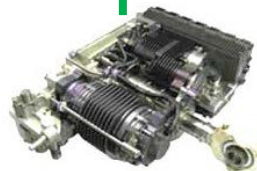


Sidestick, Control Laws, Autopilot, System Simulation

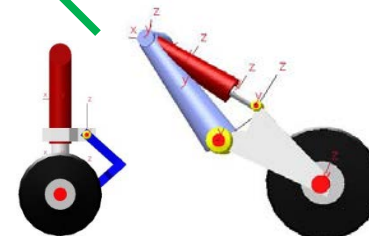
Real-time flight dynamical model of the FMTA



Geometry Data Technical Specs.



Actuator Models



Multi-Body Landing Gear

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





# Modeling – Aircraft – Future Unmanned Aircraft

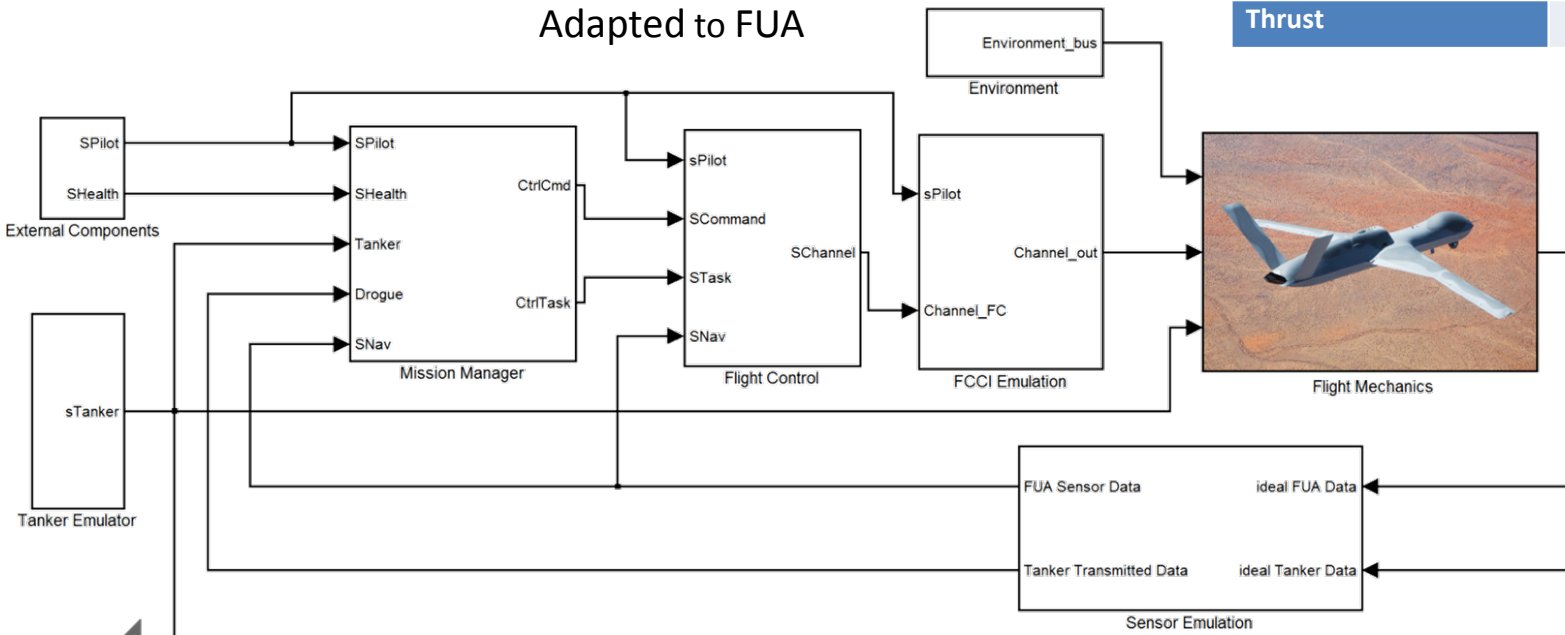


KenngroÙe	Daten
Type	Drohne
Length	12.50 m
Wingspan	20.12 m, sweep 17°
Empty weight	N/A
Max Take Off Weight	5 220 kg
Max Speed	740 km/h
Cruise Speed	N/A
Service Ceiling	18 300 m
Propulsion	<a href="#">Pratt &amp; Whitney Canada PW545B-</a>
Thrust	17.7 bis 21.3 kN

Basic Simulation  
Aerodynamic coefficients

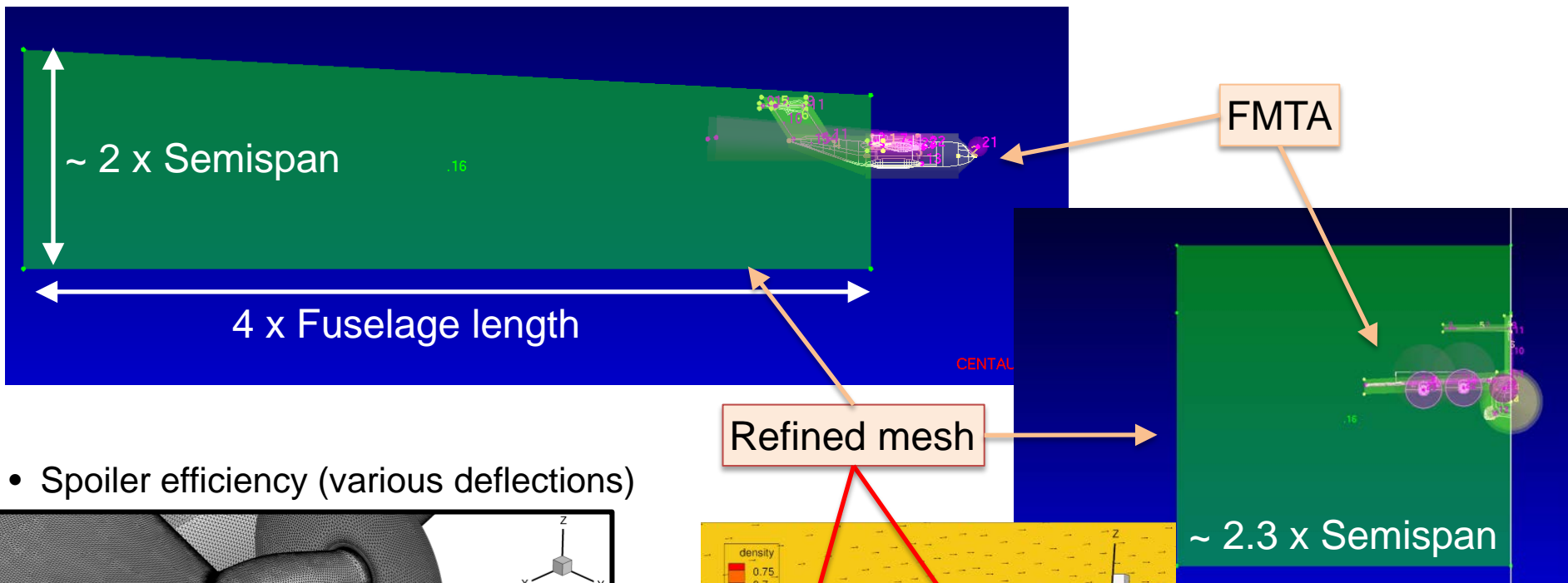
Geometry Data  
Technical Specs.

Adapted to FUA

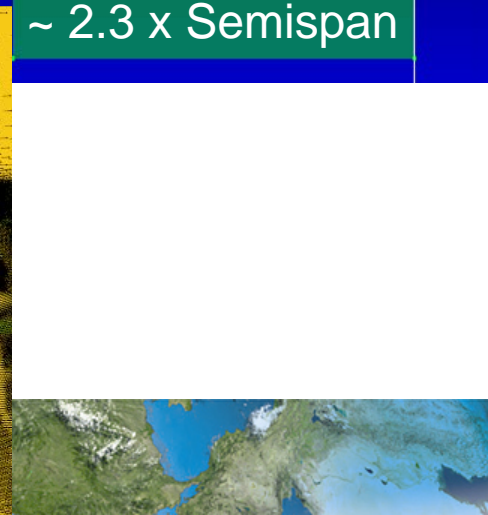
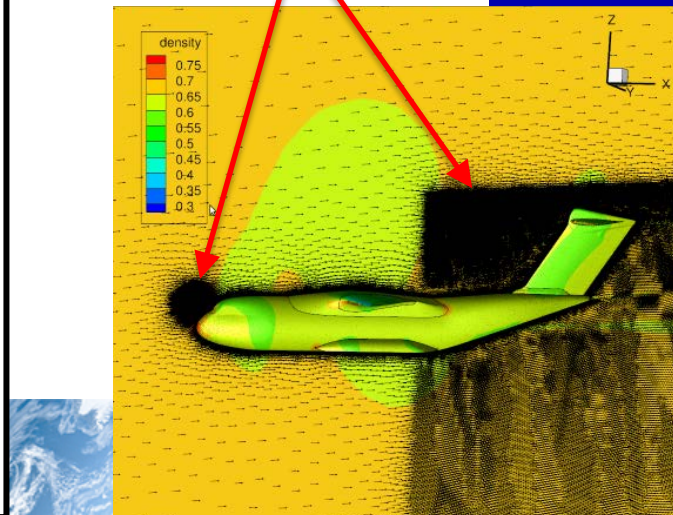
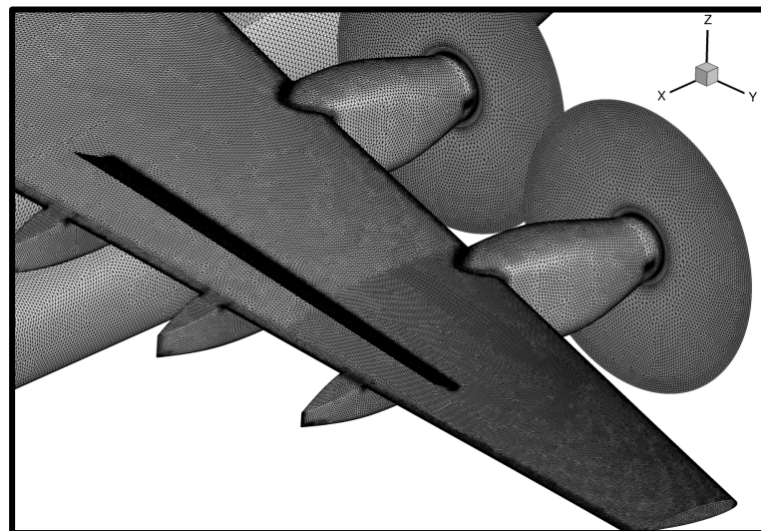


# Modeling – Aerodynamic Interaction – Wind Field (1/3)

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

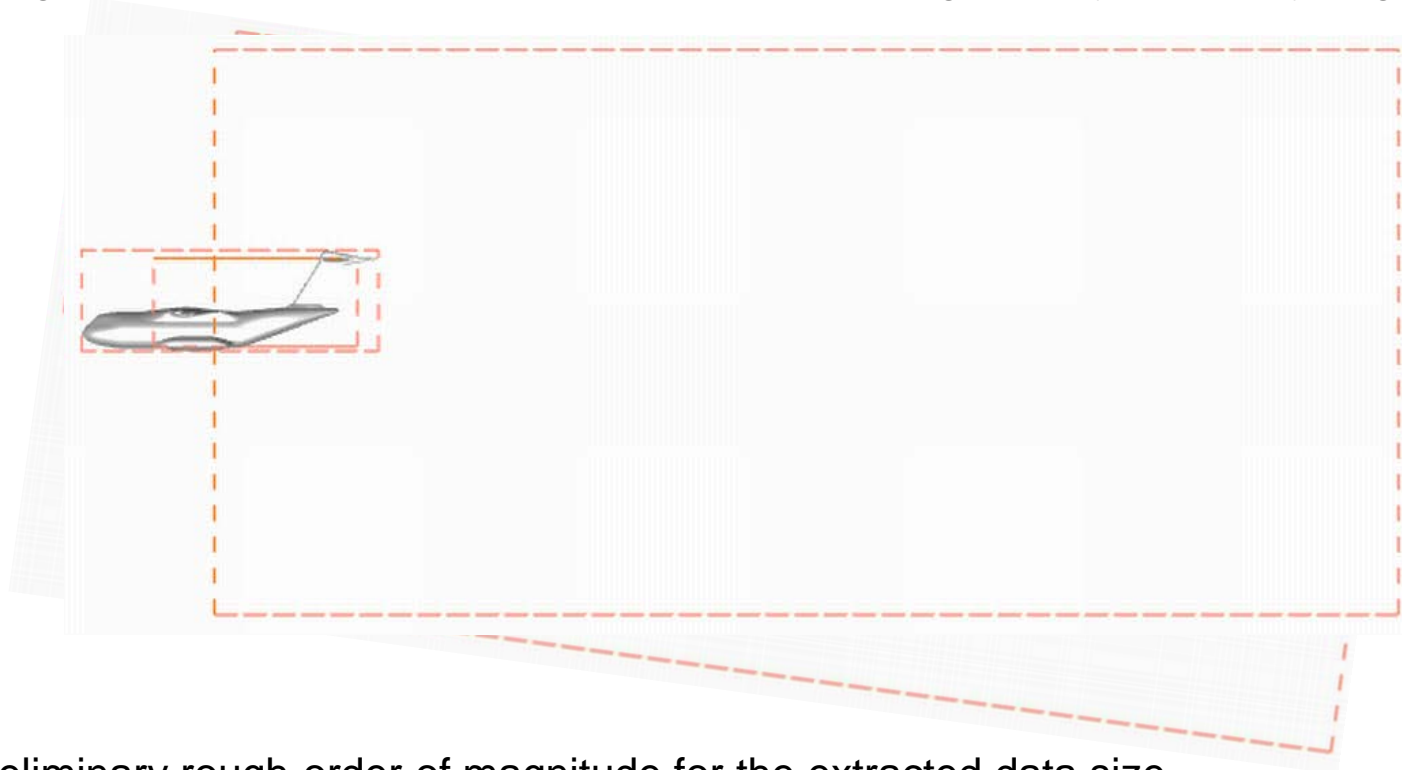


- Spoiler efficiency (various deflections)



# 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:  $x_b = -200 \dots 20$ ,  $y_b = 0 \dots 80$ ,  $z_b = -40 \dots 40$

Resolution: 2 m in  $x_b$  direction; 0,5 m in  $y_b$  und  $z_b$  direction

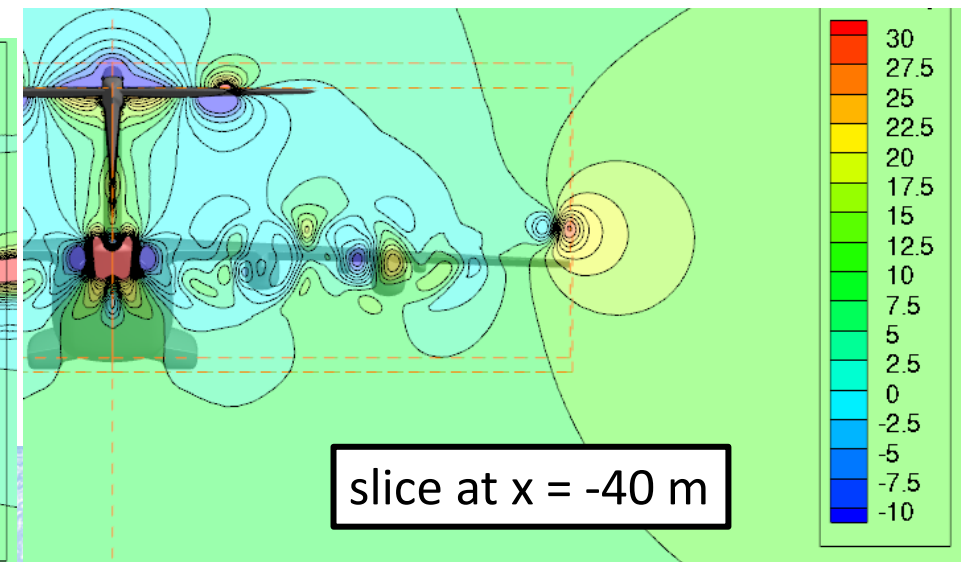
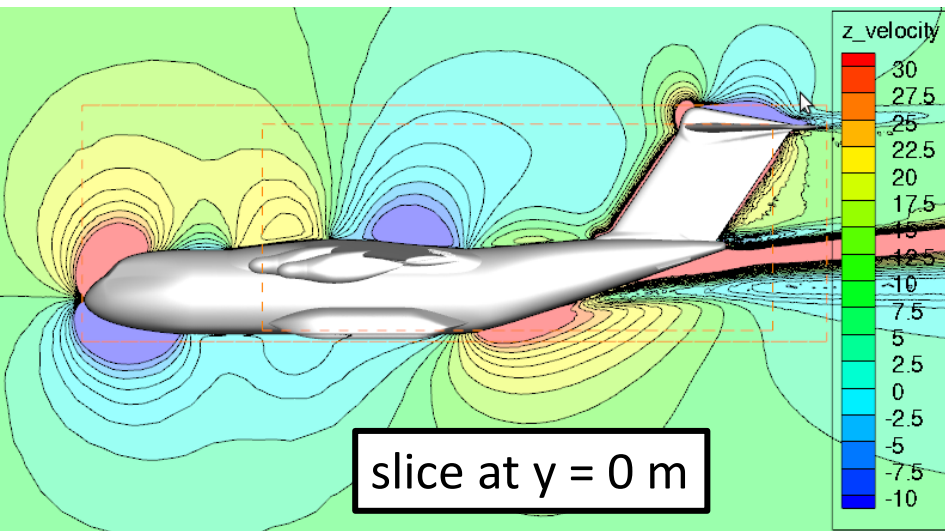
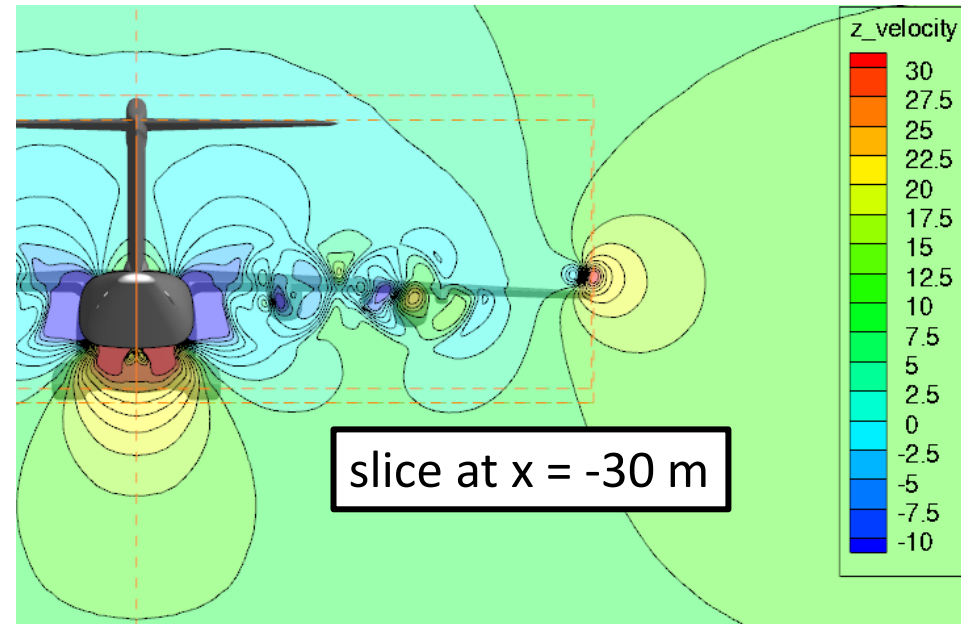
around 2.36 Million points  
(file size around 225 MB)



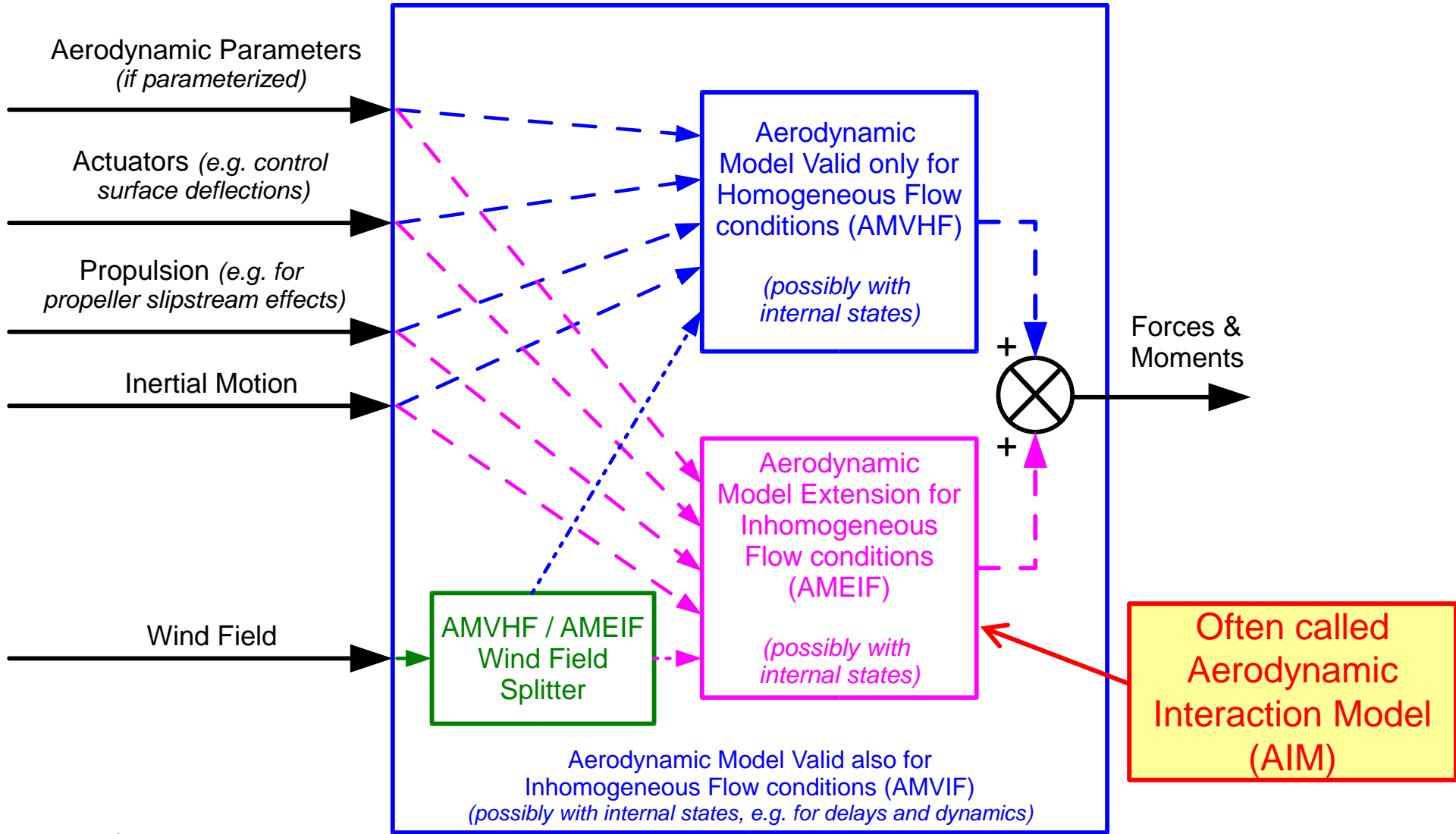


# Modeling – Aerodynamic Interaction – Wind Field (3/3)

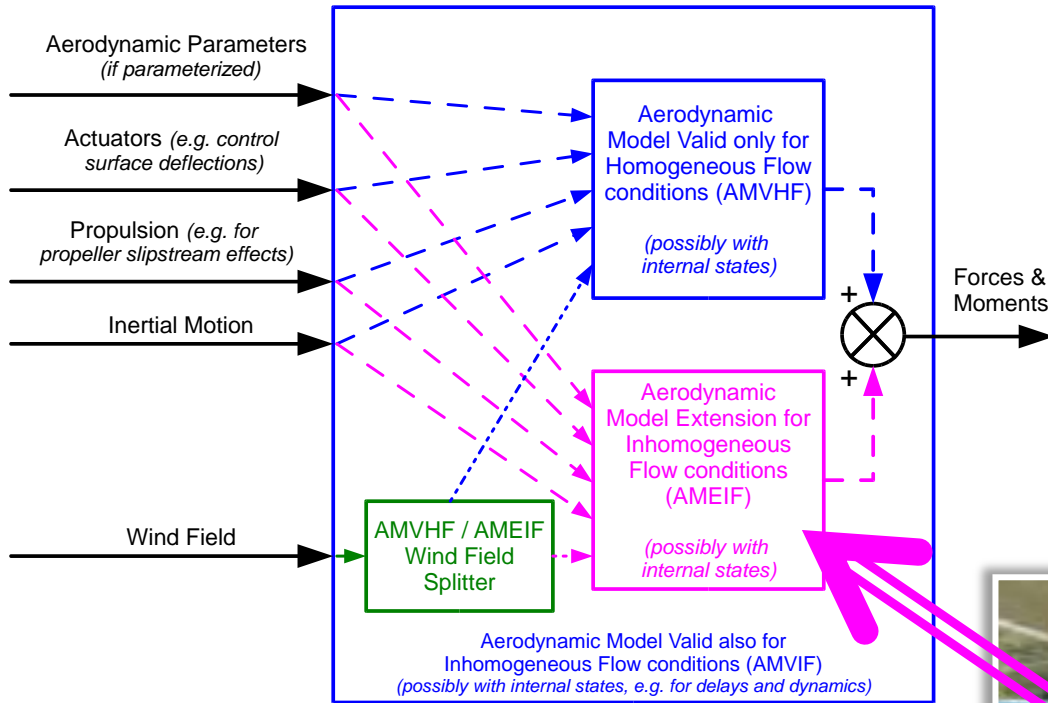
- Significant upwash induced just behind the ramp (first part of the hose)
- Even if the refueling probe is quite long, a quite significant bow wave will affect the drogue (+ strong local gradient)



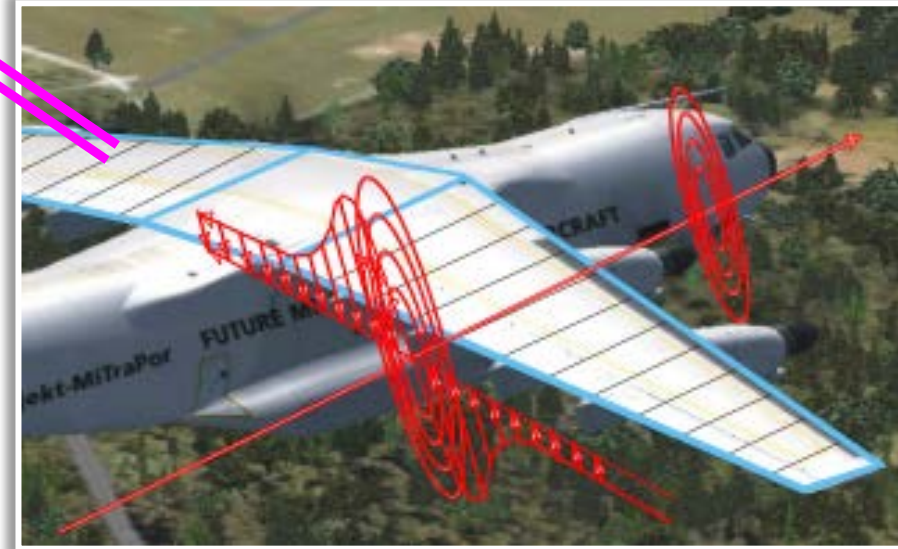
# Modeling – Aero. Interaction – $\Delta$ Forces and Moments



# Modeling – Aero. Interaction – $\Delta$ Forces and Moments



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

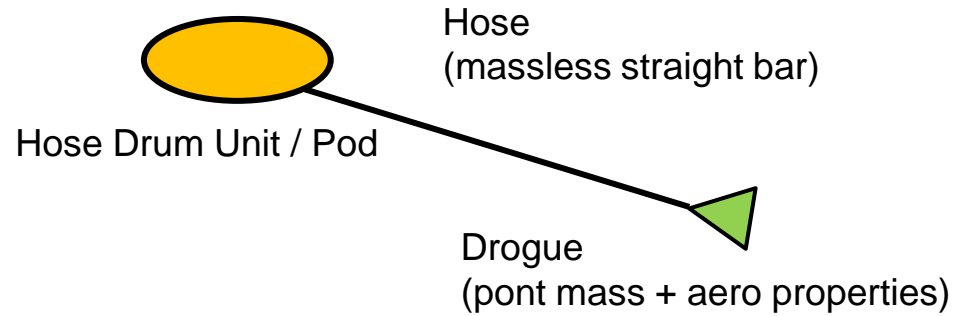




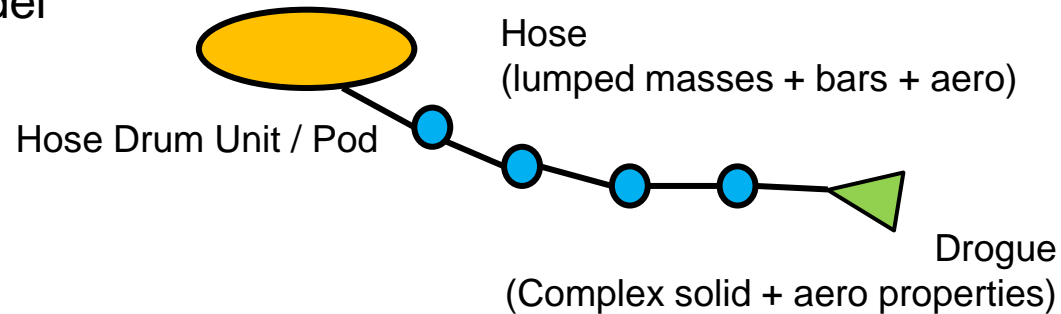
# Modeling – Hose-and-Drogue Dynamics (1/2)

- Models of the hose and drogue dynamic behavior

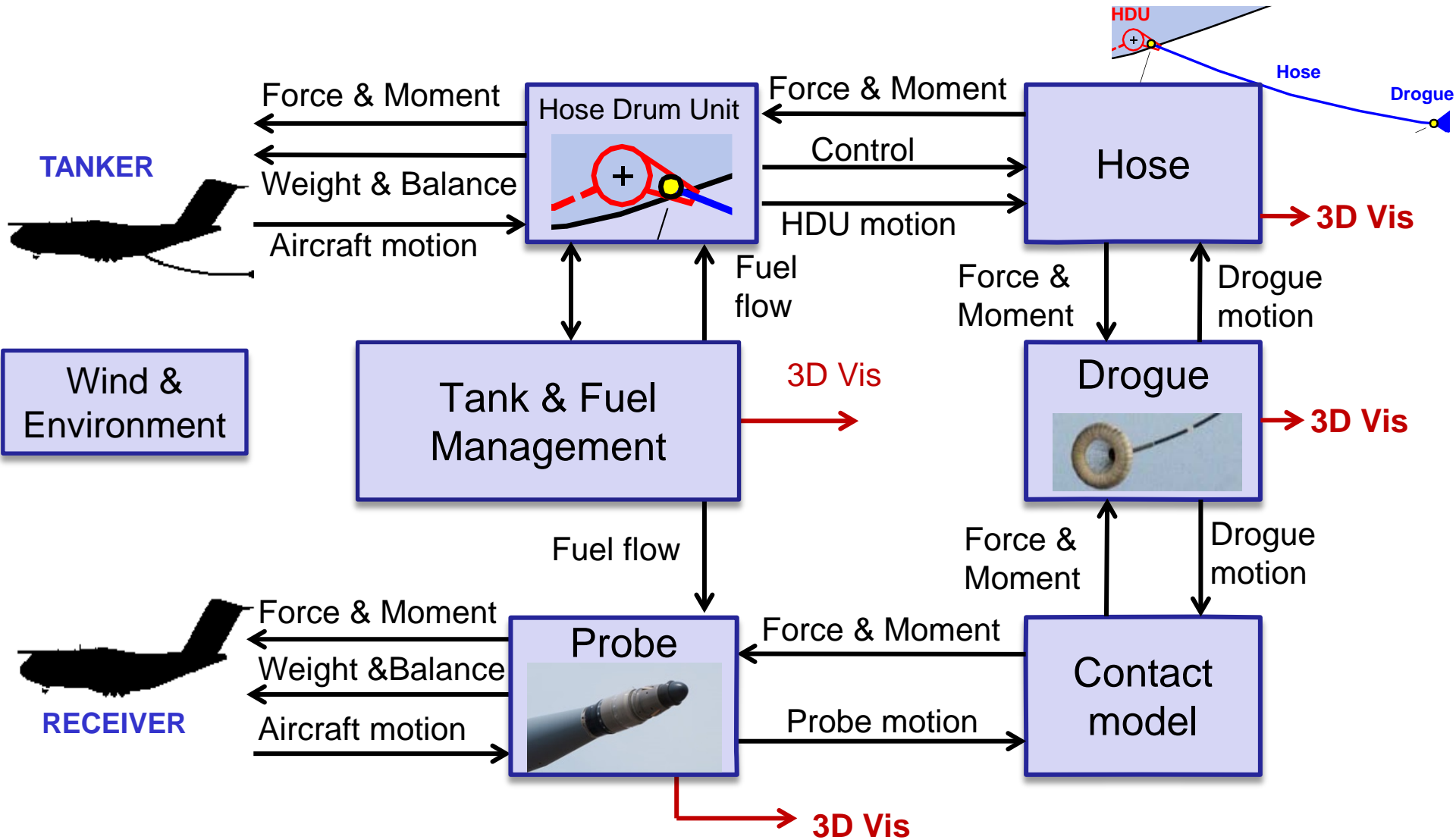
- Simple model



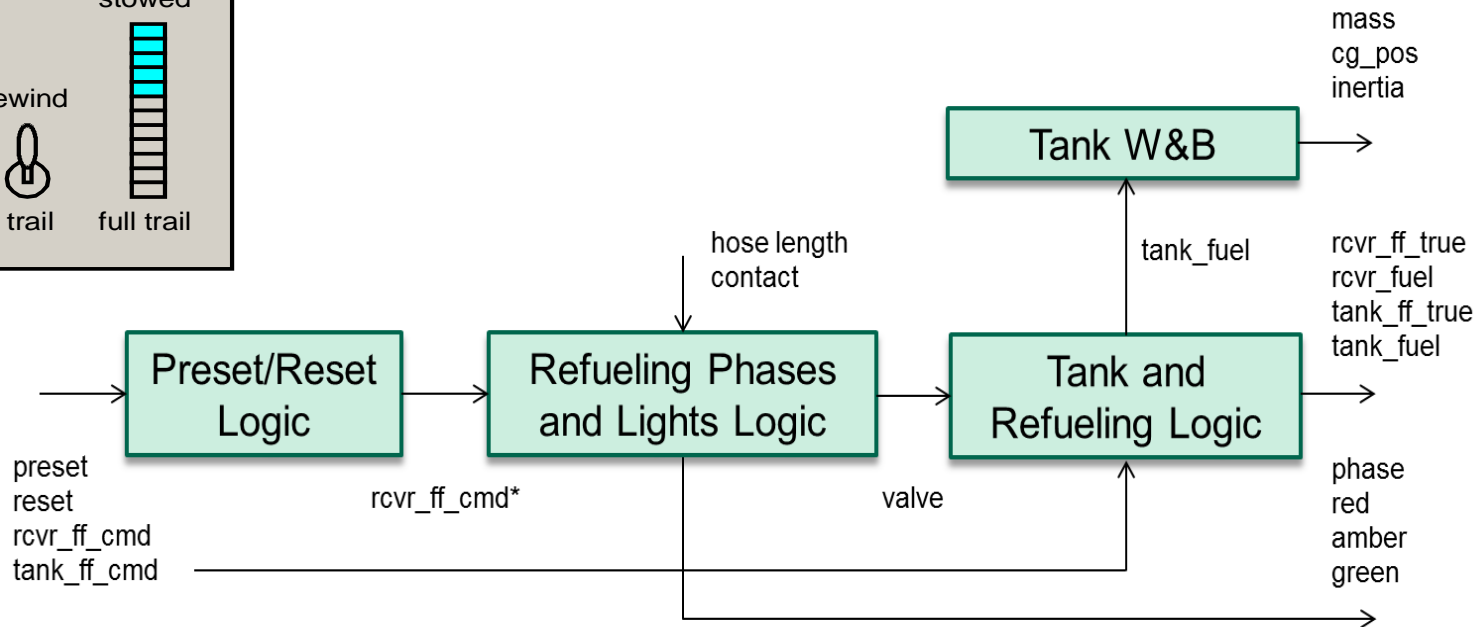
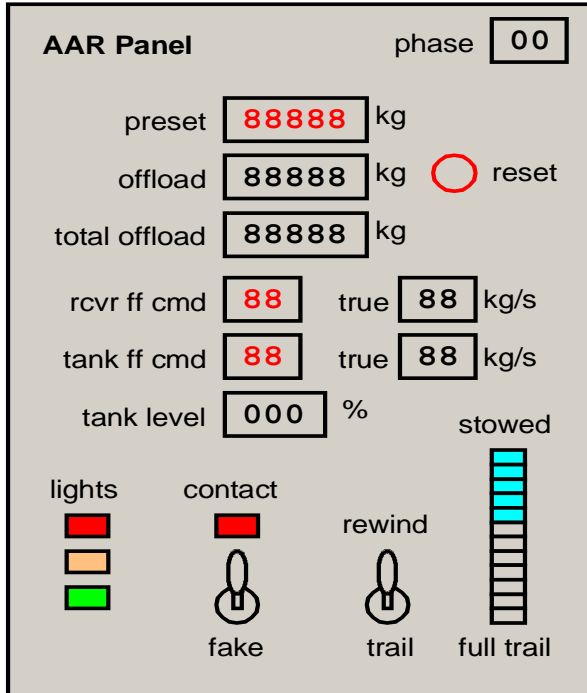
- Multi-body model



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



# Modeling – Refueling System





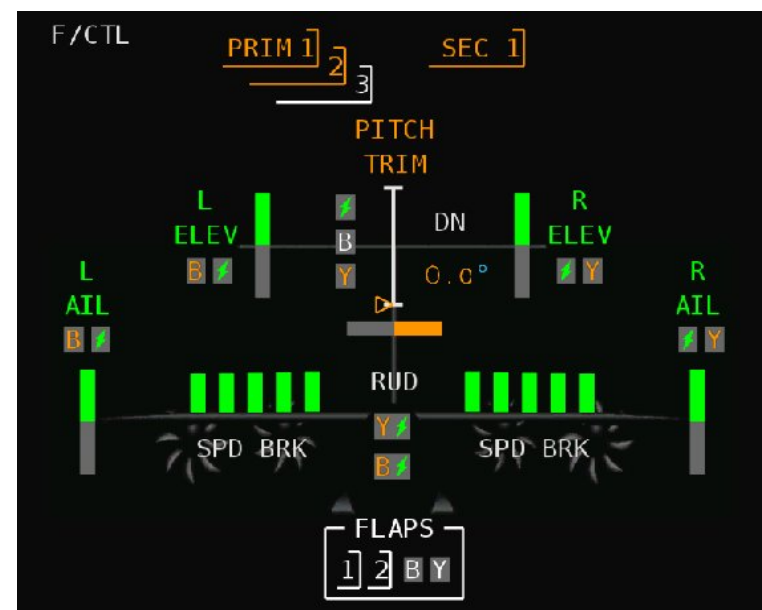
# Simulation Infrastructure: FMTA (T) – FMTA (R) (1/2)

- 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



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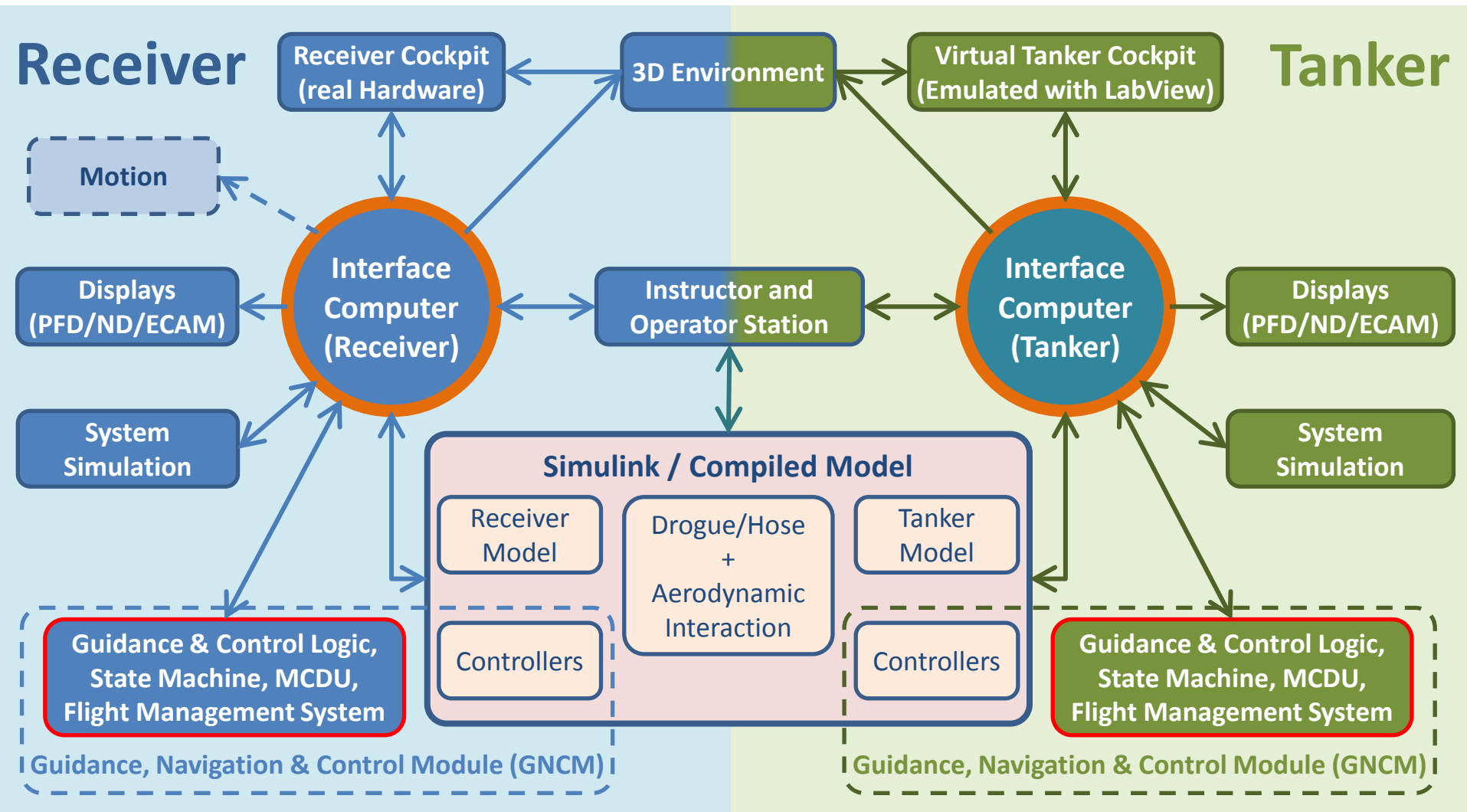


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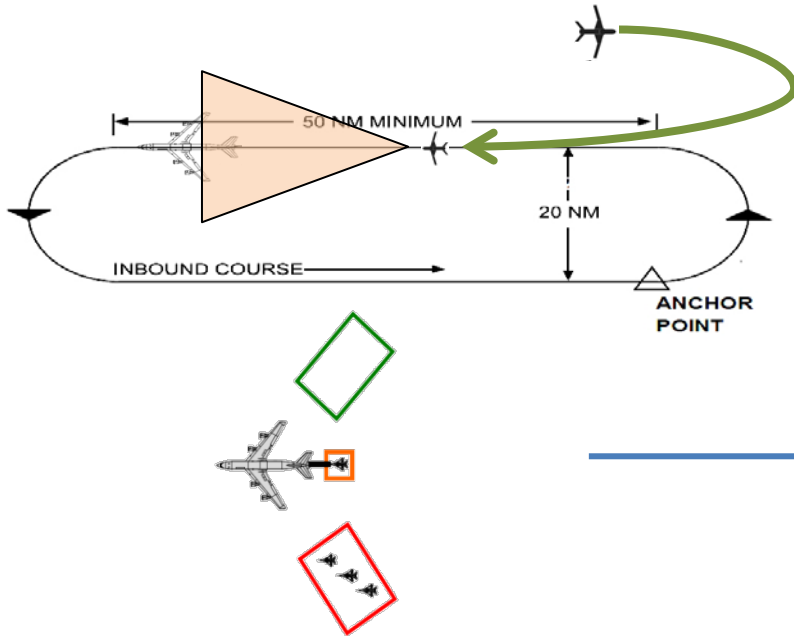


# Simulation Infrastructure: FMTA (T) – FMTA (R) (2/2)

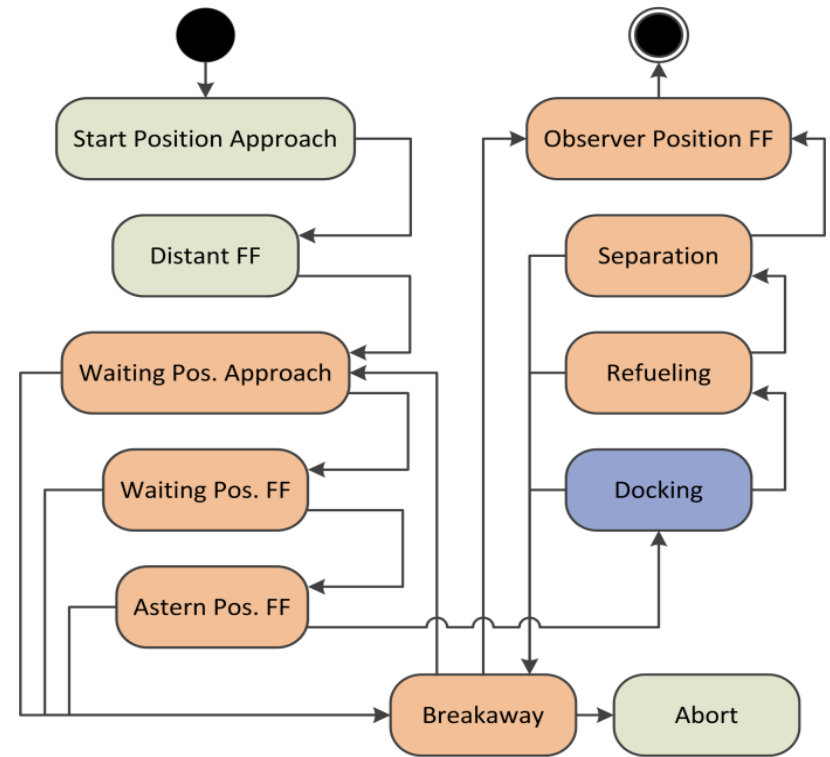




# Simulation Infrastructure: FMTA (T) – FUA (R)



- 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



**Legend:**

FF - Formation Flight  
 Required Data from Sensors and C2-Link:

Low Freq. Tanker Pos. + Vel.	High Freq. Tanker Pos. + Vel.	VHF. Drogue Relative Position
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# 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?**

