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Conceptual design of passenger aircraft for in-flight refueling operations

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Challenge the future

Introduction

- One of the biggest challenges for future aviation is represented by the increasing **cost and scarcity of fossil fuel**.
- The demand of air transportation is steadily increasing, while the constraints on the allowed environmental impact by authorities are getting more stringent
- New designs and operational concepts are required to meet the ambitious challenges devised by ACARE

The RECREATE project

- In the RECREATE (**RE**search on a **CR**uiser **E**nabled **A**ir **T**ransport **E**nvironment) project, European research institutes, universities and small businesses work together to investigate a future air transportation system based on the **cruiser-feeder** concept

- **In Flight Refueling (IFR) operations** for passenger aircraft is actually one of the two main concepts addressed by RECREATE.

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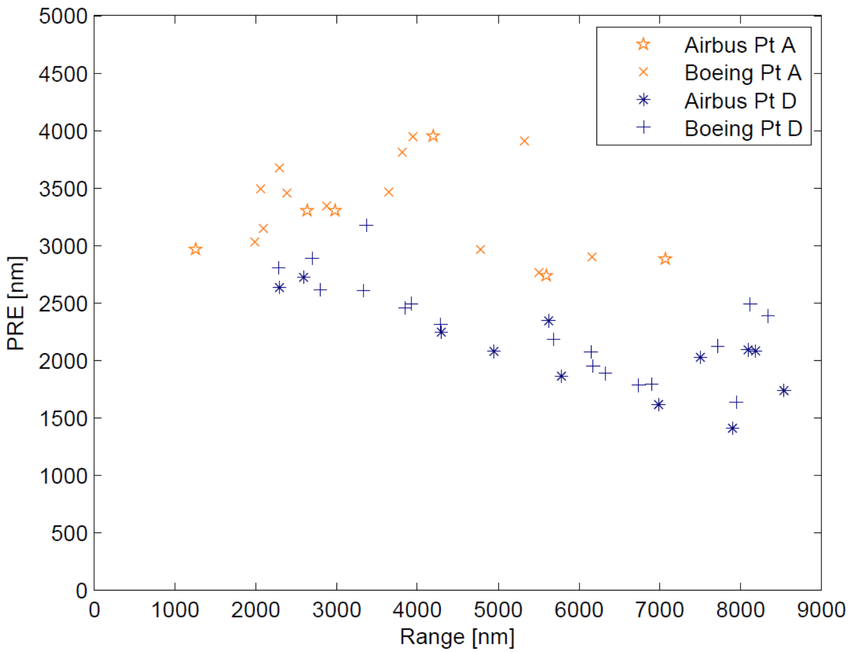
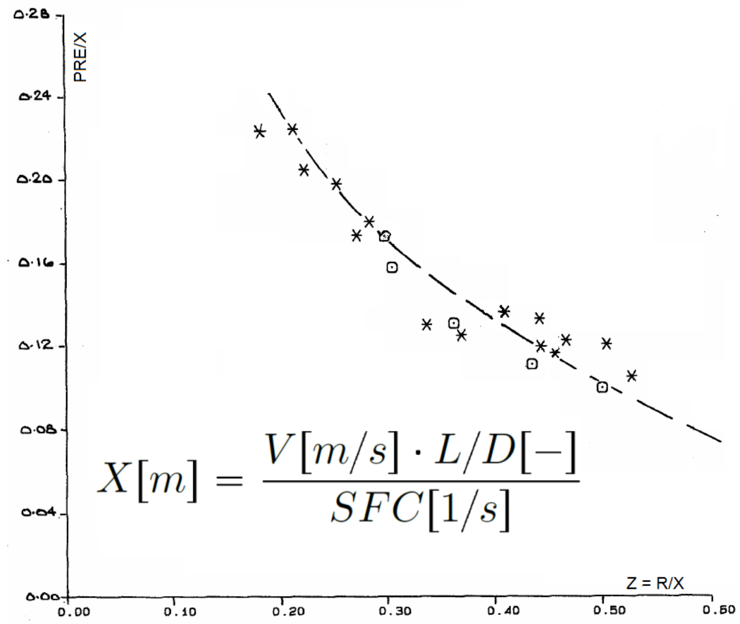
SEVENTH FRAMEWORK PROGRAMME

Payload range efficiency versus range

- The success of staged and IFR flight revolves on the assumption that, flying a mission divided in multiple smaller submissions, yields fuel savings

- Fuel efficiency between aircraft is compared by the **Payload Range Efficiency**: $PRE[m] = \frac{WP[kg] \cdot R[m]}{WFB[kg]}$





Objectives of this work

Although IFR is a time proven concept in military operations, is it possible and convenient to apply as such to passenger air transportation?


KC-135R refuels C-17A

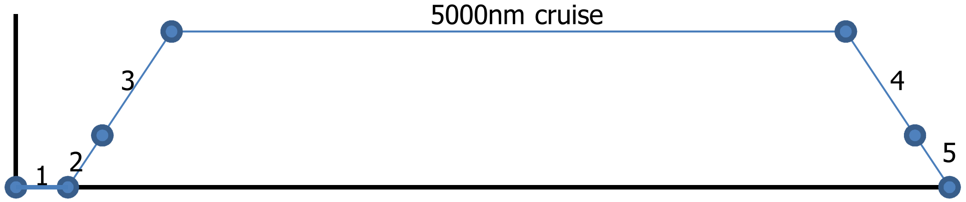
Main goal of this research*

Develop the conceptual design of a passenger aircraft (the cruiser) for IFR operations and compare its fuel consumption to direct and staged flight operation.

*sub-goal of RECREATE

Operation concepts and mission profiles

Direct flight



1 Start & Taxi
2 Take-off
3 Climb
4 Descent
5 Landing

Staged flight

IFR operation

- Rendezvous with tanker
- Change between flight phases

Cruiser Top level requirements

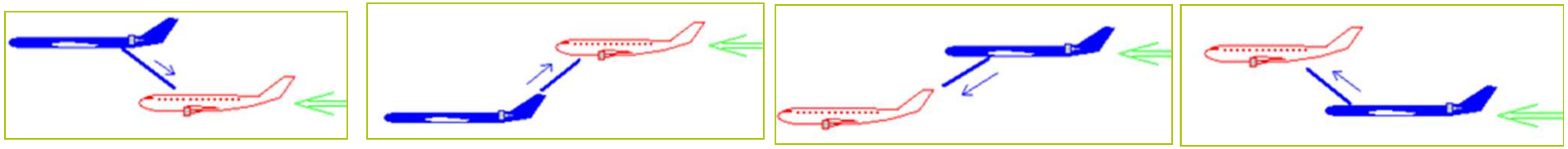
- Use a conventional configuration
- Single stage **range of 2500nm**
- **250 passengers**, single class, twin aisle, LD-3 container capability
- Take-off field length < 2000 m
- Landing field length < 2600 m
- Cruise mach number of 0.82 @ 10500 m
- Specific fuel consumption of 0.525 lb/(lbf·h)

Cruiser-tanker IFR configurations

Is this good if there are passengers here?

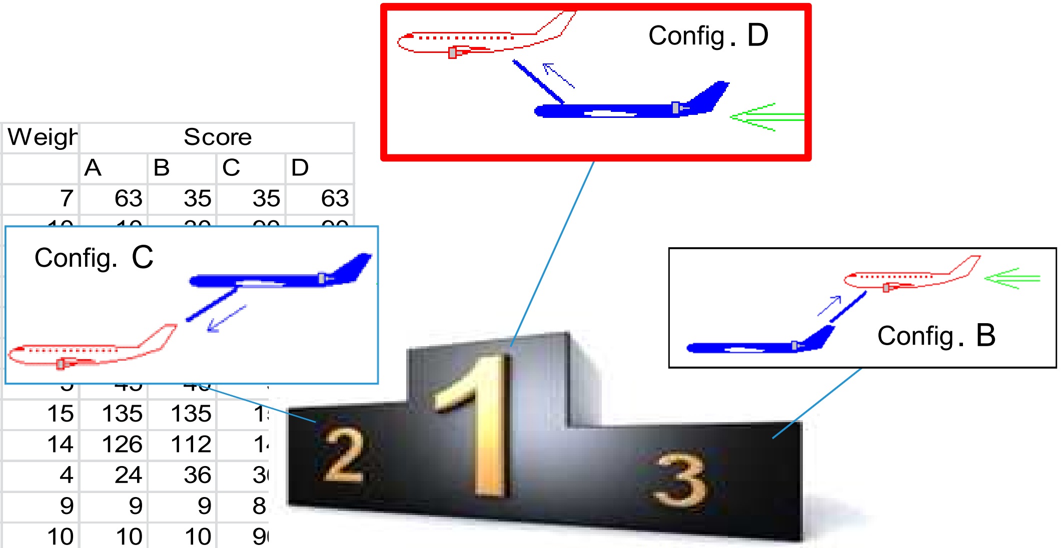
A trade-off is performed to assess possible alternatives and finally to select the most convenient procedure for civil refueling operations

Cruiser-tanker IFR configurations



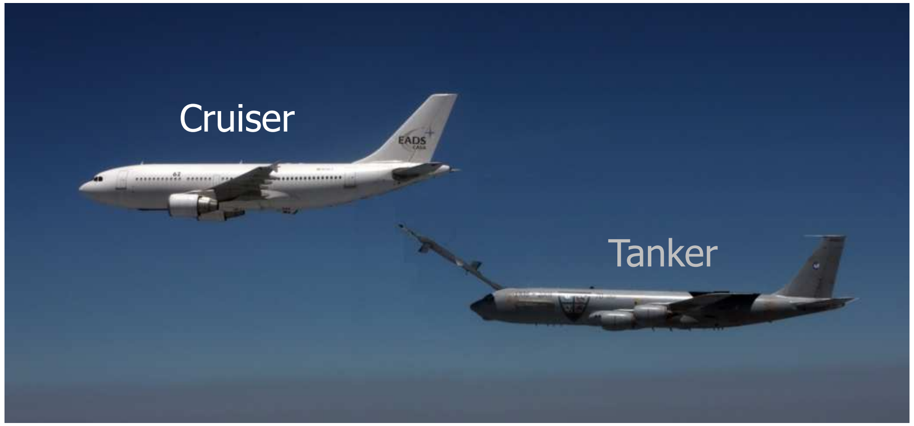
A B C D

Criteria \ Configuration	Grades (1-9) A	B	C	D	Weigh	Score A	B	C	D
c1 Pilot's visibility of approaching aircraft	9	5	5	9	7	63	35	35	63
c2 Component detachment hazard	1	3	9	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
c3 Ride quality of cruiser	1	1	9	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
c4 Noise to the cruiser	1	2	9	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
c5 Pump requirement	9	8	9	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
c6 Fuel pipe fire hazard	5	9	7	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
c7 Boom related weight	9	8	1	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
c8 Boom stability	9	9	1	1	15	135	135	[illegible]	[illegible]
c9 Maturity of boom technology	9	8	1	1	14	126	112	[illegible]	[illegible]
c10 Formation aerodynamics	6	9	9	9	4	24	36	[illegible]	[illegible]
c11 Training cost of approaching aircraft	1	1	9	9	9	9	9	[illegible]	[illegible]
c12 All weather refueling capability	1	1	9	9	10	10	10	[illegible]	[illegible]
TOTAL					100	520	536	584	628



Cruiser-tanker IFR configurations

The trade off winning configuration:



The tanker approaches the cruiser from behind and below

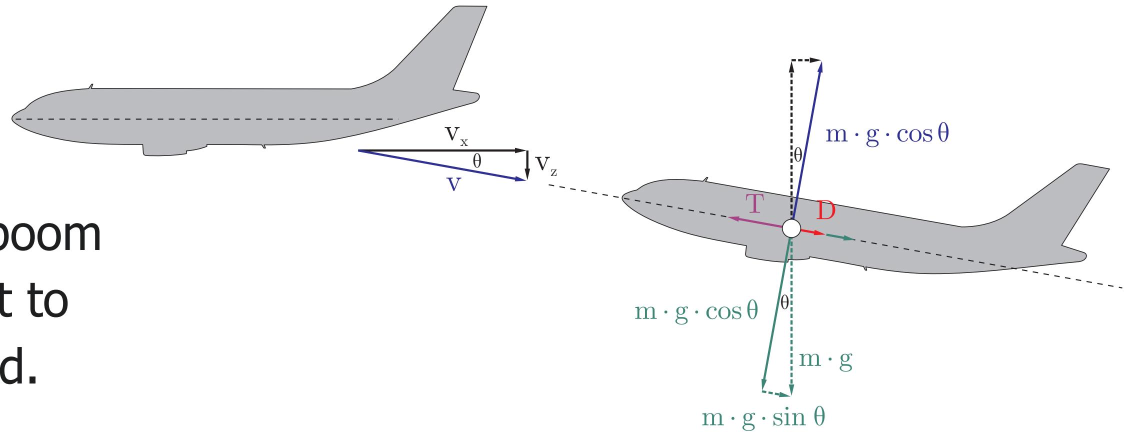
Cruiser-tanker IFR configurations

Advantages

- No hazard of collision with parts detaching from the tanker
- Cruiser pilots are not required to perform the approach maneuver
- Cruiser's architecture minimally affected by the presence of the refueling system.
- Only tanker aircraft to be provided with air-to-air radar
- Passengers not subjected to maneuvering acceleration
- no extra thrust requirement for passenger aircraft during refueling

Disadvantages

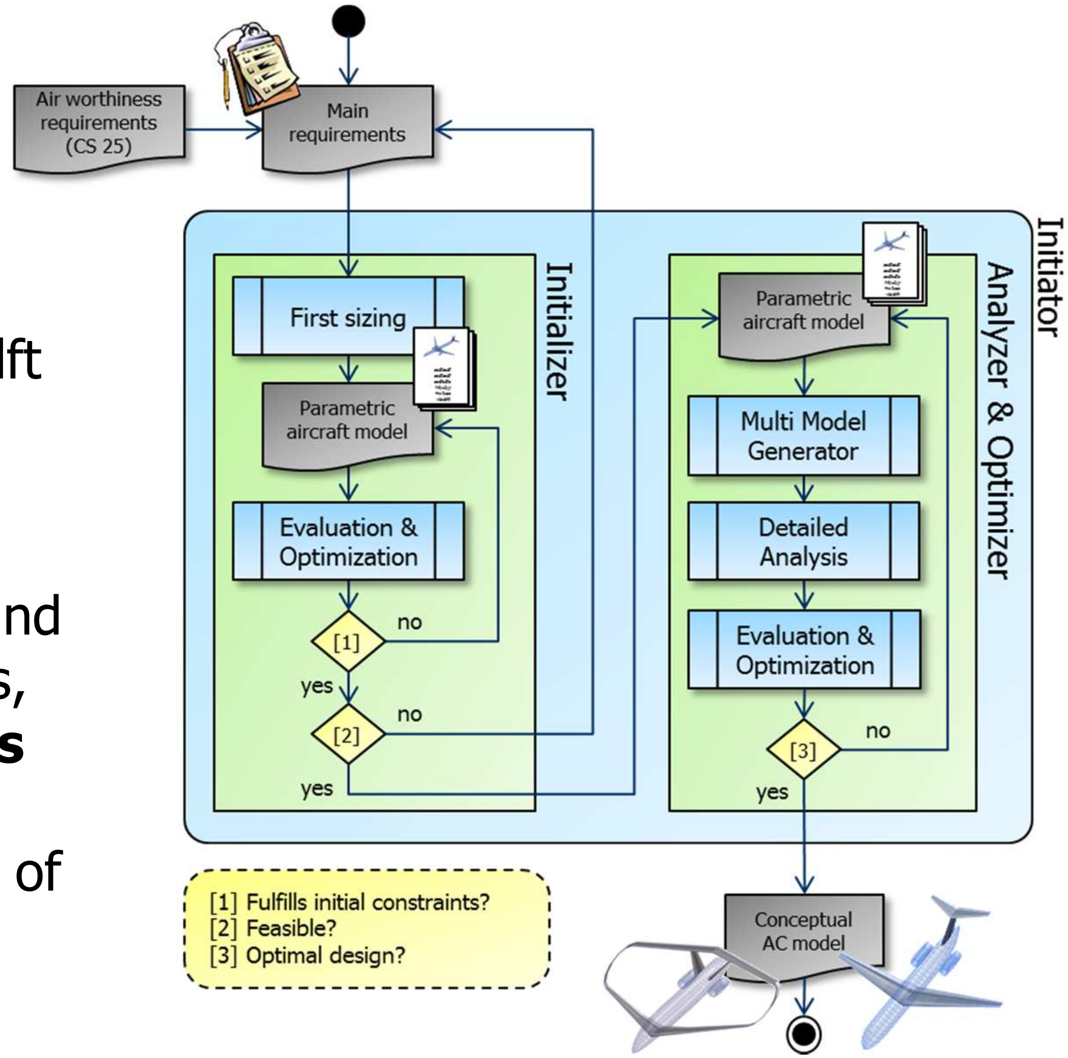
- A forward extending boom (i.e., unstable, subject to divergence) is required.



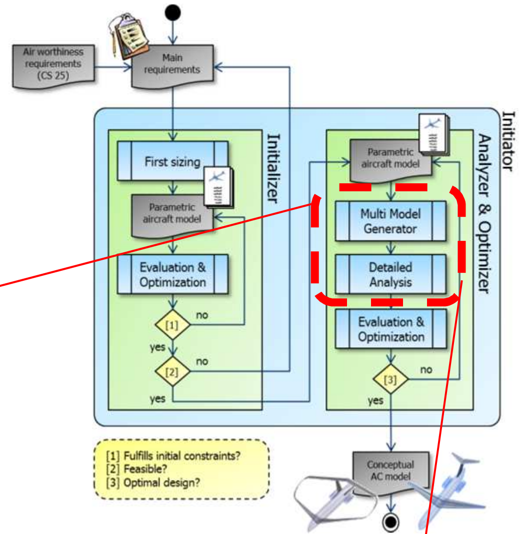
The Initiator

A software tool under development at the TU Delft for **augmented aircraft conceptual design**.

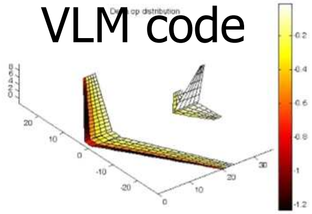
It makes use of statistics and semi-empirical design rules, **medium fidelity analysis tools**, and an optimizer to perform conceptual design of conventional and novel aircraft configurations

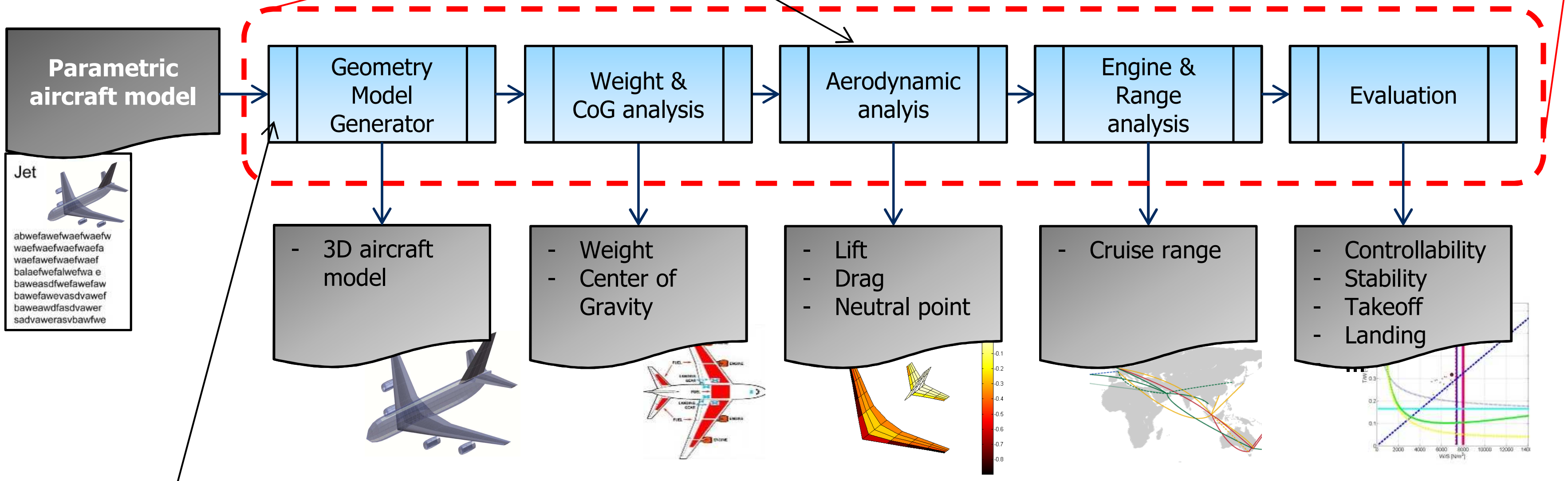


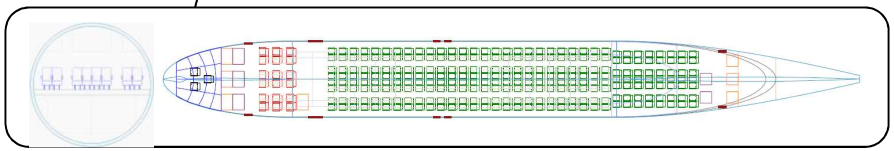
The Initiator



VLM code

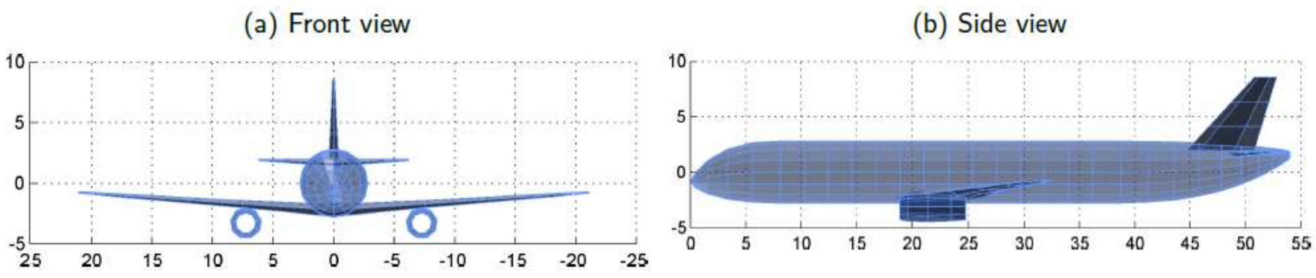


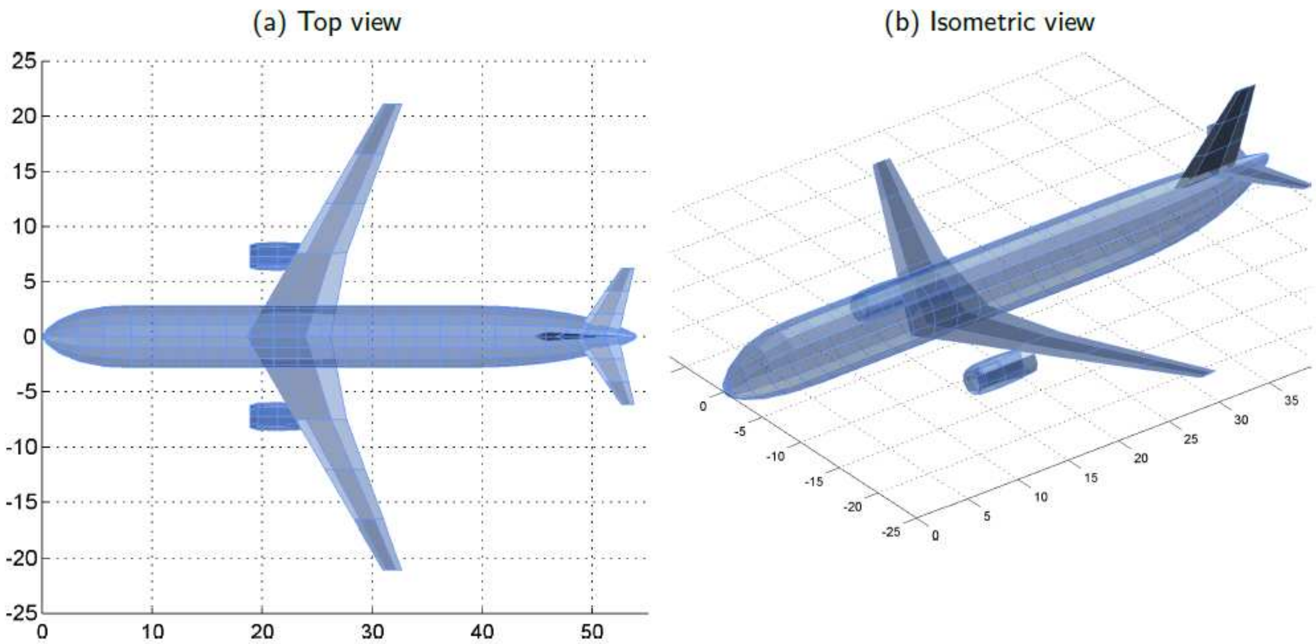




KBE fuselage configurator

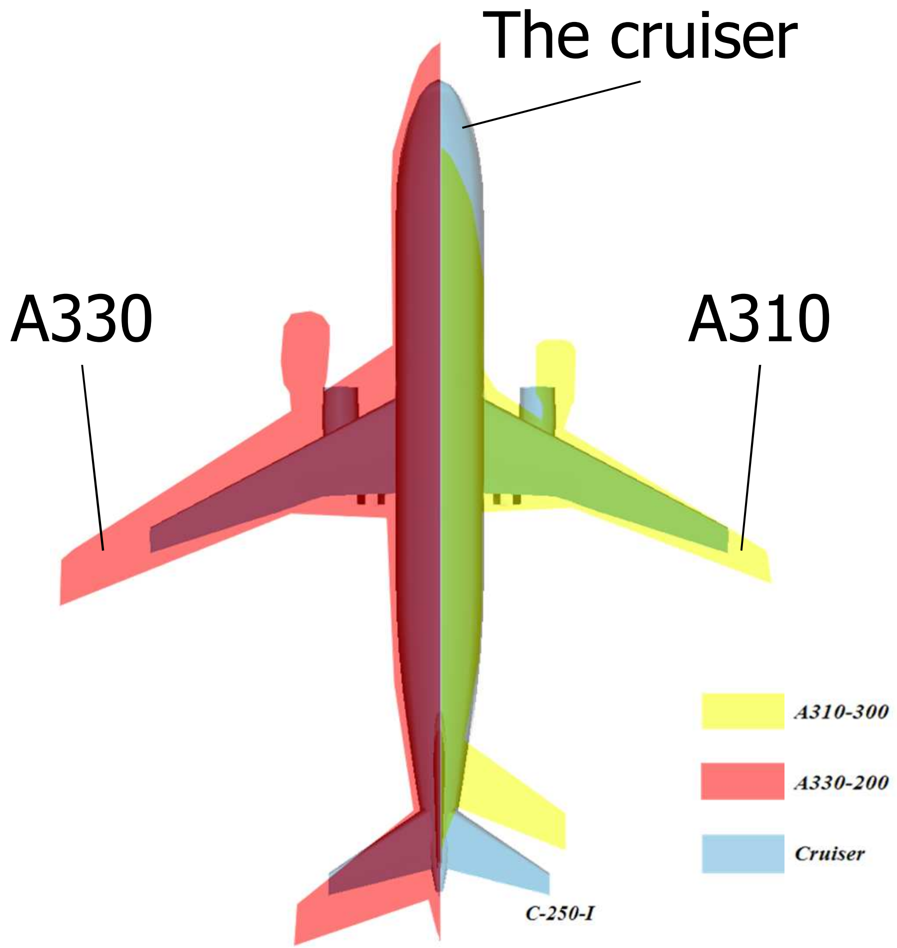
Cruiser design





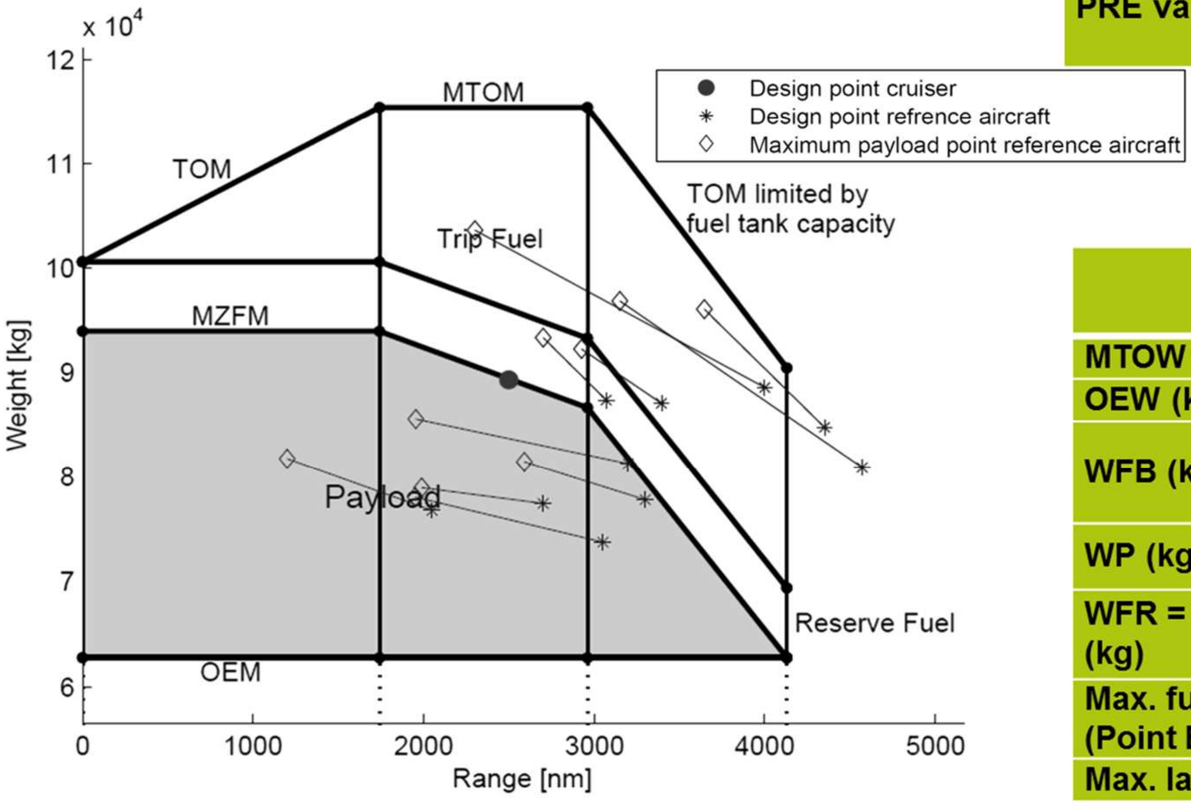
Cruiser design

Fuselage	
Length (m)	54.0
Diameter (m)	5.64
Wing	
Ref Area (m^2)	178.2
Span (m)	42.21
Aspect Ratio	10
Taper Ratio	0. 23
1/4 Chord Sweep (degree)	27.27



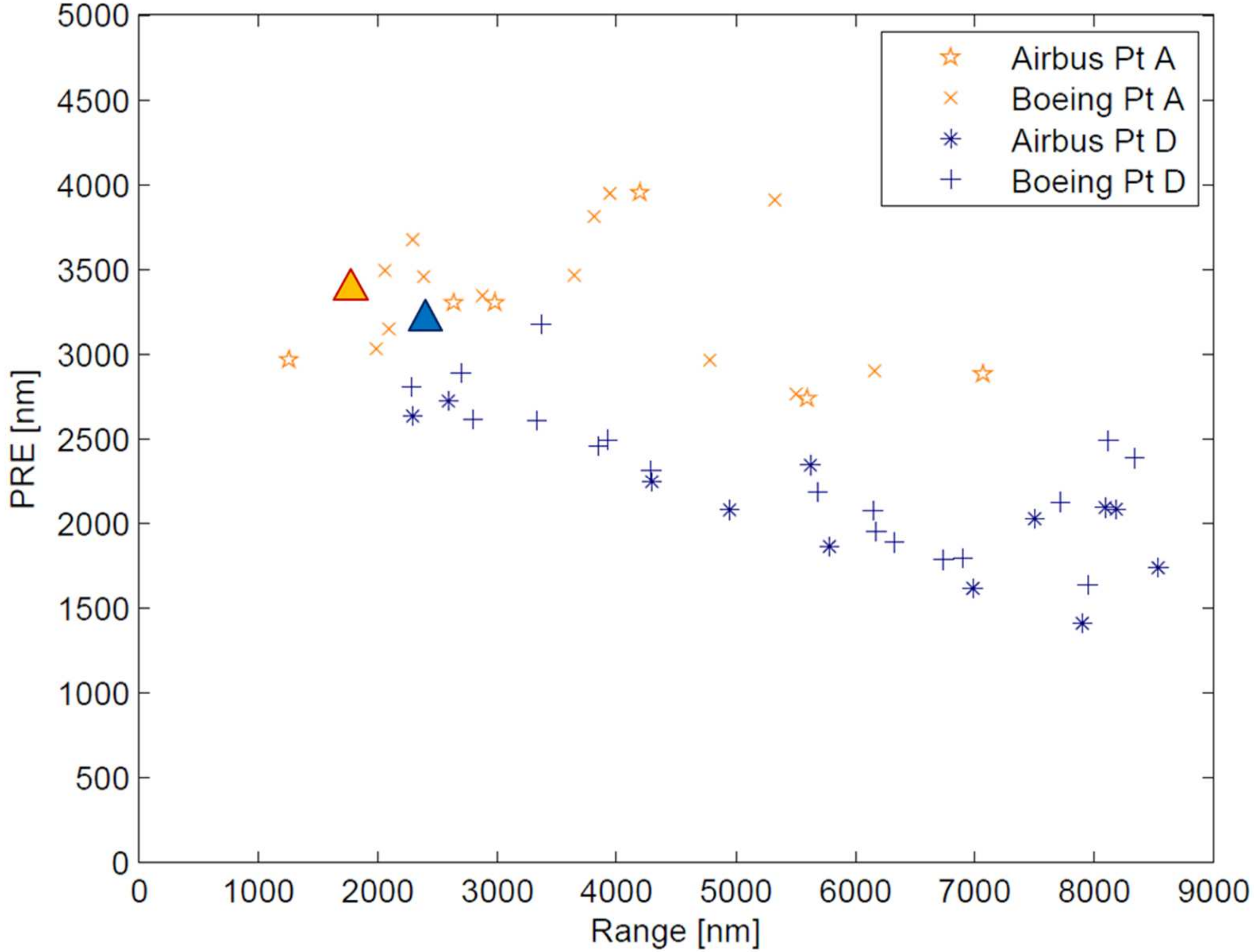
Payload range diagram

Performance			
L/D	17.9		
X	16116 [nm]		
Max. wing loading (kg/m²)	648		
Thrust/Weight Ratio	0.32		
PRE values (nm) @ pts.	A 3341	B 2992	D 3166



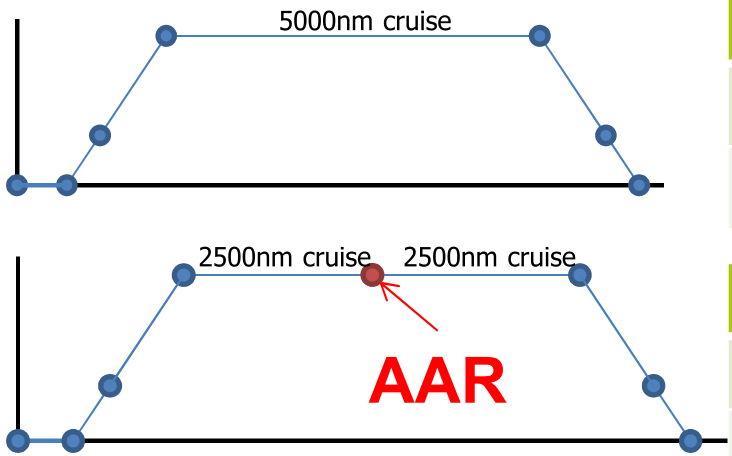
Weights and Weight Ratios			
MTOW (kg)	115396		
OEW (kg)	62774		
WFB (kg) @ pts.	A 16252	B 23578	D 20928
WP (kg) @ pts	31176	23850	26500
WFR = 4.5 % of MTOW (kg)	5192.8		
Max. fuel/MTOW (Point B)	0.25		
Max. landing/MTOW	0.83		

Payload range efficiency (PRE)



TU Delft

Non-stop versus IFR operations

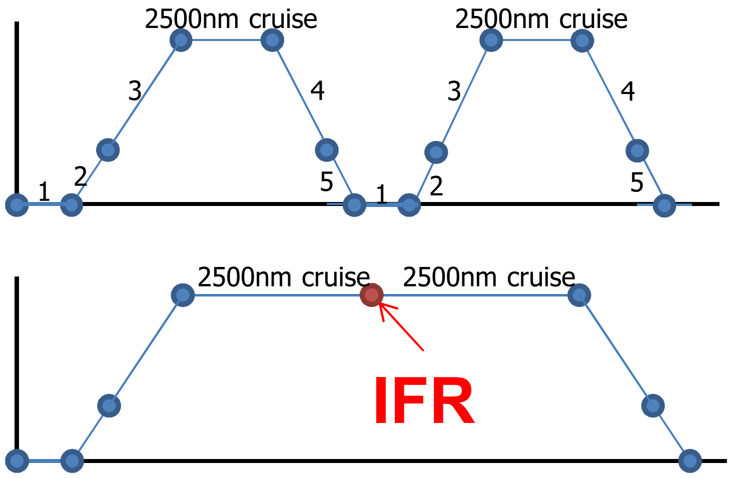


Aircraft	WFB_1 [kg]	WFB_2 [kg]	WFB_T [kg]
Cruiser	18955	18182	37137
5000nm non-stop	-	-	46652

5000nm, IFR vs. Non-stop	
Fuel received by tanker [kg]	16259
Fuel saved by cruiser w.r.t non-stop (tanker fuel not accounted!) [kg]	**9515**
Fuel_saved/Fuel_received	**0.58**

IF the fuel burnt by tanker to deliver the fuel required by cruiser (16259 Kg) < 9515 Kg, **THEN** IFR operation yields fuel saving!

Staged-flight versus IFR operations



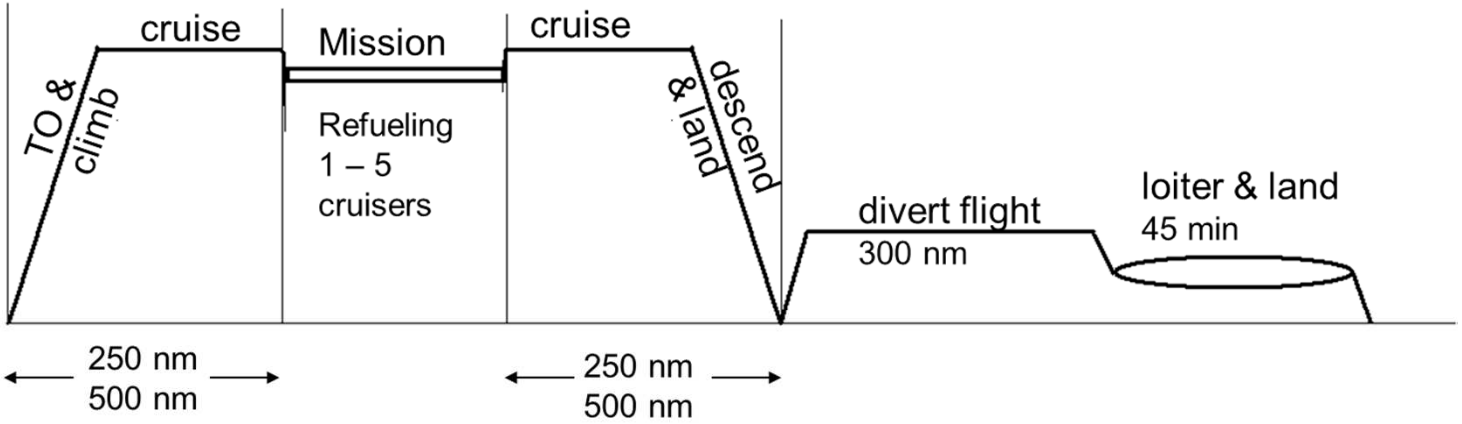
Aircraft	WFB_1 [kg]	WFB_2 [kg]	WFB_T [kg]
In-flight refueling	18955	18182	37137
Staged flight	20928	20928	41856

5000nm, IFR vs. Non-stop	
received fuel for AAR operation [kg]	16259
saved fuel by AAR operation [kg]	**4719**
Fuel_saved/Fuel_received	**0.29**

- In term of flight duration (comfort) and fatigue life, IFR is obviously better than staged-flight
- IFR with small tankers can be more fuel efficient than staged-flight operations

Tanker Design

2 families of tankers designed for **10 specific missions** (radius & no ref. ops.)



Tanker coding:

T-250-3:

Conventional tanker

Design refueling radius: 250nm

Refueling num. of cruisers: 3

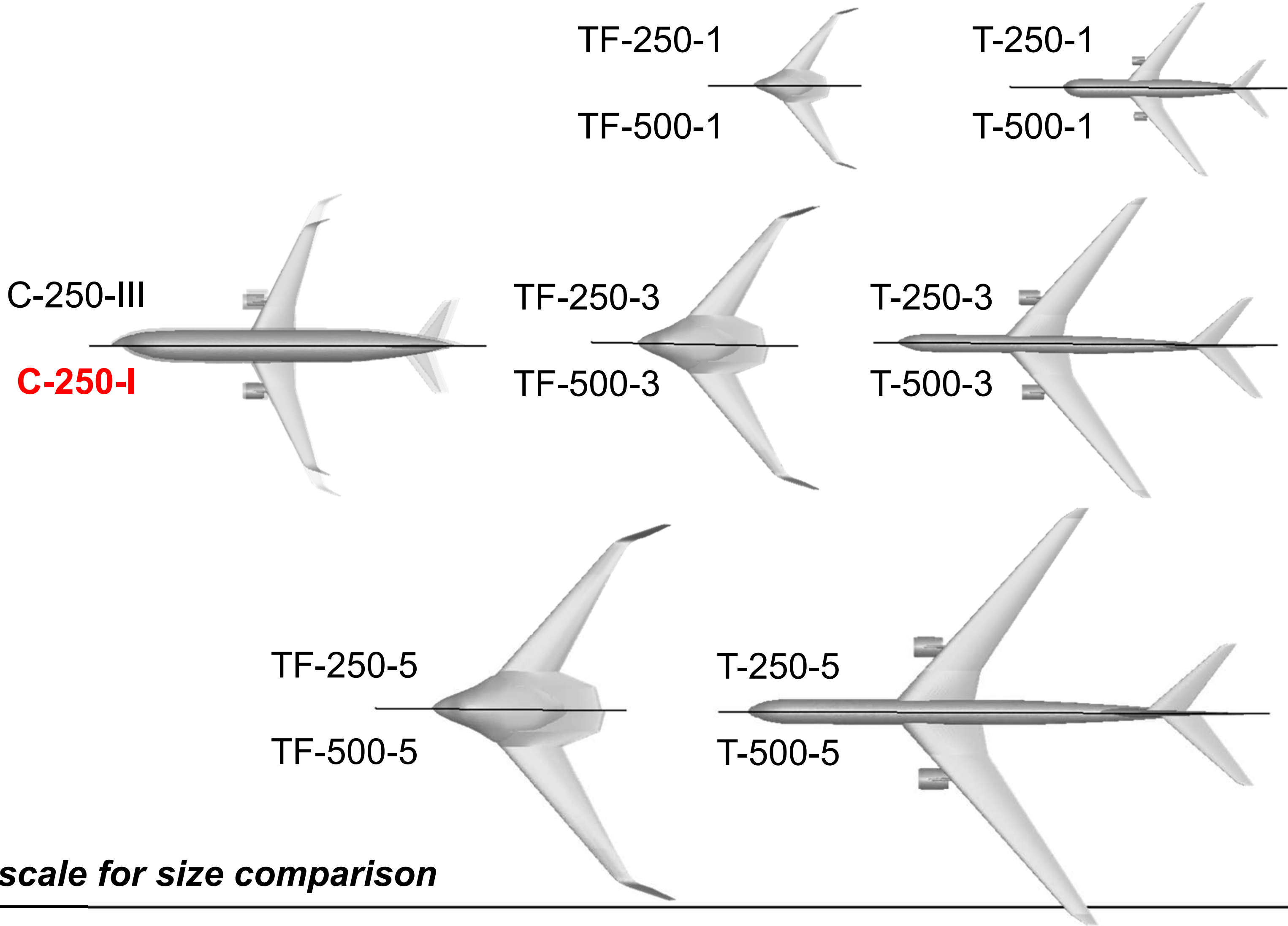
TF-500-5:

Flying-wing tanker

Design refueling radius: 500nm

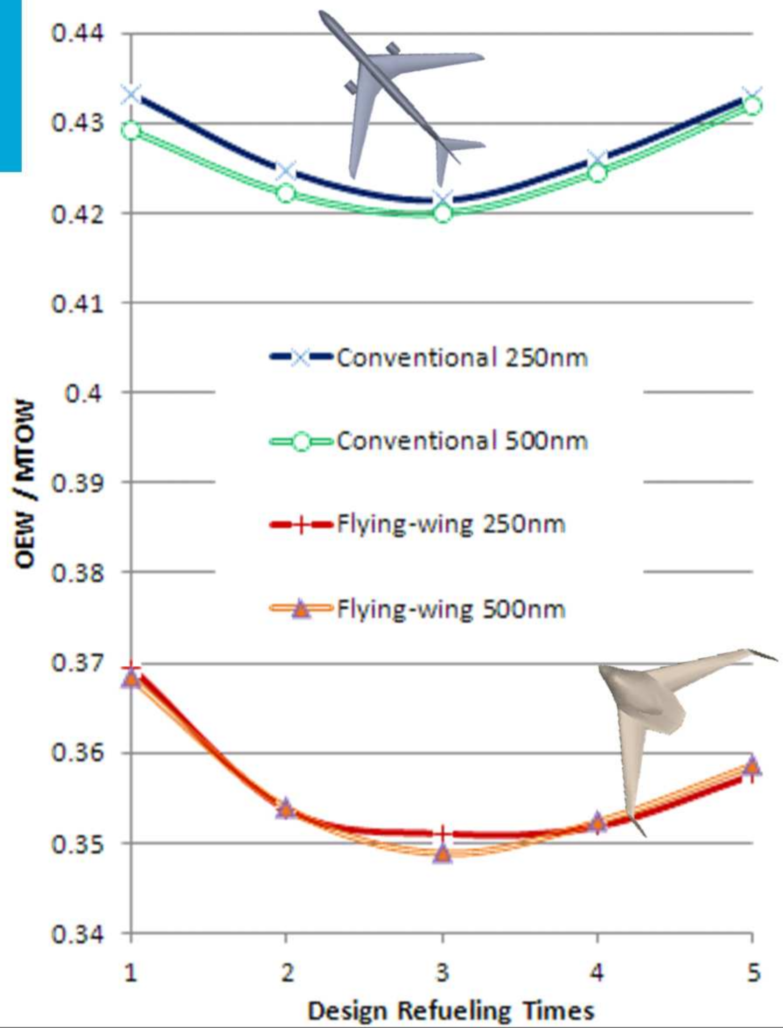
Refueling num. of cruisers: 5

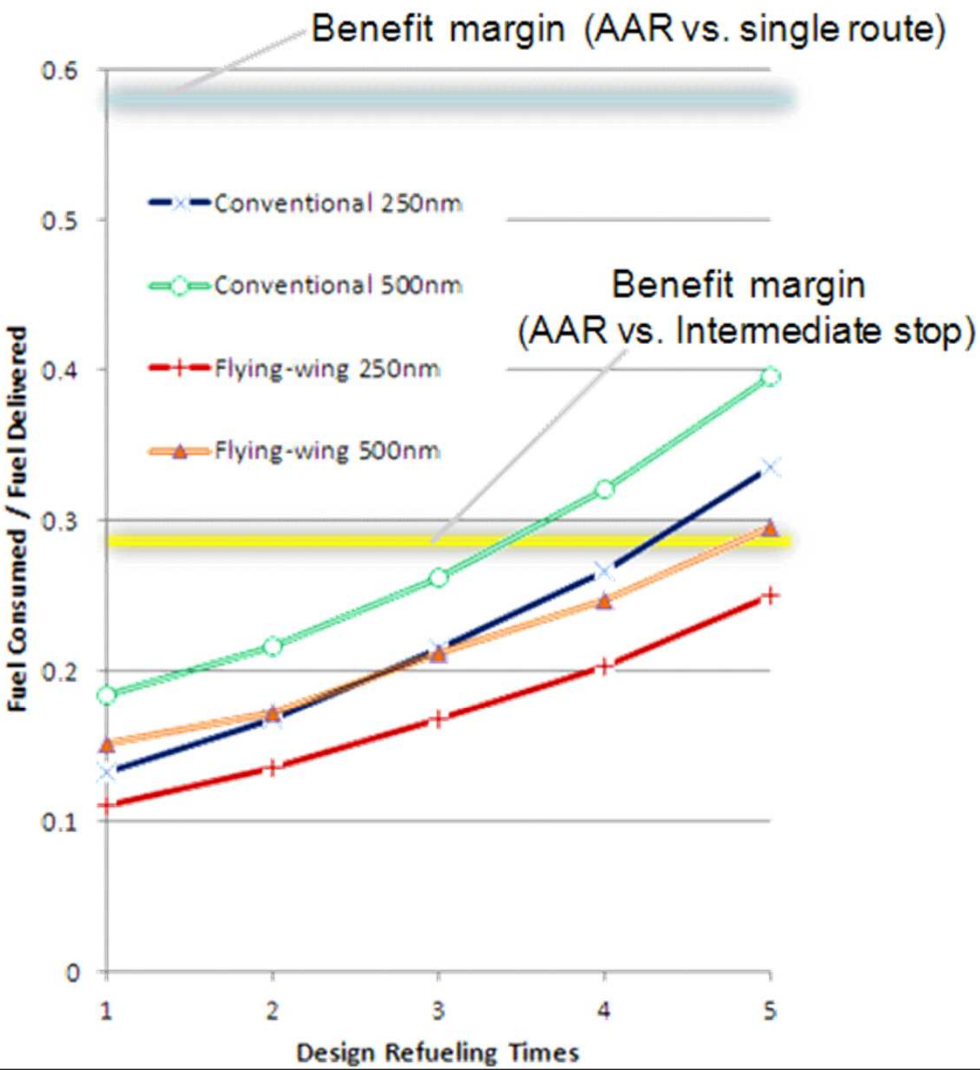
Tankers family



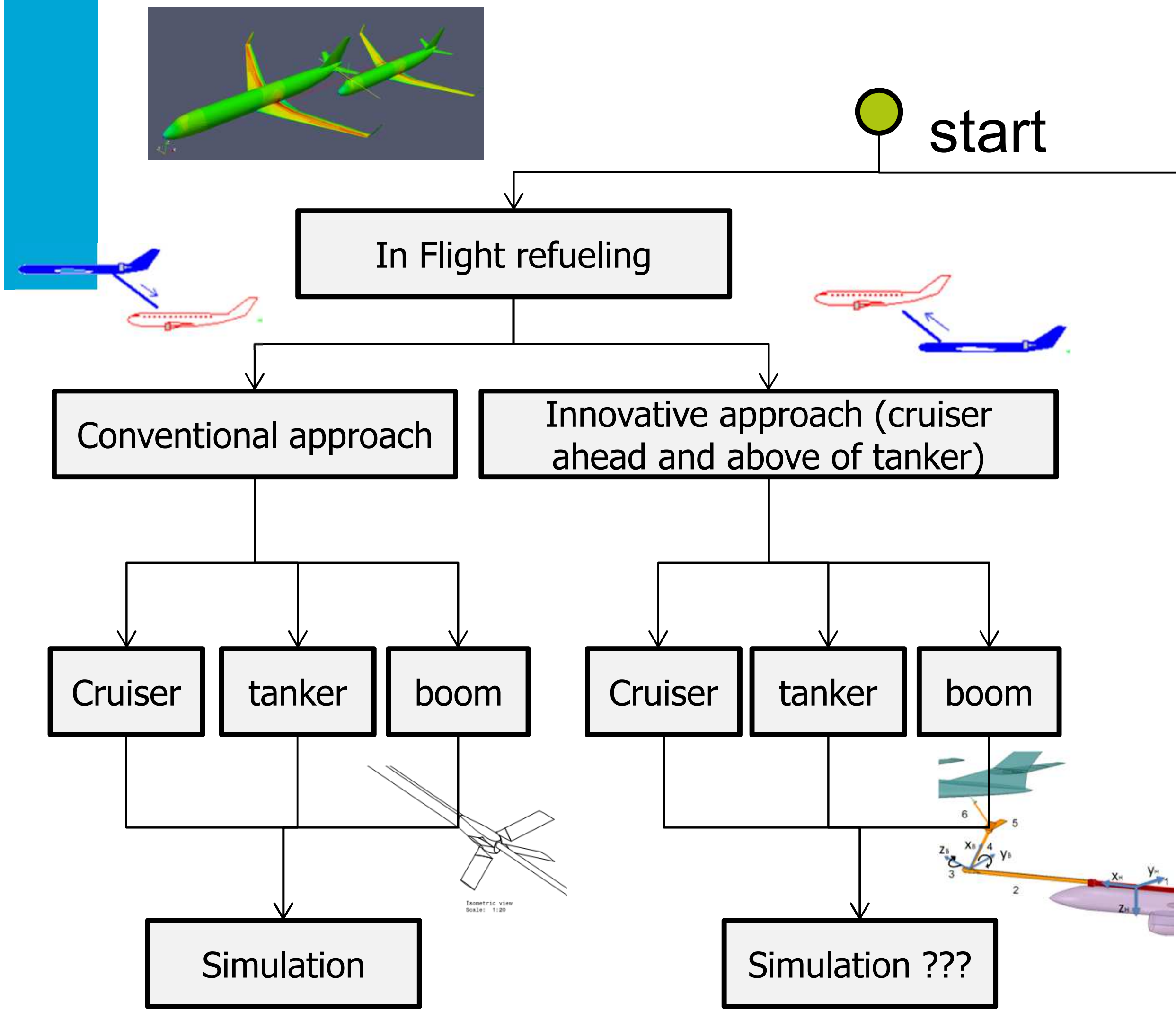
Aircraft to scale for size comparison

IFR benefit – Flying Wing VS Conventional tankers





The RECREATE design agenda



See next presentation:
Feasibility study of a nuclear propelled blended wing body aircraft for the cruiser/feeder concept

The research leading to the results presented in this paper was carried within the project RECREATE (REsearch on a CRuiser Enabled Air Transport Environment) and has received funding from the European Union Seventh Framework Programme under grant agreement no. 284741.