Conceptual design of a passenger aircraft for aerial refueling operations.

Comparison with direct and staging flight

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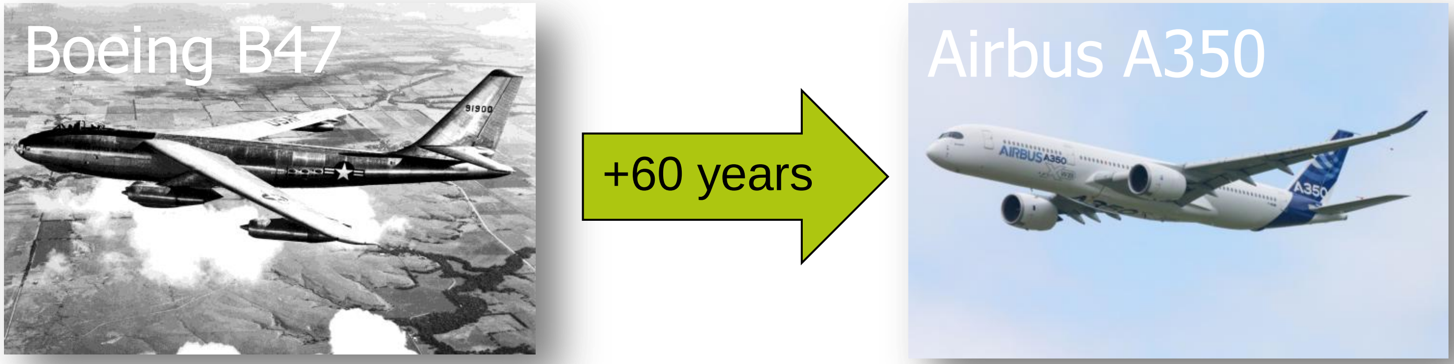
Introduction

- 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 environmental constraints are getting more stringent.
- New designs **AND** operational concepts are required to meet the ambitious challenges set by ACARE.



The FP7 project RECREATE

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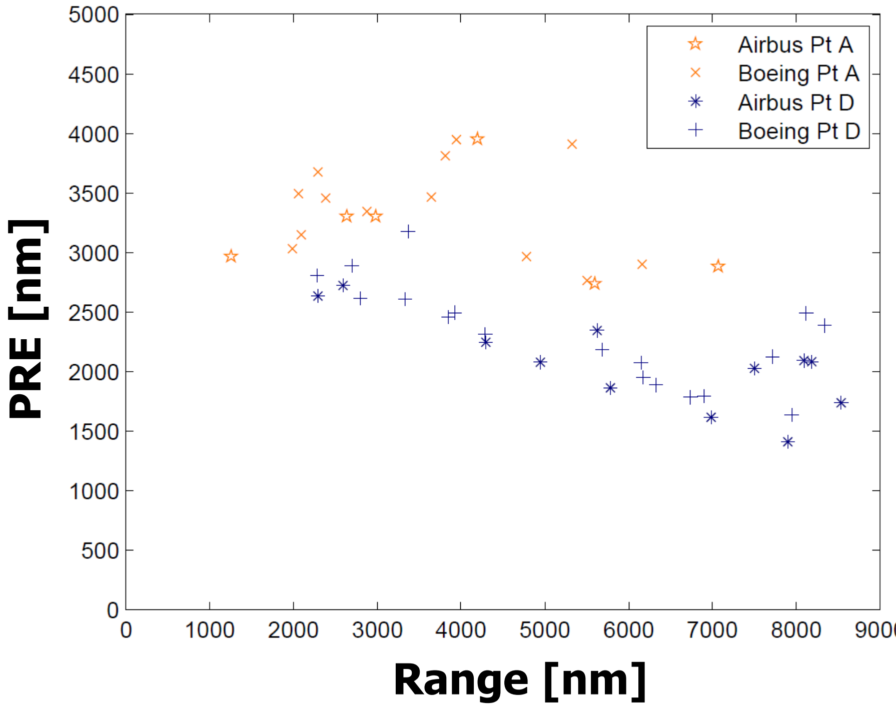
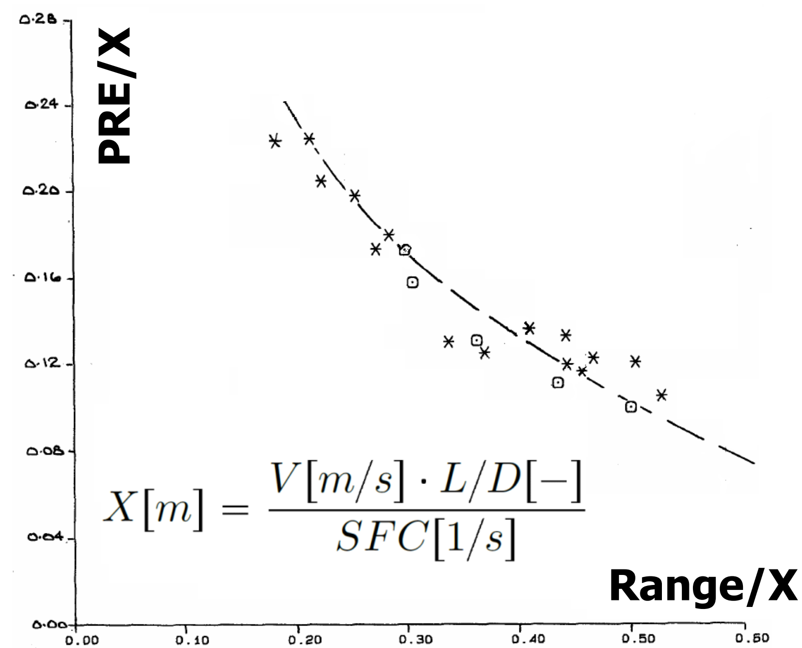
- In the RECREATE (**RE**search on a **CR**uiser **E**nabled **A**ir **T**ransport **E**nvironment) project, European research institutes, universities and small businesses work together to investigate a future air transportation system based on the **cruiser-feeder** concept.
- **Air-to-Air Refueling (AAR) operations** for passenger aircraft is one of the addressed concepts.

Payload Range Efficiency vs. Range

- Splitting a flying mission into multiple smaller submissions, either using **staging flight** or **AAR**, yields fuel savings. Less fuel is burnt to transport fuel.
- Fuel efficiency of different aircraft can be compared using the **Payload Range Efficiency (PRE)**: $\Rightarrow$ $PRE[m] = \dfrac{WP[kg] \cdot R[m]}{WFB[kg]}$





Objectives of this research work

AAR is a proven concept in military operations, however...

- *Is it possible to adopt this operational approach for passenger aircraft operations?*

- *Is it necessary to design a new aircraft or would it be possible to achieve fuel savings also using existing aircraft for AAR operations?*

- *How much fuel can be saved by implementing the AAR operational approach w.r.t. direct and staging flight?*

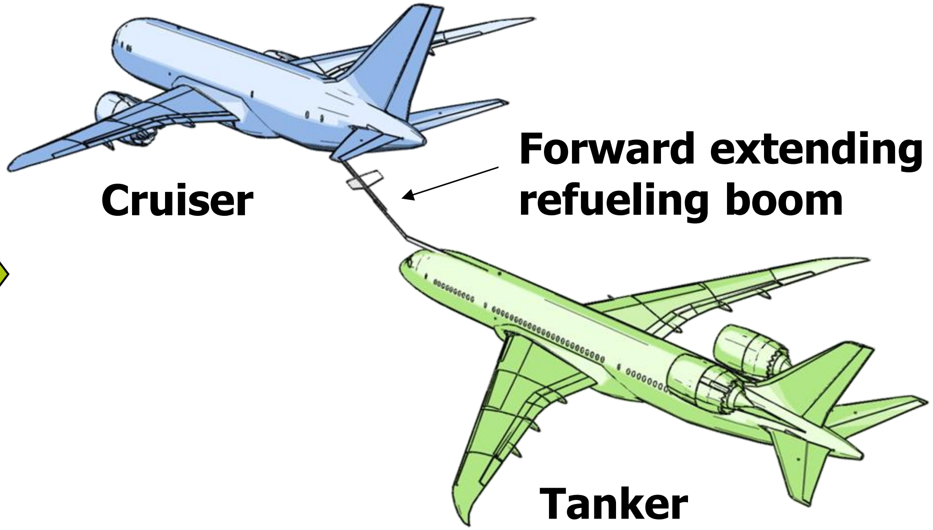
Cruiser Top level requirements

Payload	• 250 Pax at 106kg incl. luggage • No extra freight, cargo hold sized for LD3 containers
Total range	9260km (5000nm)
Number of refueling	1 @ ≈ 2500nm (half mission)
Cruise conditions	M0.82 @ 10668m altitude (35000ft)
Refueling conditions	M0,82 @ 8000m altitude
Engine technology	SFC = 0.525Kg/N·h
Cabin Comfort	Twin aisle, single class Seat pitch 85cm; Seat width 48cm; Aisle width 50cm
TO & Landing performance	2500m BFL according to CS
Climbing gradient	According to CS
Climbing rate	348m/min (OEI)
Fuel reservation	250 nm to alternate airport + 30 min loiter +5%

Cruiser-tanker configuration during AAR

Is this the most convenient AAR configuration when 250 passengers are sitting on board of the refueled aircraft?

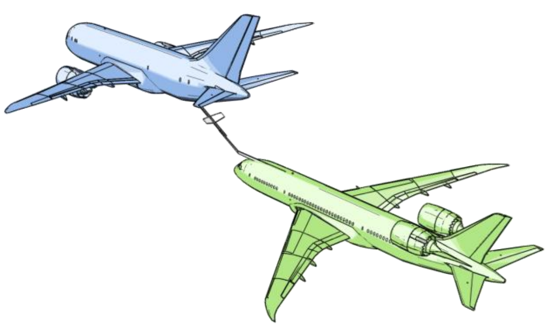
This was the selected configuration

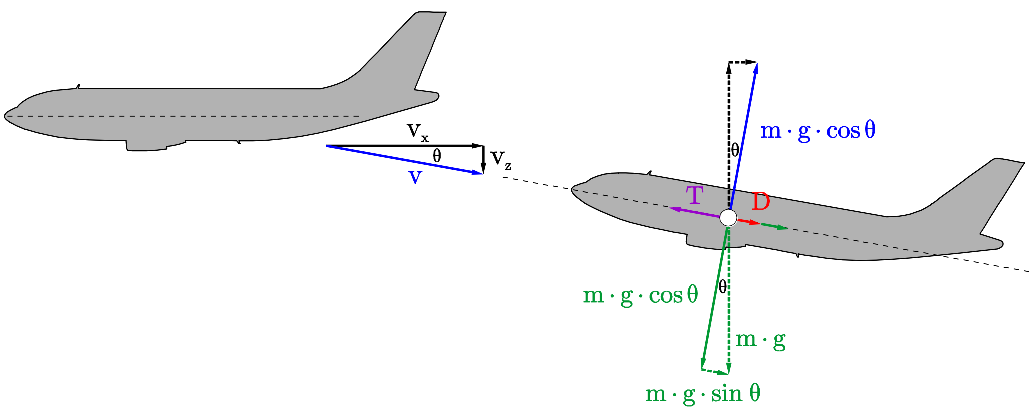


Cruiser-tanker configuration during AAR

Advantages

- No hazard of collision with parts detaching from the tanker
- Cruiser pilots are not required to perform the approach maneuver
- 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
- Cruiser's architecture and payload volume minimally affected by the presence of the refueling system (boom on tanker).

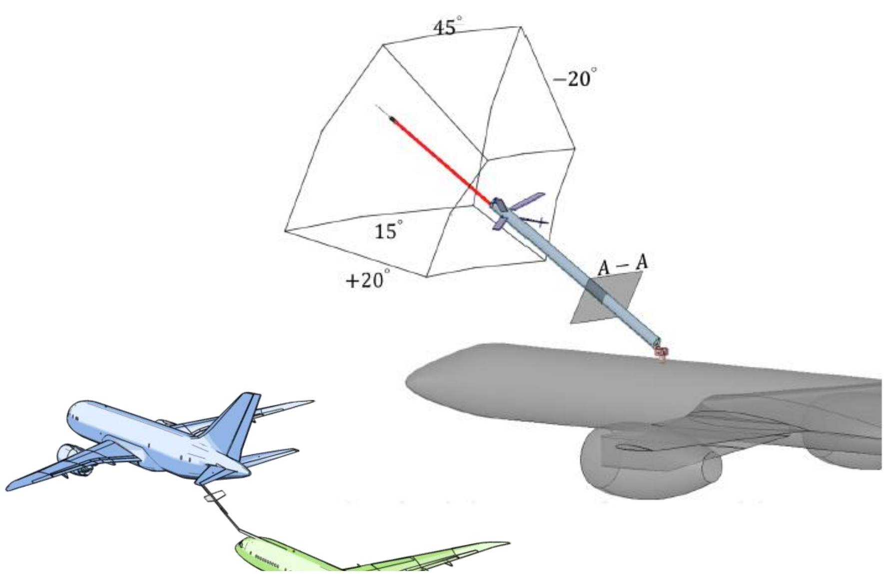


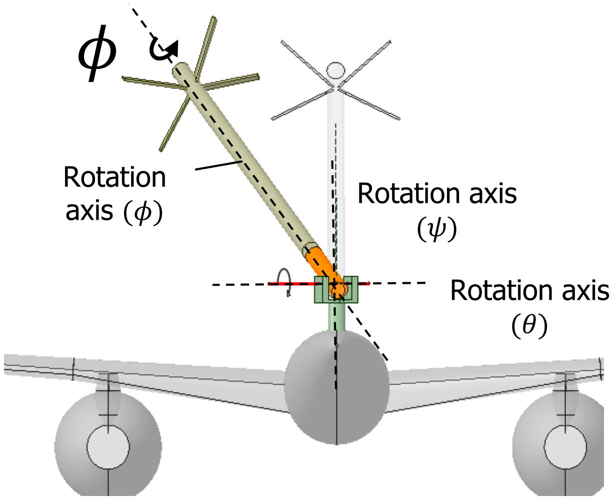


Cruiser-tanker configuration during AAR

Disadvantages

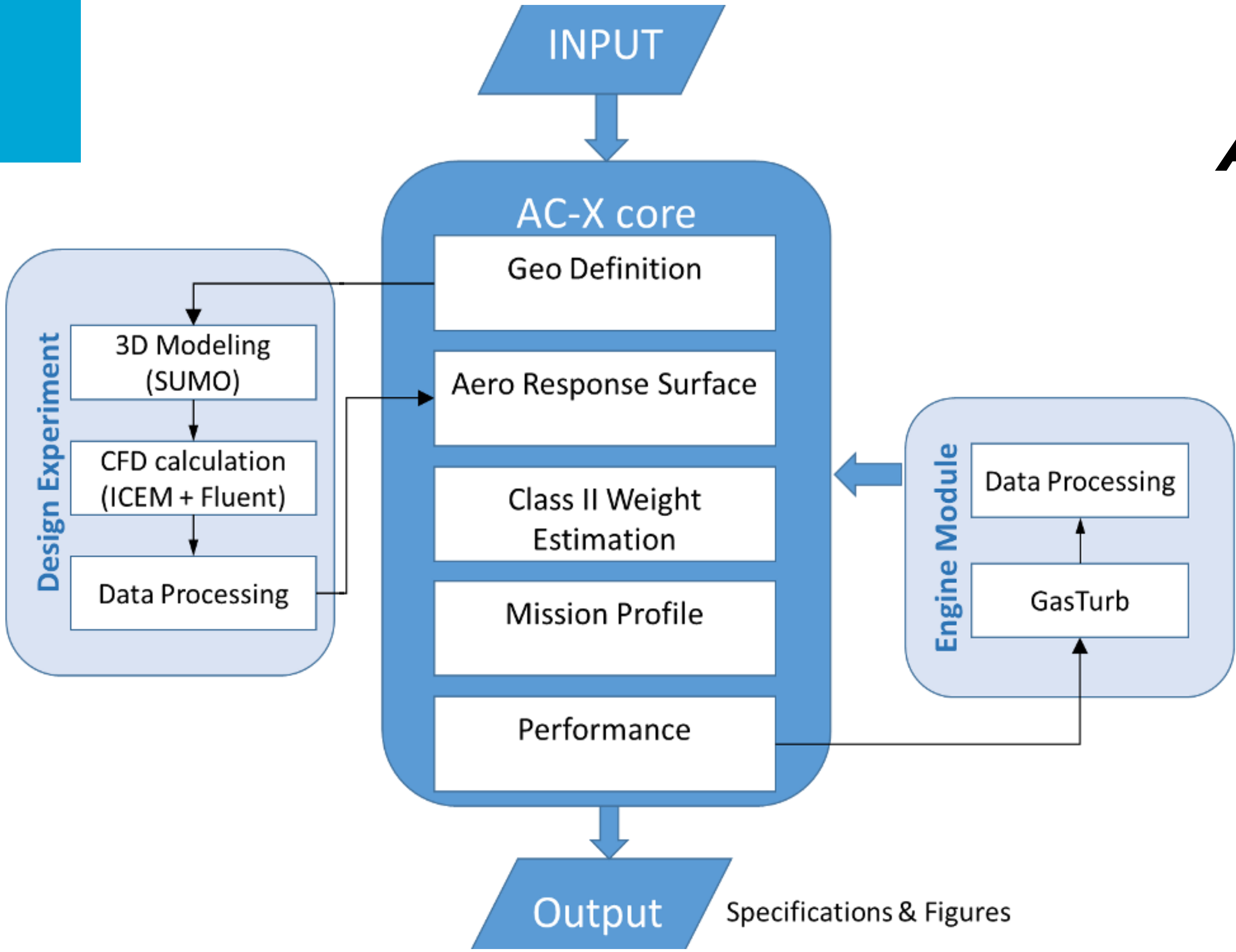
- Gravity force cannot be used to transfer fuel. A pump is required.
- An unconventional forward extending boom is required, able to extend against wing and gravity (i.e., unstable, subject to divergence)





Proposed solution in: Timmerman, H.S. and La Rocca, G. *Feasibility study of a forward extending flying boom for passenger aircraft aerial refueling*. in: RAS Applied Aerodynamics Conference 2014, Bristol, 2014.

Design tool (*AC-X*) development

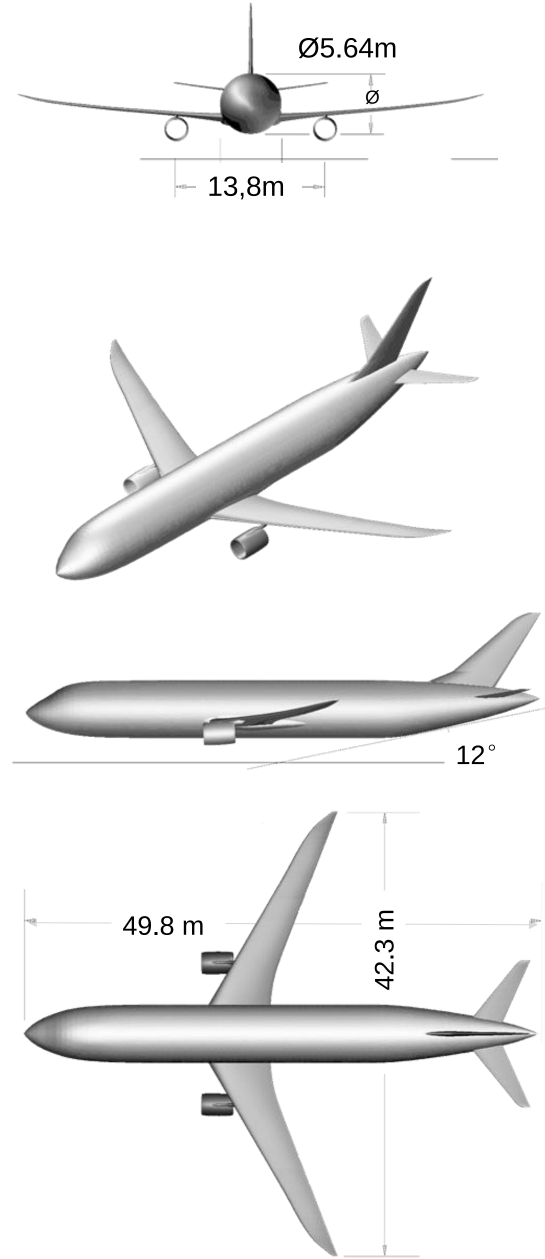


AC-X main features

- Largely Excel based
- Usable for both Cruiser and Tanker
- Allows complex missions definition
- Aerodynamic analysis based of response surfaces from CFD analysis (FLUENT)
- Allows engine design (GASTURB)
- Allows plenty of user interaction

Design of the cruiser

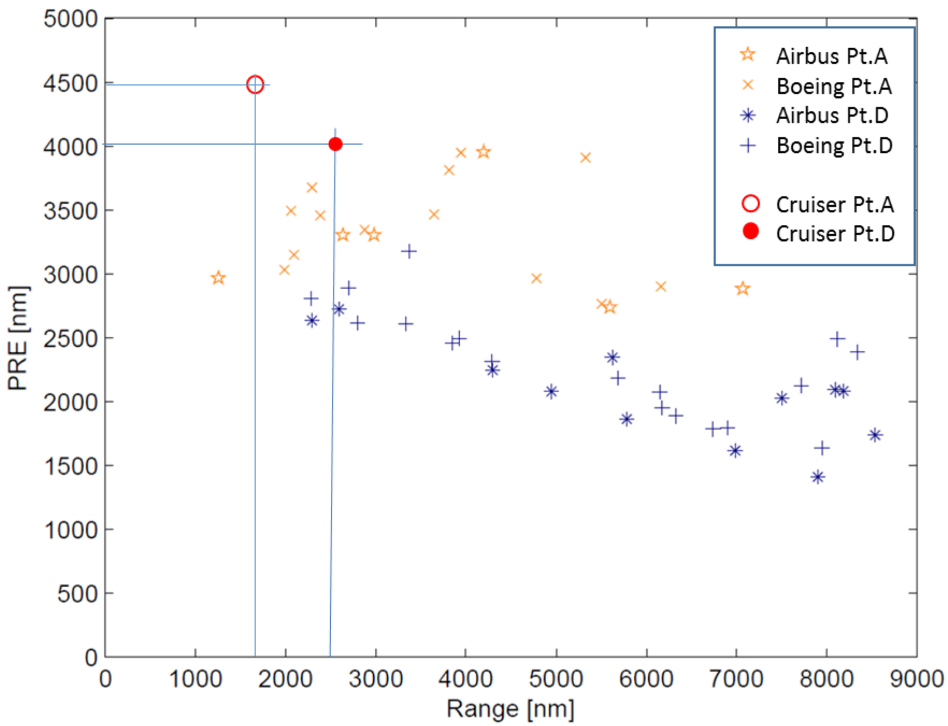
OEW [kg]	52,589
MTOW [kg]	100,865
OEW / MTOW	0.52
Total mission fuel weight [kg]	32,929
Fuel received via AAR [kg]	14,505
Fuel reservation [kg] (250nm diversion+30 minutes loitering+5%	3,352
T/MTOW	0.3
Wing Area [m²]	164
Span [m]	42.4
Aspect Ratio	11
Cruise L/D	16.2
PRE [nm]	4,024
X [nm]	14,409
PRE/X	0,279

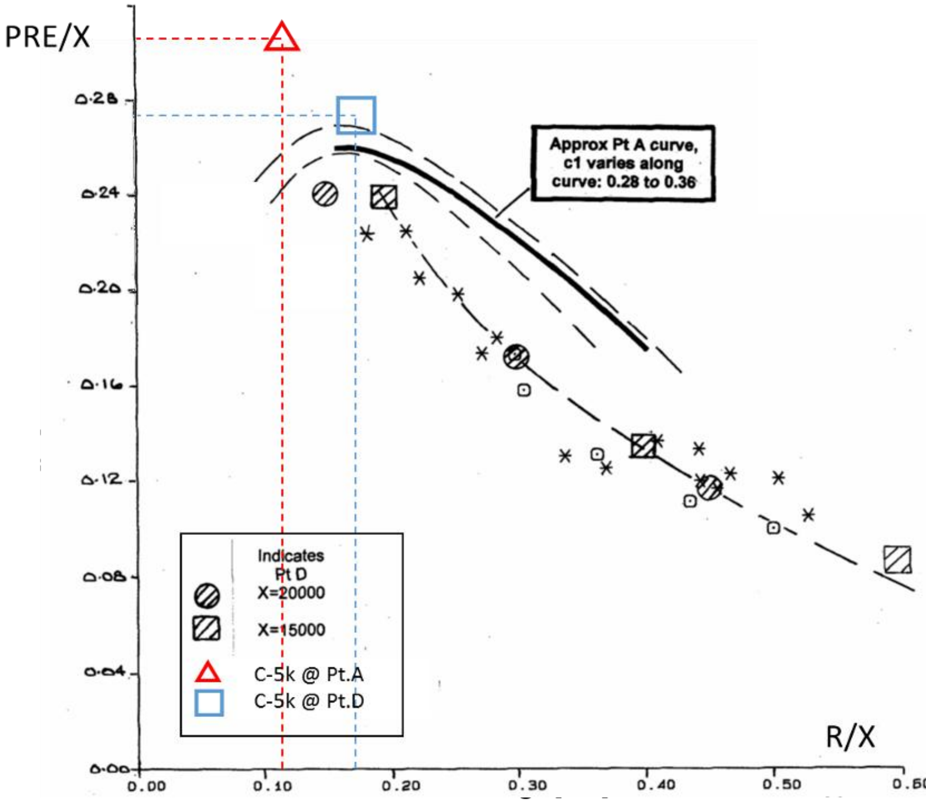


Design of the cruiser

$$PRE[m] = \frac{WP[kg] \cdot R[m]}{WFB[kg]}$$

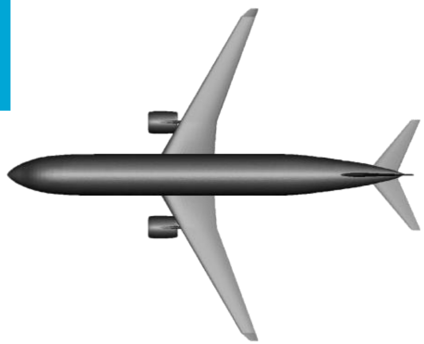
$$X[m] = \frac{V[m/s] \cdot L/D[-]}{SFC[1/s]}$$



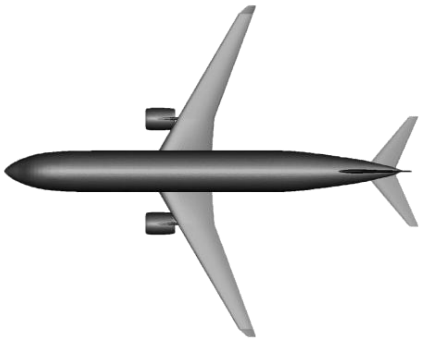


How does the AAR cruiser compare with respect to direct and staging flight?

Comparison of AAR with Staging and Direct flight

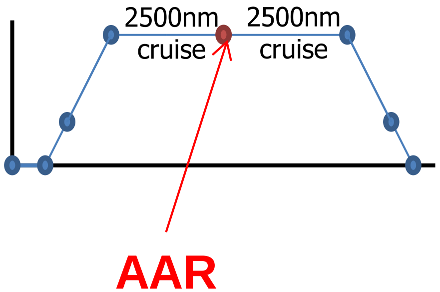


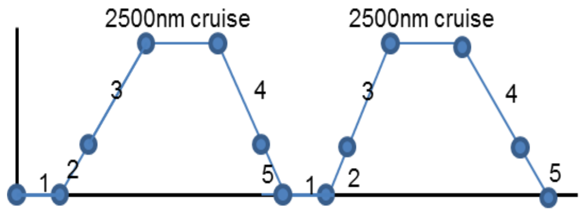
AAR cruiser ***C-5k***
5000nm with AAR

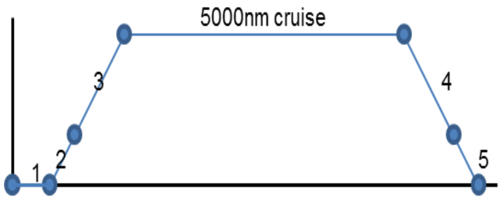


I-2.5k
Intermediate stops
2500nm range

D-5k
Direct flight variant
5000nm range

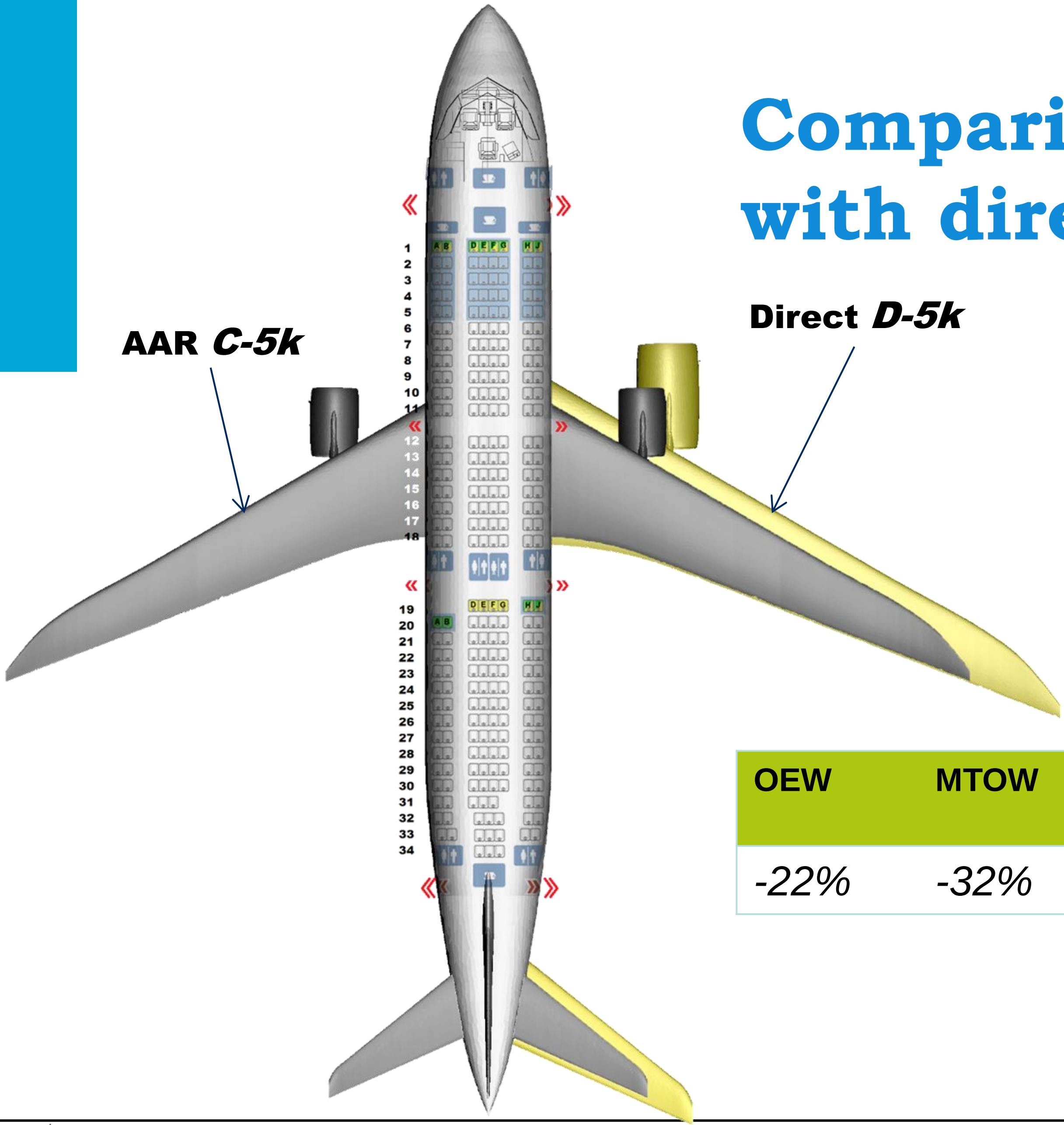






All aircraft designed with same tool

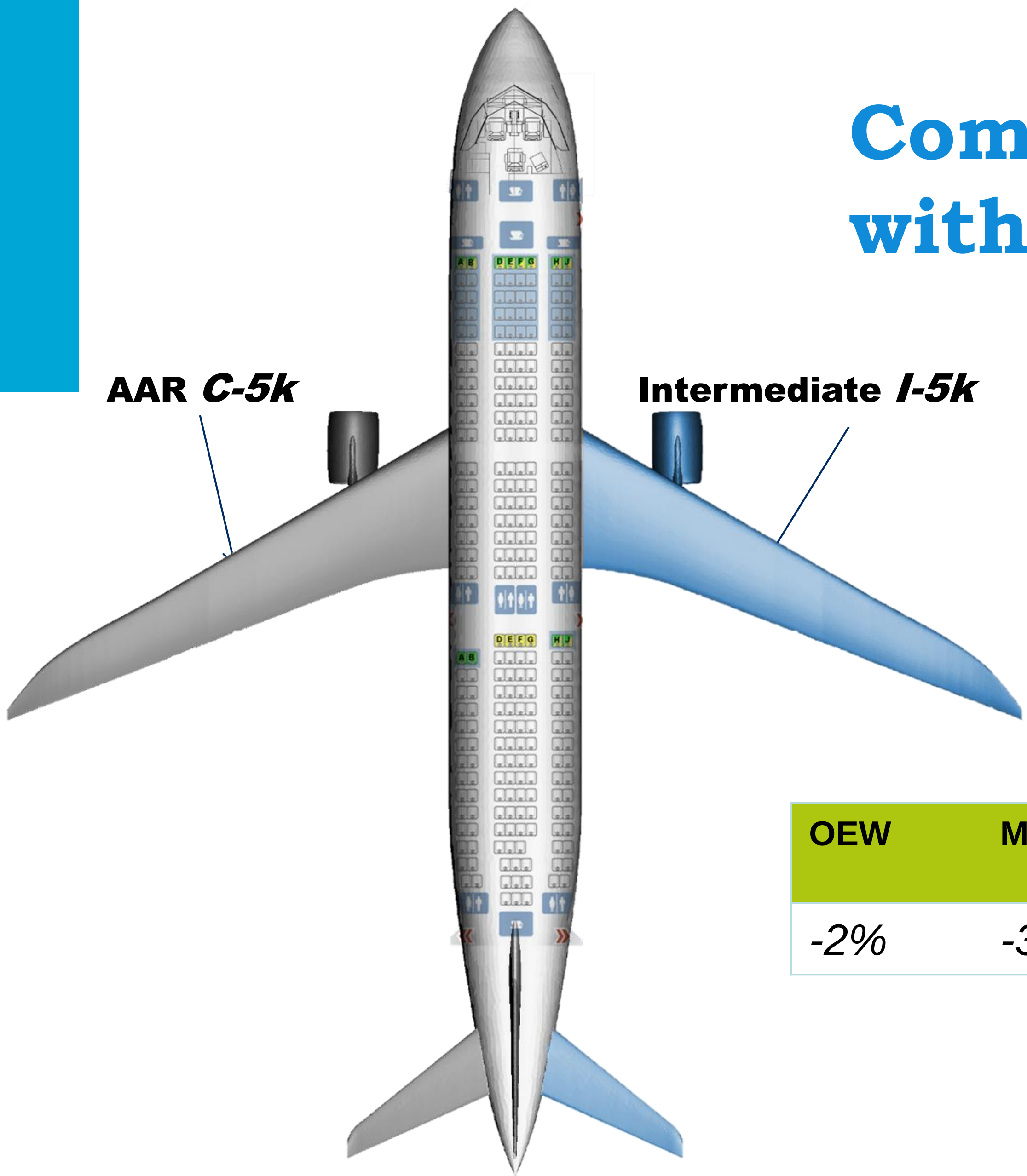
Comparison of AAR with direct flight



AAR vs Direct Flight
(Cruiser only, excluding the tanker)

OEW	MTOW	Mission Fuel	Engine Thrust	Wing Area
-22%	*-32%*	***-20%***	*-32%*	*-31%*

Comparison of AAR with staging flight



AAR vs Staging Flight
(Cruiser only, excluding the tanker)

OEW	MTOW	Mission Fuel	Engine Thrust	Wing Area
-2%	-3%	**-7%**	-4%	-4%

What about implementing the AAR operational approach with existing passenger airplanes?

Comparison of the Cruiser with existing aircraft when used for AAR

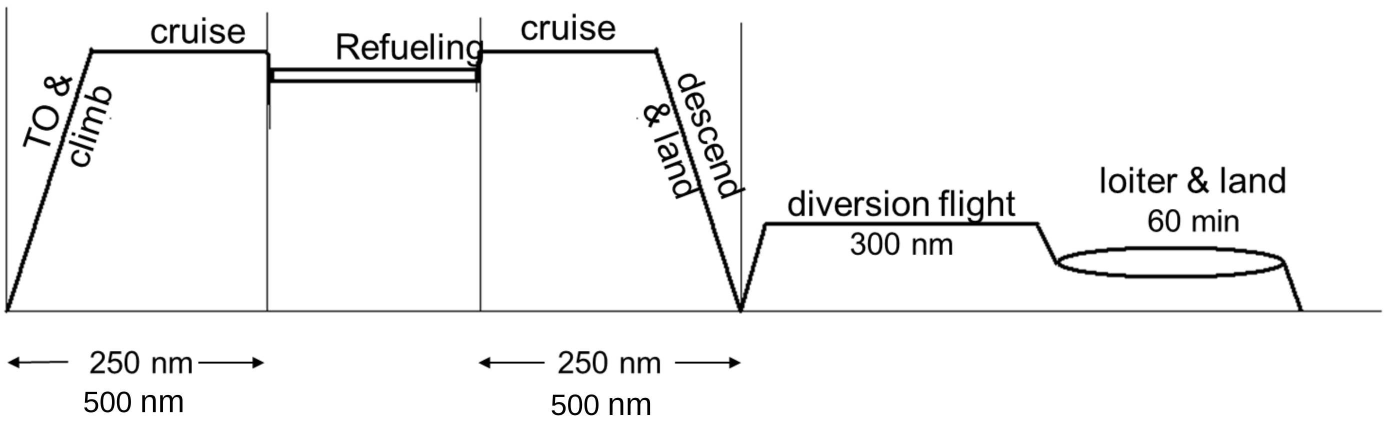
Cruiser vs B737-800 & B767-300 (same **5,000nm AAR** mission)

	Cruiser	B737-800*	Δ	B767-300**	Δ
MTOW [kg]	**100,865**	75,477	-25.1%	147,985	46.7%
OEW [kg]	**52,589**	38,624	-26.5%	79,028	50.3%
Payload [kg]	**26,500**	18,587	-29.9%	25,017	-5.6%
Pax	**250**	186	-25.6%	260	4.0%
Seat Pitch [m]	**.85**	.76	-10.4%	.80	-5.9%
Mission fuel [kg]	**32,929**	28,201	-14.3%	51,140	55.3%
PRE [nm]	**4,024**	3,297	**-18.1%**	2,446	**-39.2%**
PRE/X	**0,279**	0,267	**-4,2%**	0,187	**-33%**

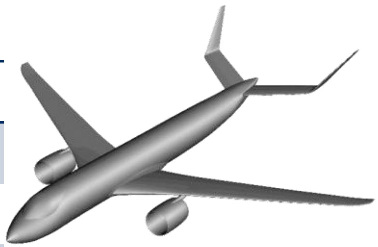
*B737-800 similar design range **B767-300 similar passenger capacity

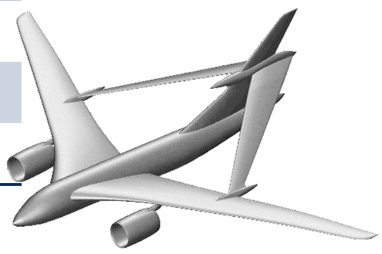
What is the overall fuel saving yielded by AAR operations, when accounting for the fuel burnt by the tanker?

Design of the tanker

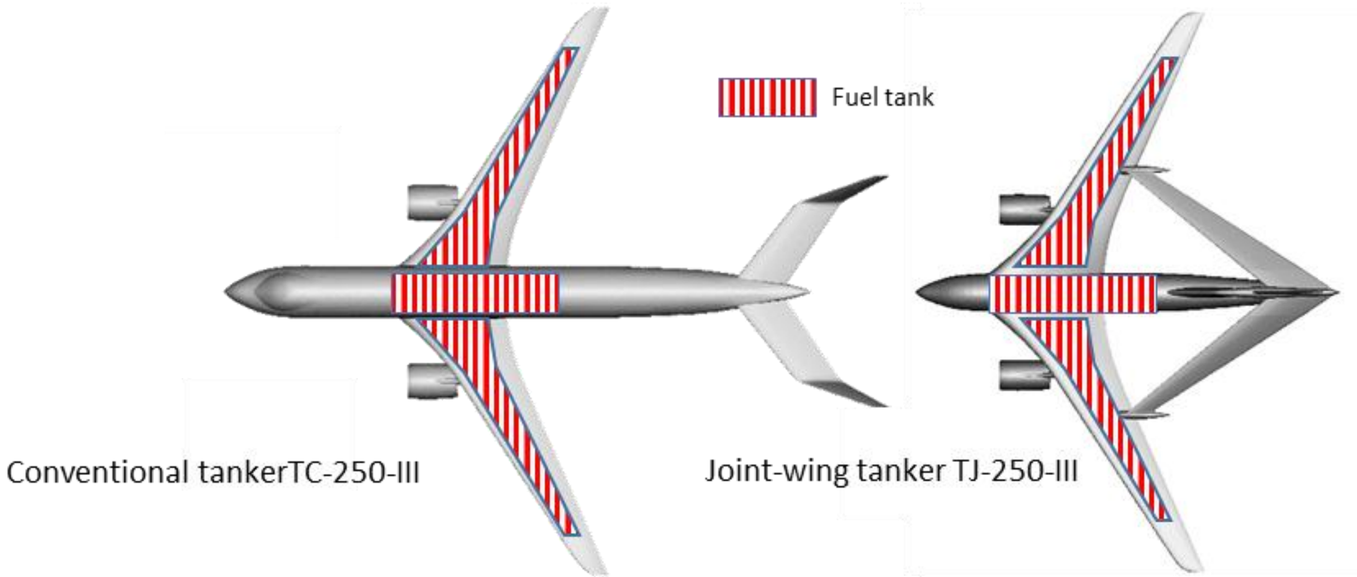


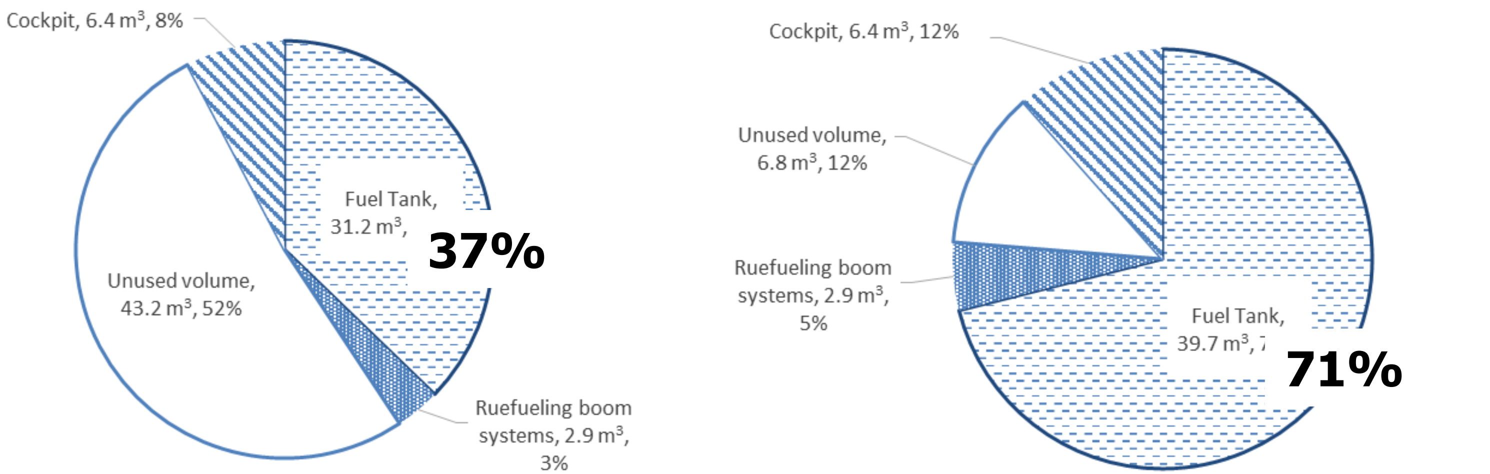
Fuel offload per tanker [kg]	14,505
Number of refueled cruisers per mission	**1-5**
Refueling radius [nm]	**250-500**
Contact time during refueling [min]	20
Waiting time between refueling [min]	20
Mach @ cruise	0.82
TO&L field Length at sea level [m]	2500





Design of the tanker





Design of the tanker

Li, M. and La Rocca, G. *Conceptual design of a joint-wing tanker for civil operations*. in: RAS Applied Aerodynamics Conference 2014, Bristol, 2014.

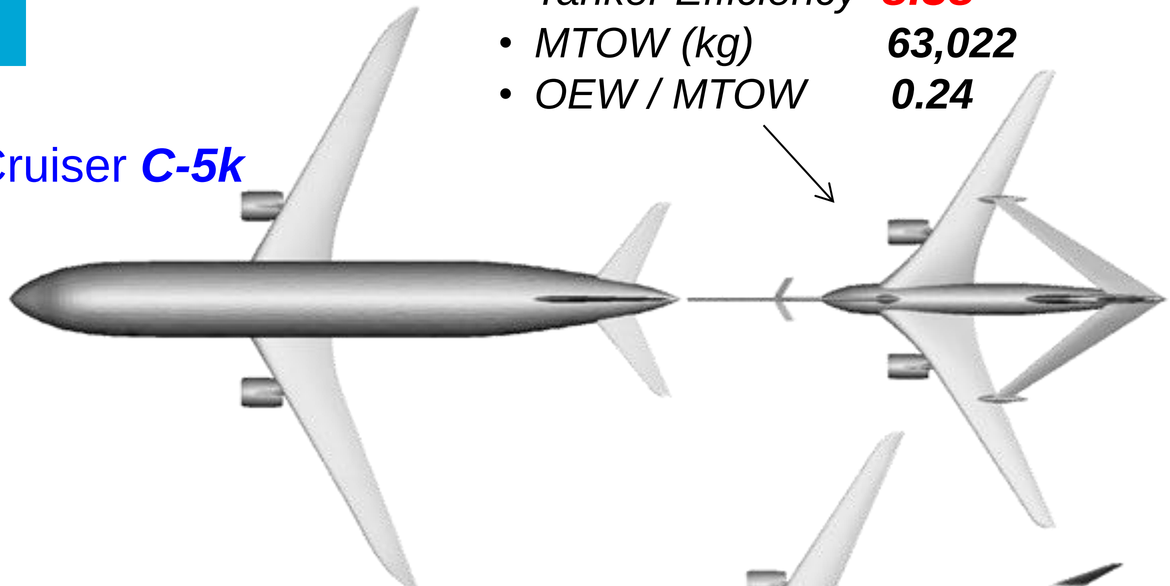
Tanker ***TJ-III-250***

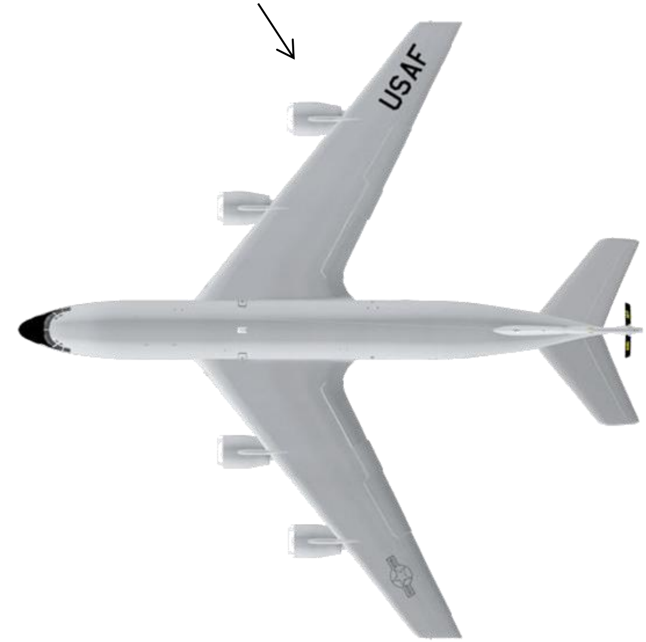
- *Tanker Efficiency* ***8.38***
- *MTOW (kg)* ***63,022***
- *OEW / MTOW* ***0.24***

Tanker ***KC-135***

- *Tanker Efficiency* ***4.02***
- *MTOW (kg)* ***117,246***
- *OEW / MTOW* ***0.31***

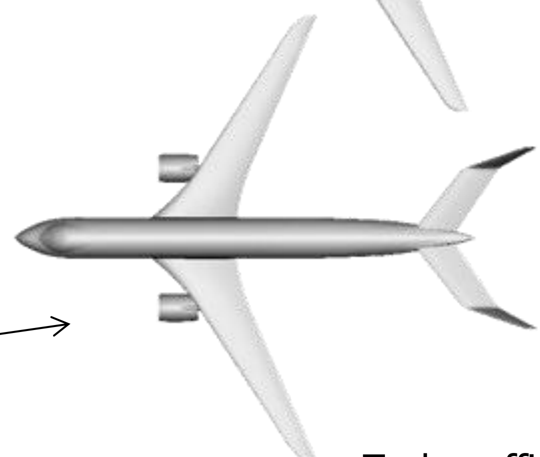
Cruiser ***C-5k***





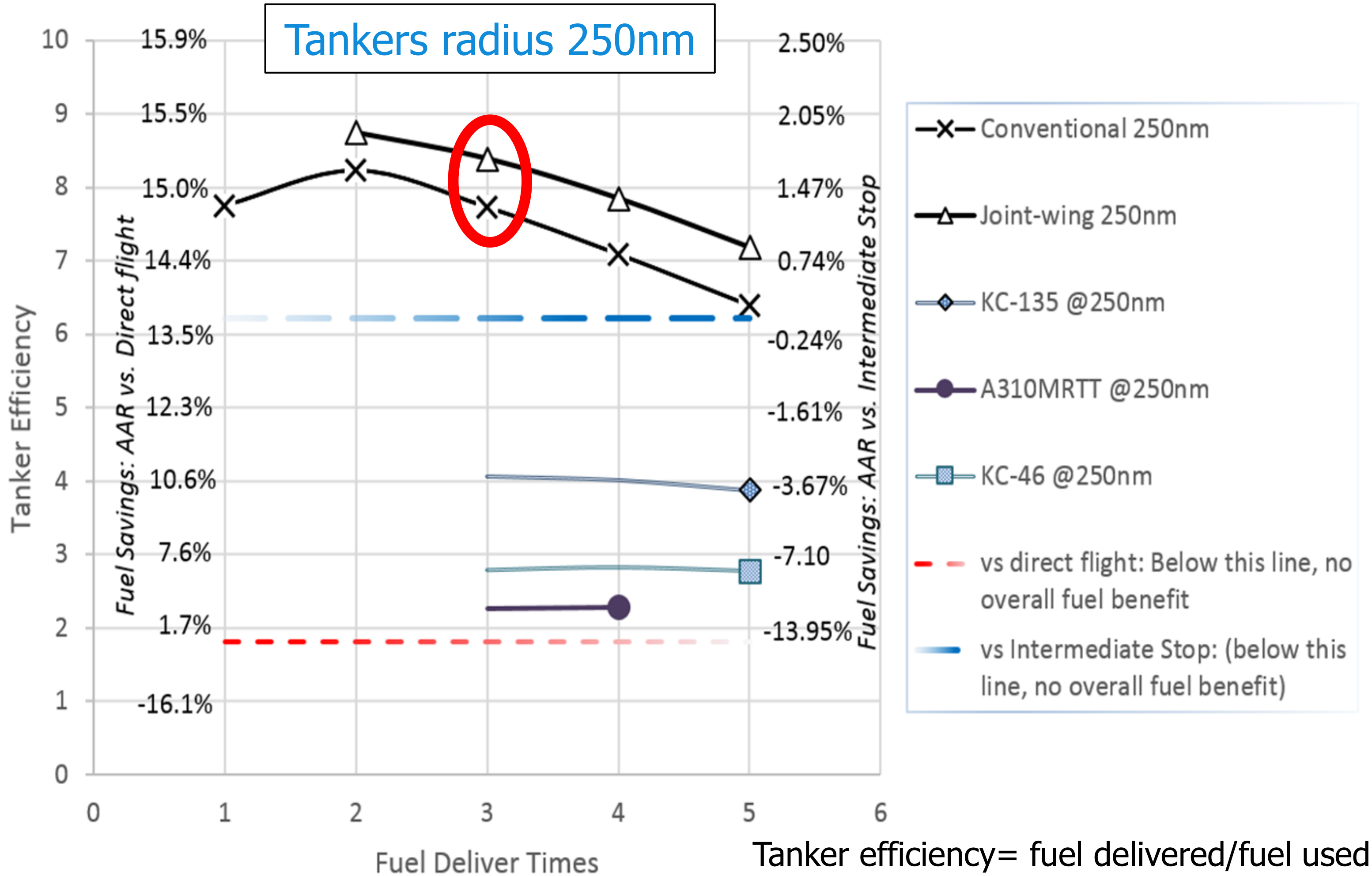
Tanker ***TC-III-250***

- *Tanker Efficiency* ***7.74***
- *MTOW (kg)* ***67,154***
- *OEW / MTOW* ***0.28***



Tanker efficiency= fuel delivered/fuel used by tanker

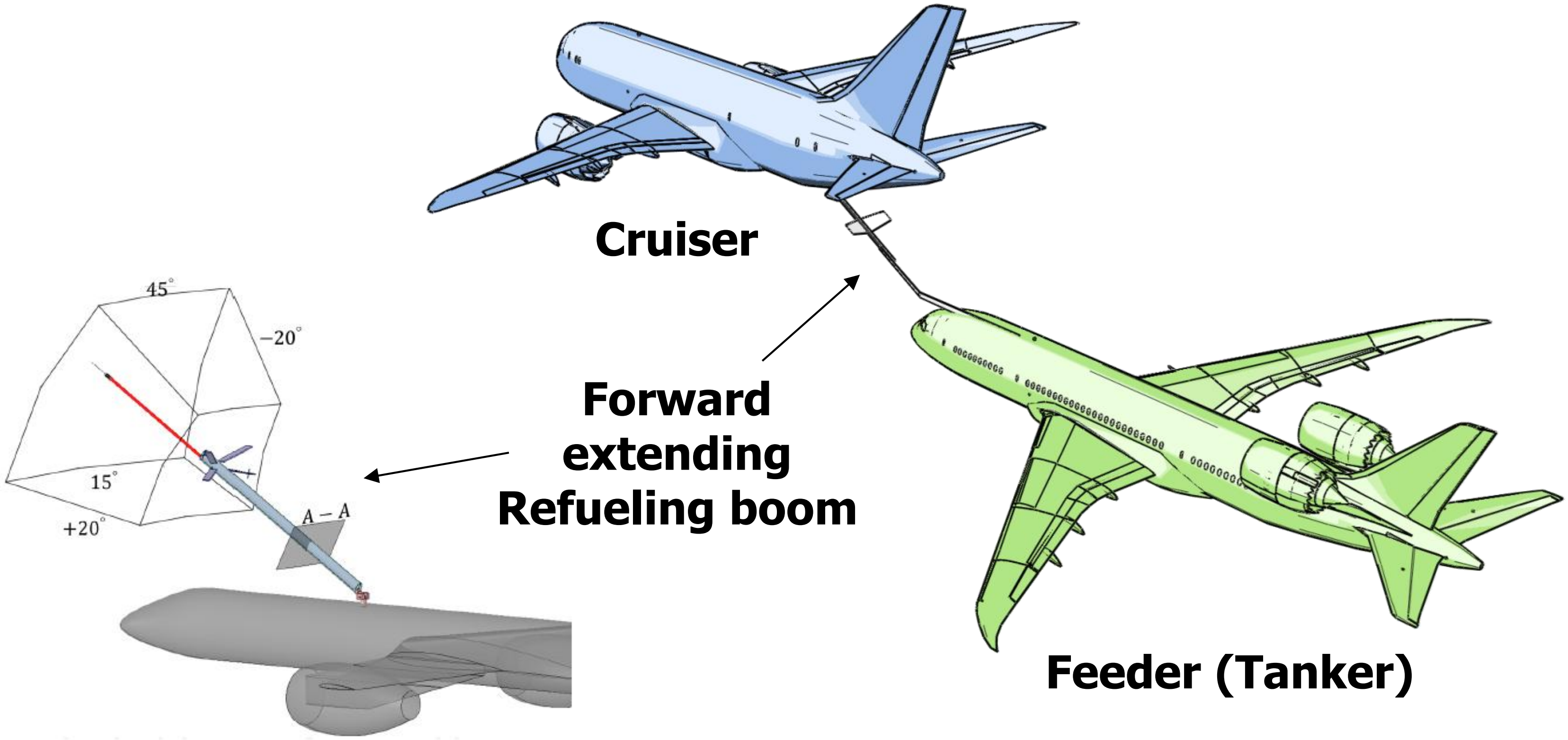
Overall fuel savings:
AAR versus Direct and Staging flight



Tanker efficiency= fuel delivered/fuel used by tanker

Conclusions (1/3)

Is it possible to adopt the AAR operational approach used by military aircraft also for passenger aircraft?



Conclusions (2/3)

Is a new aircraft design necessary or would it be possible to achieve fuel savings also using existing aircraft for AAR operations?

	Cruiser	B 737-800	Δ	B767-300	Δ
MTOW [kg]	**100,865**	75,477	-25.1%	147,985	46.7%
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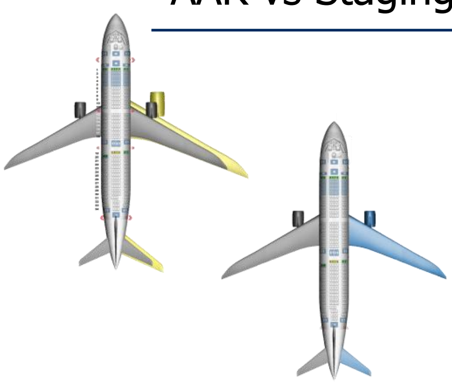
PRE/X	**0,279**	0,267	**-4,2%**	0,187	**-33%**

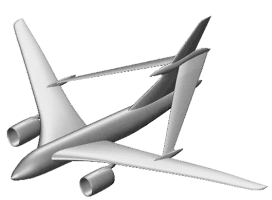
$$PRE[m] = \frac{WP[kg] \cdot R[m]}{WFB[kg]} \qquad X[m] = \frac{V[m/s] \cdot L/D[-]}{SFC[1/s]}$$

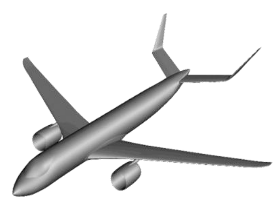
Conclusions (3/3)

How much fuel can be saved with the AAR operational approach with respect to direct and staging flight?

Fuel savings	**with Joint Wing tanker** Radius: 250nm N. of served cruisers: 3	**with Conventional Tanker** Radius: 250nm No. of served cruisers: 3	**with best existing tanker**
AAR vs direct	**15.2%**	**14.8%**	**10%**
AAR vs Staging	**1.7%**	**1.3%**	**-3.7%**







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SEVENTH FRAMEWORK PROGRAMME

RECREATE

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