Feasibility study of a nuclear powered blended wing body aircraft for the Cruiser/Feeder concept

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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 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

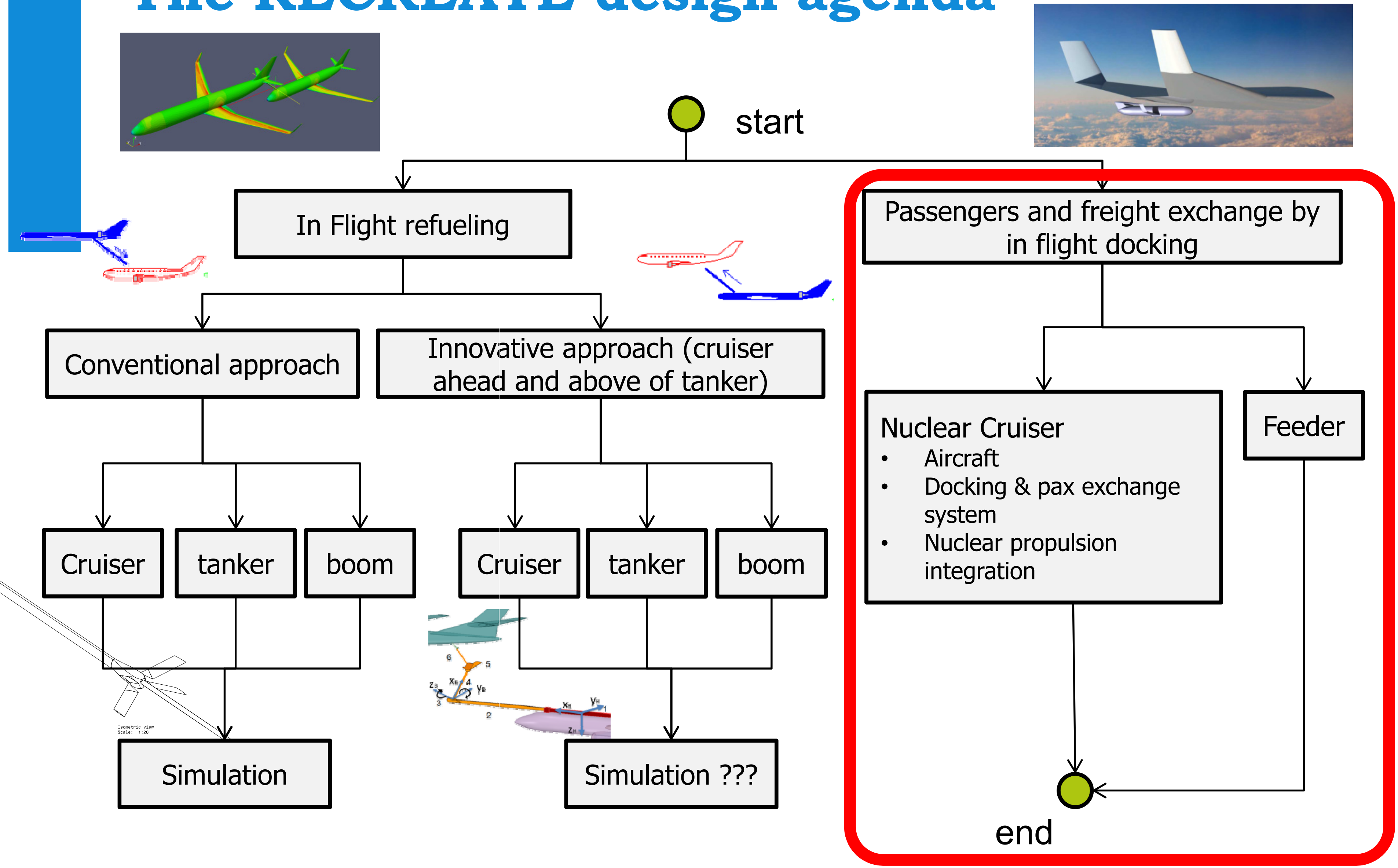
+60 years

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

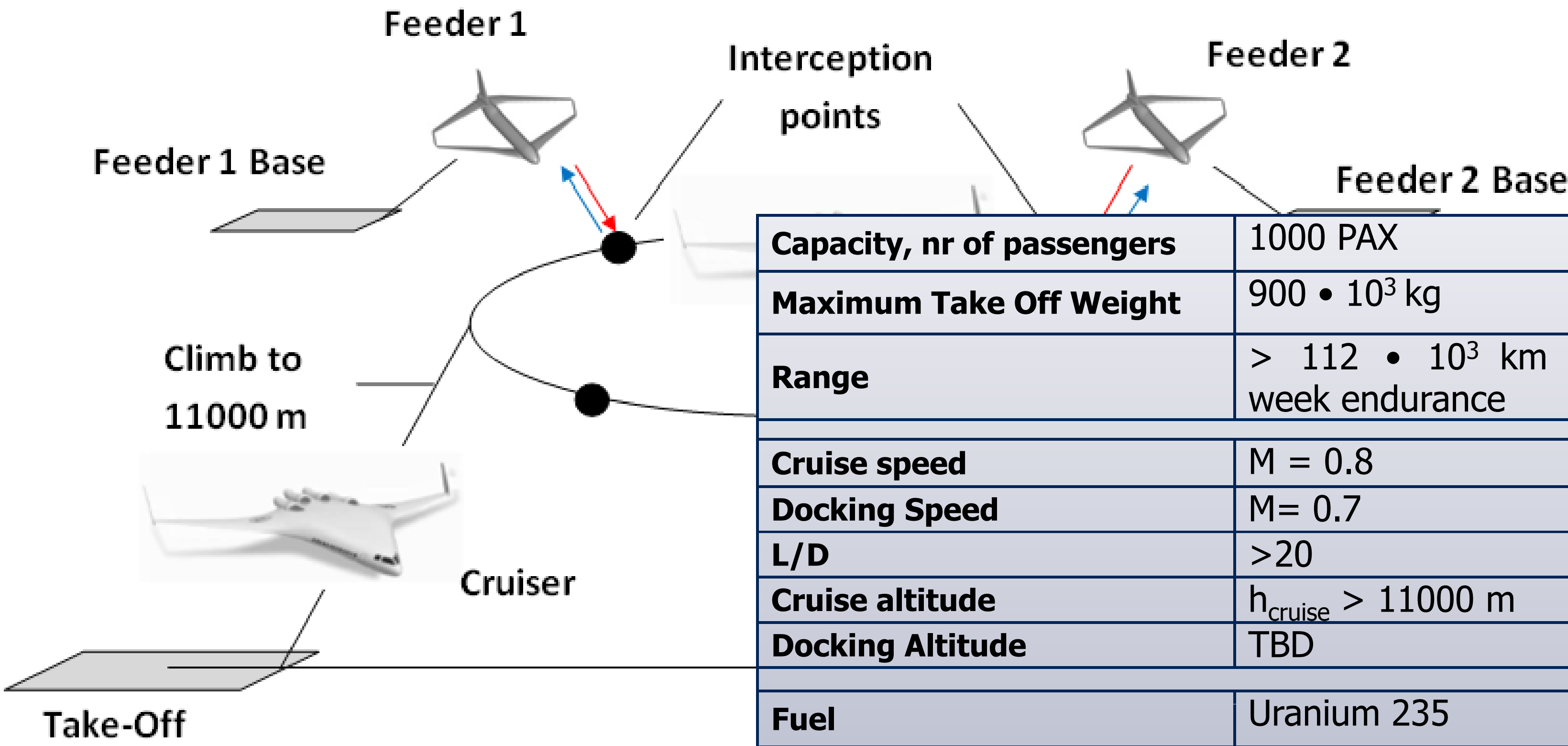
- Next to **In Flight Refueling operations** for passenger aircraft, the **feasibility study of Nuclear Powered Blended Wing body aircraft for in flight exchange of payload** is second concept addressed by RECREATE.

The RECREATE design agenda



The Cruiser/Feeder concept

Mission Profile and Requirements

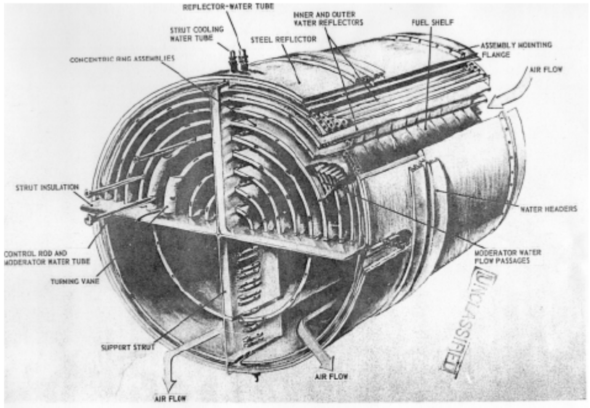


Capacity, nr of passengers	1000 PAX
Maximum Take Off Weight	900 • 10^3 kg
Range	> 112 • 10^3 km / 1 week endurance
Cruise speed	M = 0.8
Docking Speed	M= 0.7
L/D	>20
Cruise altitude	h_{cruise} > 11000 m
Docking Altitude	TBD
Fuel	Uranium 235
Payload Transfer Concept	Single container station concept (100 pax each)

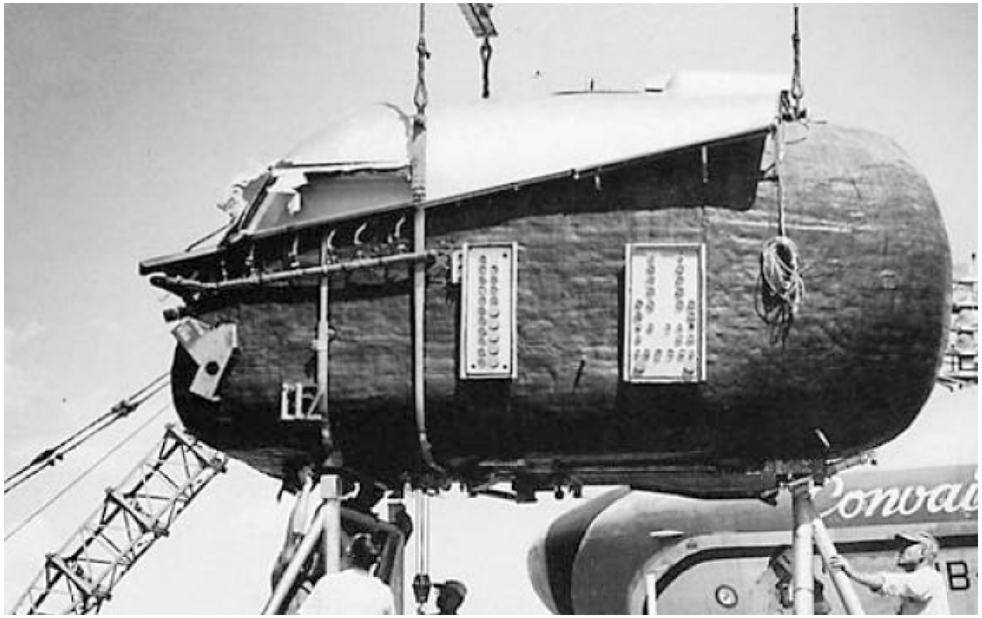
Nuclear Power for aircraft propulsion

Early 1950ies. A B-36 and some Tupolev TU-119 converted for testing of nuclear radiations shielding.

The B-36 carried a **1 MW**, air cooled nuclear reactor with a **4 ton** lead disc shield to protect crew from radiation.



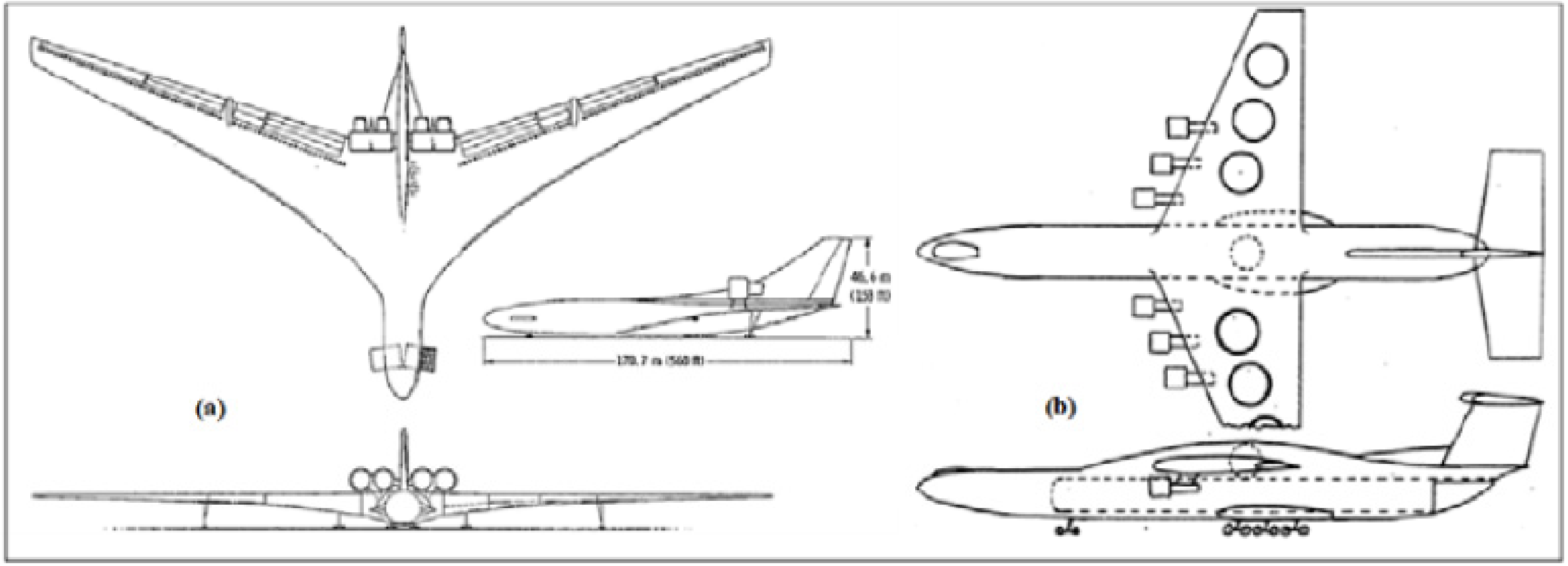
Nuclear Power for aircraft propulsion



The B36 cabin crew was situated in a massive **11 ton structure** from lead.

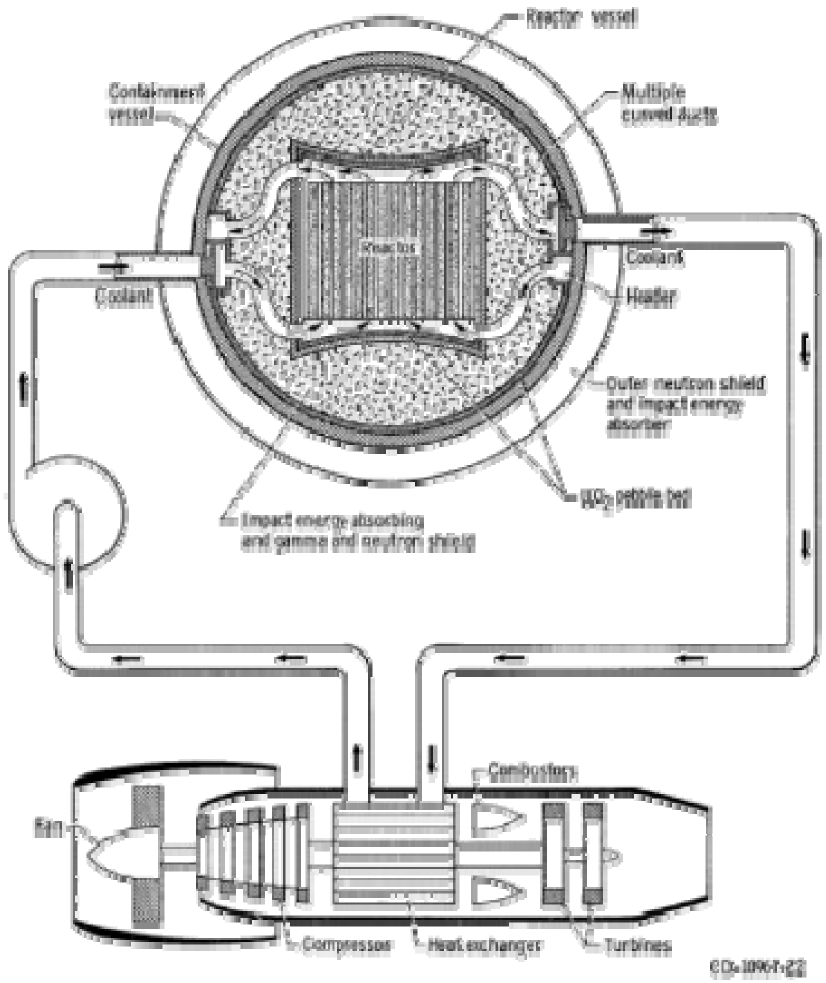
Rubber and water tanks were placed at the aft to absorb any escaping radiation

Nuclear Power for aircraft propulsion



Preliminary NASA studies from late 60ies, early 70-ies

Nuclear Power for aircraft propulsion



- **Indirect Brayton cycle**. A heat exchanger transfers the heat generated by the nuclear reactor (helium cooled) to the compressed air

- Possibility of **hybrid propulsion**:
  - Nuclear mode oversea
  - Standard kerosene mode overland

Payload exchange concepts

Considered air vehicles configurations:

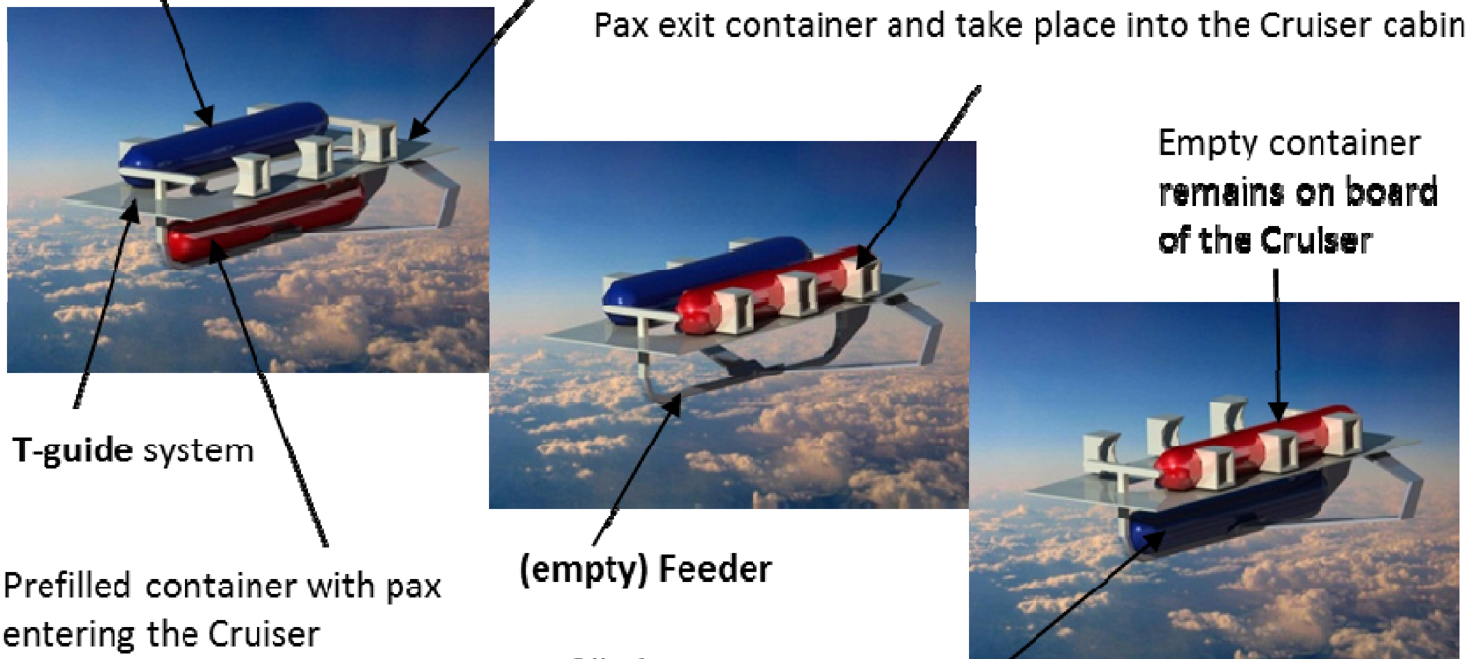
- **Cruiser: Nuclear powered BWB**
- **Feeder: Prandtl Plane**

Considered concept for pax exchange:

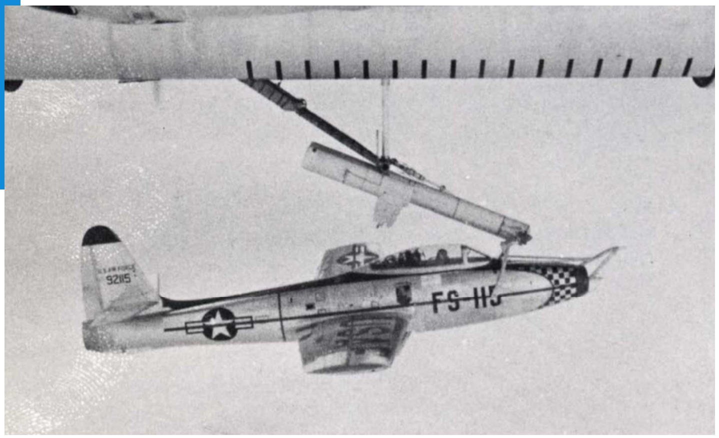
- **Through pressurized, prefilled containers (100 pax each)**

Payload exchange concepts

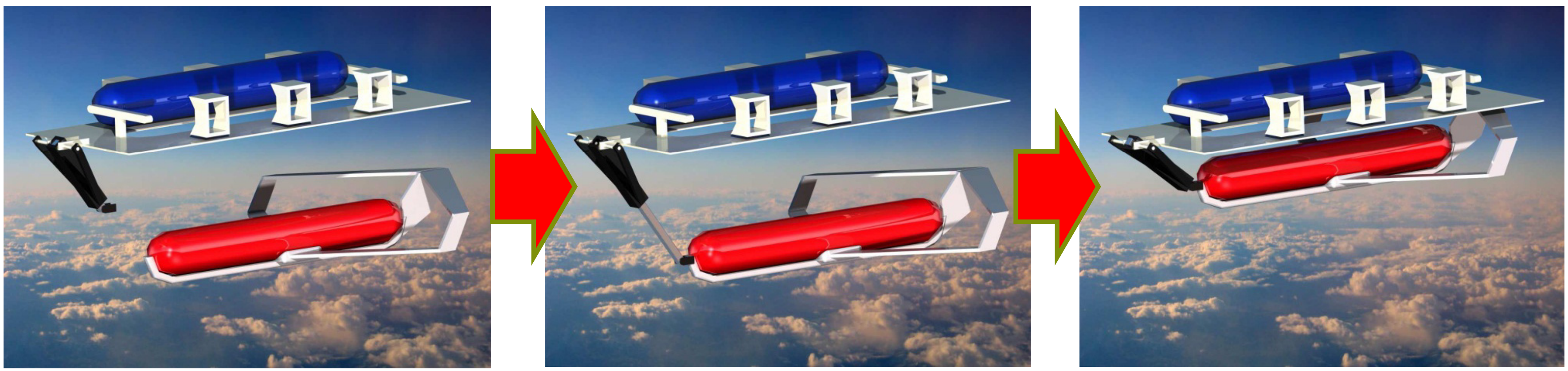
Passengers exchange approach (detachable containers)



Payload exchange concepts



Large aircraft use trapeze to catch small aircraft (USAF 1955)



Hook up mechanism feeder/cruiser (trapeze system)

Nuclear cruiser conceptual design

Conceptual design challenges:

- It is a blended wing body
  → payload collocation, aerodynamics, stability and control strongly affect each other
  → Very scarce statistics to support/initiate the design

- There is no fuel!…Breguet cannot help us : (

- Power and size of the reactor depend on aircraft weight,
  …….which depends on the weight of the reactor shielding,
  ……….which depends on the power and size of the reactor…

Nuclear cruiser conceptual design

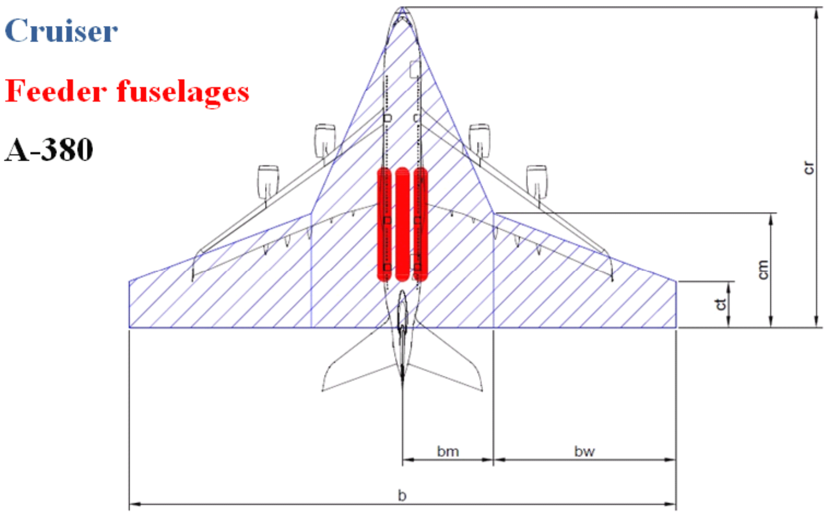
A possible way out:

1. **Start sizing the planform:**

    - **Center body** size based on inside-out approach
        - 1000 pax
        - Containerized freight
        - Two reactors with shields (5 m X 10 m)
        - Two fuselage like containers (3 m X 25 m)

    - **Outer body** size based on required total span and surfaces to achieve L/D>20 (from reqs)

Nuclear cruiser conceptual design



Payload: 1000 pax + freight
(100 pax X 10 docking operations)

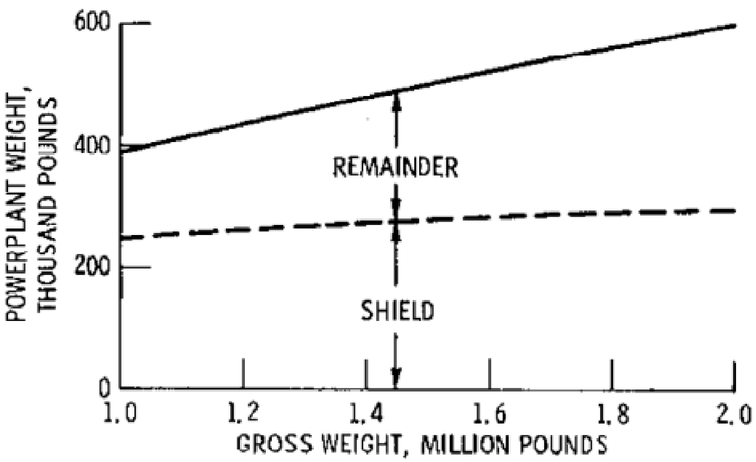
Description	*Symbol*	*Value*
Maximum root thickness	$\mathbf{t_{root}}$	10m
Root chord length	$\mathbf{c_r}$	60m
Inner part taper ratio	$\mathbf{l_1\ (c_m/c_r)}$	0.416
Main wing taper ratio	$\mathbf{l_2\ (c_t/c_m)}$	0.25
Inner part length	$\mathbf{b_m}$	20m
Outer wing length	$\mathbf{b_w}$	40m
Span length	**b**	120m
Wing Surface	**S**	2947m^2
Aspect ratio	**A**	4.89
Zero Lift Drag Coefficient	$\mathbf{C_{D0}}$	0.006
Maximum aerodynamic efficiency	$\mathbf{(L/D)_{max}}$	23.32

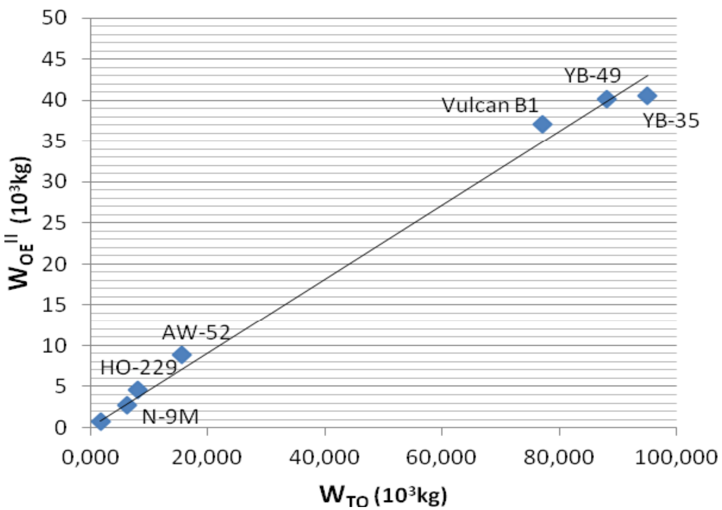
Nuclear cruiser conceptual design

A possible way out (continued):

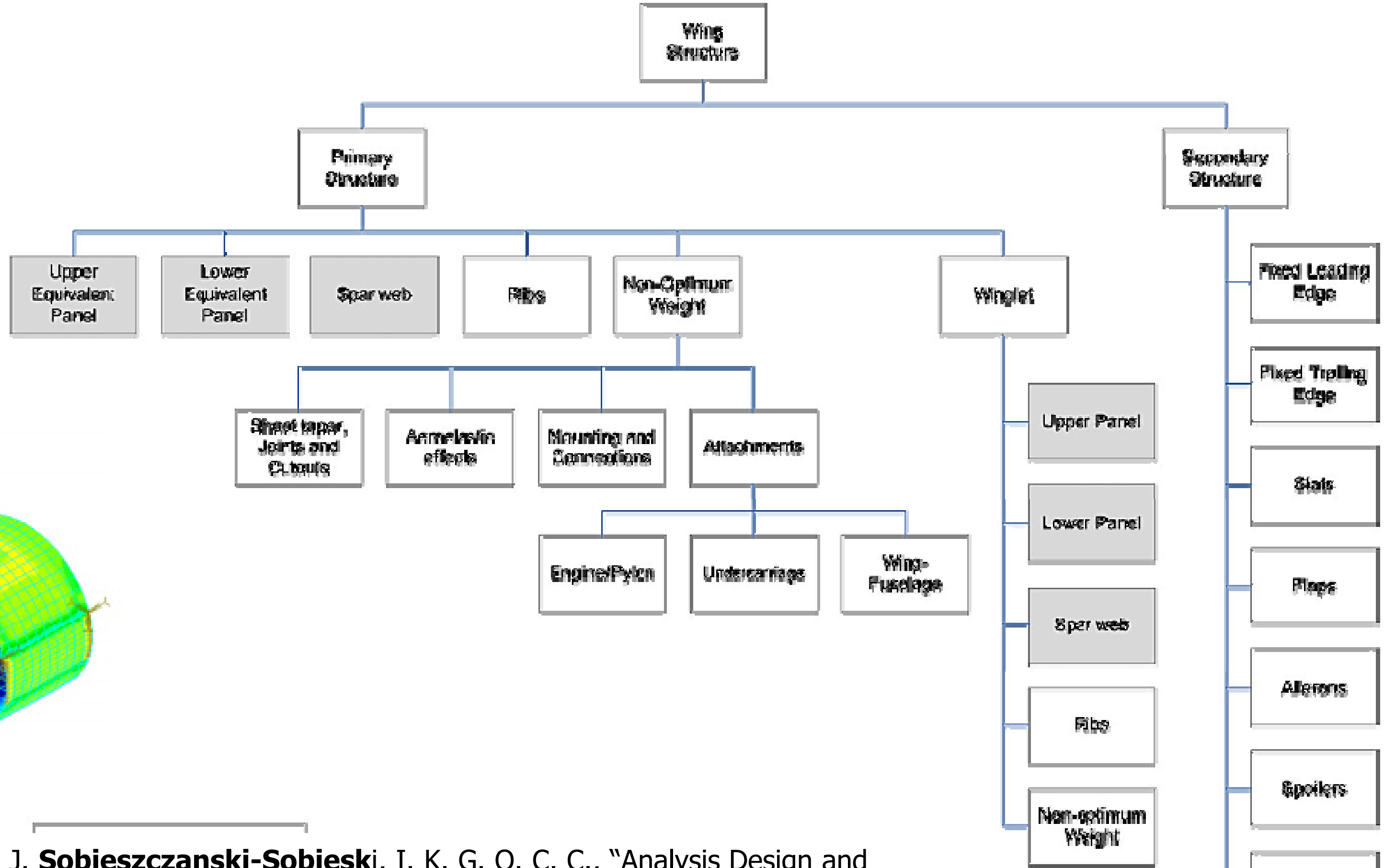
2. Breguet-less preliminary weight estimation

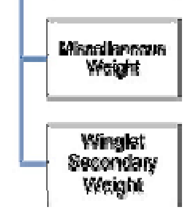
- Nuclear propulsion system weight estimation
- Some statistics (large aircraft, paper study, etc..)
- Class II-1.2 weight approach
- Iterate…

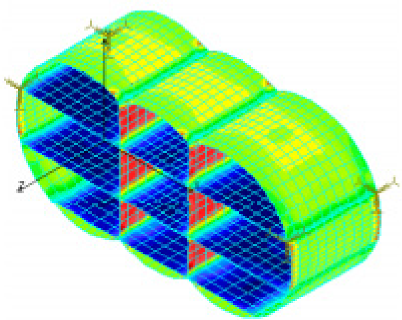




Class II-1/2 wing weight estimation tool







V. **Mukhopadhyay**, J. **Sobieszczanski-Sobiesk**i, I. K. G. Q. C. C., "Analysis Design and Optimization of Non-cylindrical Fuselage for Blended-Wing-Body (BWB) Vehicle," Proceedings of the 9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Sept 2002.

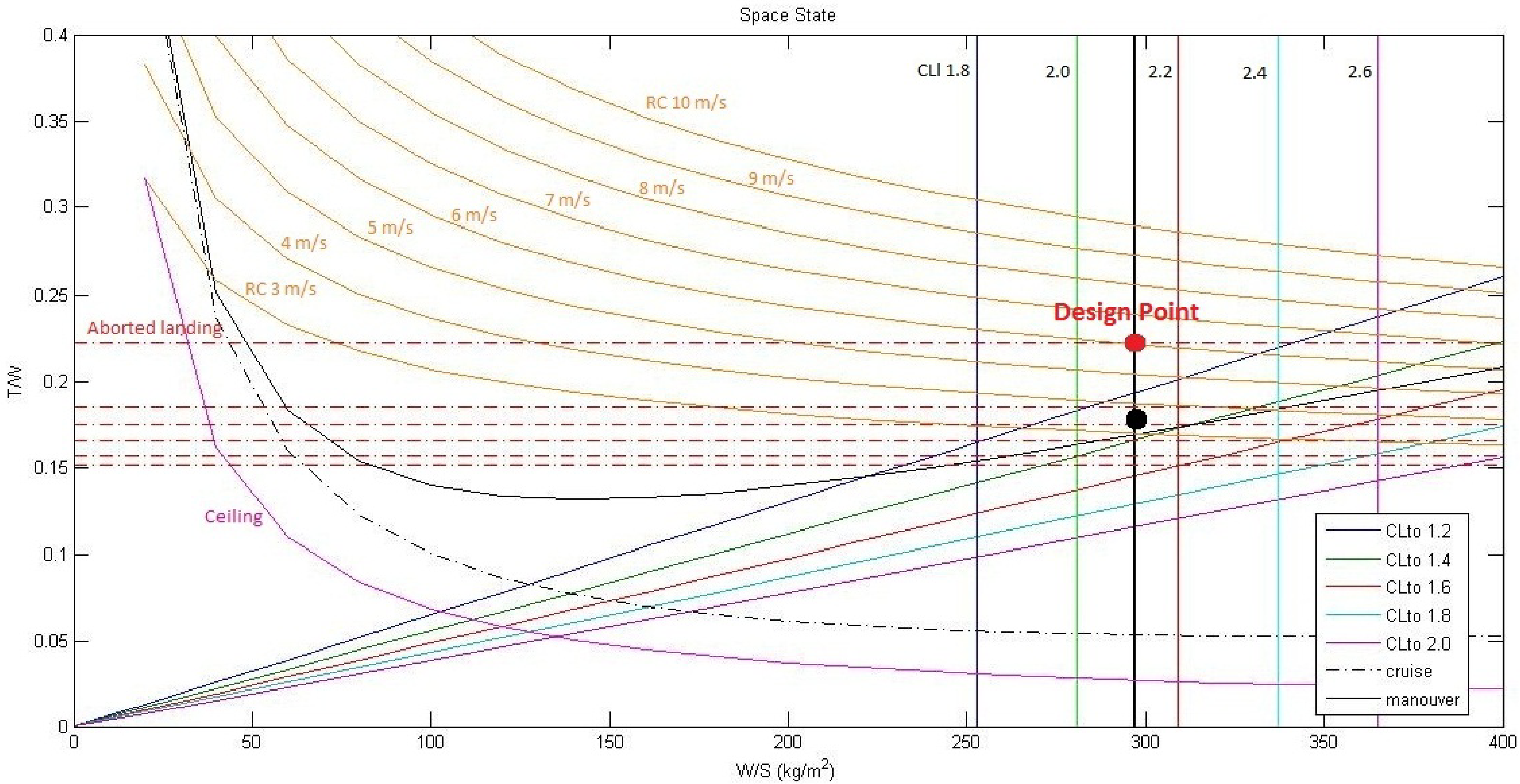
*__Elham__, A, **La Rocca**, G. and **van Tooren** M.J.L. "*Development and implementation of an advanced, design-sensitive method for wing weight estimation*," Aerospace Sciences and Technology, 29 (2013) 100–113

Nuclear cruiser conceptual design

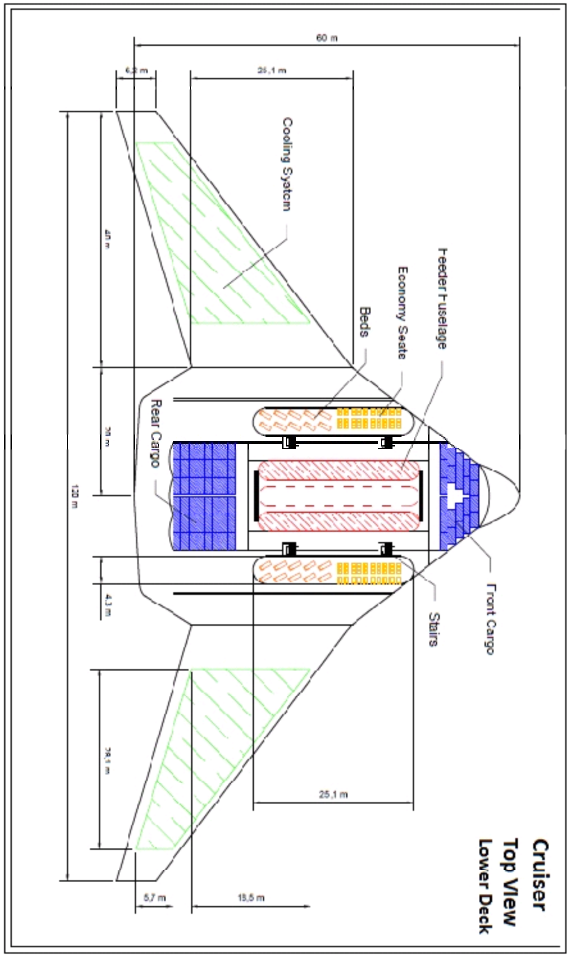
	Cruiser	% W_{TO}		A-380	% W_{TO}		B-747	% W_{TO}
W_{TO} (10^3kg)	875	-		560	-		343	-
W_{OE} (10^3kg)	383.3	43.7		277	49.5		212	61.8
W_{PL} (10^3kg)	250	28.6		85	15.2		60.5	17.6
W_P (10^3kg)	241.7	27.6		-	-		-	-

- W_{TO}: maximum take off weight (note the cruiser can takeoff empty and reach maximum weight during cruise)
- W_{OE}: Operational Empty Weight
- W_{PL}: passengers plus freight
- W_P: weight of propulsive system (shielding, fuel, core, cooling systems, but NO engines)

Nuclear cruiser conceptual design

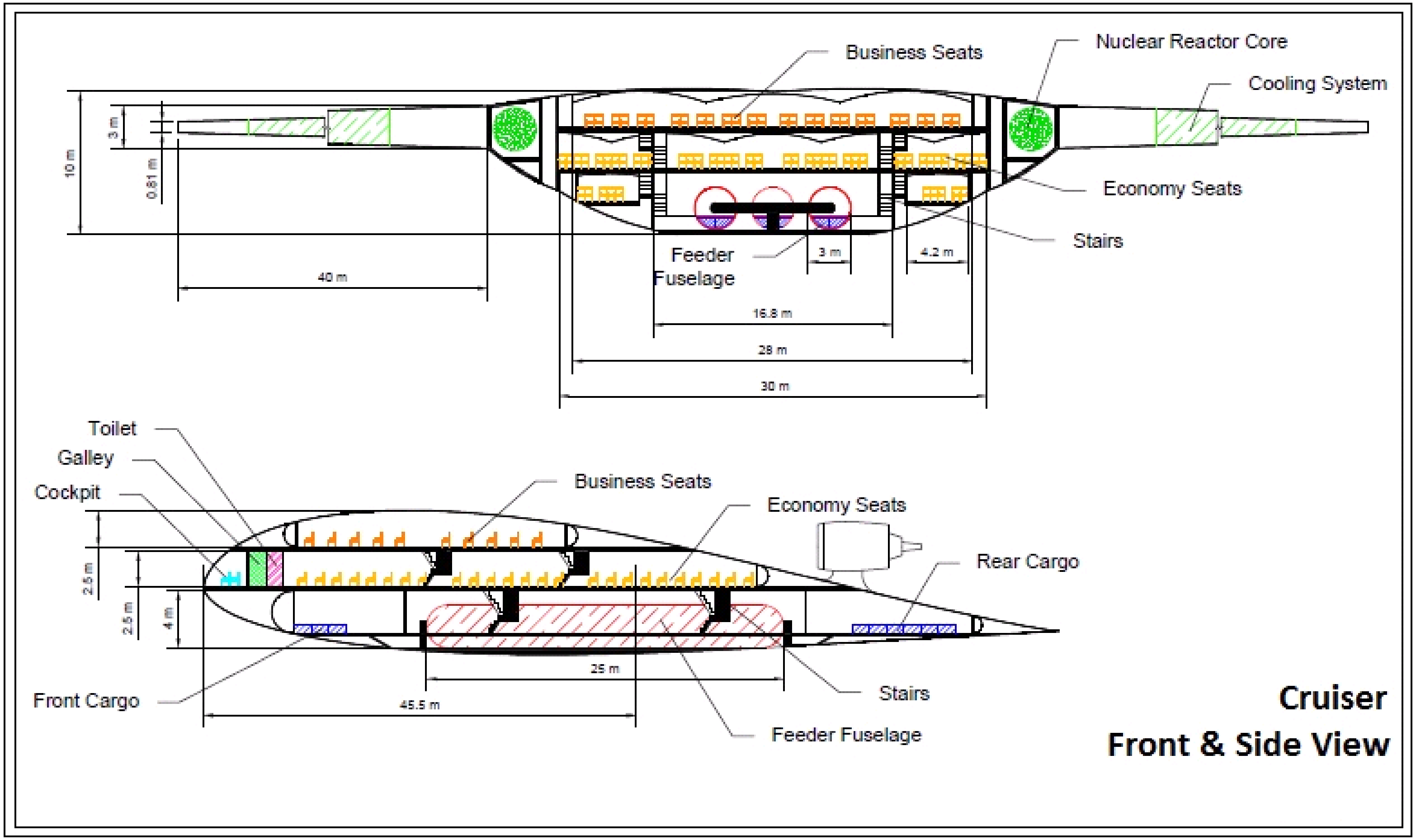


Nuclear cruiser conceptual design

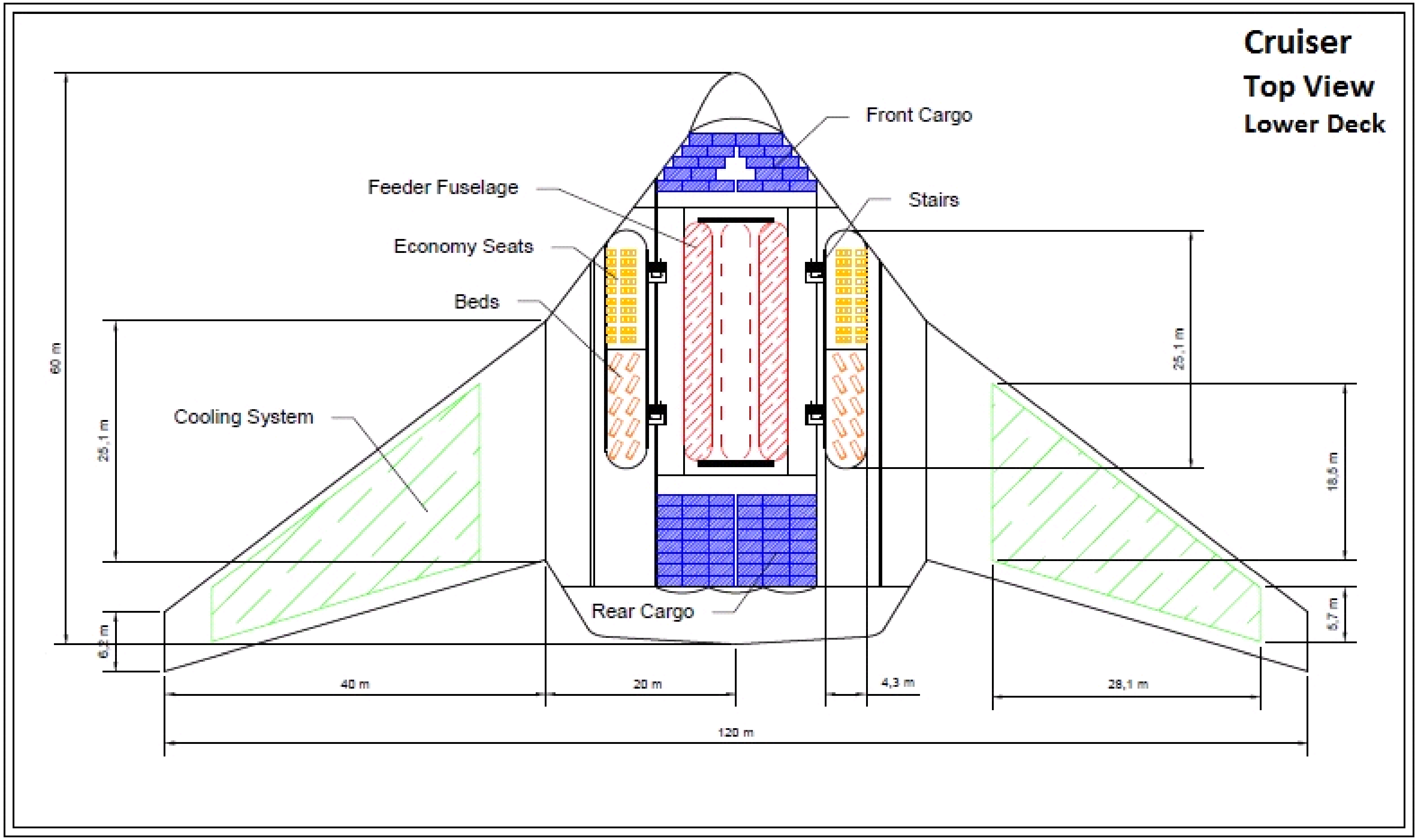


	Symbol	Value	Units
Root thickness	t_{root}	10	m
Span width	b	120	m
Wing Surface	S	2947	m^2
Aspect Ratio	A	4.89	-
Aerodynamic Efficiency	L/D	23.32	-
Take-Off Weight	W_{TO}	875	10^3 kg
Operative Empty Weight	W_{OE}	383.3	10^3 kg
Payload Weight	W_{PL}	250	10^3 kg
Power Plant Weight	W_P	241.7	10^3 kg
Wing loading	W/S	297	kg/m^2
Thrust	T	1900	kN
Power	P	344.5	MW
Rate of Climb	RC	6	m/s
C_{Lmax} take-off	C_{L-TO}	1.4	-
C_{Lmax} landing	C_{L-L}	2.2	-

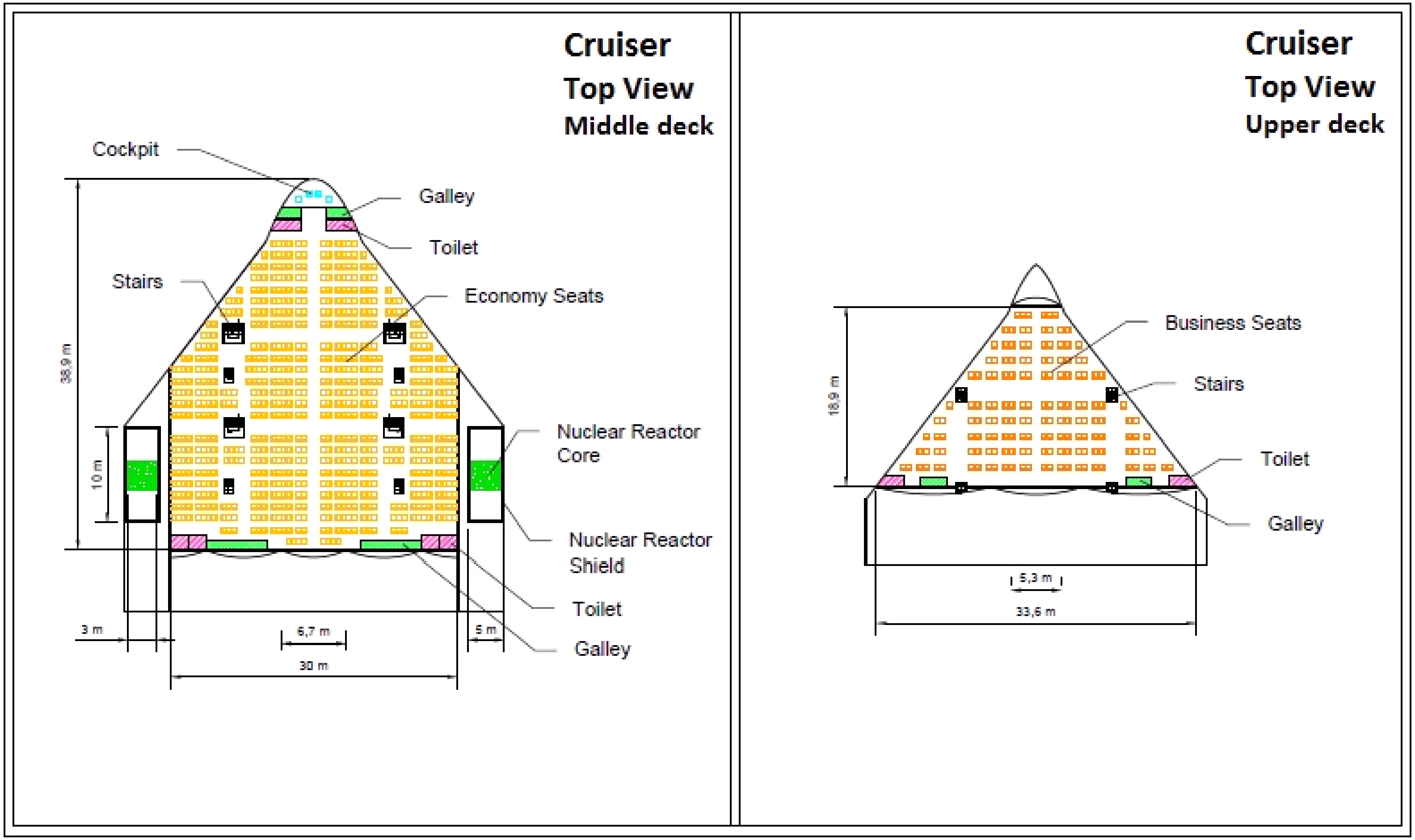
Nuclear cruiser conceptual design



Nuclear cruiser conceptual design

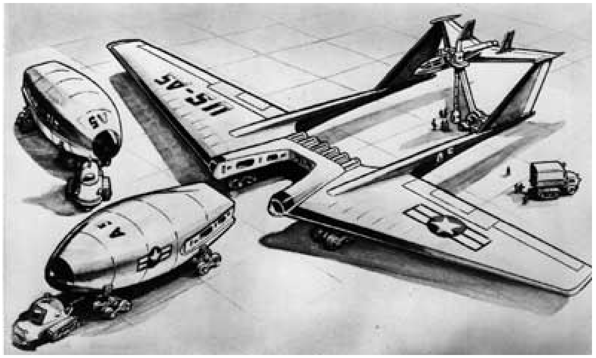


Nuclear cruiser conceptual design



What next?

- Revision and consolidation of the current conceptual design
- Focus on the design and integration of the nuclear propulsion system (including shielding analysis by means of NRG codes)
- Design of the docking and loading mechanism for pax exchange
- Hybrid propulsion (nuclear + standard fuel)
- Other engine concept (Rankine instead of Brayton?)



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.

Nuclear cruiser conceptual design

Operative Condition	*Assumptions*	*T/W*	*T (kN)*	*P (MW)*
Cruise	• $C_{D0c} = C_{D0} + 0.03$ • $v = 236.3$ m/s • $h = 11000$ m	0.053	457 @ h 1254 @ s.l.	108 300
Maneuver	• $n_{max} = 2.5$ • $h = 11000$ m • $v = 236.3$ m/s	0.17	1458	**344.5**
Take-off	• $X_{TO} = 3000$ m • Sea level			
Landing	• $v_{st} = 43.73$ m/s • Sea level			
Rate of Climb	• $C_{LTO} = 1.4$			
Ceiling	• $RC_{ceiling} = 1.5$ m/s	0.0273	234 @ h 637 @ s.l.	55.3 150
Climb Gradient	• 4 engines • $C_{LTO} = 1.4$ • $C_{LL} = 2.2$ • $v_2 = 1.2^* v_{st}$	Initial climb 0.157 Transition climb 0.165 Second part climb 0.174 Route climb 0.151 Aborted landing 0.184 Aborted landing 0.222	**1900**	100

Class I weight estimation

WTO is the sum of the following three weight components:

- **WPL (Payload Weight).** It is the sum of passengers weight Wpax and cargo weight Wcargo.

- **WOE (Operative Empty Weight).** It includes the weight contributions of structures, engines, lubricants, and crew.

- **WP (Power Plant Weight).** It includes the weight of the nuclear reactors, the cooling system and the shielding. It does not include the weight of the engines, whose contribution is accounted in WOE).