Critical Design Review

Our Team

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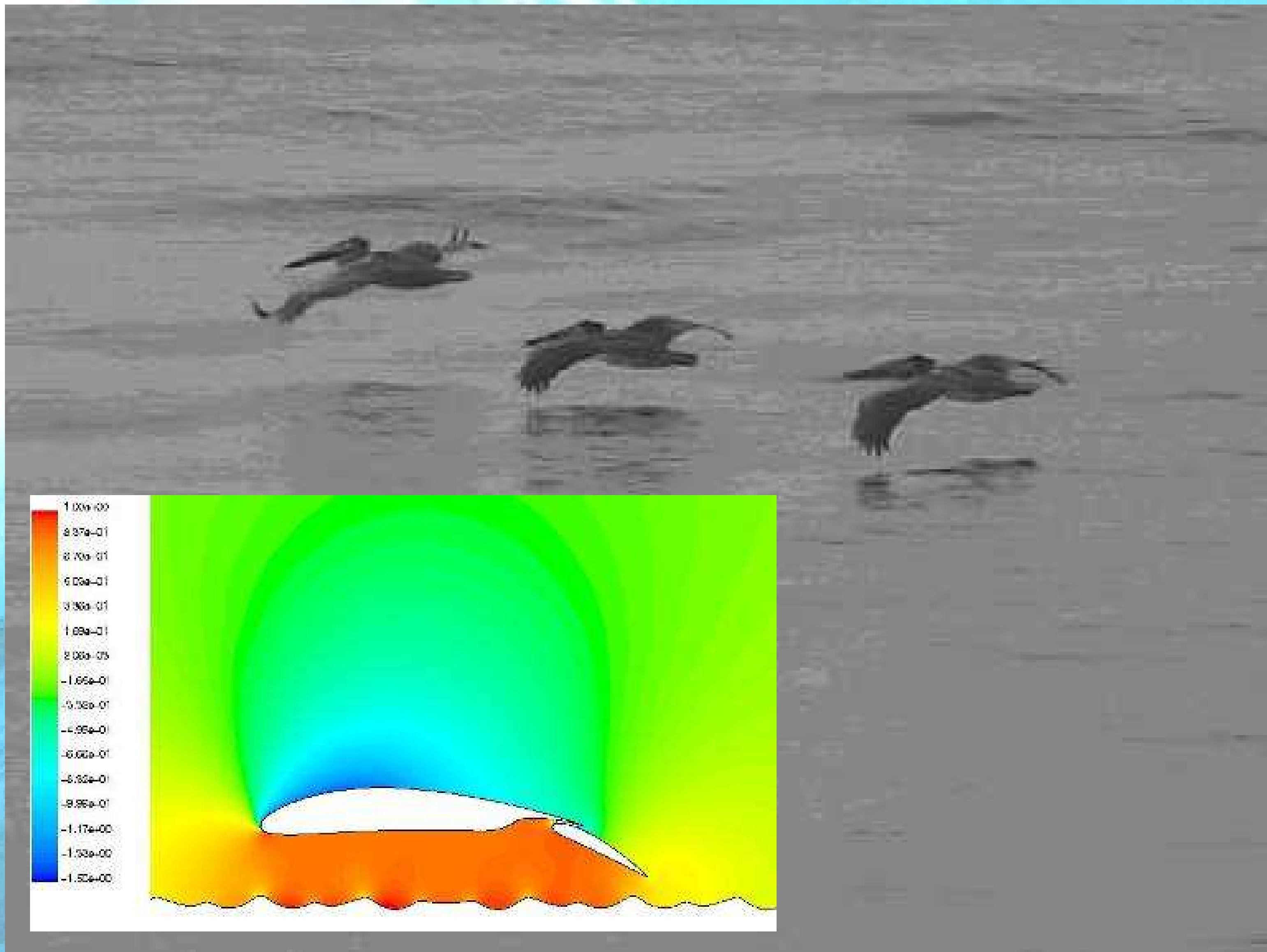
04A
Samson

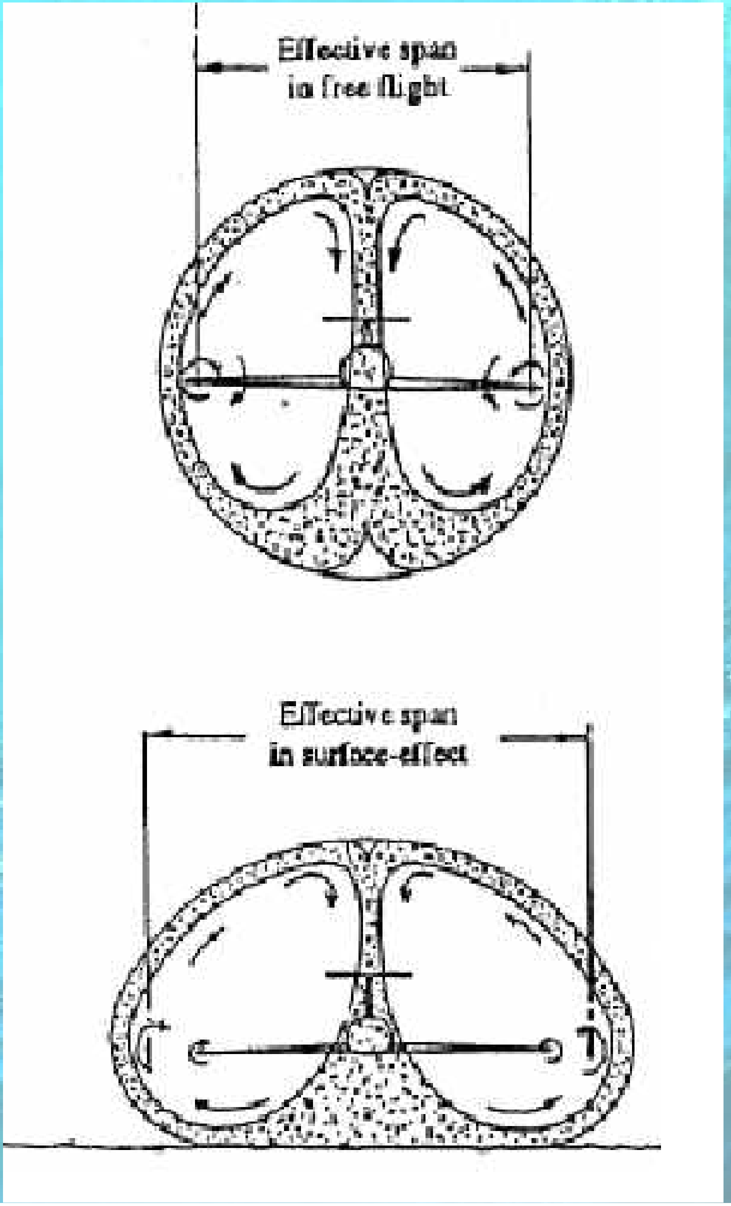
Ground Effect:



Ground Effect:

- Tip vortex decrease
- The pressure under the wing increases

- Lift increases
- Drag decreases

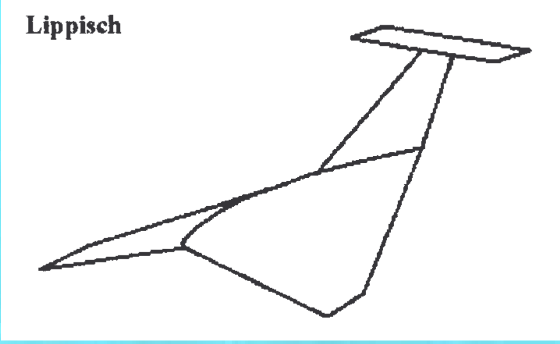


WIG Craft History

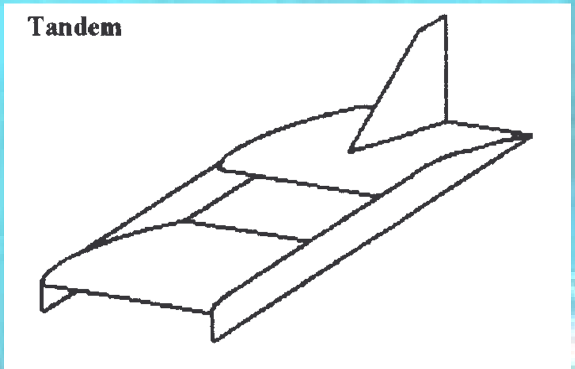
- 1930s - first design proposals
- 1960s – serious WIG designs
  - Central Hydrofoil Design Bureau in USSR
  - A. Lippisch reverse delta wing designs in USA
- Current Status of WIG Craft
  - All large Russian projects closed due to lack of funding
  - Most of the projects that appeared in 90's are terminated
  - Only one small ekranoplan is in production
  - The concept is still alive

Basic Design Concepts

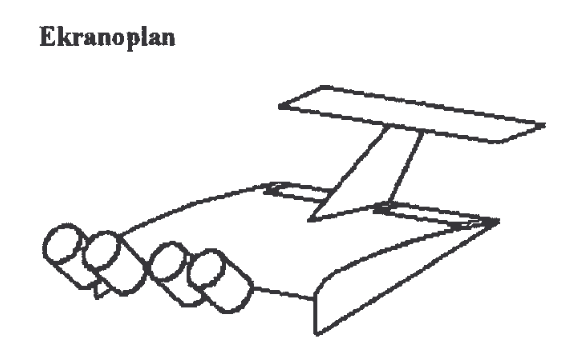
- Reversed Delta (Prof. Lippisch Principle)



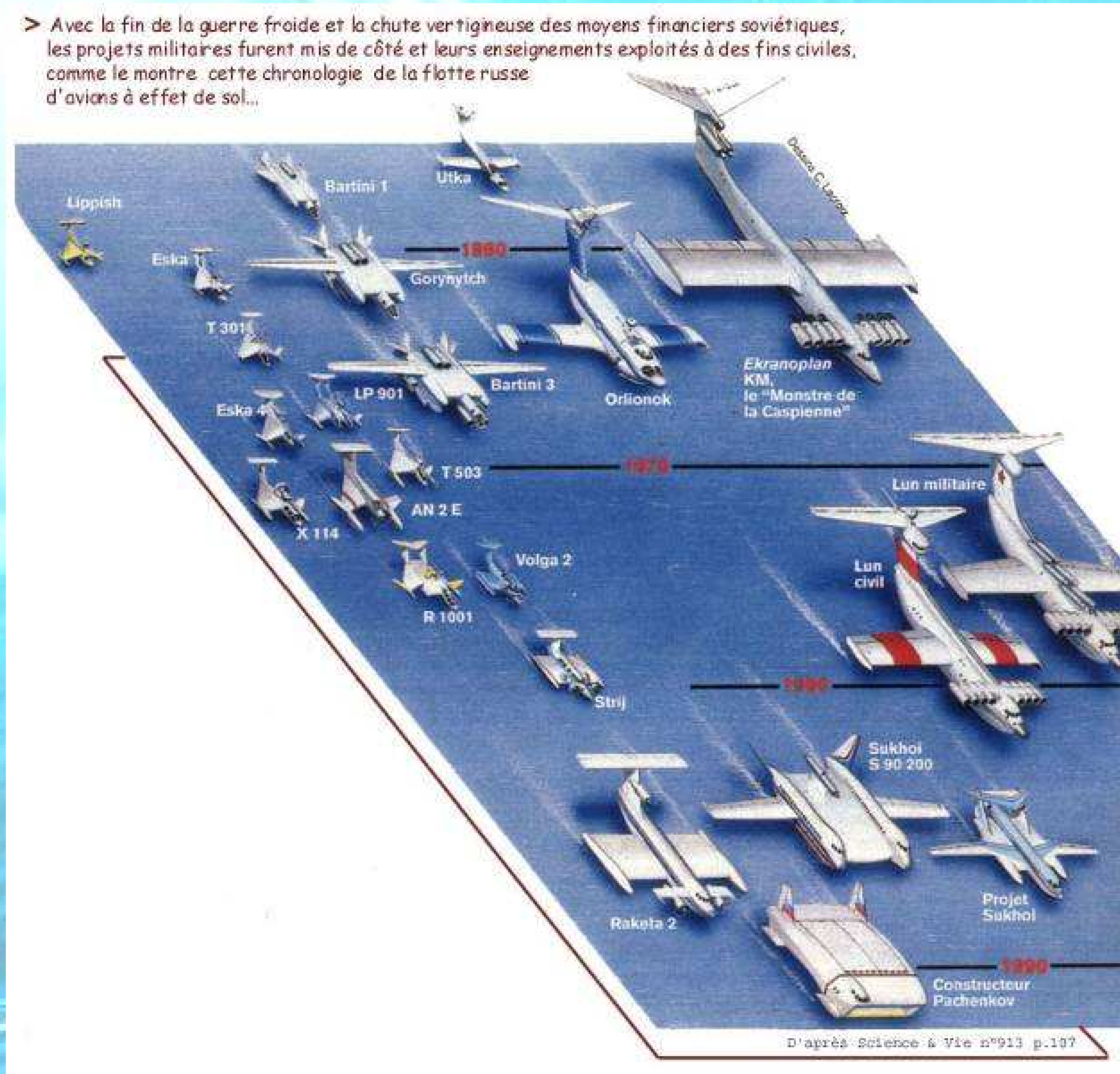
- Tandem (Joerg Principle)



- Ekranoplan (Power Augmented Ram Wing in Ground Effect)



Russian WIG Craft Timeline



Russia

KM, 1967

Orlenok, 1974

Lun’, 1987

Amphistar, 2000

Other Countries

AFD X-114, 1977

Guangzhou Tianxiang TY-1, 1997

Flightship FS-8, 2001

Boeing Pelican, concept

Advantages and disadvantages of ekranoplans

Advantages and disadvantages of ekranoplans

➢ **Advantages**:

- Ground effect reduces drag
- No pressurization is needed
- No need for extra fuel for holding - runway is always below
- Potentially lower operating costs

Advantages and disadvantages of ekranoplans

- **Disadvantages**:
  - WIGs are sensitive to weather conditions such as wave height and wind speed
  - Ekranoplans flight close to the ground, therefore, $\left(L/D\right)_{max}$ is reached at lower velocities than in higher altitudes of flight
  - Short service life because of corrosion
  - There is a constraint to flight only above seas, oceans or smooth plains
  - Providing thrust for takeoff (extra weight of start engines)
  - Fuselage must be strong enough to withstand water takeoff and landing

Specifications of Samson ekranoplan

- **Name: Samson**
- **Country of Origin: Israel**
- **Type: Long range, low-level (ground-effect) marine transport.**

Specifications

➢ Performance:

- Max cruise speed: 250 [knots] (463 [km/hr])
- Economy cruise: 217 [knots] (403 [km/hr])
- Range at economy cruise speed (with 60 ton fuel and 120 ton payload): 3176 [nm] (5880 [km])
- Range at economy cruise speed (with 110 ton fuel and 70 ton of payload): 6495 [nm] (12225 [km])

Specifications

- **Weights:**
  - Empty: 120 [ton] (263,000 [lb])
  - Max take-off : 300 [ton] (661,500 [lb])
  - Max payload: 138 [ton] (304,175 [lb])

Specifications

- **Accommodation:**

  Normal Flight crew of three (including 2 pilots and a freight handler)

- **Cargo arrangement:**

  Two decks:

  - Upper deck: one row of 21 containers.
  - Lower deck: two rows, total of 45 containers.

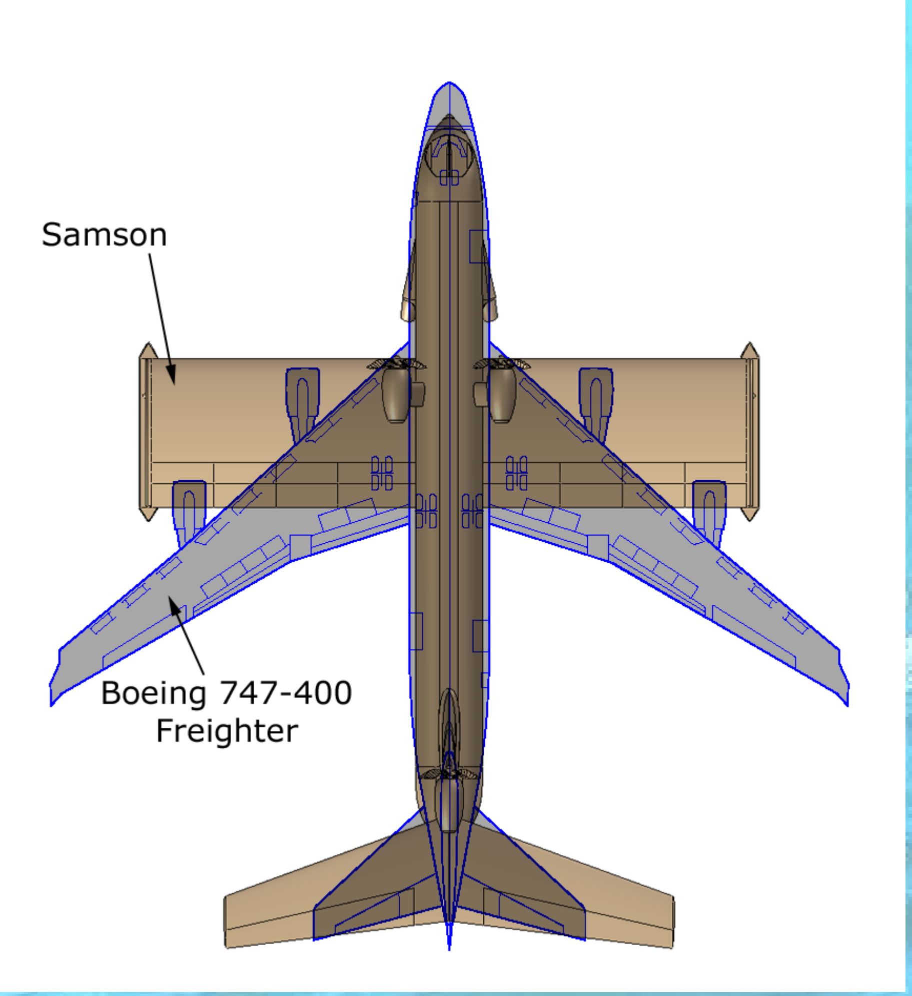
Specifications

- **Power plant:**
  - Two HK jet engines. Power: 25 ton maximum thrust each engine, used for takeoff only.
  - Three EUROPROP TP400-D6 turboprop engines. Power: 13000 SHP each engine, used for takeoff & cruise.
- **Takeoff distance:**

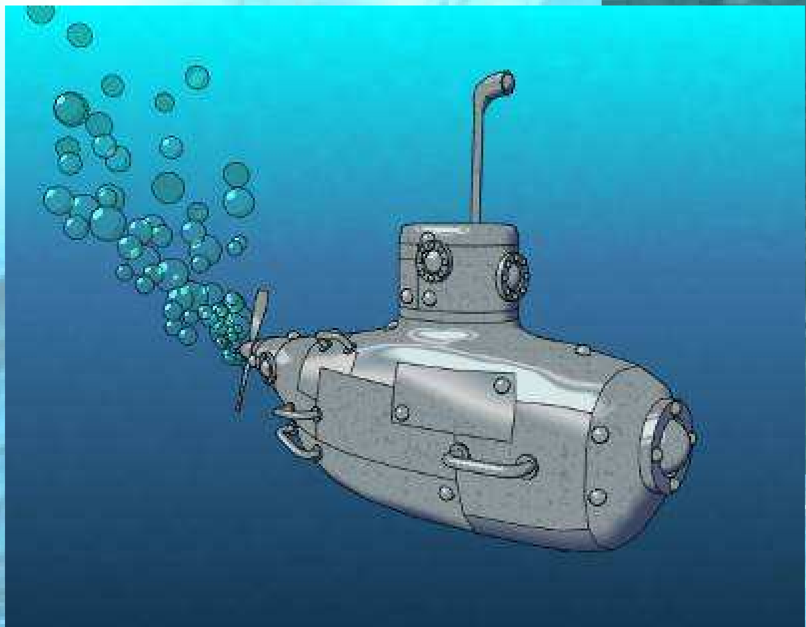
  1.04 [nm] (1900 [m])

Specifications

- **Dimensions**:
  Span: 48 m
  Length: 70 m
  Height: 7.18 m
  Rectangular wing.
  Wing area: 576 m^2
  Wing chord:12 m
  Aspect-Ratio-wing: 4
  Horizontal tail: (swept T)
  Tail area: 230 m^2
  Tail span: 36 m
  Tail Aspect-Ratio: 5.6

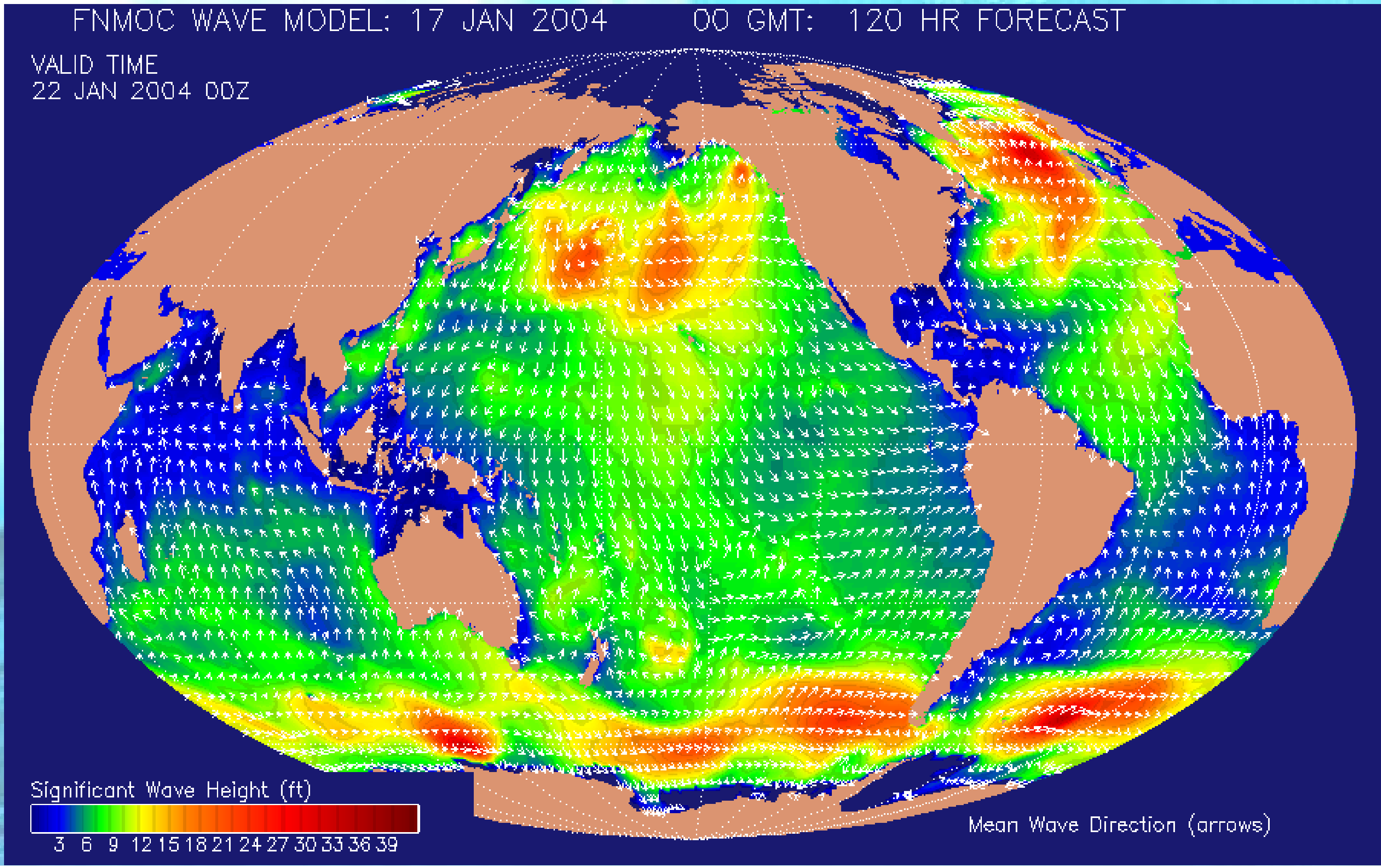


Flight Conditions &Wave Height



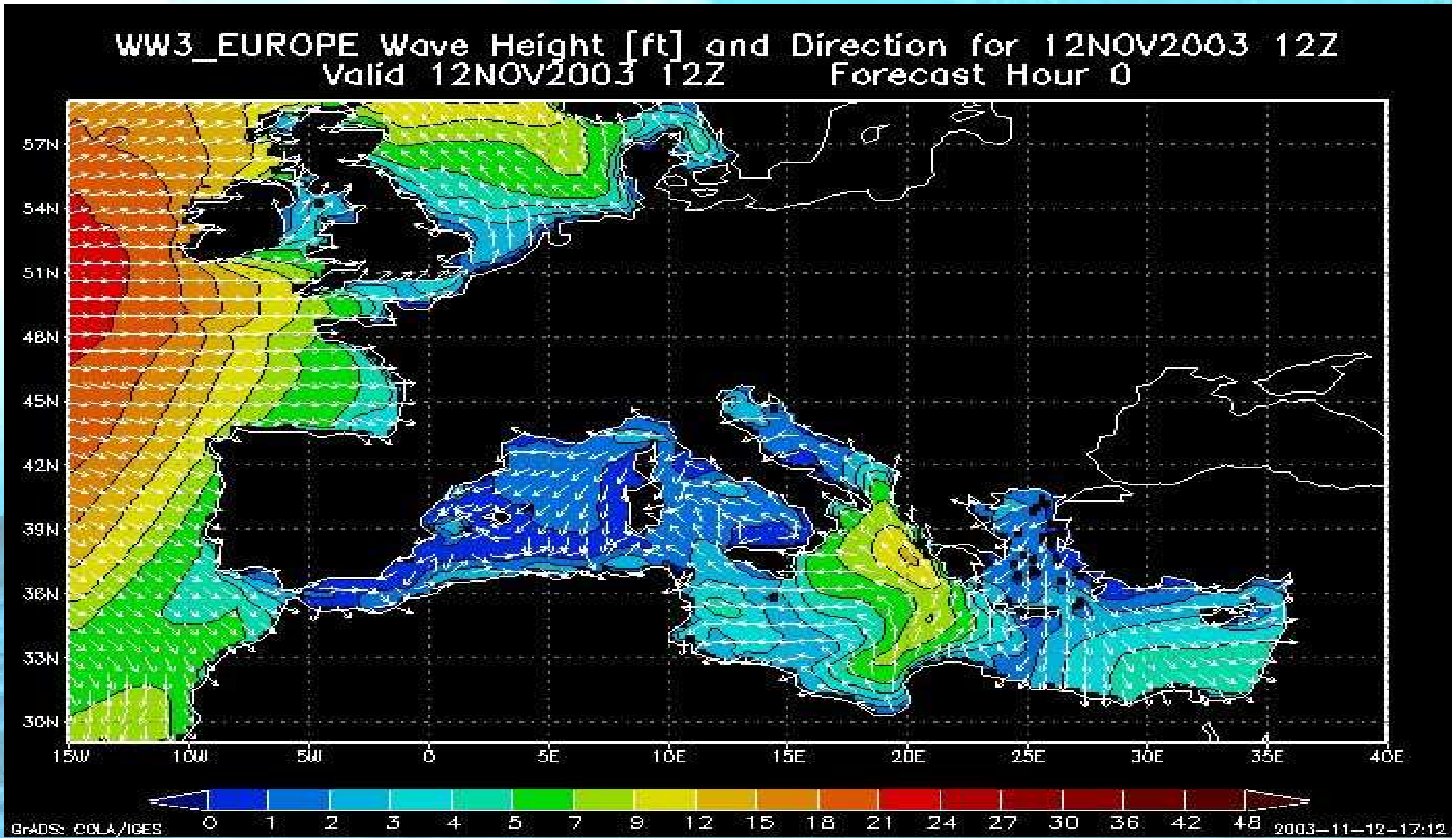
Flight Conditions &Wave Height

Global chart :



Flight Conditions &Wave Height

Mediterranean Sea chart :



Flight Conditions &Wave Height

Conclusions :

- Near ocean coastline, in many areas in deep ocean and in Mediterranean sea the wave height is mostly lower than 3 meters.
- Efficient flight altitude of Samson is when waves height is lower then ~3 meters .
- Therefore, Samson is able to fly in many regions - not only above seas, but also above oceans.

Configuration development -weight

$$G.E. \propto \frac{altitude}{chord} \rightarrow \text{high altitude} = \text{large chord}$$

large chord $\rightarrow$ large wing area

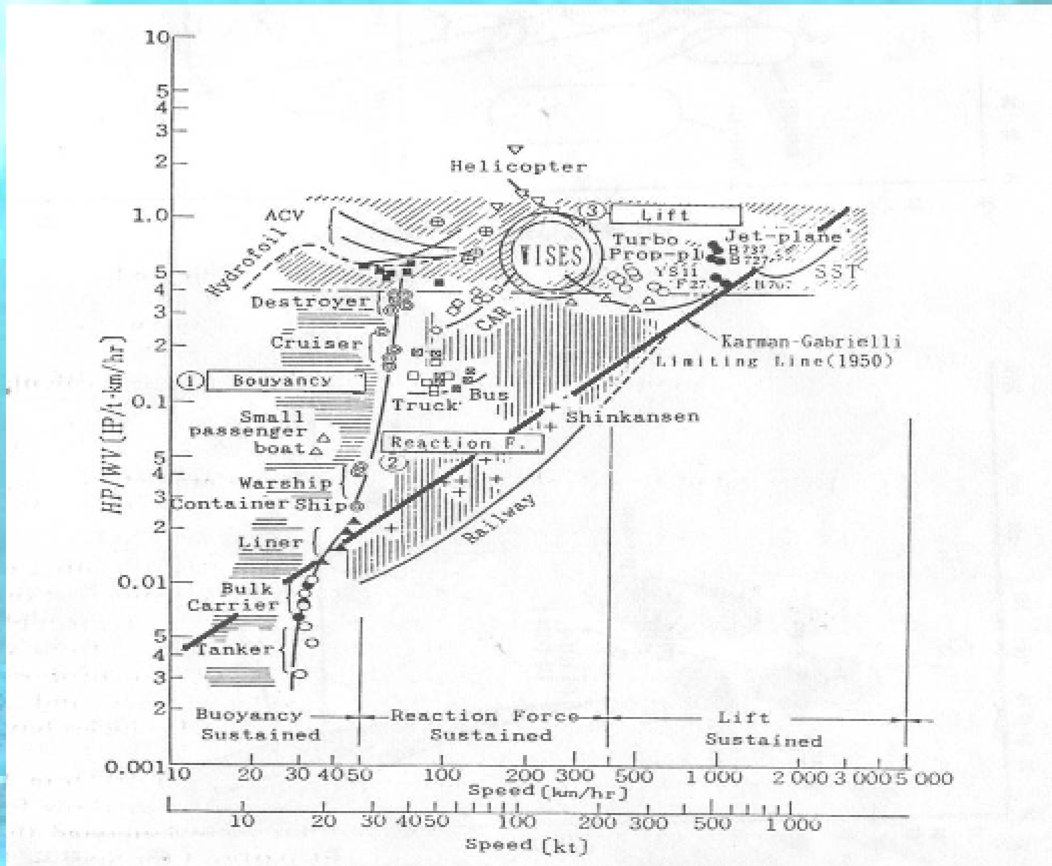
large wing area $\rightarrow$ high weight

W=300 [ton]

Configuration development - velocity

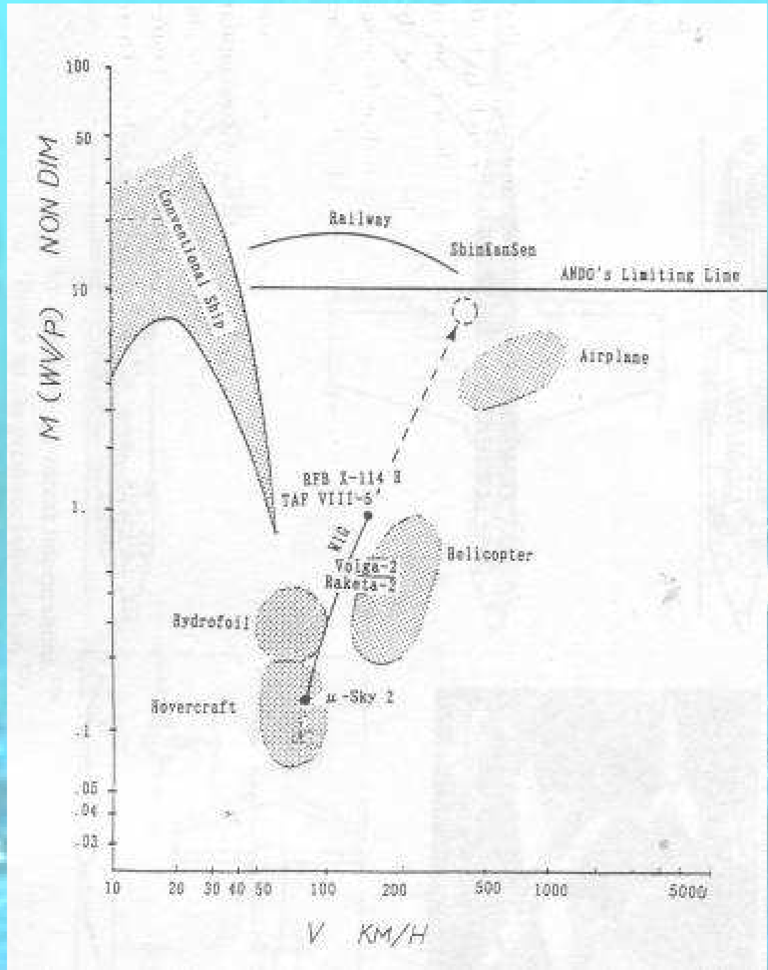
"Some topics on WIG (ekranoplan) design" by Shigenori Ando

- Vehicles lying on the "Limiting Line" have the best operational efficiency at every speed.



Configuration development - velocity

- Velocity of 400 to 500 km/h in order to challenge existing aircrafts.



Wing Area and Aspect Ratio

Wing Area and Aspect Ratio

- Given: Takeoff weight = 300 ton
- Goals: Takeoff below 140 kt and cruising above 240 kt
- Choosing: Wing chord of 12 m => have full benefit from G.E. and fly relatively high

- Wing area (= wing loading) affects performance
  - Takeoff speed
  - Best cruise speed

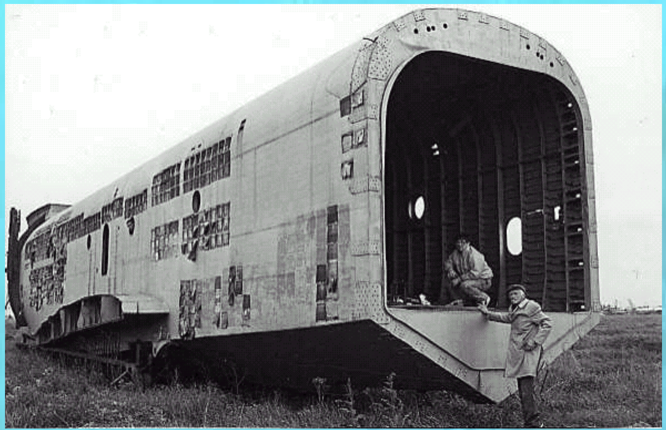
Wing Area and Aspect Ratio

- Choosing: AR=4 => Trade-off between low AR wing typical for WIG craft and more efficient conventional wing
- Therefore: $S = 576\ m^2$, $W/S = 521\ kg/m^2$
- Assuming C_{Lmax} of 2.5 can be reached => V_{TO}=123 kt
- Max. L/D is 19.7 at 220 kt

Cross section and cargo arrangement:

Cross-Section Shape

➢ **Rectangular cross section with triangular bottom was chosen**



<u>The reasons for that choice are:</u>

- Low angels of attack
- Sea level cruising → no need in cabin pressurization
- Better volumetric efficiency relatively to a circular cross section
- Take off from water → ship like triangular bottom

Cross-Section Shape

- **Dimensions determination of the cross section**

LD3 Container

Air cargo containers

ALP Container

<u>Weight:</u> from 163 lb / 74 kg
<u>Dimension:</u>
length 1534 mm
bottom width 1562 mm
top width 2007 mm
height 1626 mm
<u>Gross Weight:</u> 3.500 lb / 1.588 kg

<u>Weight:</u> from 440 lb / 200 kg
<u>Dimensions:</u>
length 1534 mm
width 3175 mm
height 1626 mm
<u>Gross Weight:</u> 7.000 lb / 3.175 kg

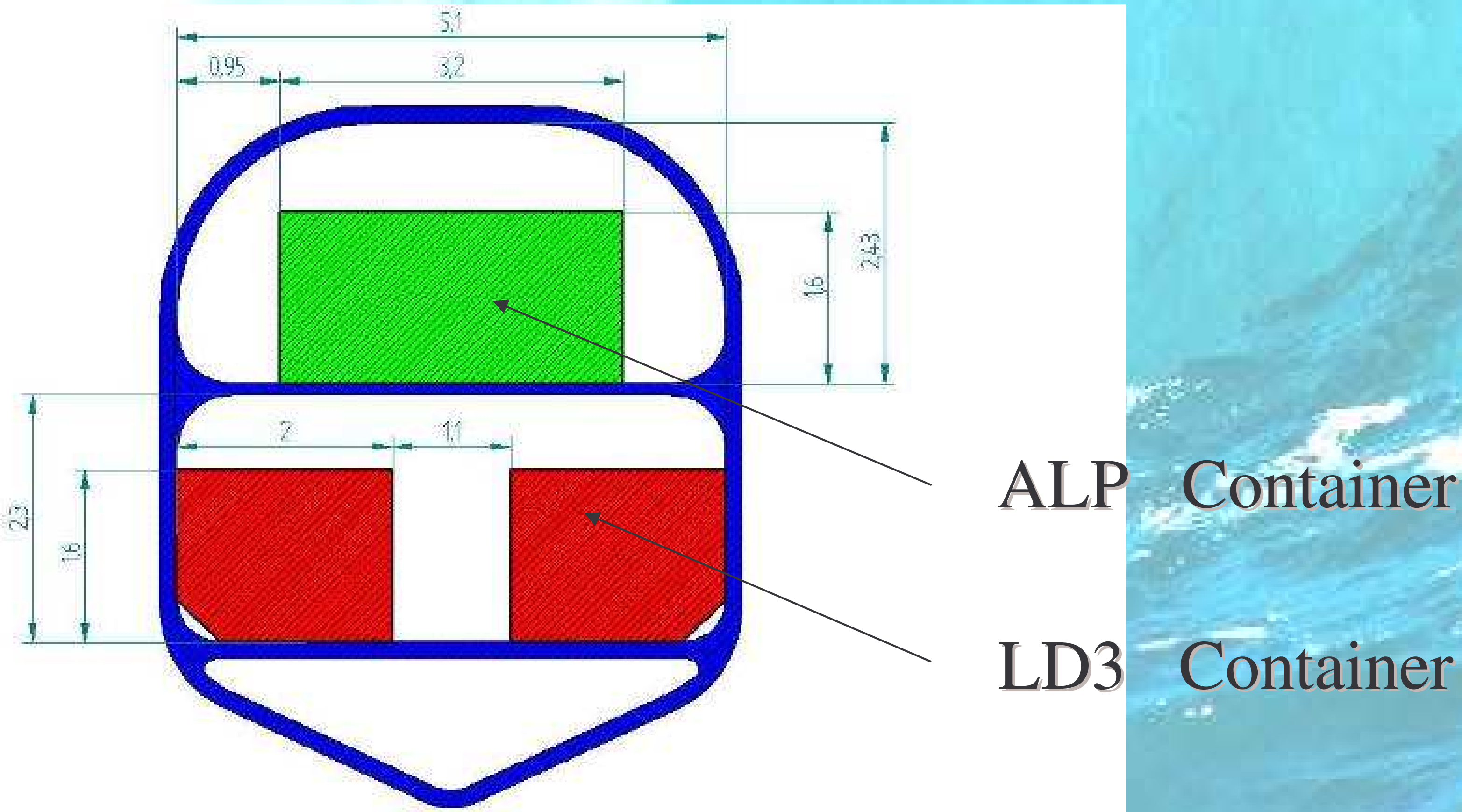
Cross-Section Shape

- **Two deck configuration**

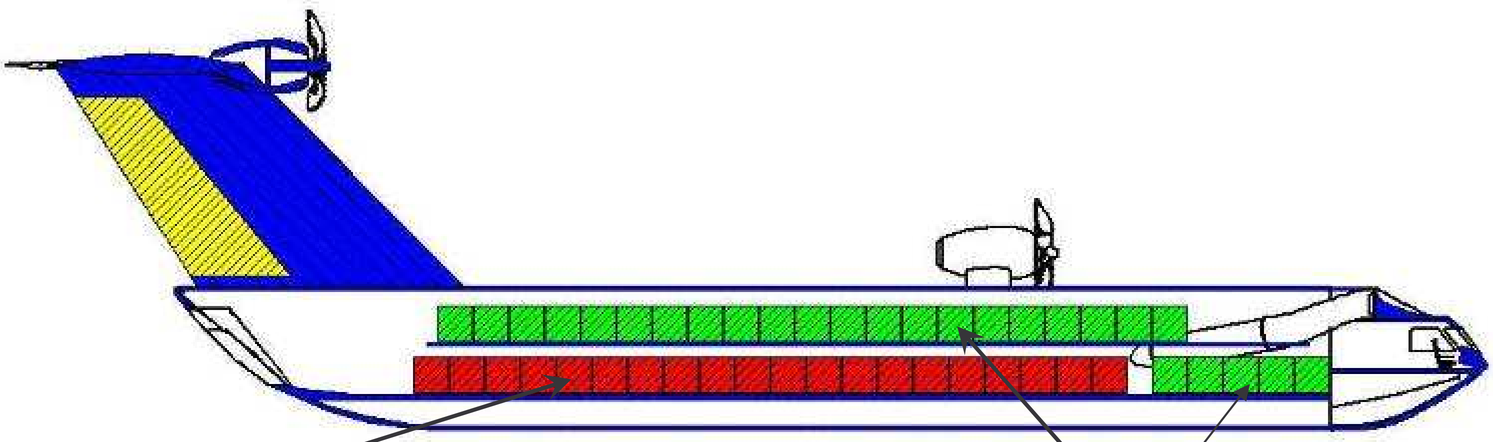
  - Double capacity relatively to the one deck configuration.
  - Structural advantage as result of strengthening of cross section by partition between two decks.

Cross-Section Shape

- **Samson cross section with containers**

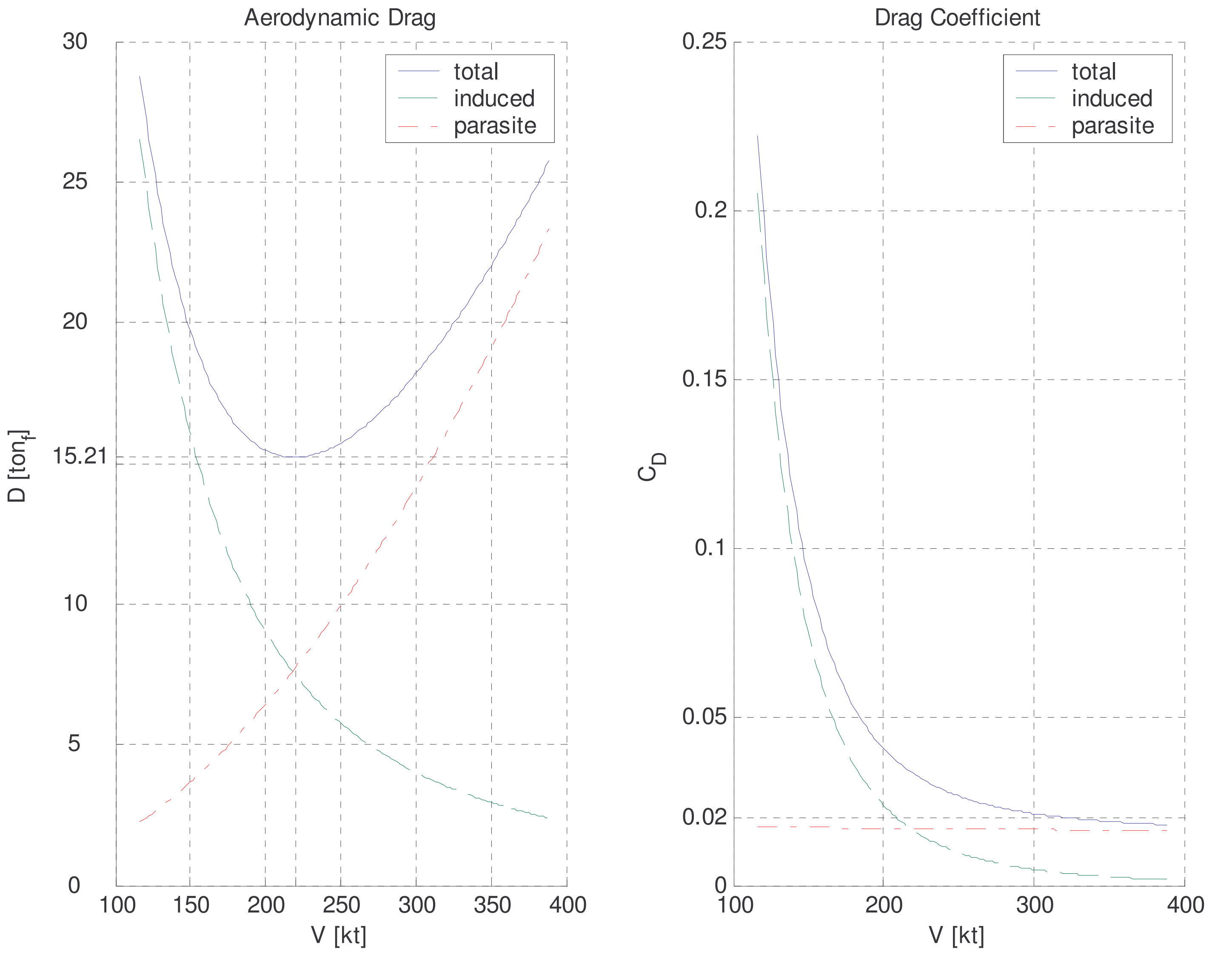


Containers arrangement

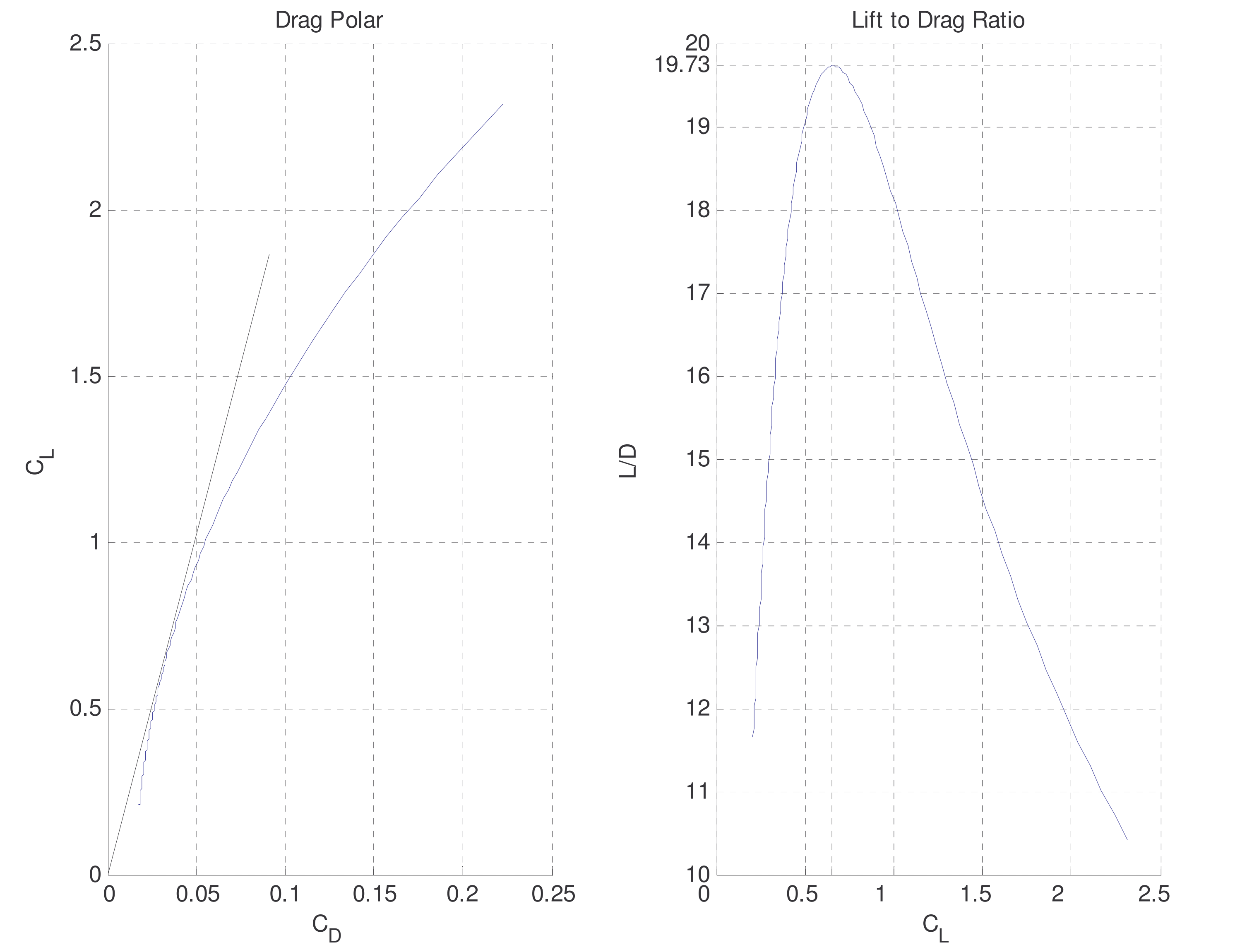


Maximum payload weight: <u>138 ton</u>

Aerodynamic Drag



Aerodynamic Drag



Take-Off Simulation

Take-Off Simulation

- <u>The importance of ekranoplan T/O analysis :</u>
  - Interaction of ekranoplan body with water during T/O.
  - Engine thrust evaluation (hydrodynamic drag consideration)

Take-Off Simulation

First approach : Hydrofoils

This concept was dropped due to:

- Enormous stresses developing in hydrofoils.
- Additional drag due to hydrofoils.

Therefore a special hydrodynamic shape was acquired to ekranoplan lower fuselage part in order to enable it to lift itself above water.

Take-Off Simulation

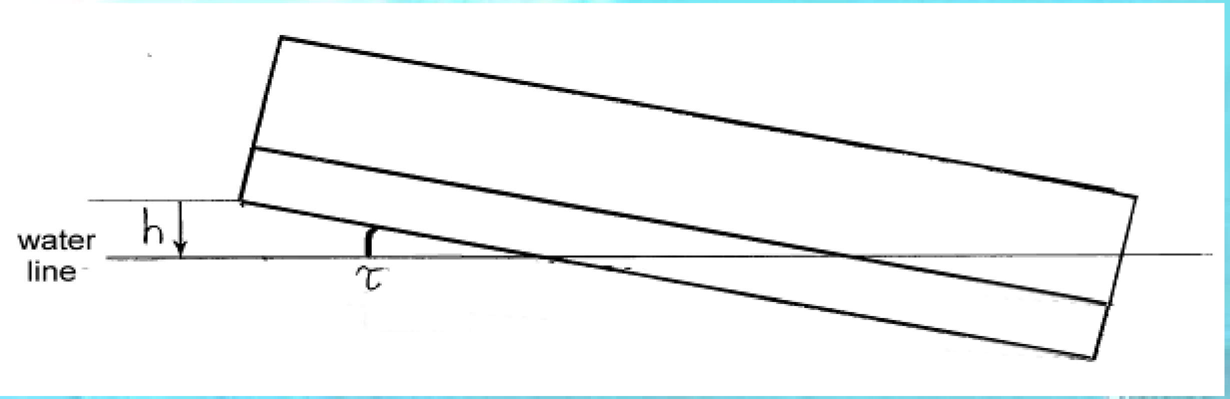
➢ <u>Hydrodynamic Forces Breakdown :</u>

- Planing force (lift + drag)
- Buoyancy force (lift)
- Shape drag
- Friction drag
- Wave/Spray drag

Take-Off Simulation

➢ Simplified ekranoplan model :

- Rectangular-shaped body with prismatic hull.
- Coordinates we have chosen :

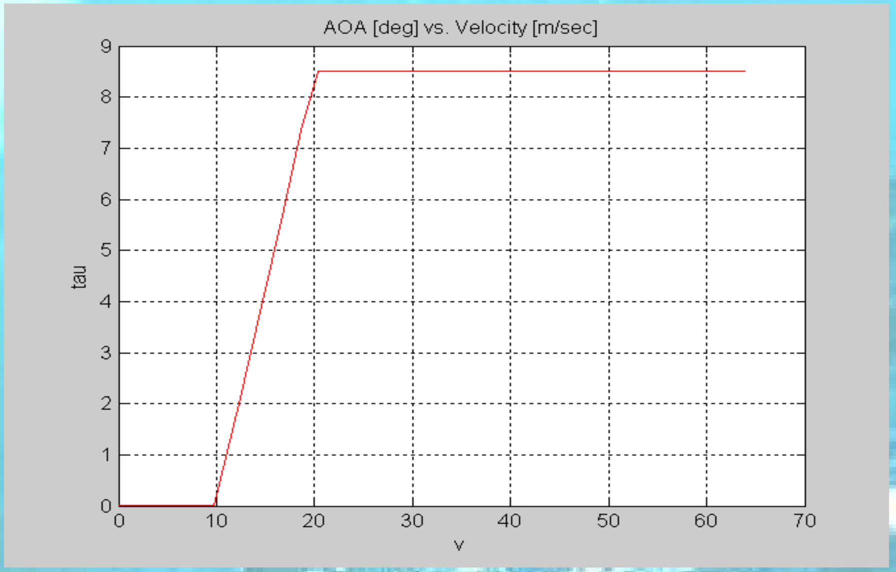


3 degrees of freedom:

- Axial movement
- h -- ekranoplan's nose lower part height relative to the water surface
- Tau -- ekranoplan's AOA in the water

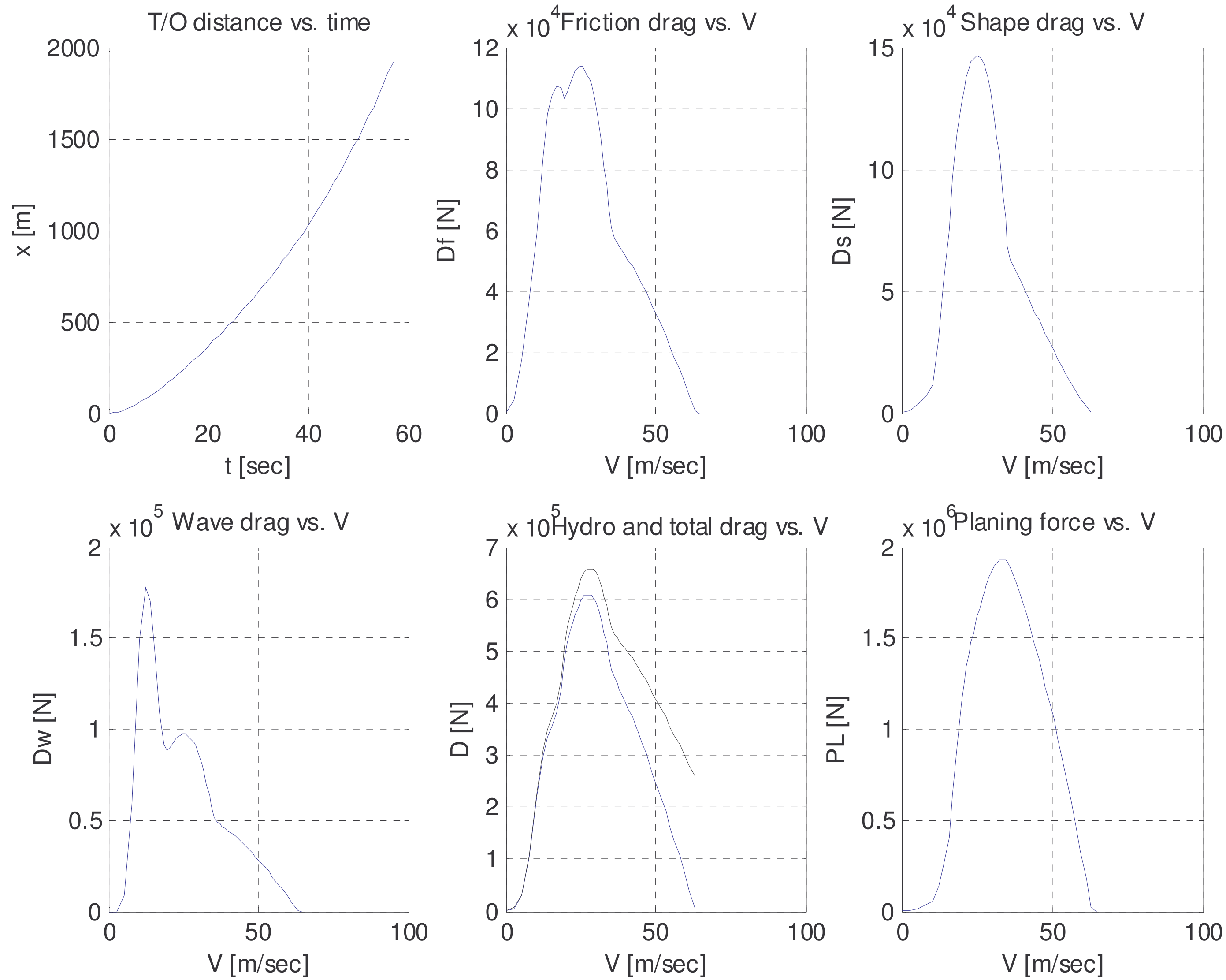
Take-Off Simulation

- Ekranoplan's angular position was defined by assuming AOA (Tau) at any instant of time in the following way :



- We obtained an optimal AOA (Tau) value that gives us minimal T/O time distance and drag.

Take-Off Simulation

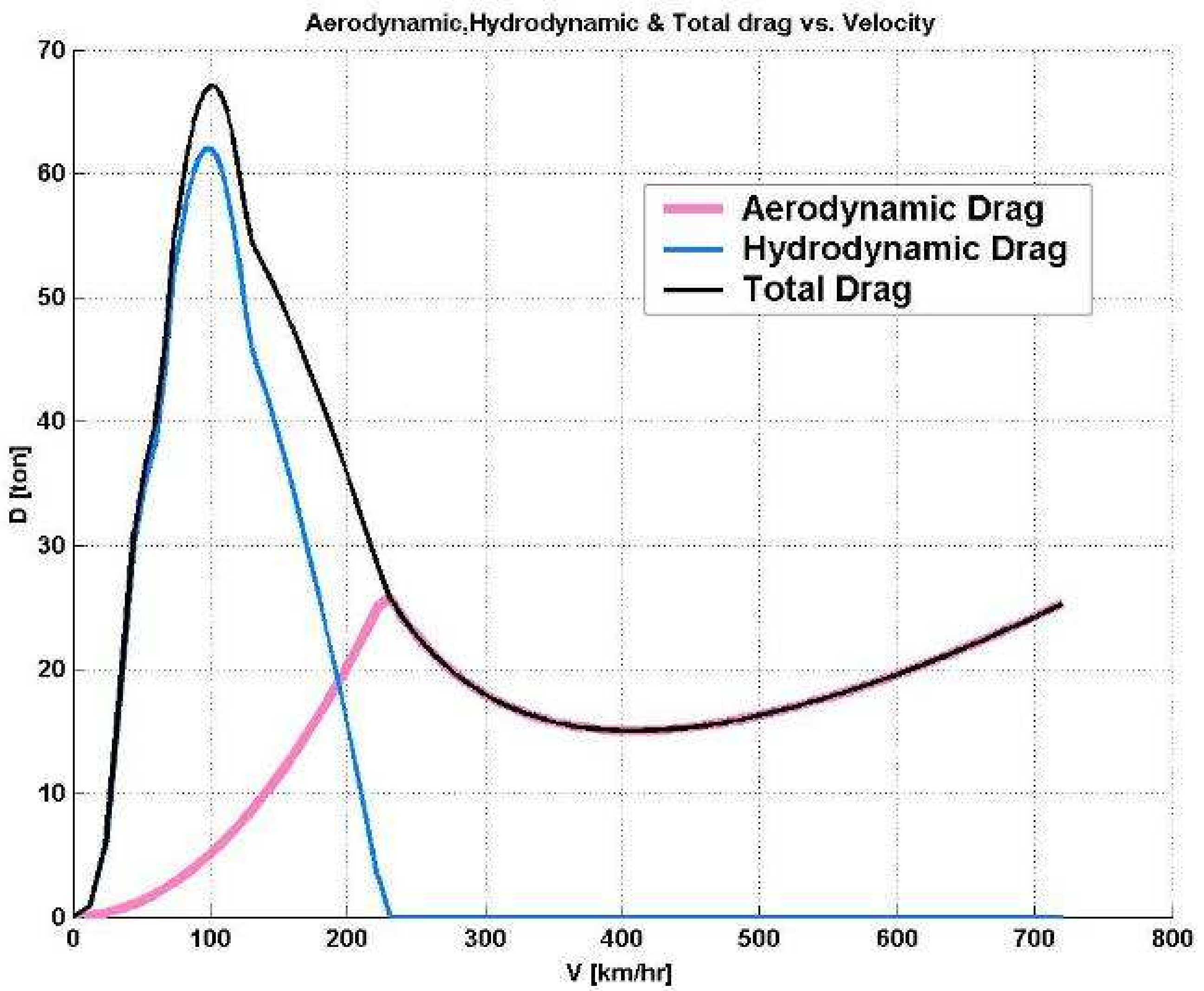


Take-Off Simulation

- We obtained that the optimal Tau value equals 8.5 deg. For this value the important T/O parameters are :
- T/O time : 57 [sec]
- T/O distance : 1920 [m]
- Maximal total drag : 67 [tonf]

Propulsion

Drag Model



Aerodynamic,Hydrodynamic & Total drag vs. Velocity
Aerodynamic Drag
Hydrodynamic Drag
Total Drag
D [ton]
V [km/hr]
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
700
800

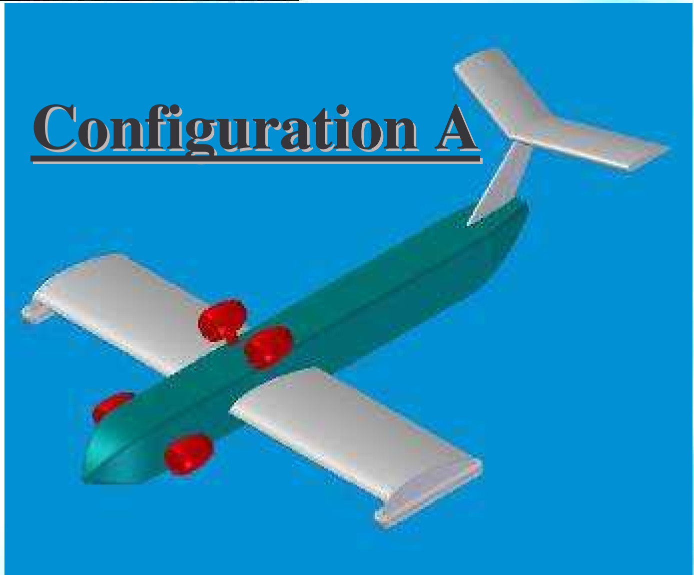
Engine location

Engines on the top:

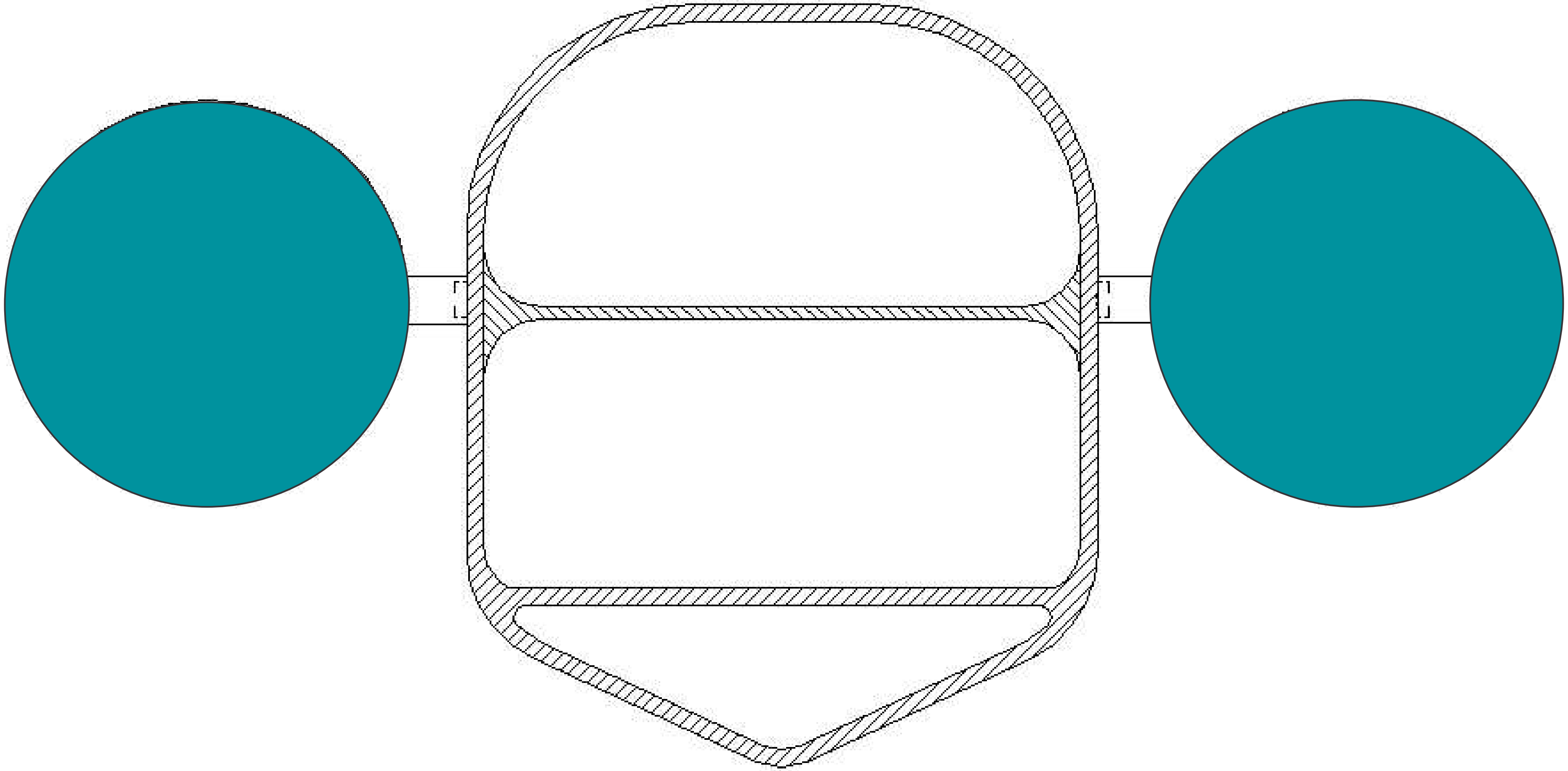
Engine on the tail:

Engines on the nose:

Engine selection



Front section with folding engines



Take off engines
(for configurations C):

HK-32

Fan diameter [m]	1.460
Length [m]	6
Dry weight [kg]	3,400
Max thrust [ton]	25(AB)
TSFC (max thrust) [kg/hr/kgf]	1.7(AB)
Cruise thrust [ton]	14
TSFC (cruise) [kg/hr/kgf]	0.72
Adjustable nozzle	+
Aircraft applications	Tu-160

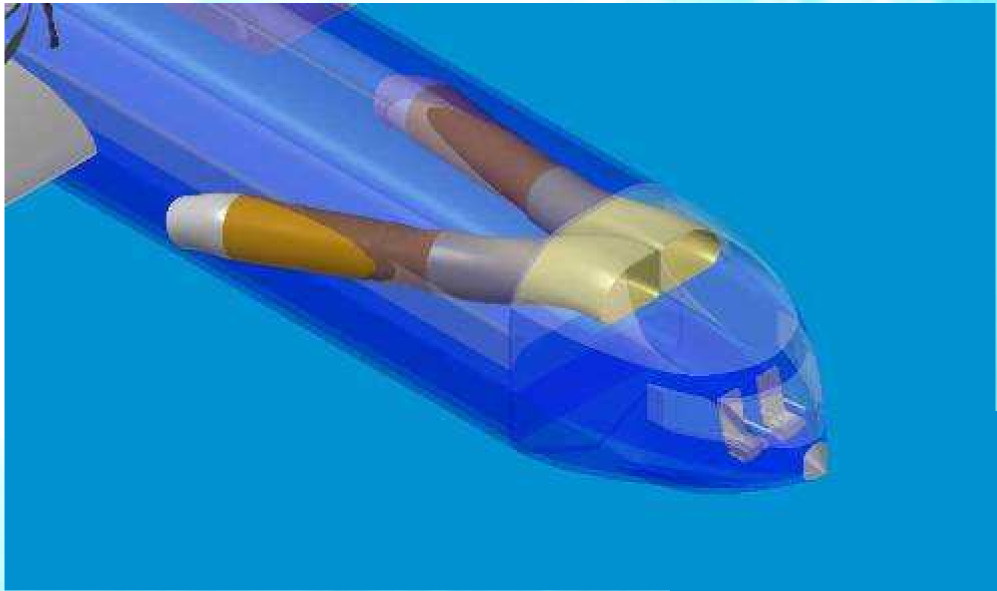
Cruising engines
(for configuration C):

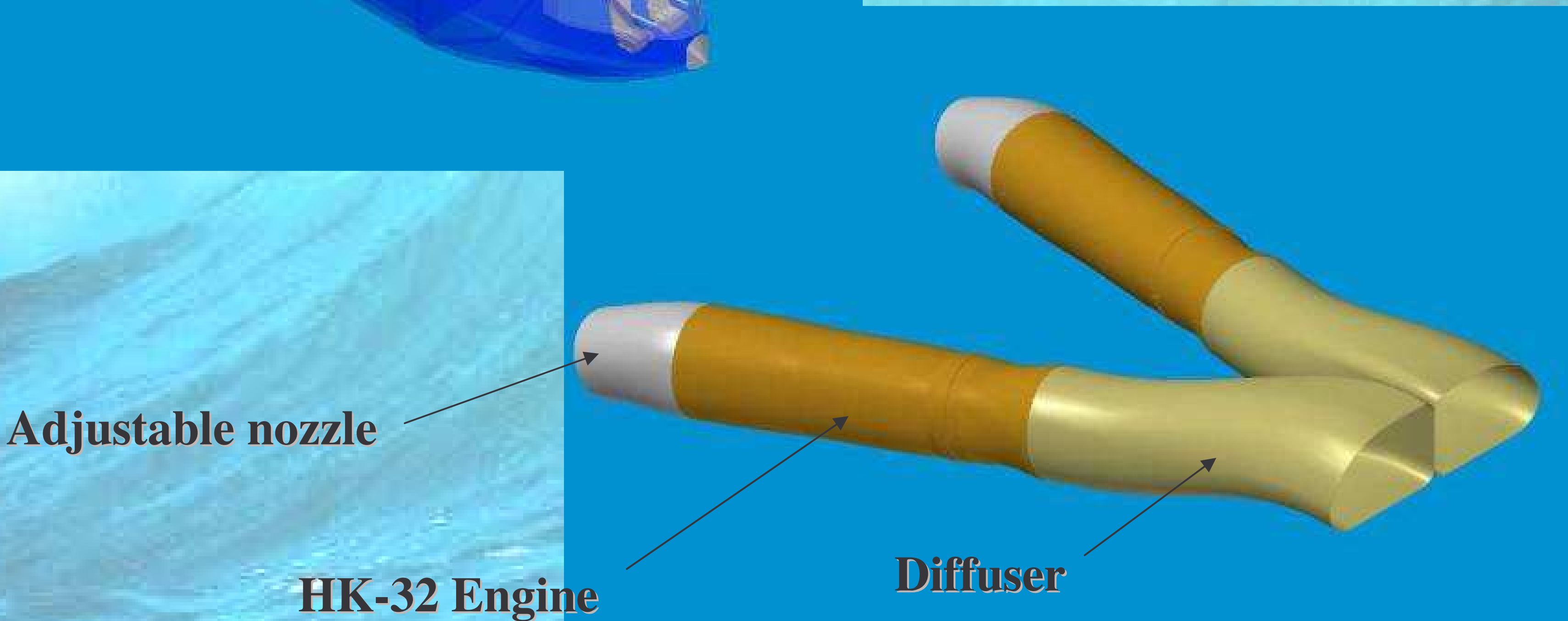
Europrop
TP400-D6

- Prop diameter: 5 [m]
- Length: 3.5 [m]
- Max power: **13,000** [SHP]
- RPMmax : 840
- Dry weight: 1,830 [kg]
- SFC : 0.17 [kg/hr/SHP]

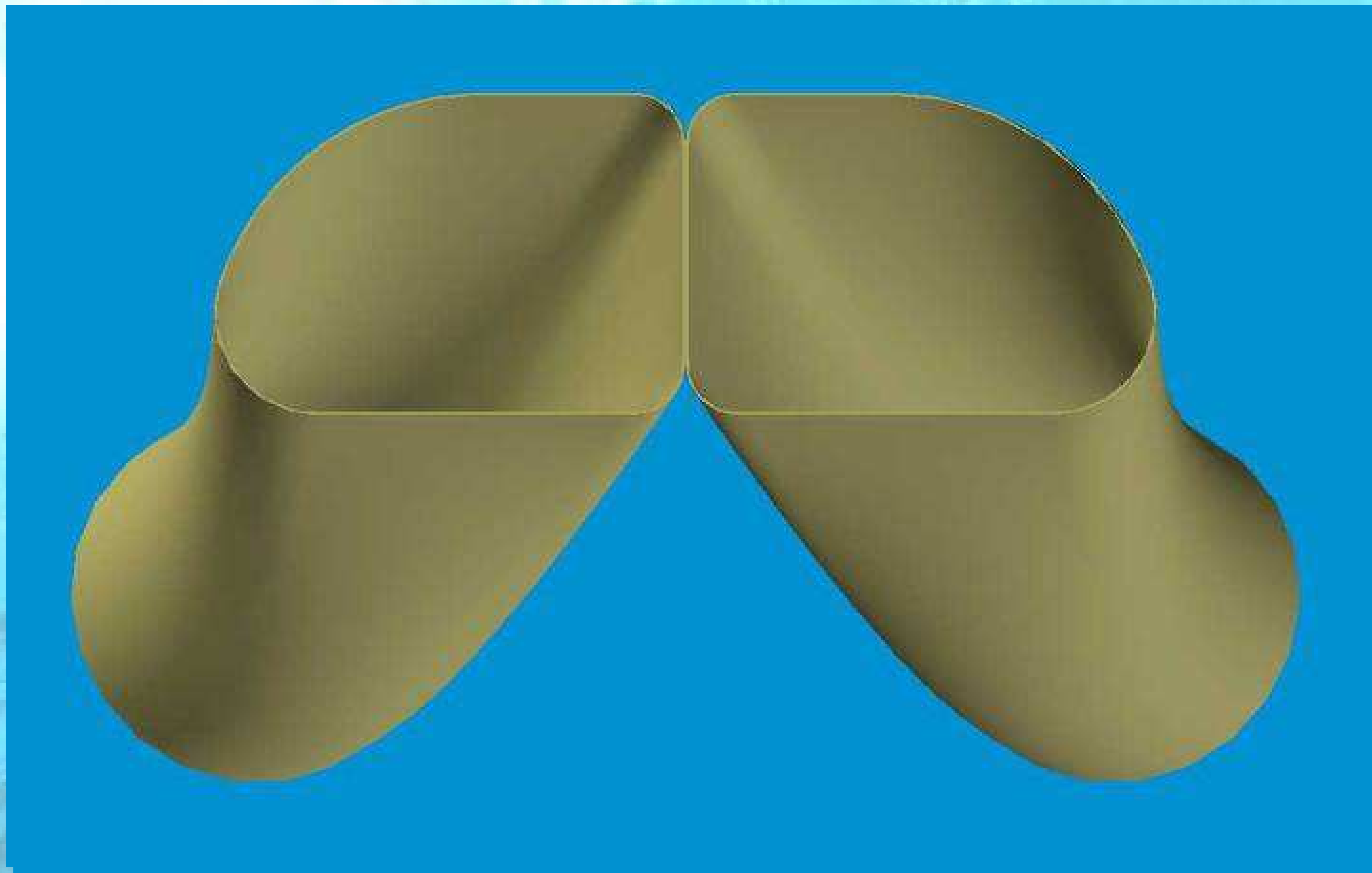
- Aircraft applications: Airbus A400M

Configuration C





Diffuser



Range calculation

Configuration	V [km/hr] ([knots])	Max Range [km] ([nm])	
A	536 (290)	2914 (1573)	@ $(D/V)_{min}$=1197 [Nt/m/sec]
B	403 (217)	5680 (3067)	@ $(L/D)_{max}$ = 19.24
C	403 (217)	5880 (3176)	@ $(L/D)_{max}$ = 19.73

$$\text{Range}_{\text{JET}} = \frac{2\sqrt{2}\cdot\sqrt{C_L}}{g\cdot TSFC\cdot C_D\cdot\sqrt{\rho\cdot S}}\cdot\left(\sqrt{W_i}-\sqrt{W_f}\right), \quad @\ TSFC, C_L = \text{Const}$$

$$\text{Range}_{\text{PROP}} = \frac{\eta_{pr}\cdot C_L}{g\cdot SFC\cdot C_D}\cdot\ln\left(\frac{W_i}{W_f}\right), \quad @\ SFC, C_L = \text{Const}$$

The main requirement is

max range ➔ Configuration C

Payload=120 ton, range = **5880** [km] (**3176** [nm])

Ranges from Haifa

City	Range [km]	Range [nm]
Antalya ✓	635	343
Istanbul ✓	1777	960
Napoli ✓	2704	1460
Venice ✓	2787	1505
Marseille ✓	3090	1669
Barcelona ✓	3455	1866
London X	6836	3691

Weight and balance

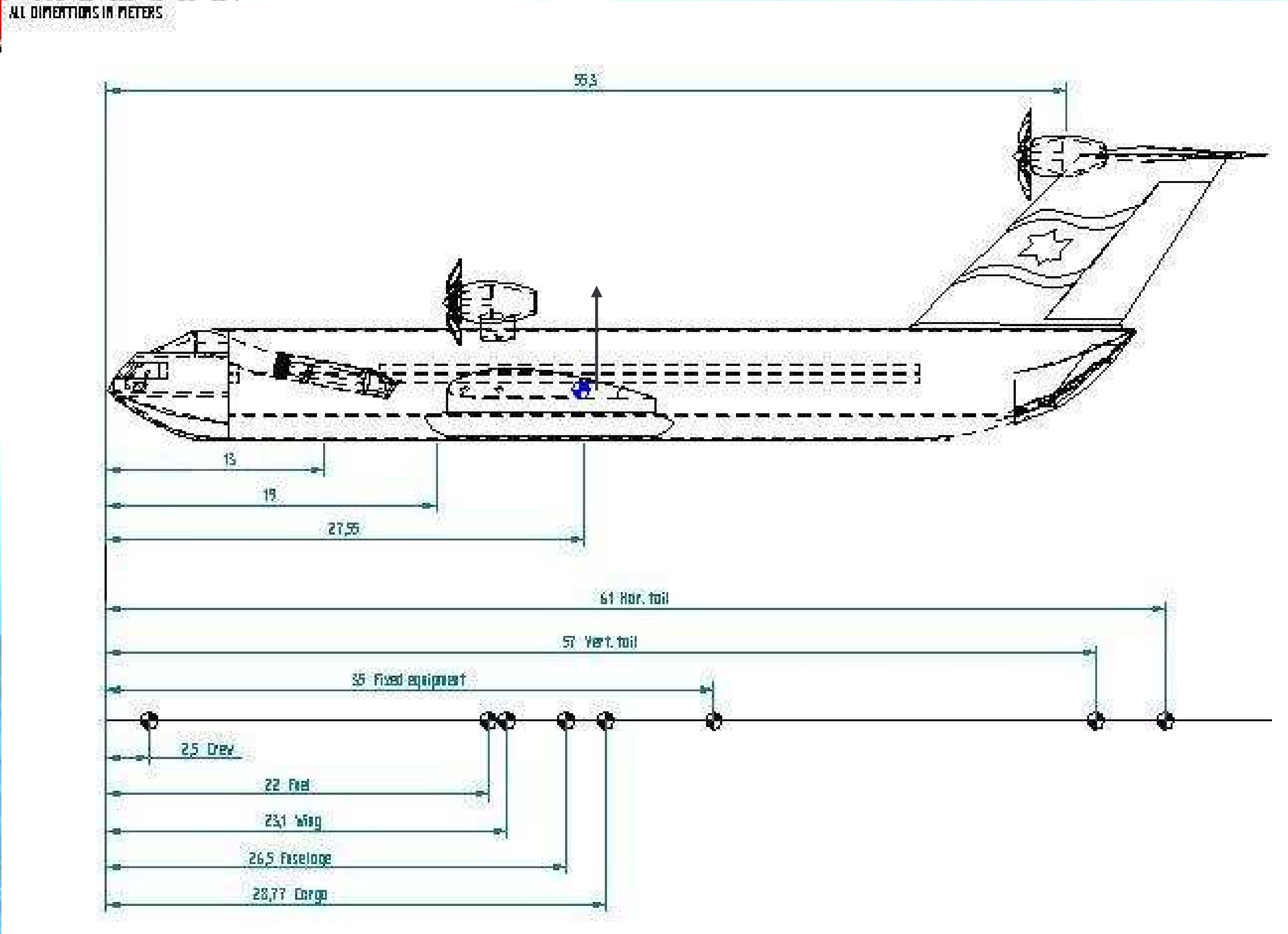
Weight estimation:

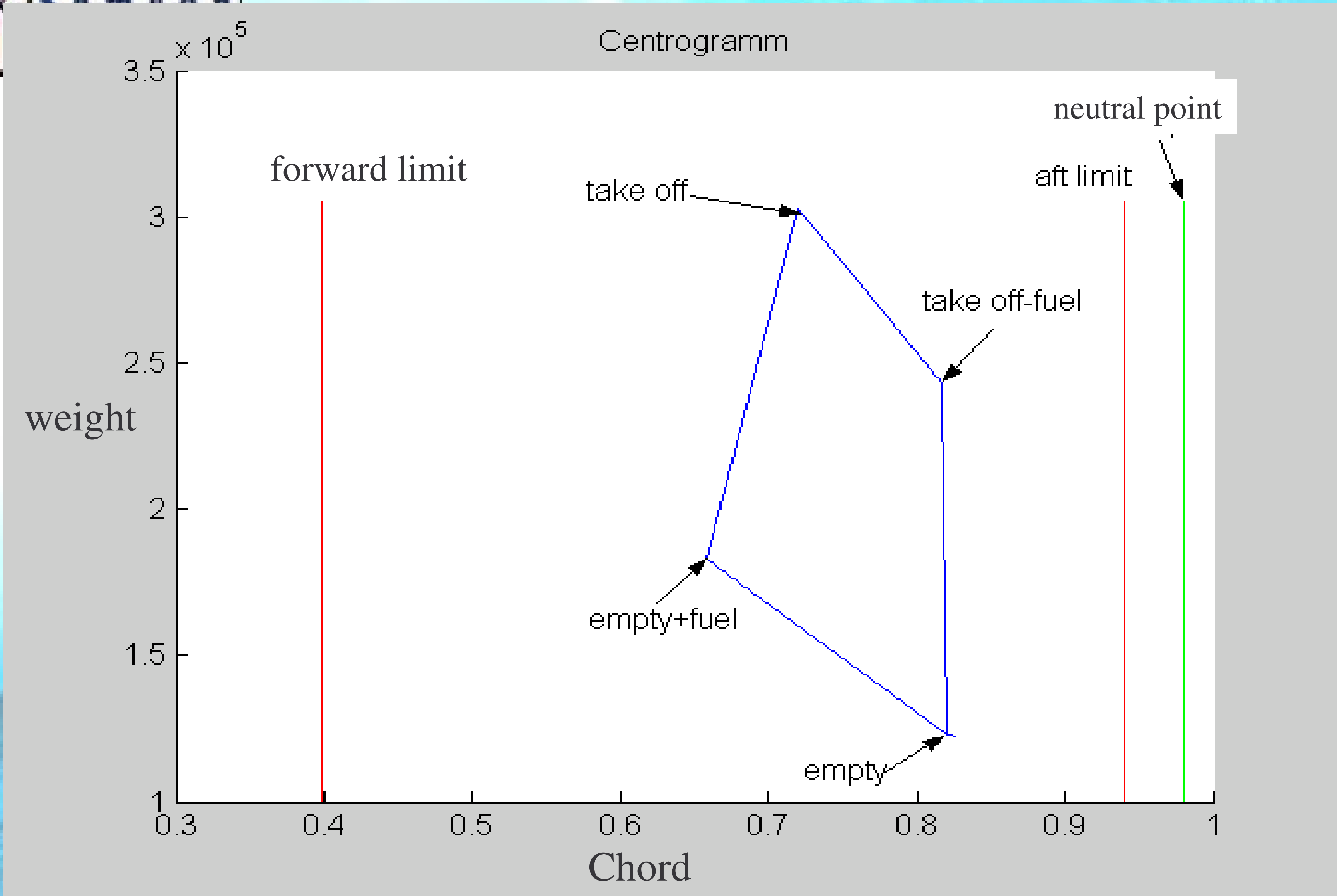
- Wing and fuselage weights were calculated on the basis of their design.
- Other component weights were estimated by statistical review of some big WIG airplanes.

The weights are:

component	Weight [Kg]	Location [m]
fuel	60000	22
wing	23000	23.1
horizontal tail	7262	61
vertical tail	3157	57
tail prop	2659	56.3
props	5317	23.1
jets	11123	10
nacelles+power plant	16742	
fixed equipment	15970	22
fuselage	43145	26.5
payload	120000	28
crew	280	2.5
TOTAL	303000	

Locations:


ALL DIMENTIONS IN METERS
55,3
13
19
27,55
61 Hor. tail
57 Vert. tail
35 Fixed equipment
2,5 Crew
22 Fuel
23,1 Wing
26,5 Fuselage
28,77 Cargo


Centrogramm
x 10^5
3.5
3
2.5
2
1.5
1
weight
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Chord
forward limit
take off
take off-fuel
aft limit
neutral point
empty+fuel
empty

Stability:

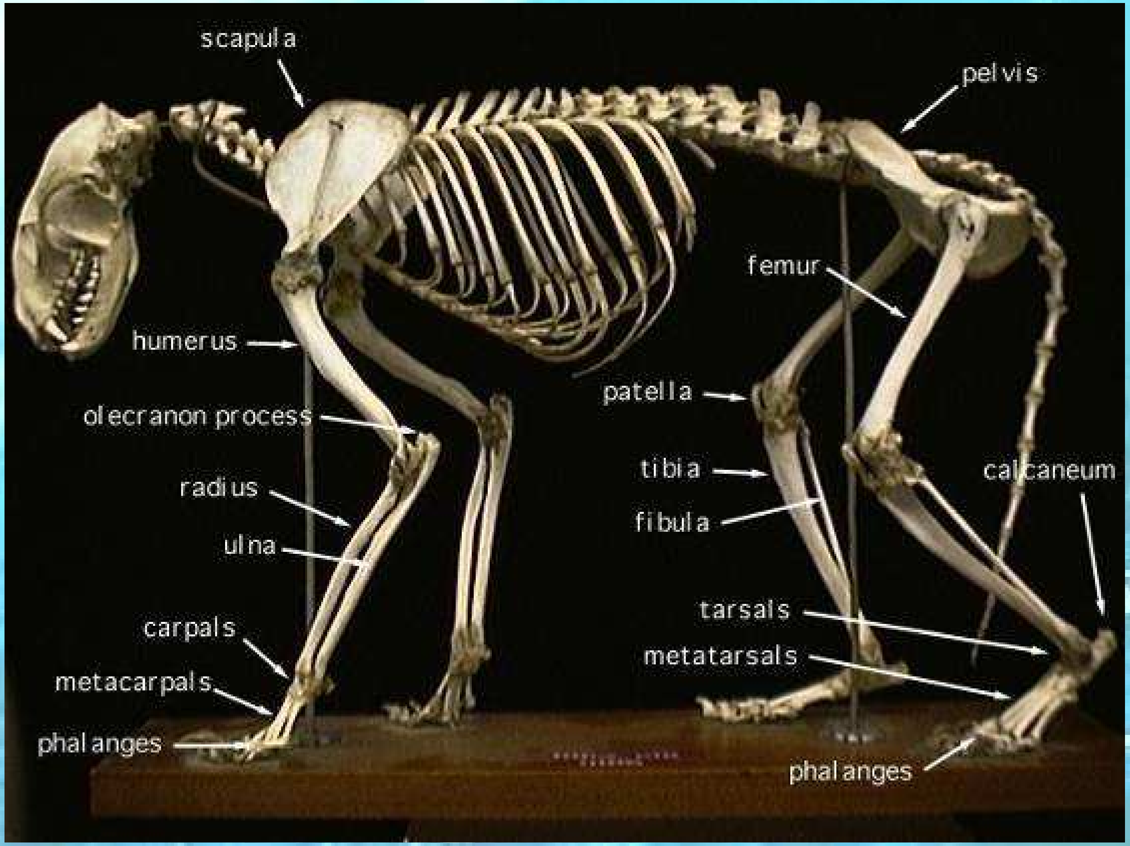
- Maximum Xcg. movment: 16.7%
- Stability range : 8%=>aft limit.
- Trimming Clmax=>forward limit.
- Influence of ground effect at height 5 meter:

  $$c_{L\alpha}(oge) = 3.85$$

  $$c_{L\alpha}(ige) = 5.68$$

- Stability was checked for all fly conditions.

Structure design

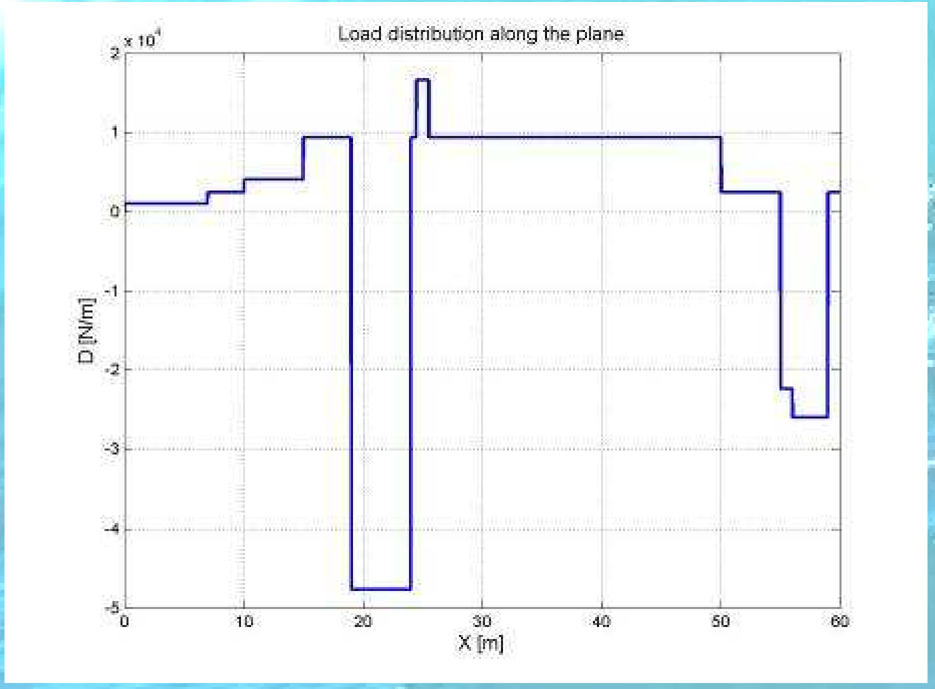


Fuselage Structure Design

- Fuselage structure design was divided into three different parts:
  1. Stringer design.
  2. Frame design.
  3. Bottom hull design.
- Each part was designed using different considerations.
- Aluminum 7075 was chosen for manufacturing of all parts.

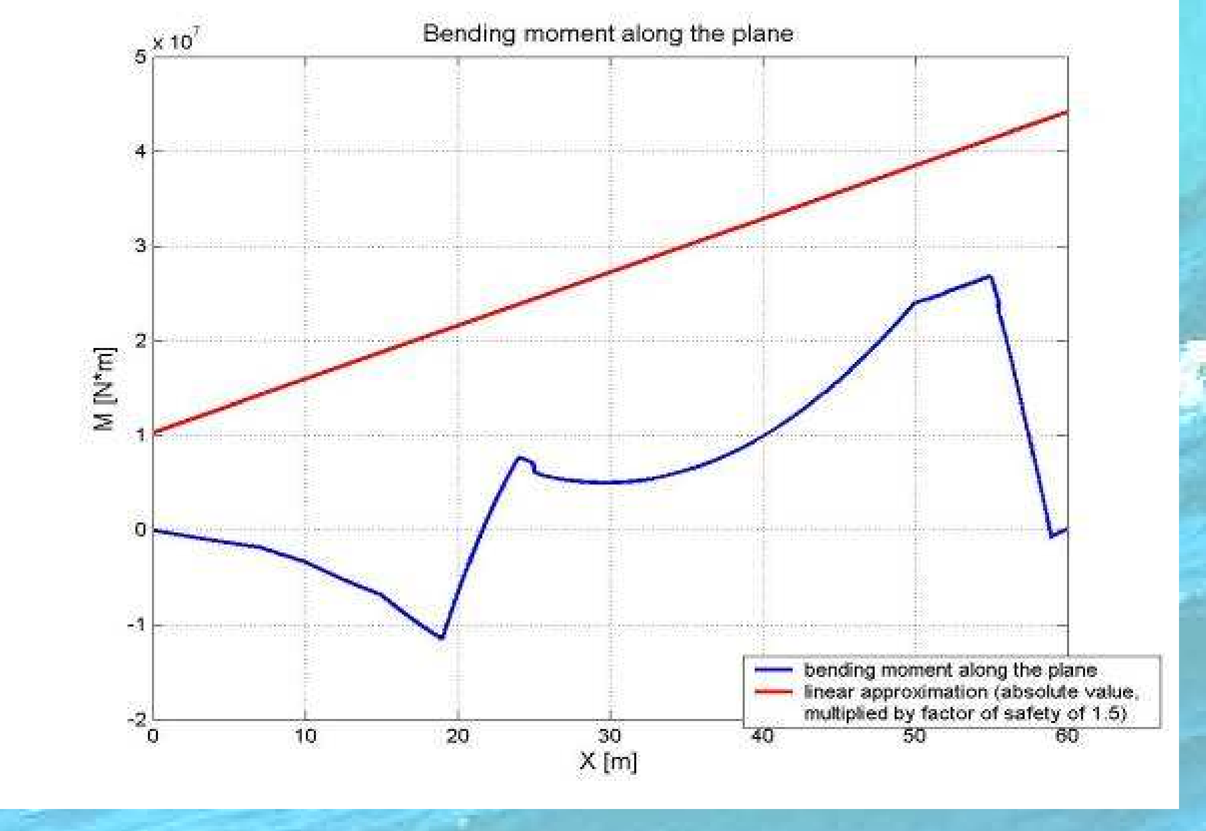
Fuselage Structure Design/Stringers

- Stringers' shape and location along the plane's outer surface is derived from bending load considerations.
- Weight distribution of every part of the plane is assumed to be constant:



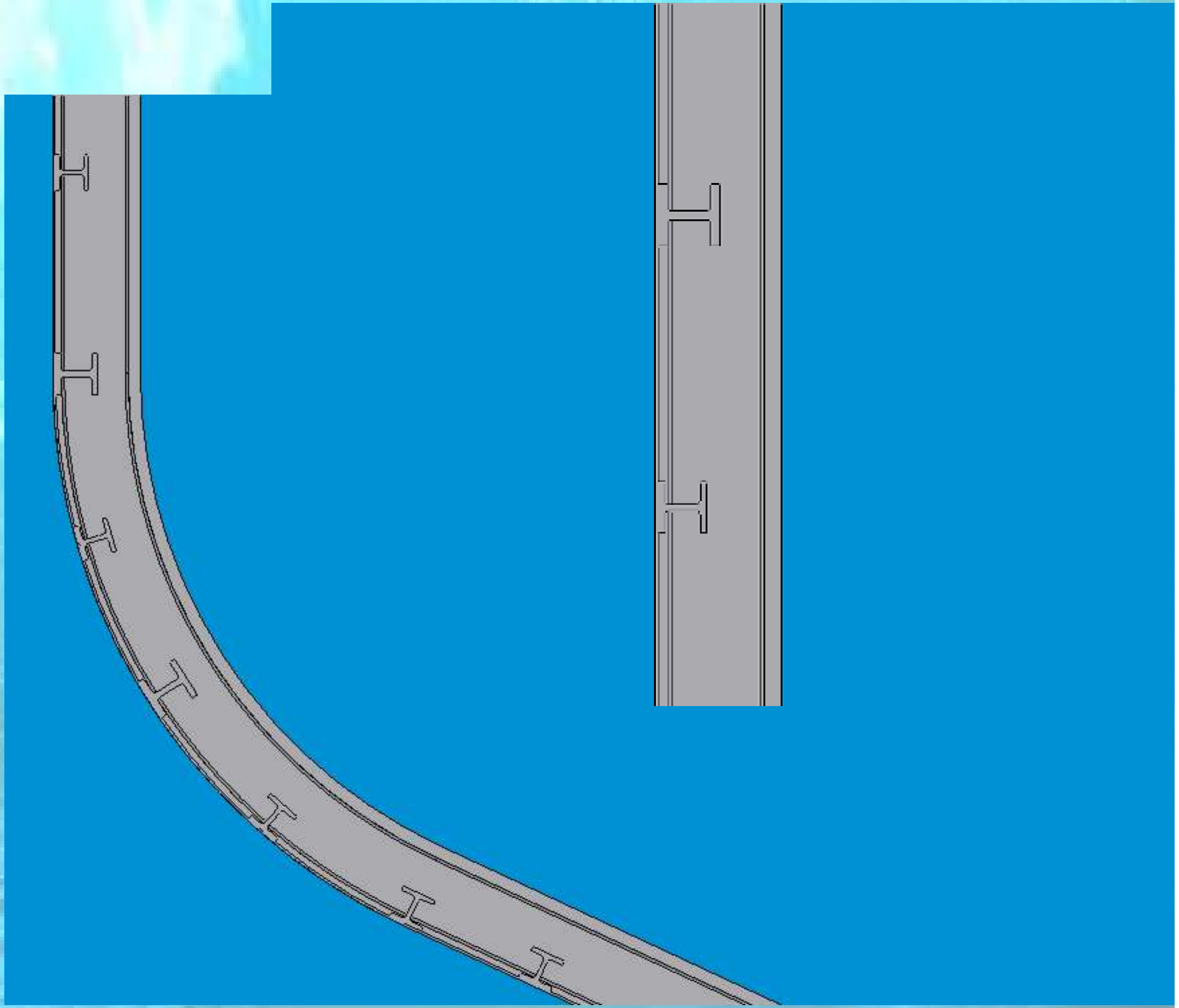
Fuselage Structure Design/Stringers

- Bending moment along the plane is obtained then by simple integration (for calculations linear approximation is used):



Fuselage Structure Design / Stringers

- Stringer arrangement that provides the needed moment of inertia

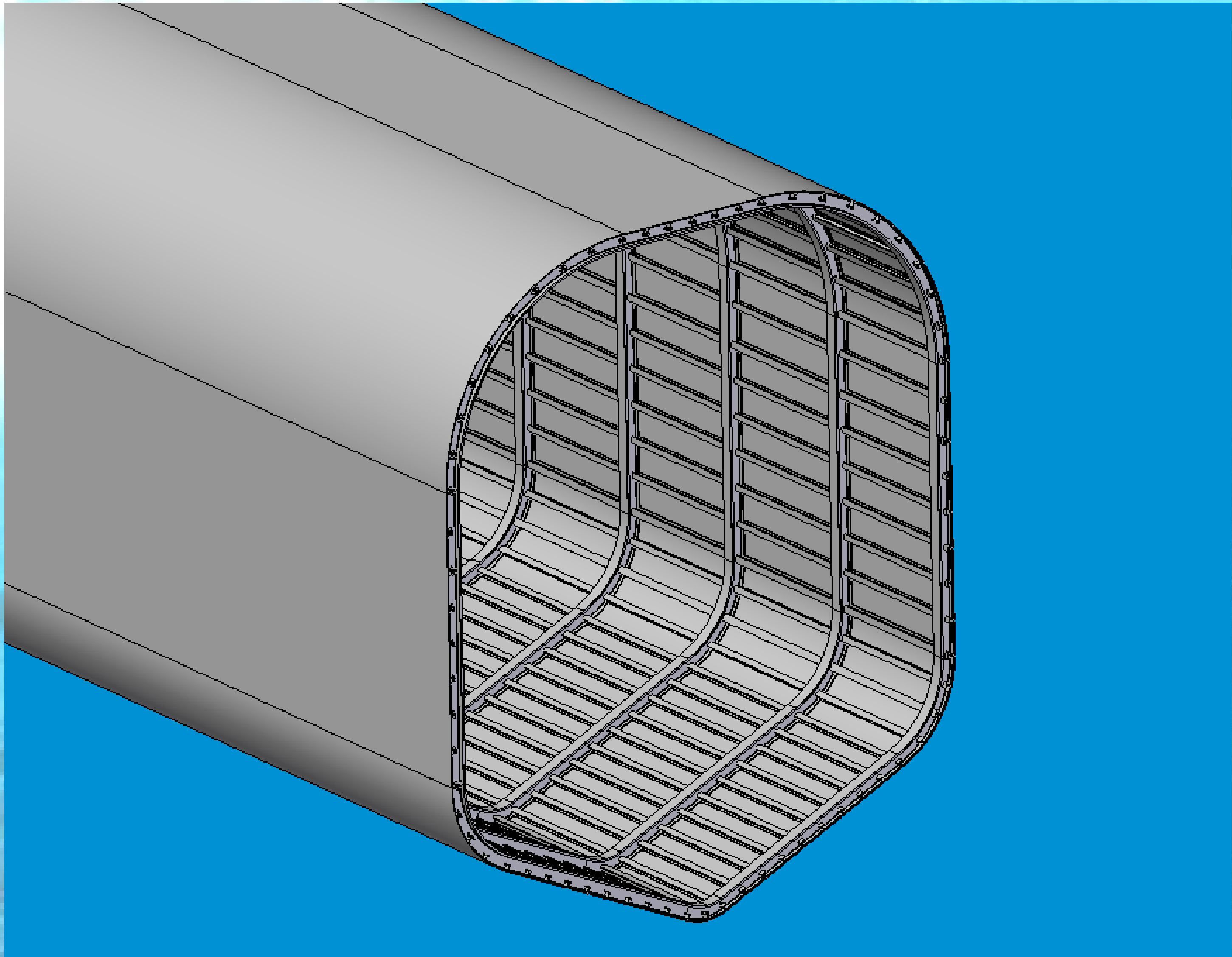


Fuselage Structure Design / Frames

- Frame shape and location along the axis of the plane are derived from buckling load considerations.

- Frame clustering in certain places of the fuselage is due to concentrated loads on the fuselage in these places (like wing-fuselage connection, etc.).

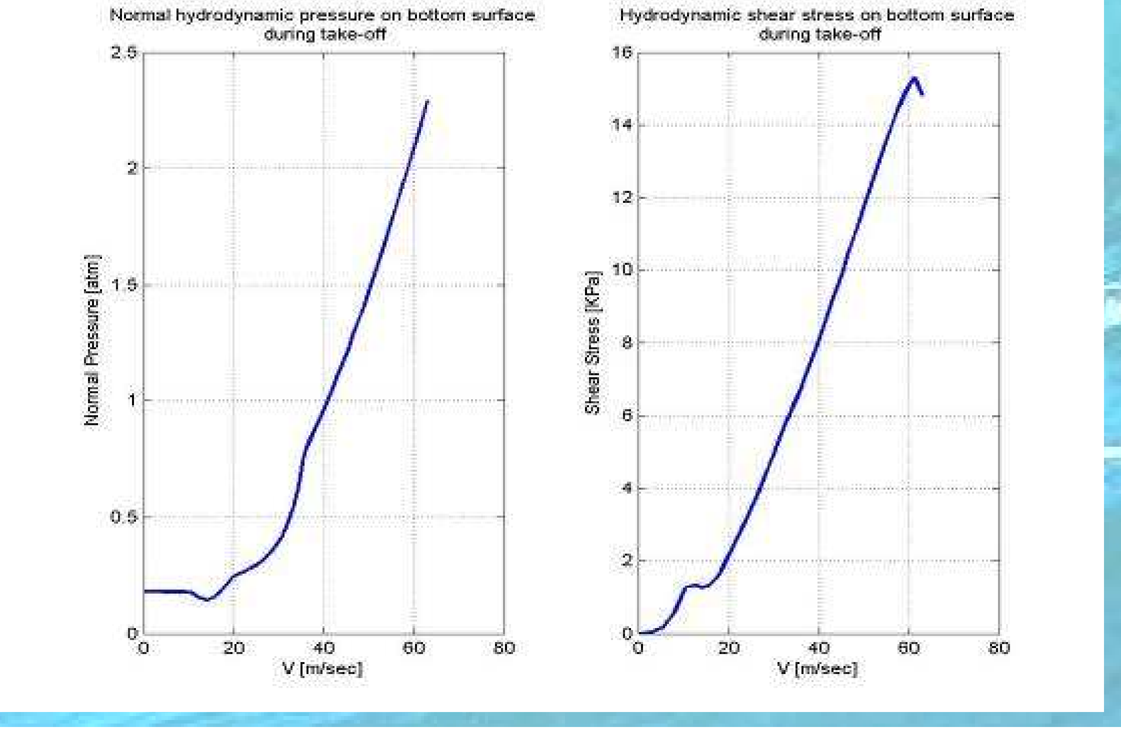
Fuselage Structure Design/Frames



Fuselage Structure Design/Frames

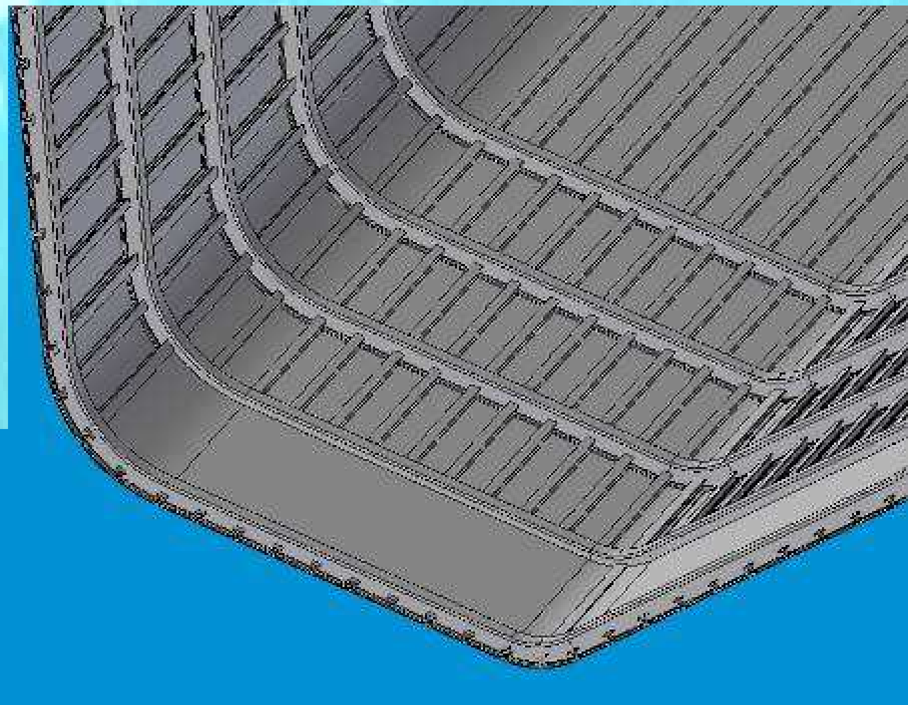
Fuselage Structure Design/Bottom Hull

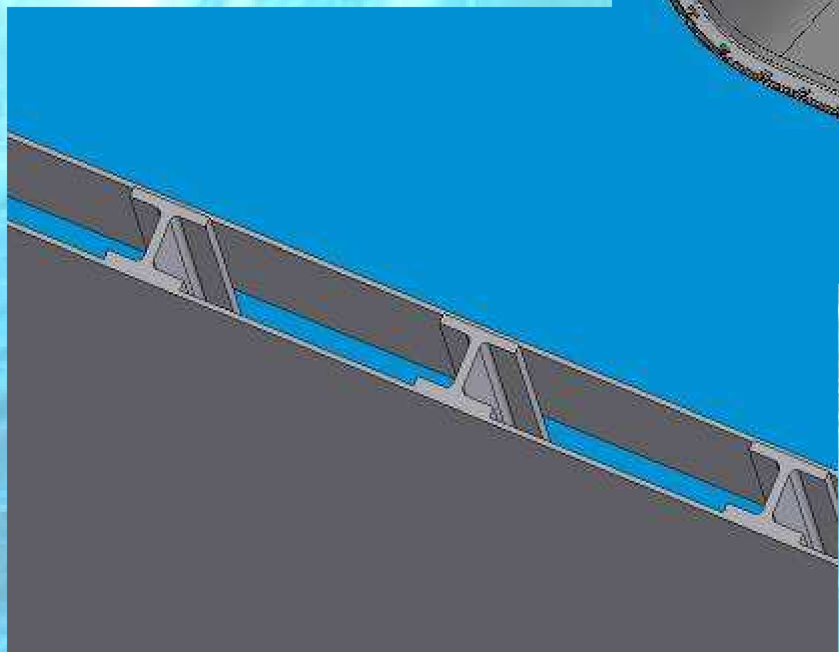
- Lower part of the fuselage (hull) is derived from the hydrodynamic loads considerations.
- During take-off the lower fuselage part is subjected to the following hydrodynamic loads:



Fuselage Structure Design/Bottom Hull

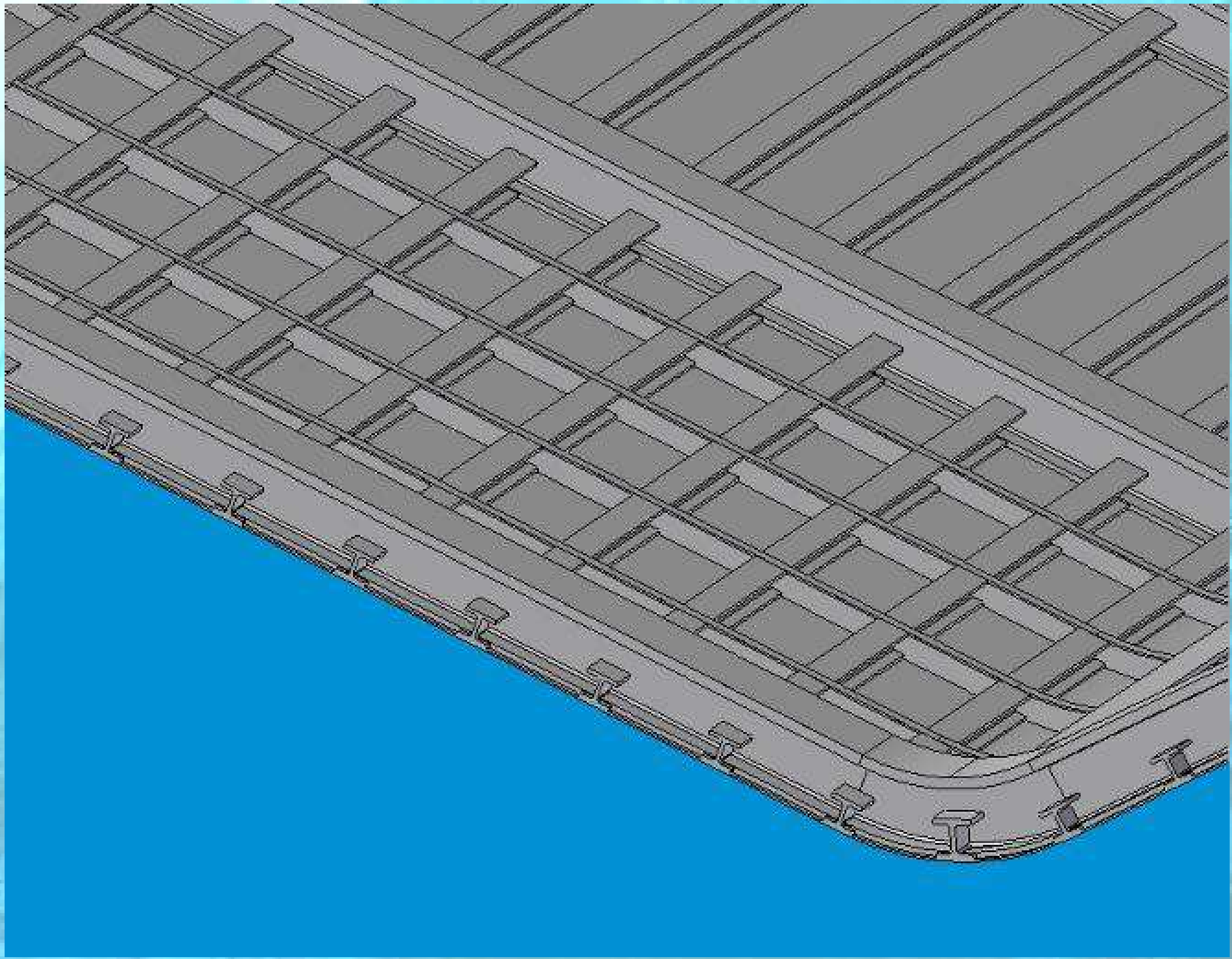
- In order to stand the hydrodynamic loads, double skin configuration was chosen for bottom hull





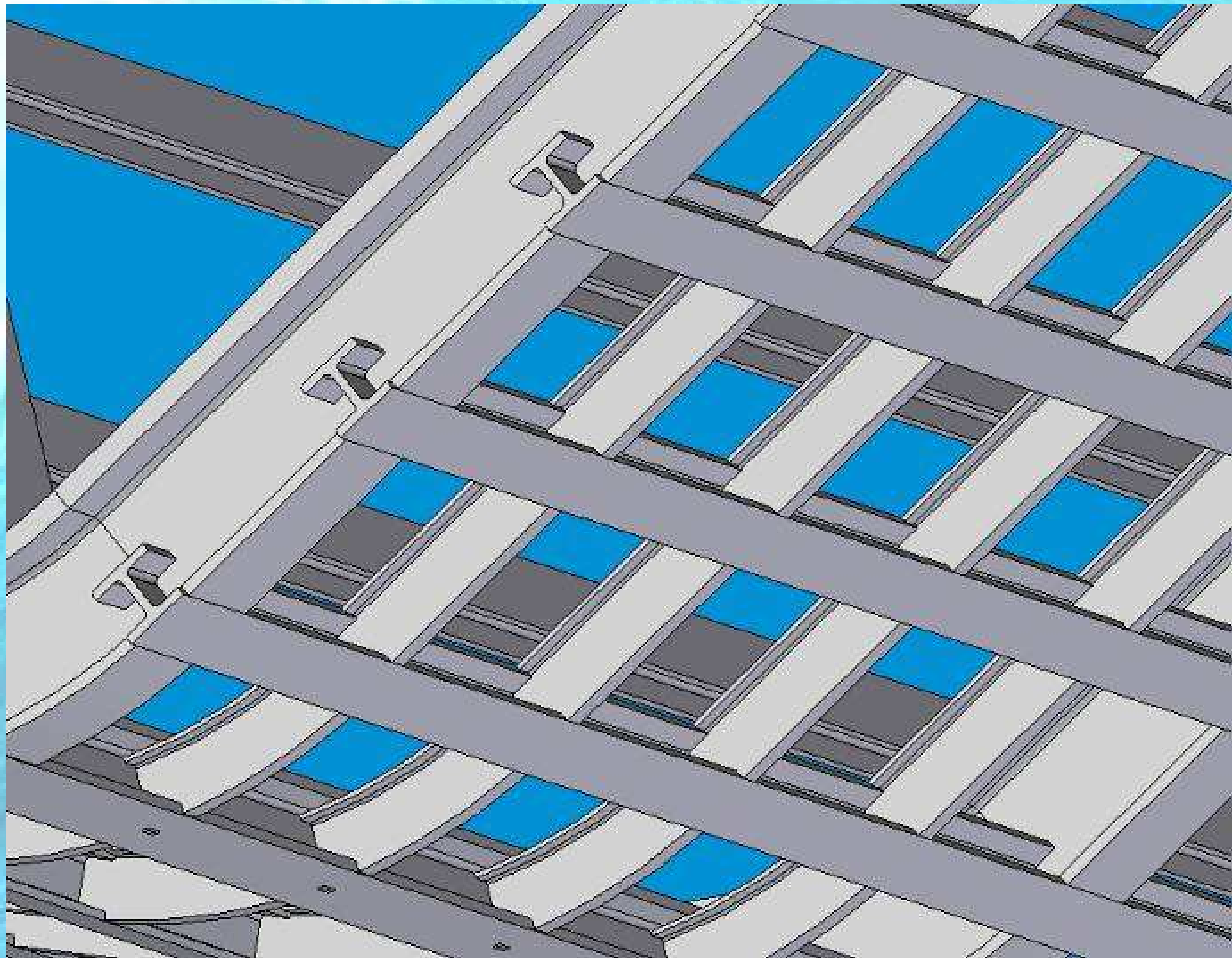
Fuselage Structure Design/Bottom Hull

- Inner skin lays upon stringers and special small bottom hull frames



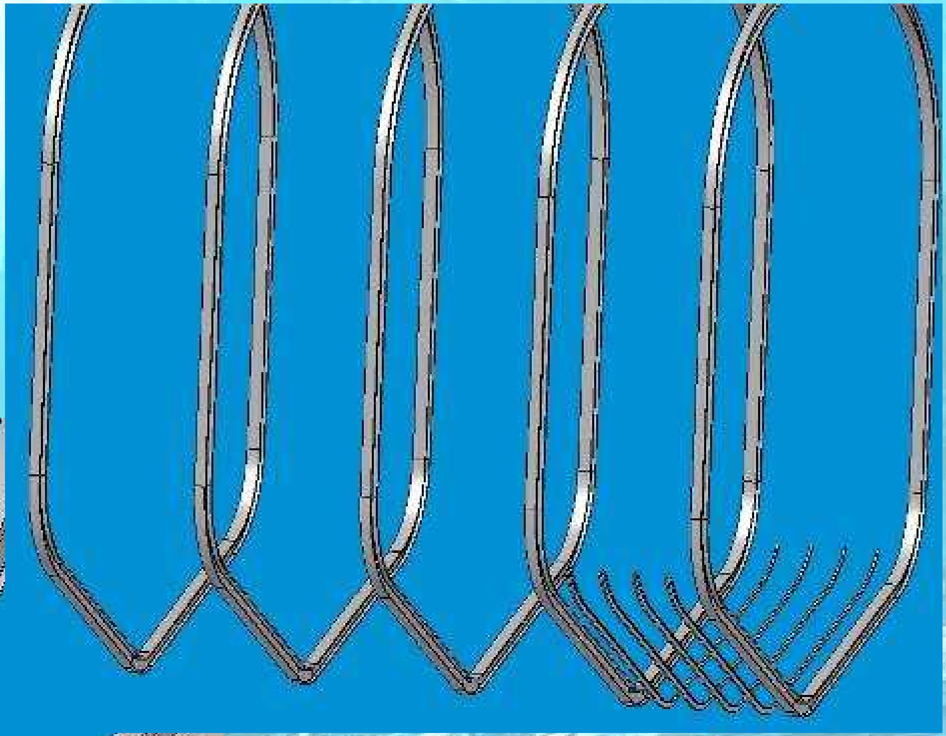
Fuselage Structure Design/Bottom Hull

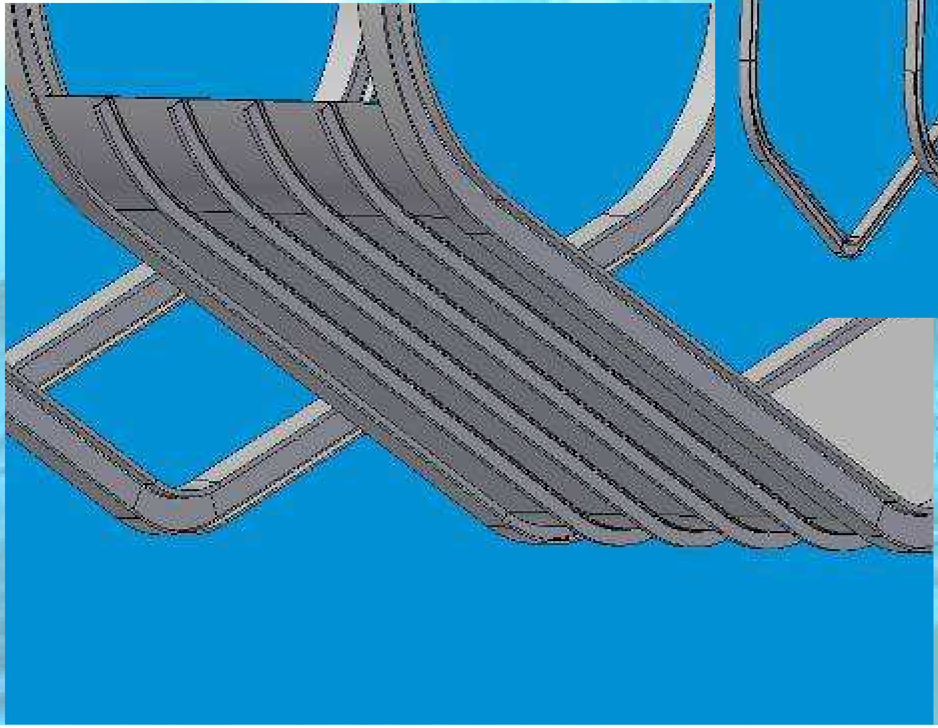
- Bottom hull frames & stringers



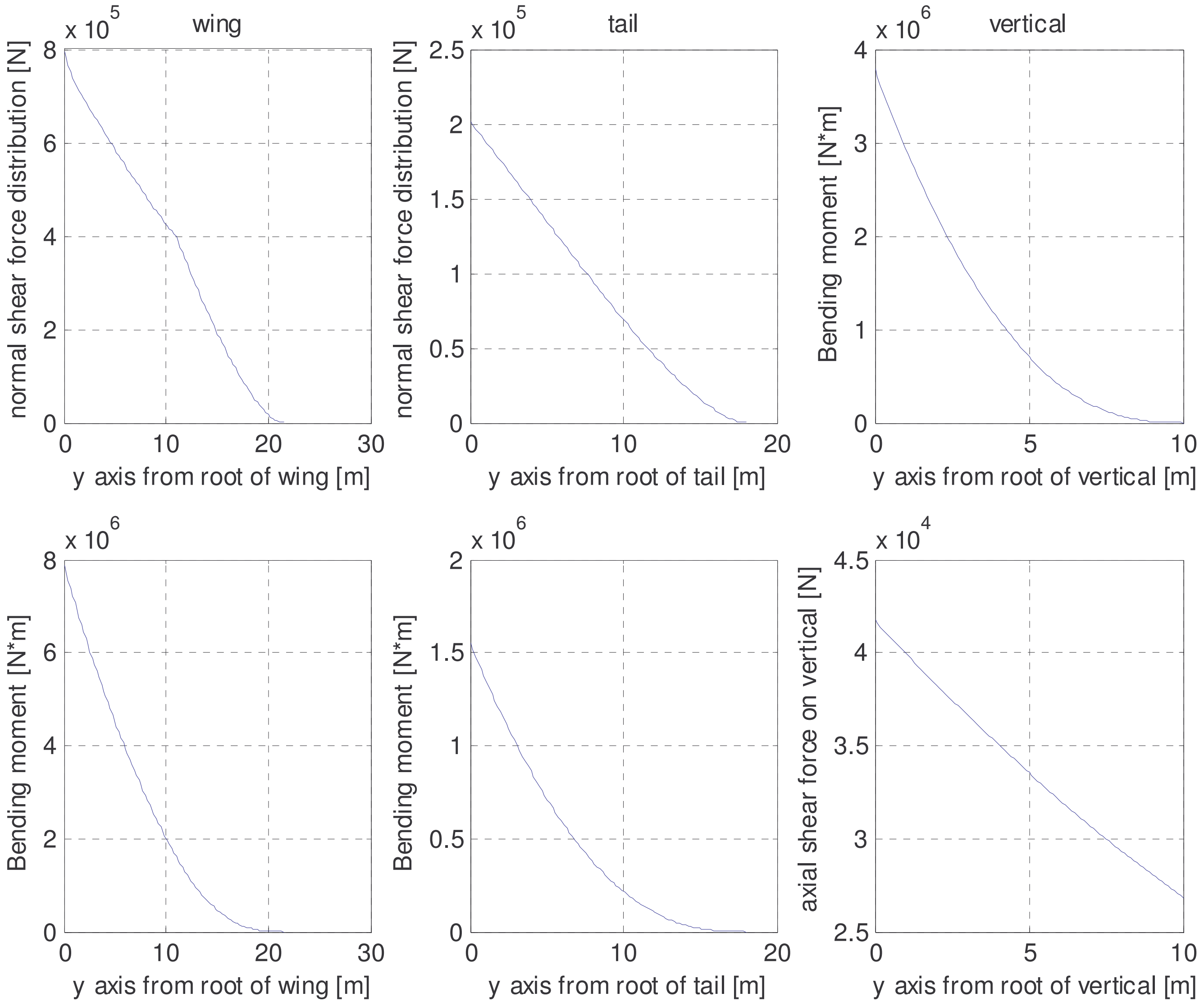
Fuselage Structure Design/Bottom Hull

- Frames & bottom hull inner skin





Forces on wing, horizontal and vertical tail



Wing Structure

- We performed preliminary design of wing structure
- Basic features:
  - Cantilever
  - Multispar
  - Construction material: Al 7075 T6
  - Uses integral machined or extruded elements
  - Will contain integral fuel tanks

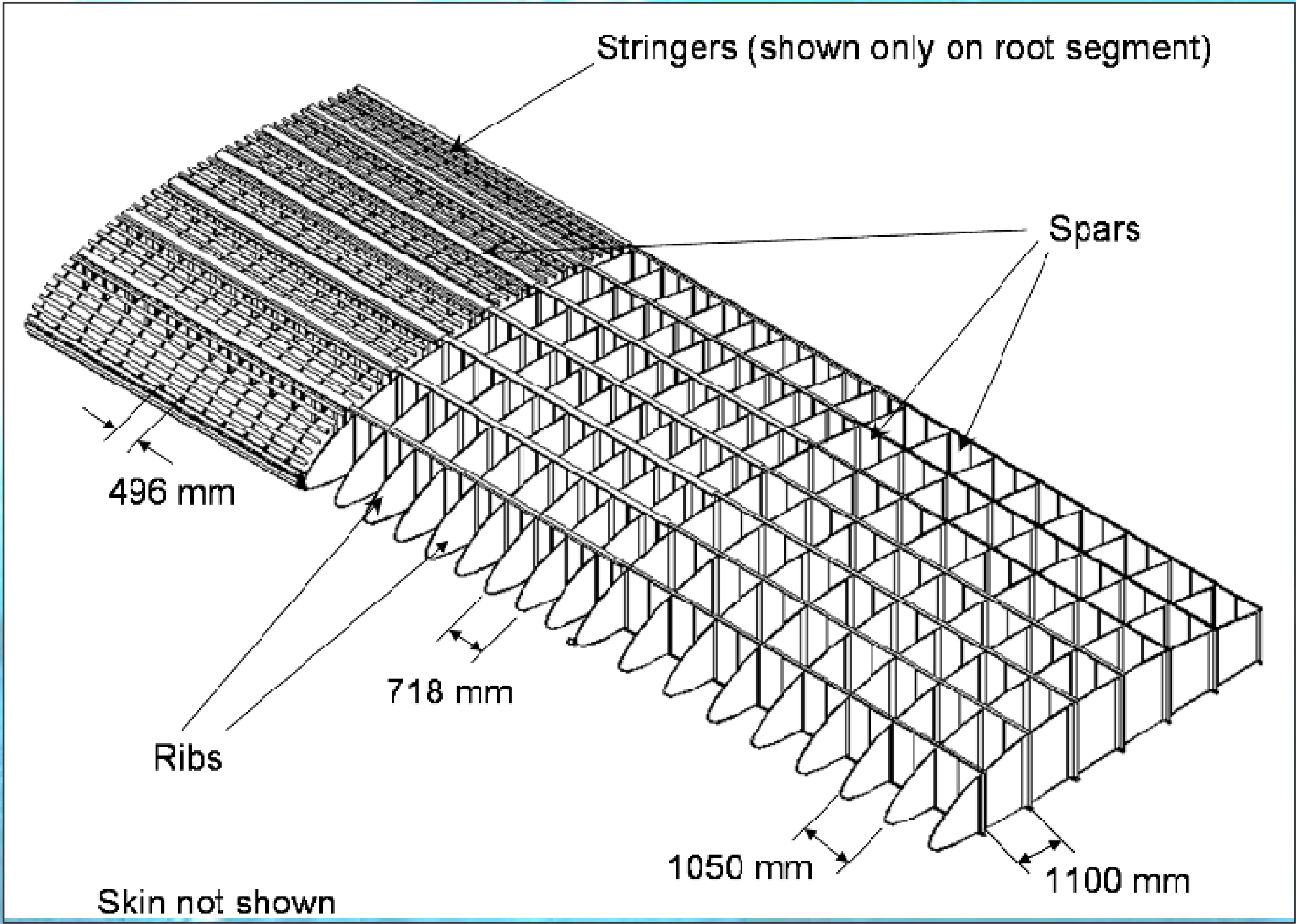
Wing Structure

- Initial sizing was based on approximate stress calculations
- Load cases considered:

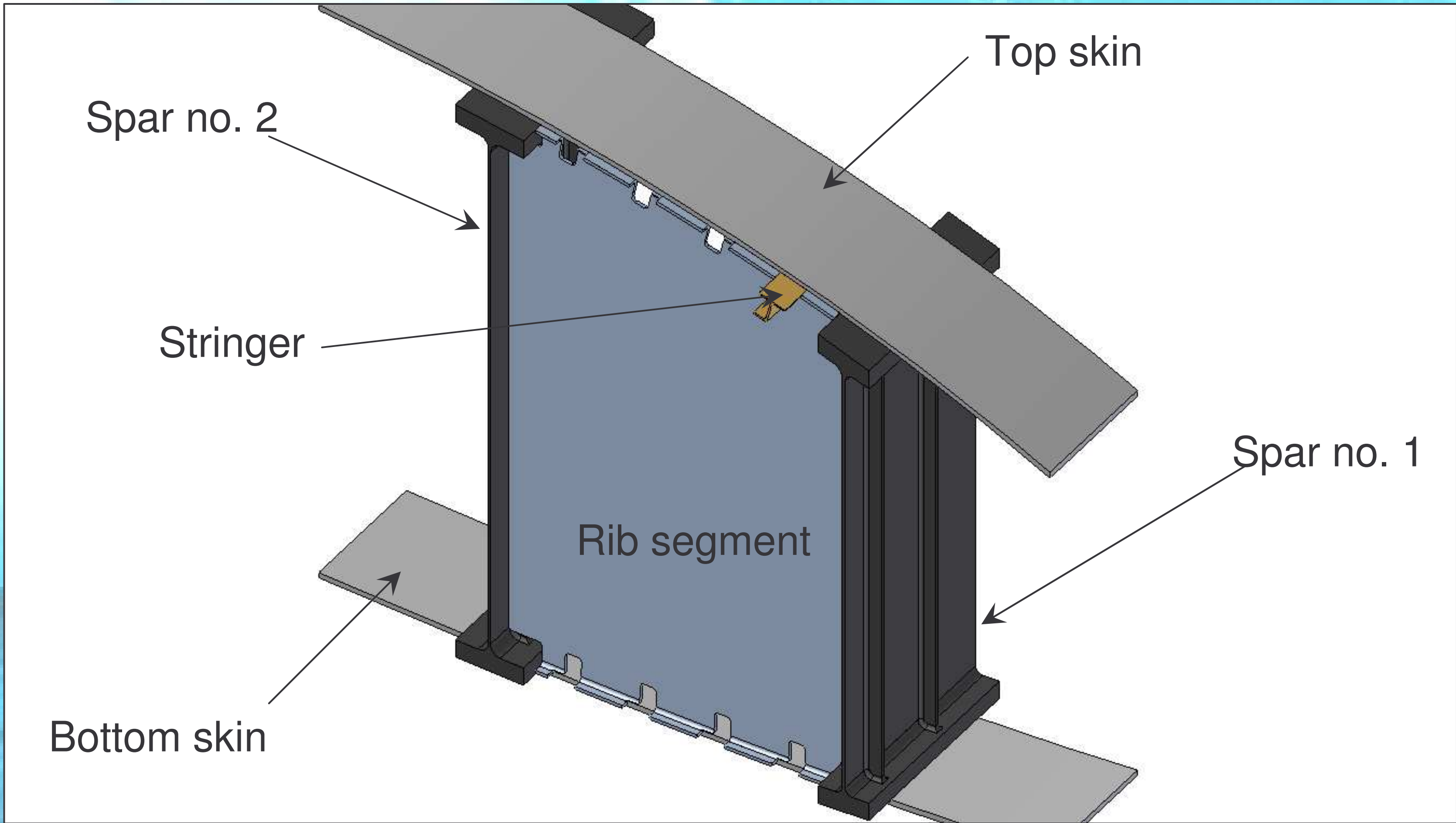
  V = 60÷140m/s
  n_z = -1÷2.5
  Fuel: 0÷110 ton
  Max. takeoff weight

- Safety factor: 1.5
- Direct stresses are carried by 7 spars, skin and stringers
- Shear stresses are carried by spar webs and skin
- Stringer and rib spacing is driven by skin stability considerations

Wing Structure Arrangement



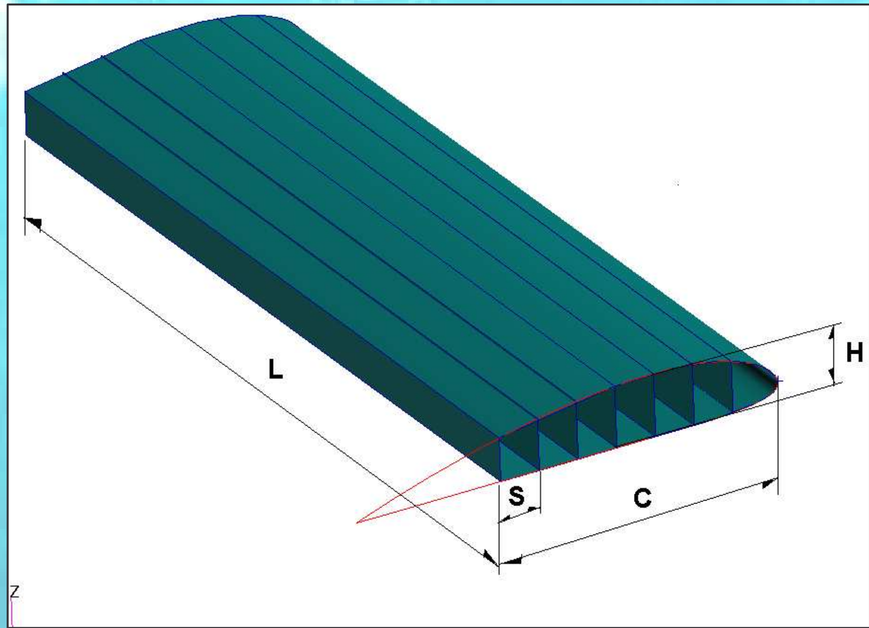
Wing Structure Arrangement

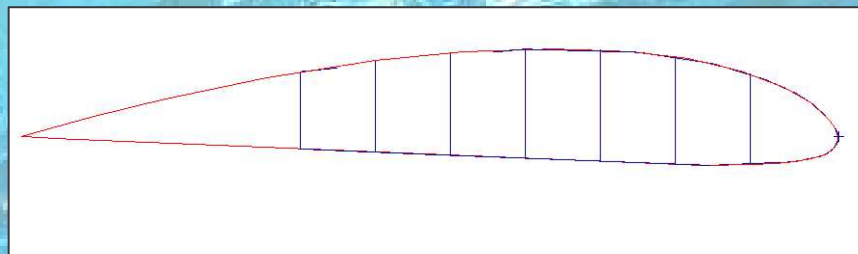


Wing Structure: FE Analysis

- Done using MSC Patran/Nastran
- Special thanks to Shabtai Temoraz, IAI for assistance
- Basic geometry:

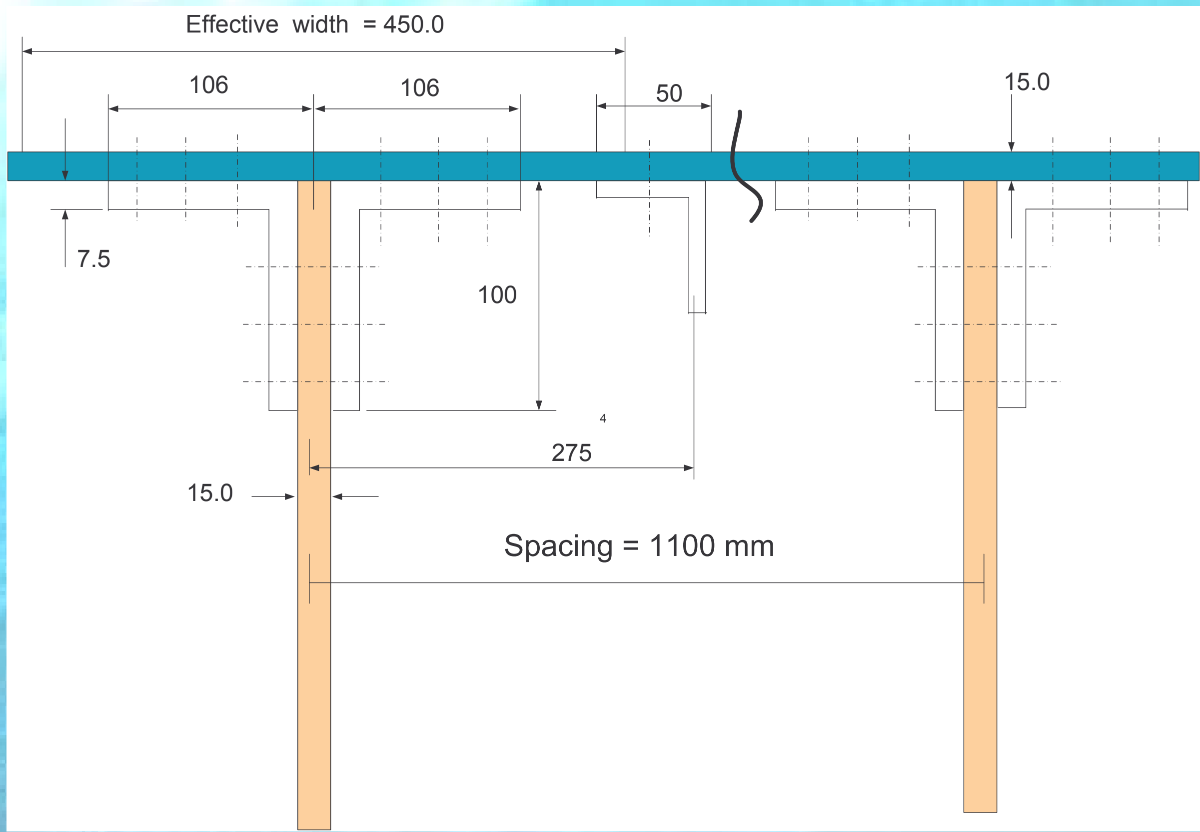
L =	21000	mm
C =	7918	mm
H =	1638	mm
S =	1100	mm



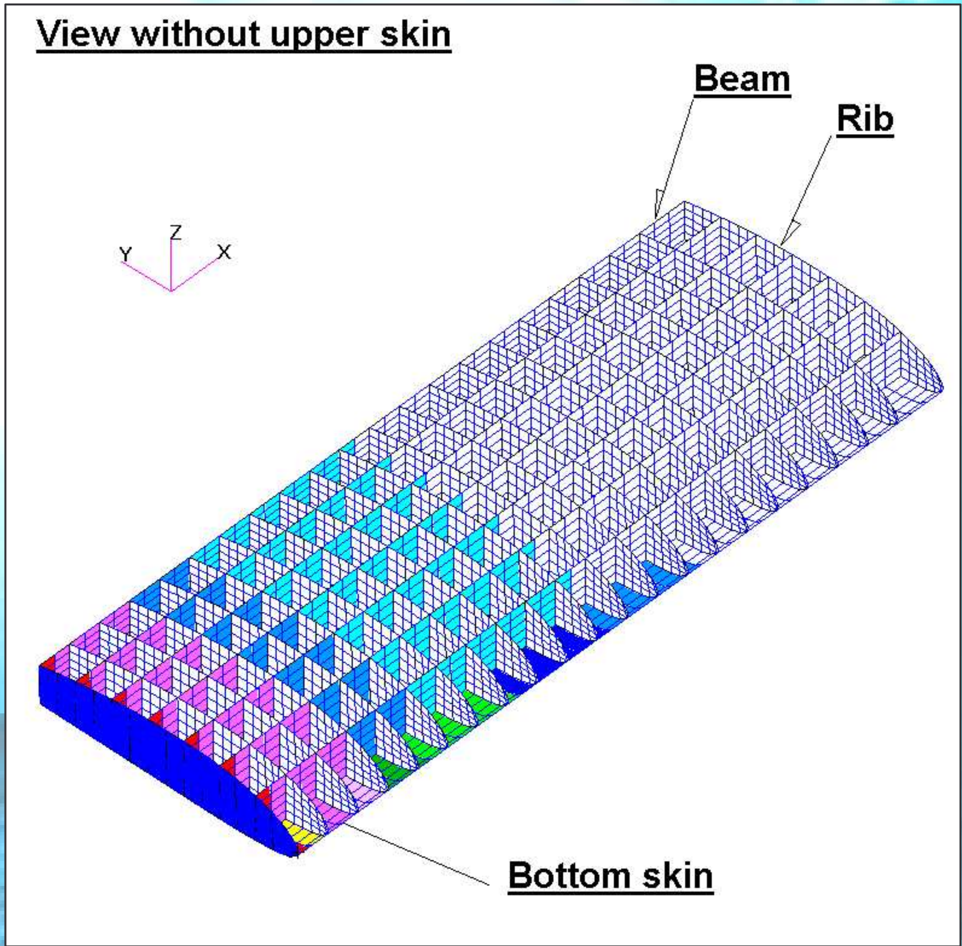


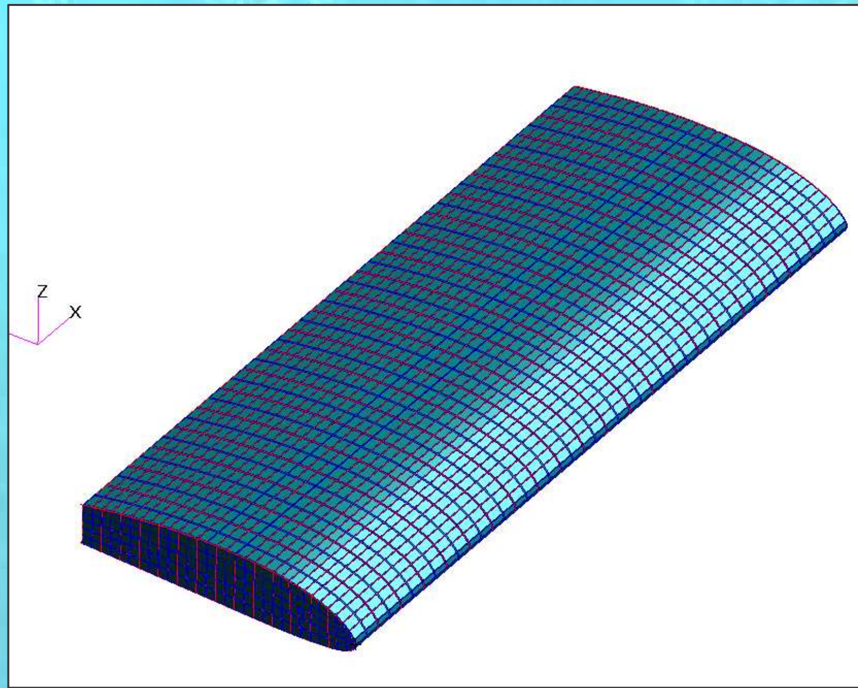
Wing Structure: FE Analysis

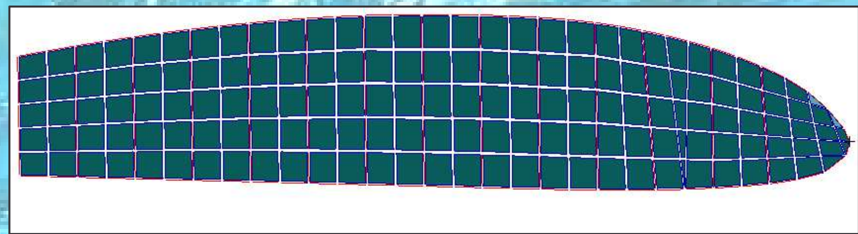
➢ Representative section



Wing Finite Element Model

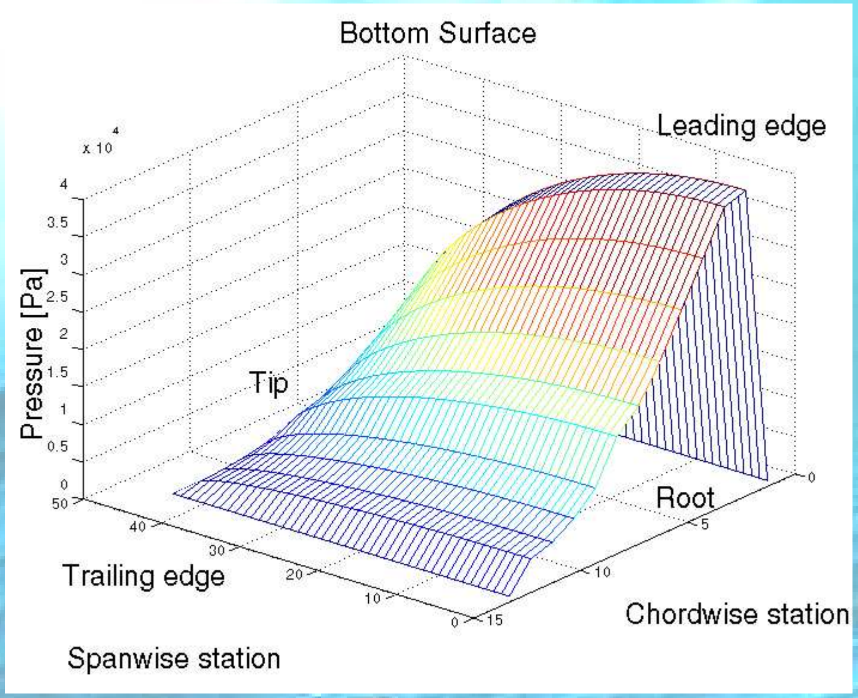


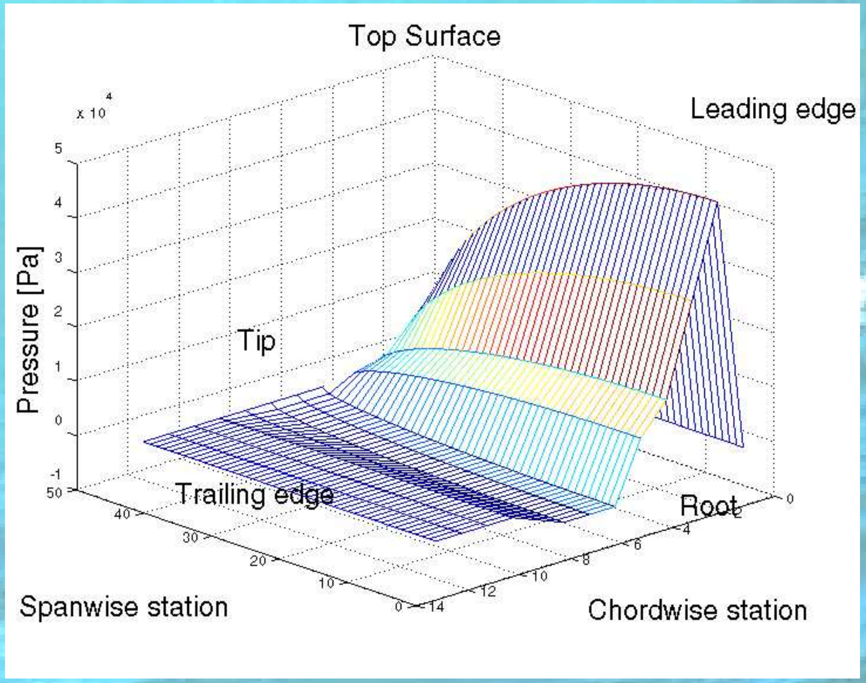




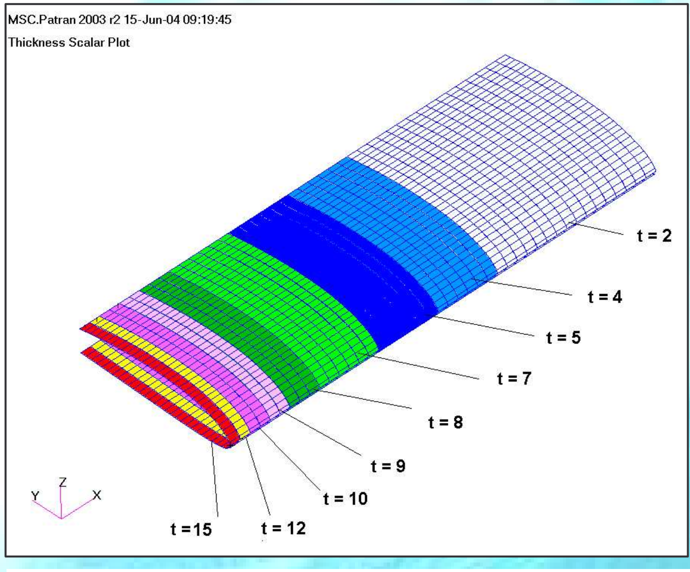
Loading case for FE Analysis

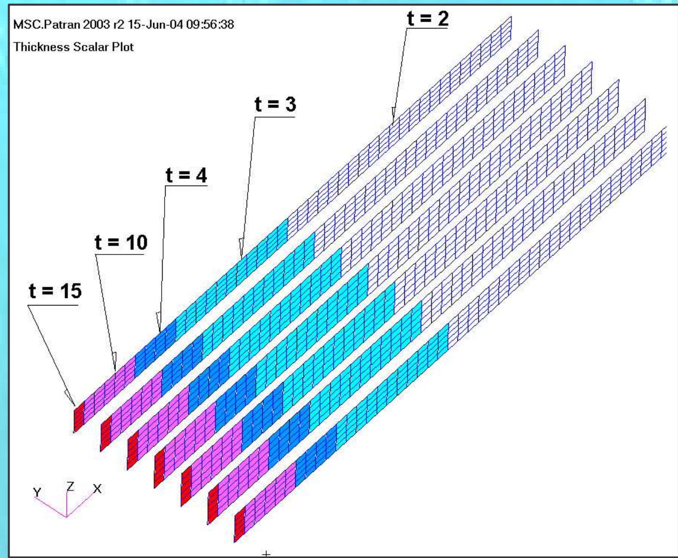
- Approximate pressure distribution
- Corresponds to flight at V=130 m/s, n_z=2.5

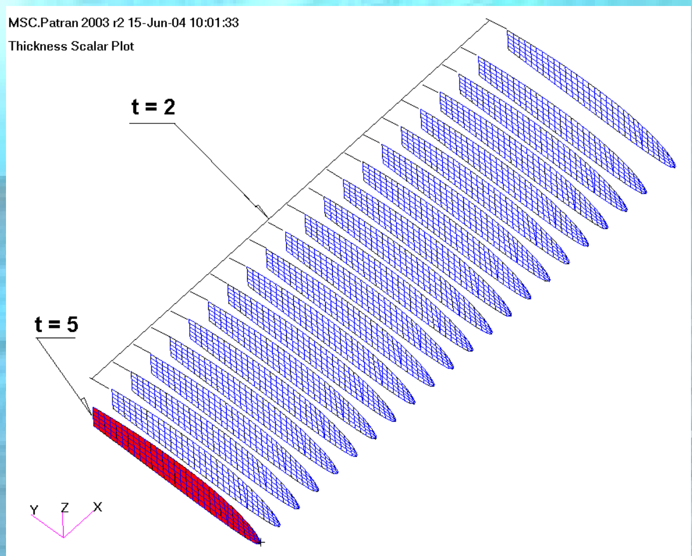


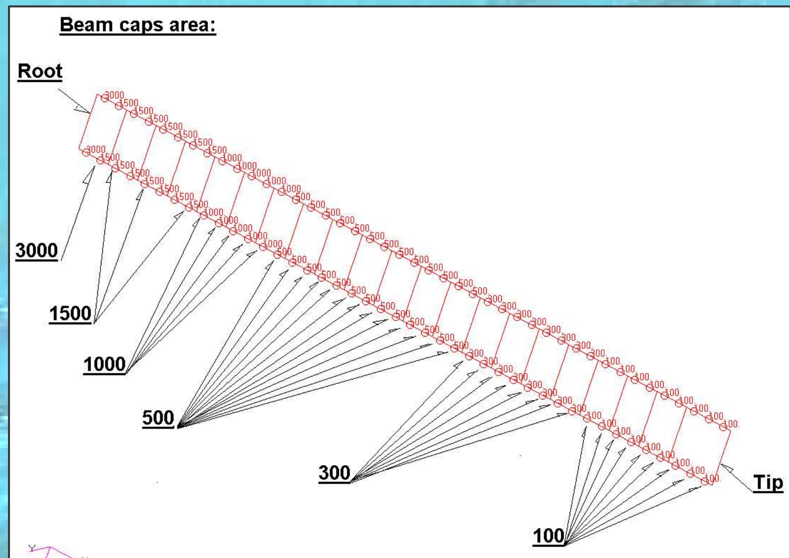


FE Analysis: Refined Sizing

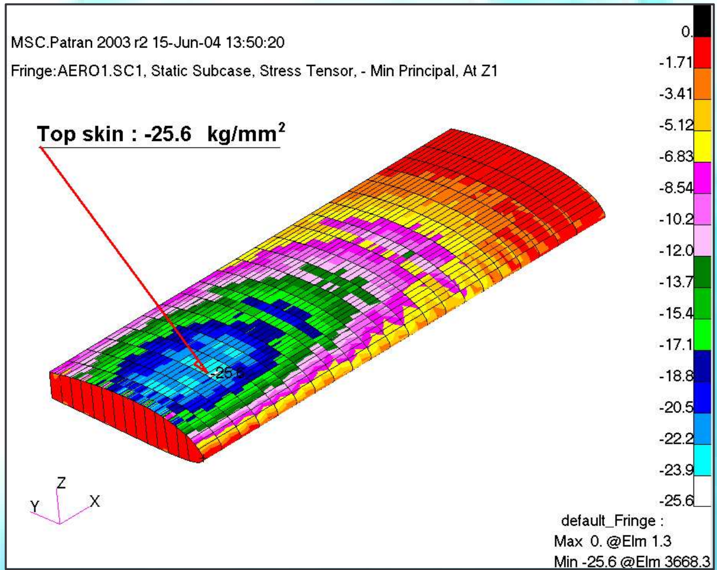


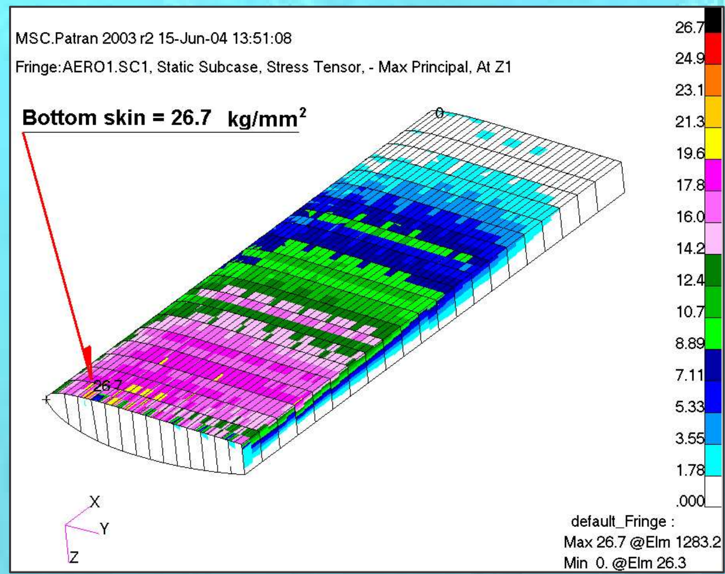


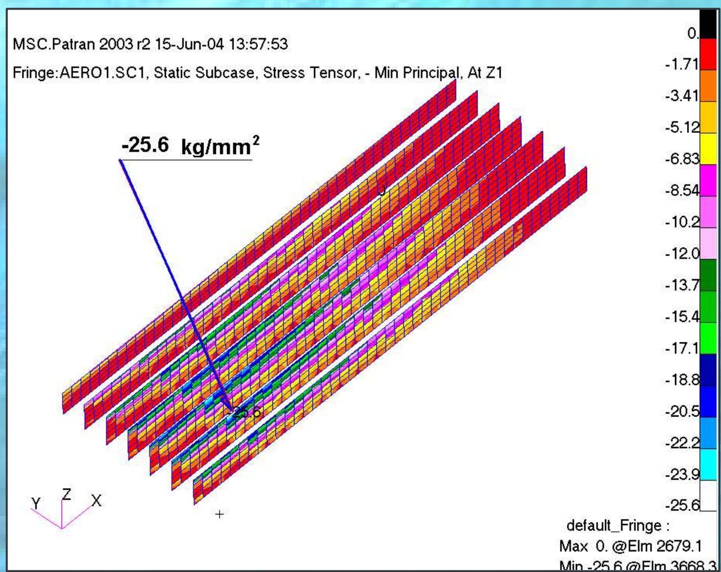


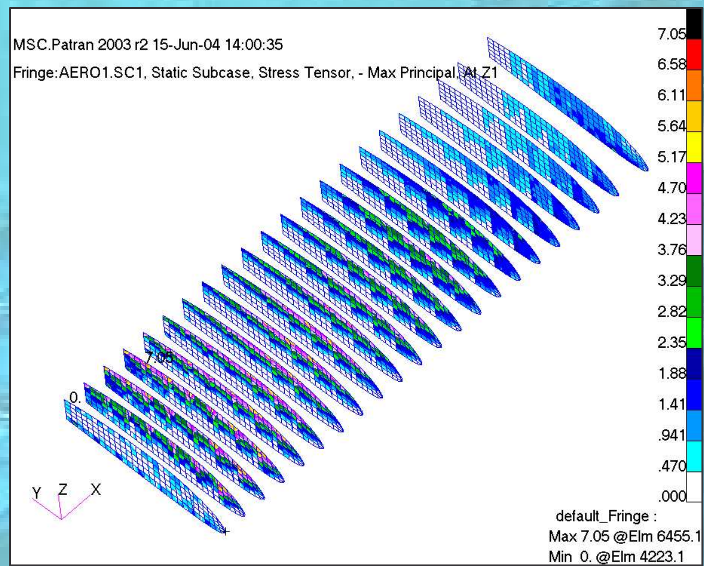


Finite Elements: Results

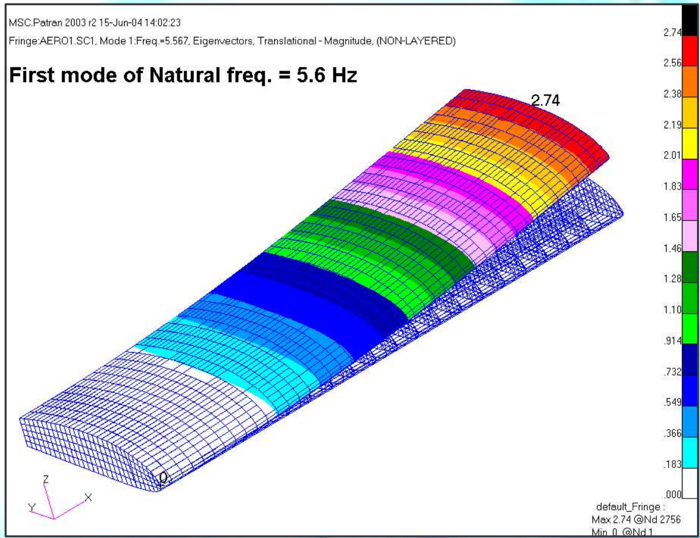


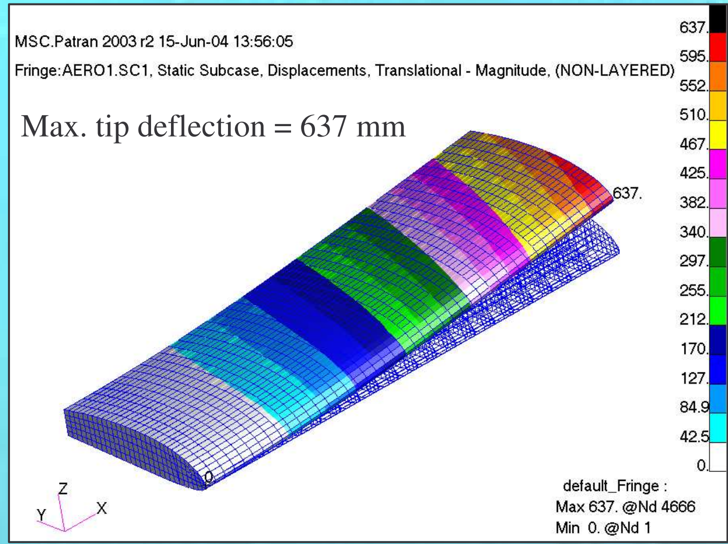






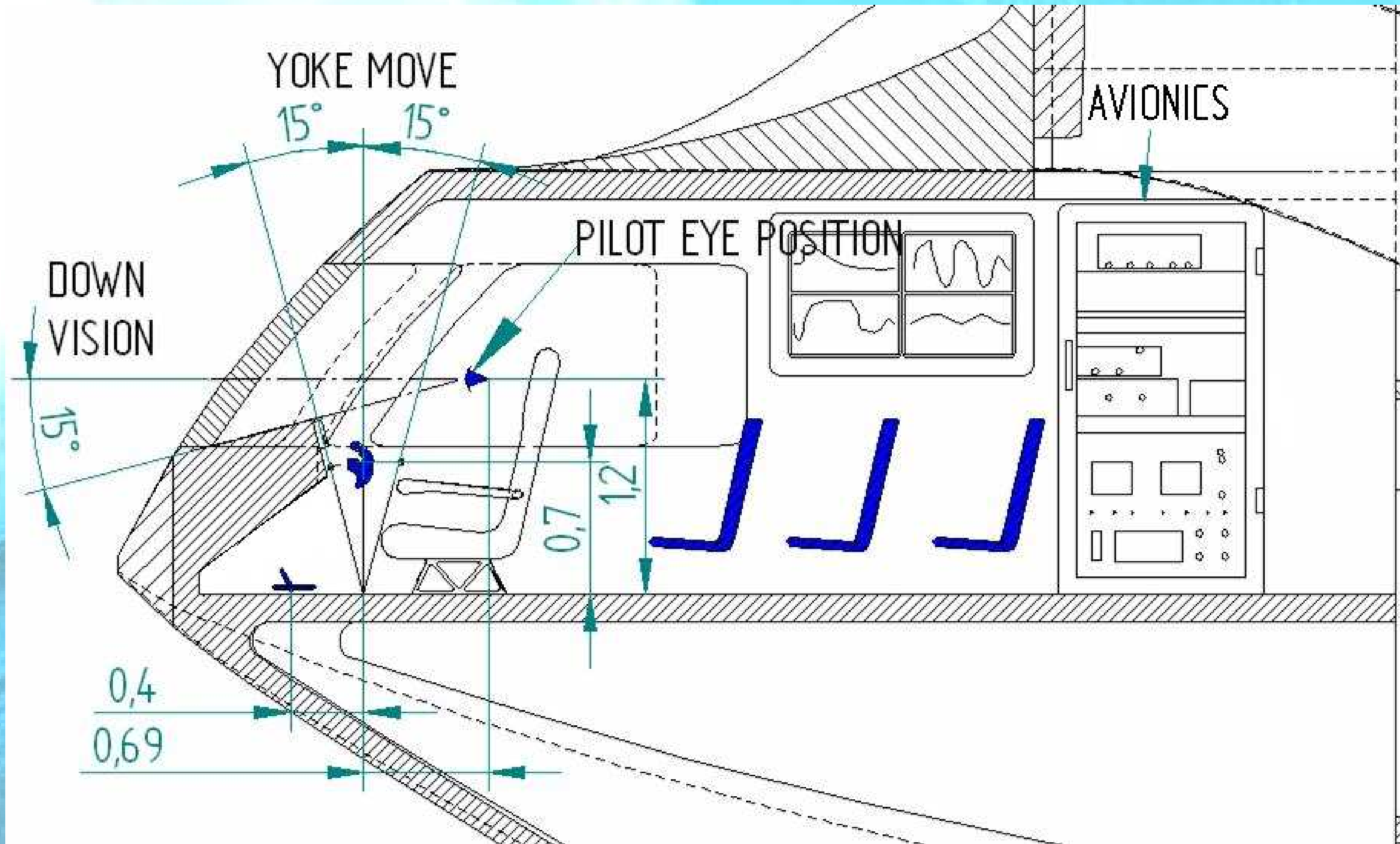
Finite Elements: Results



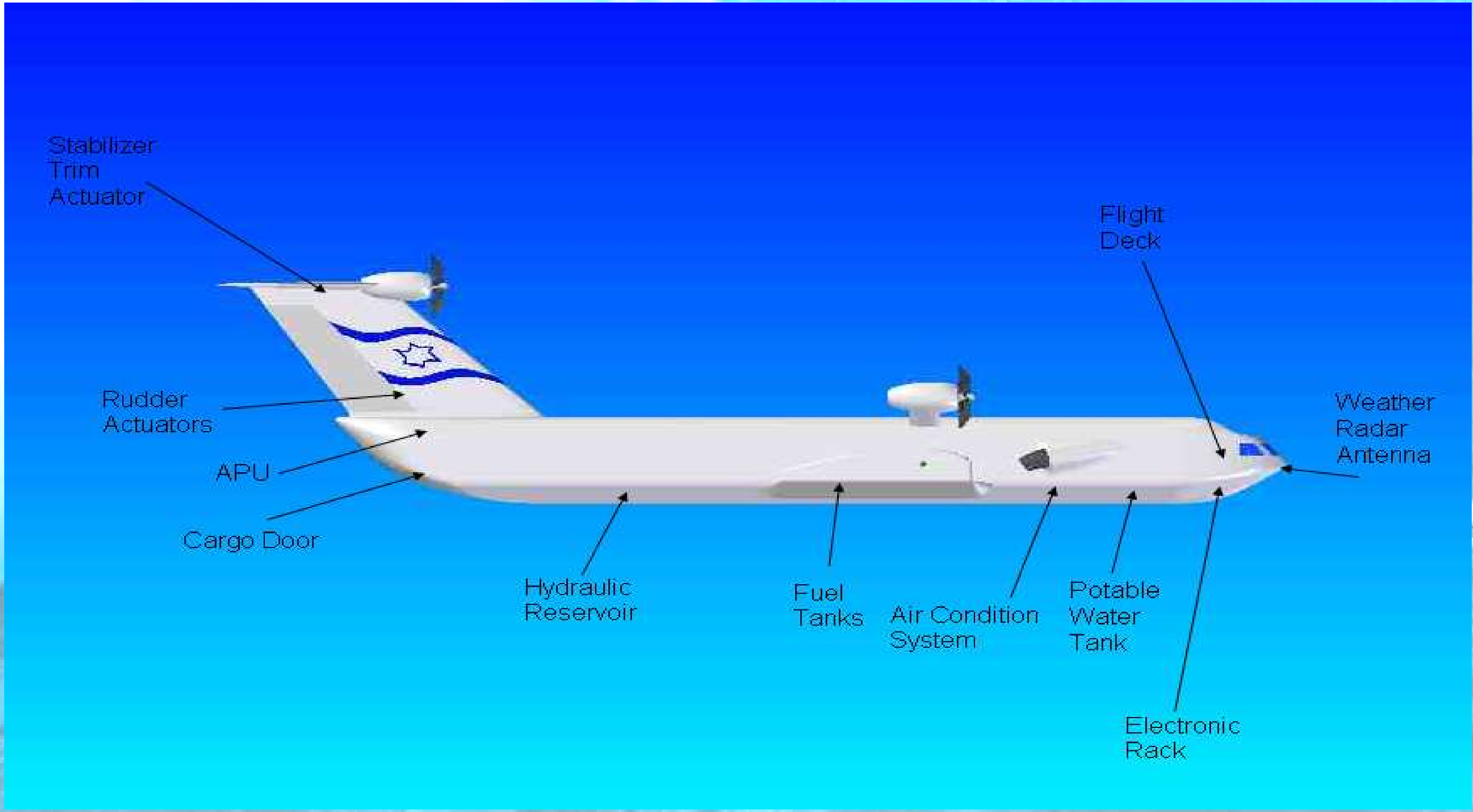


- Conclusions:
  - The stiffness of the structure should be improved due to low first natural freq. of 5.6 Hz
  - Additional optimization should be considered by addition of lightening holes and bids
  - Estimated total weight of wing structure after additional optimization will be about 18-23 tons

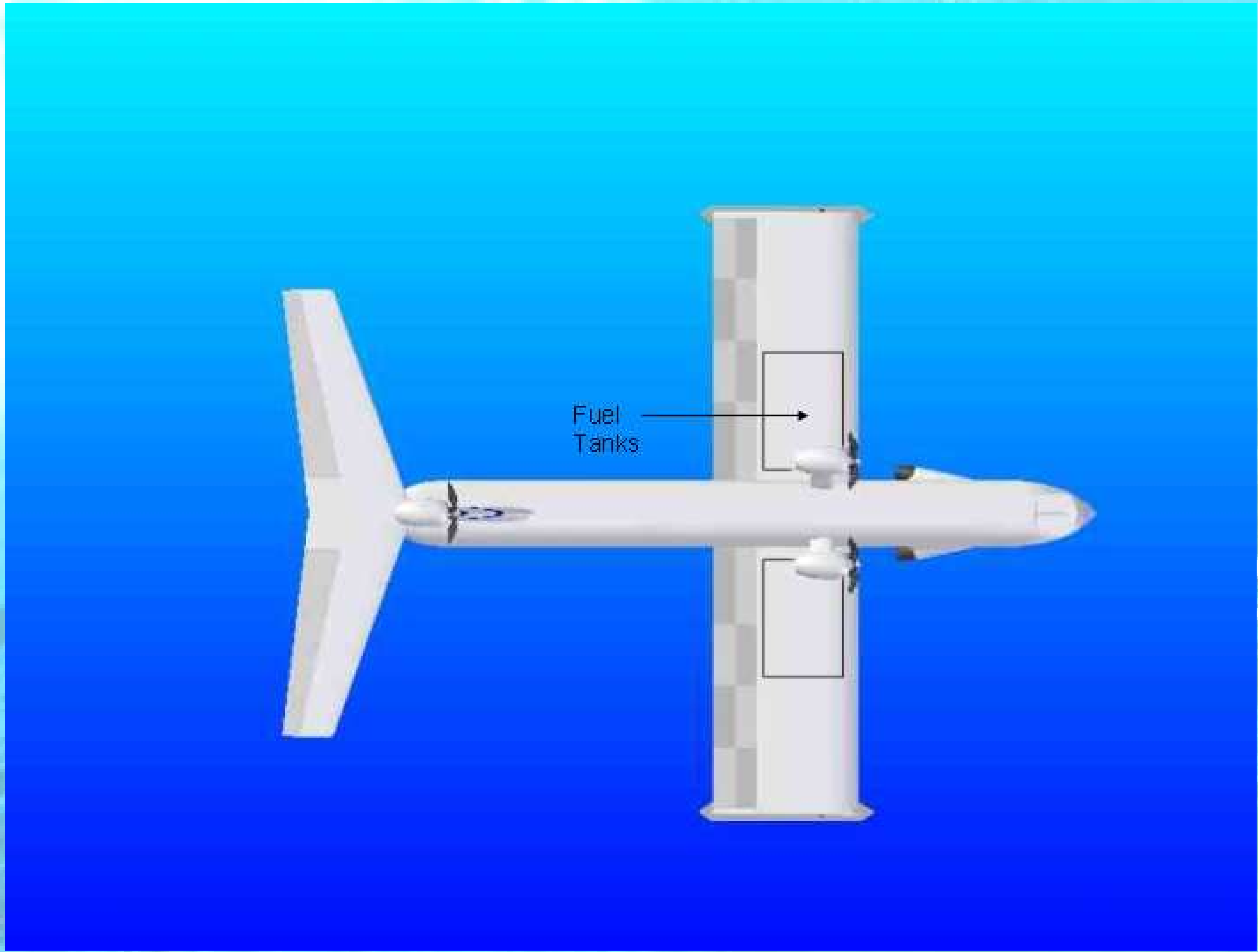
Cockpit arrangement



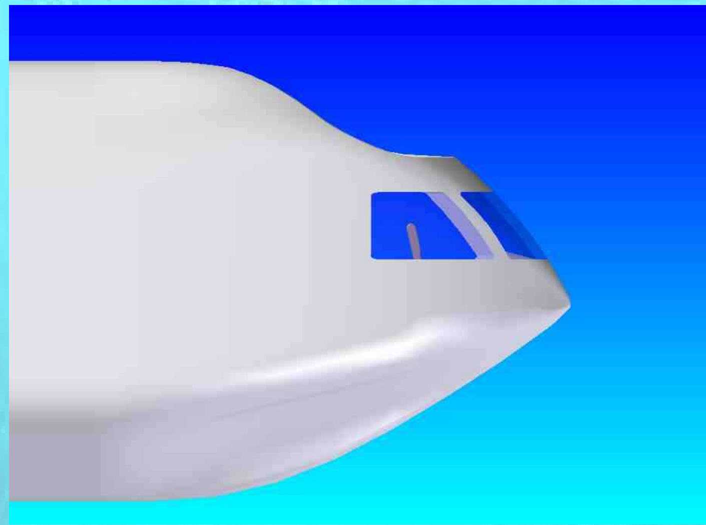
Systems arrangement



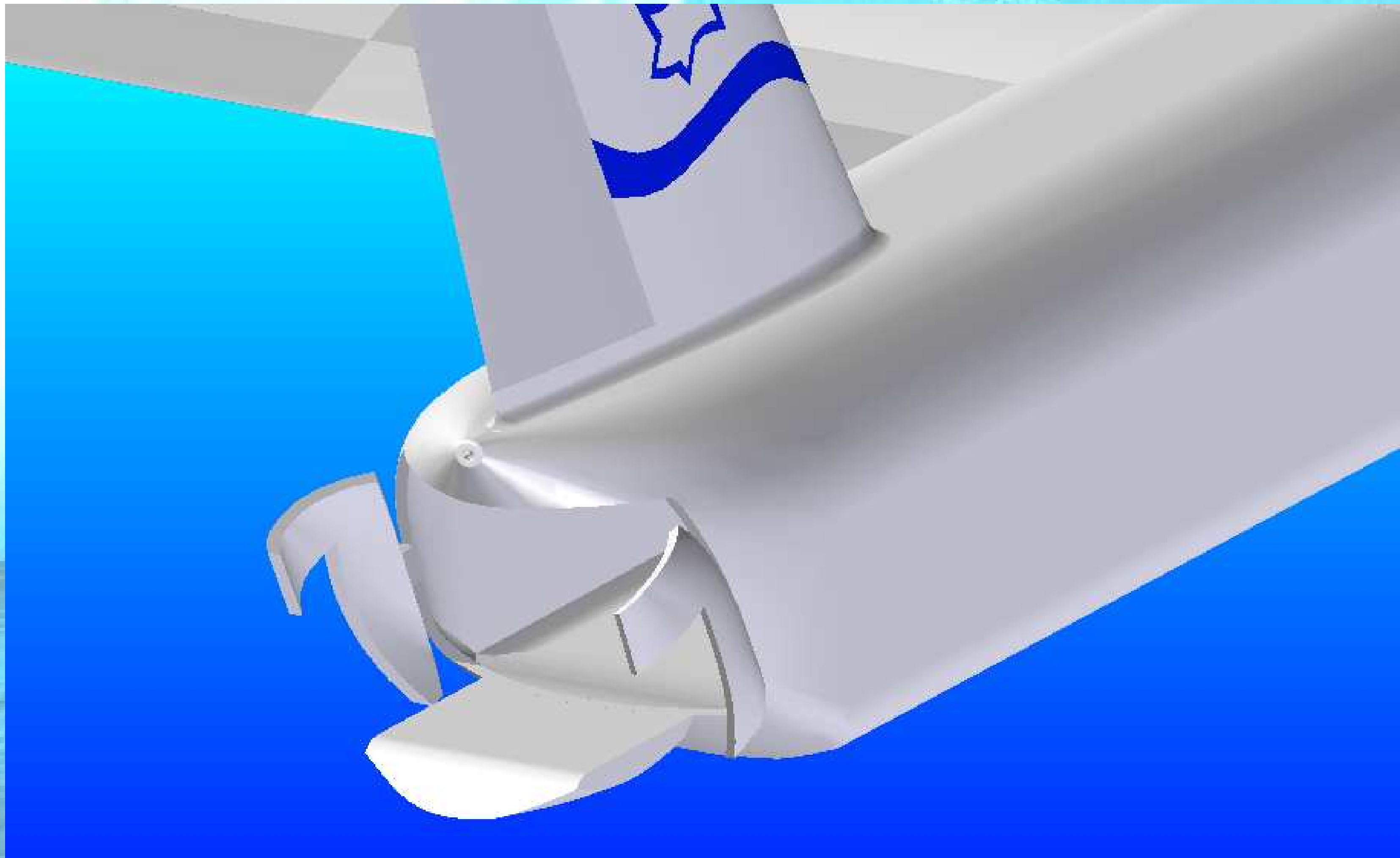
Fuel arrangement



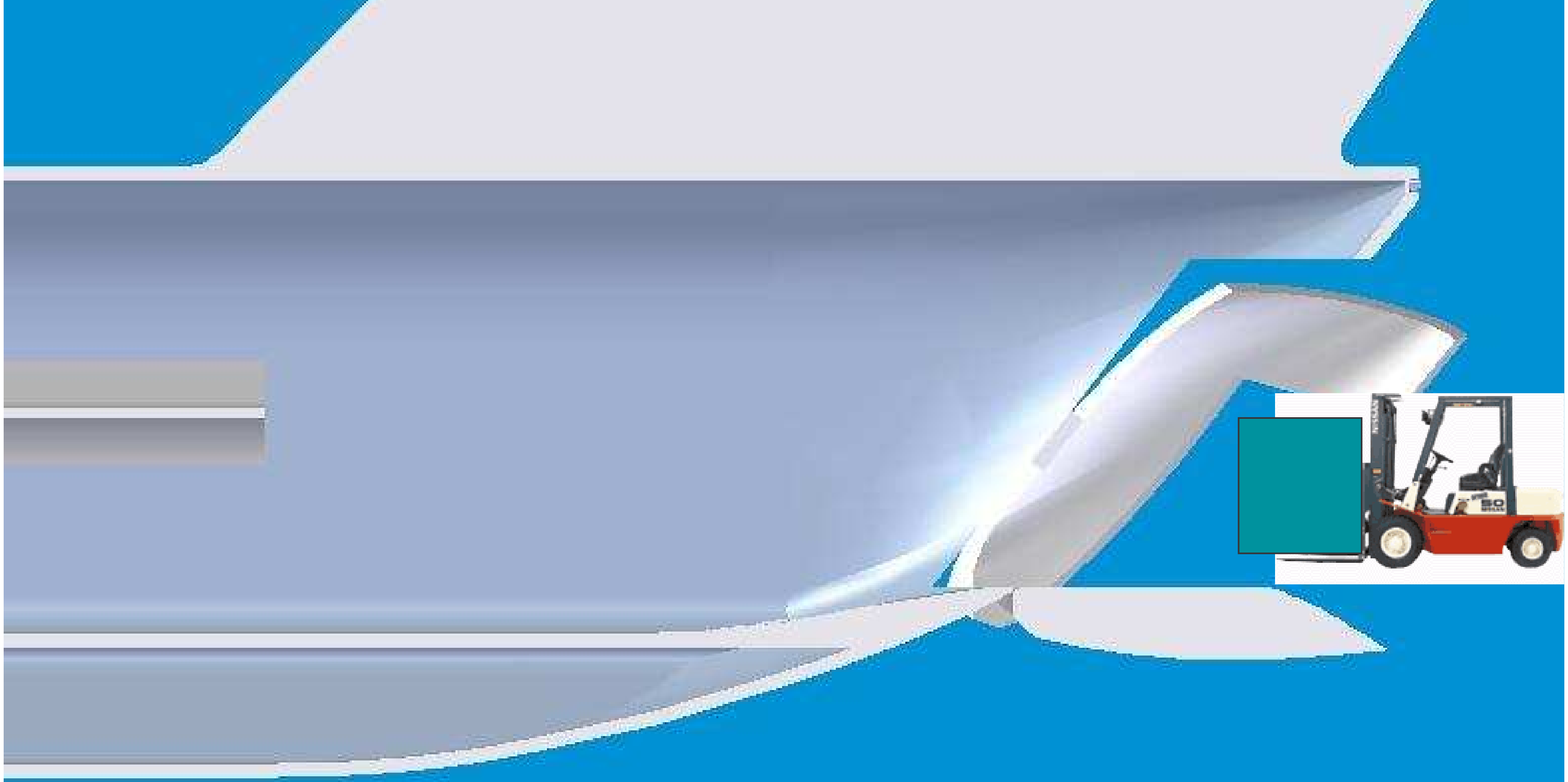
Cockpit views



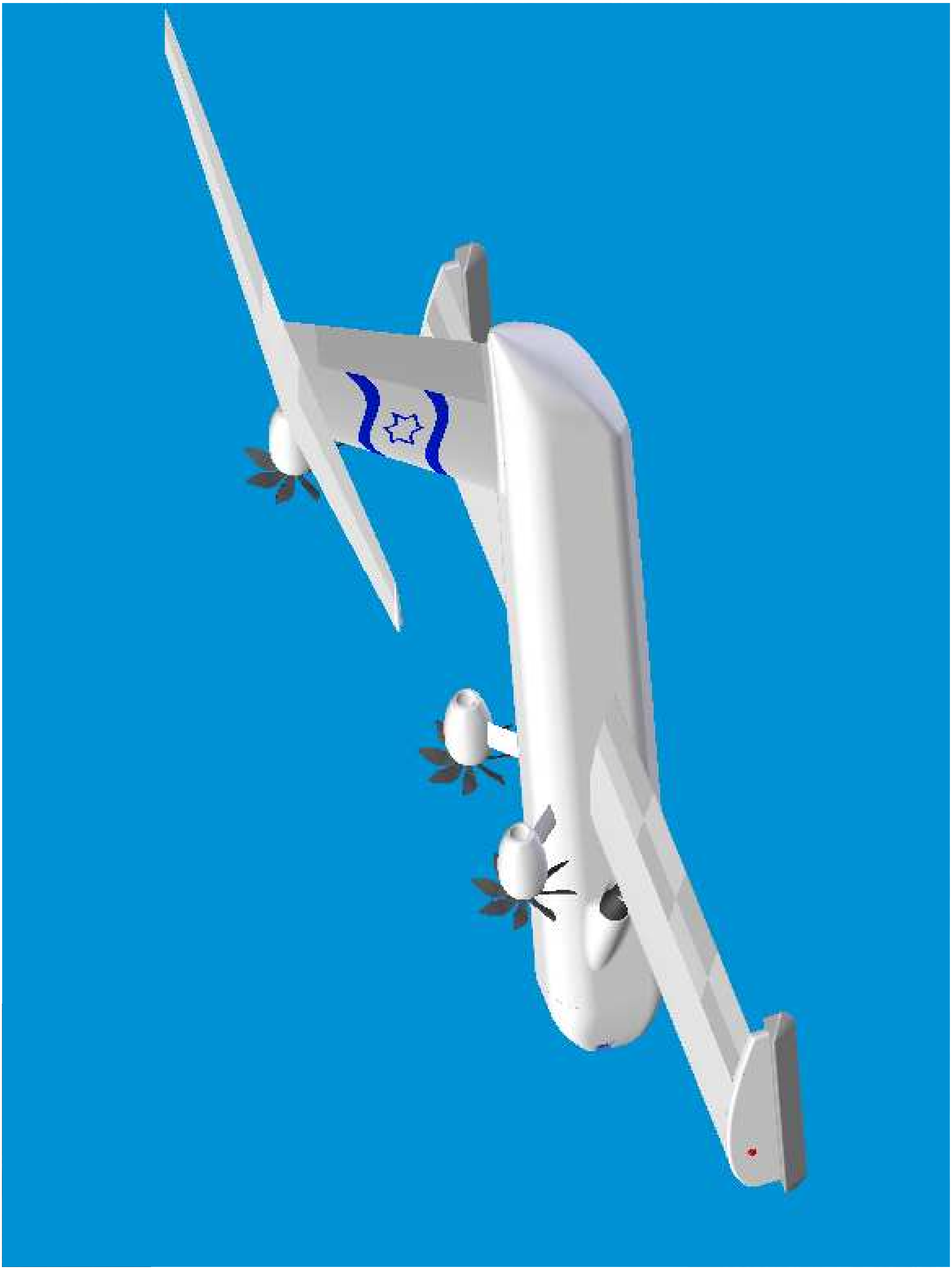
Cargo door design

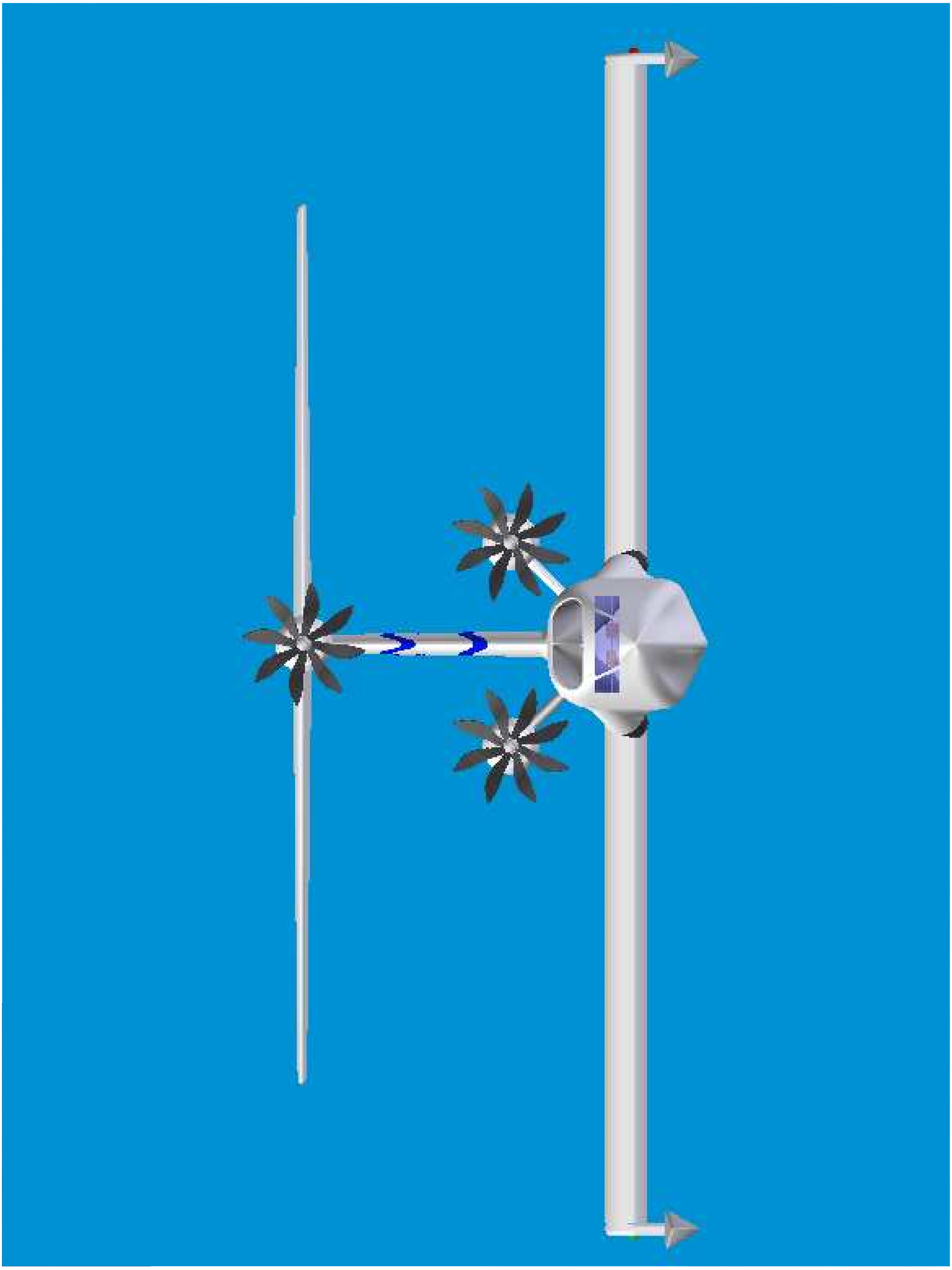


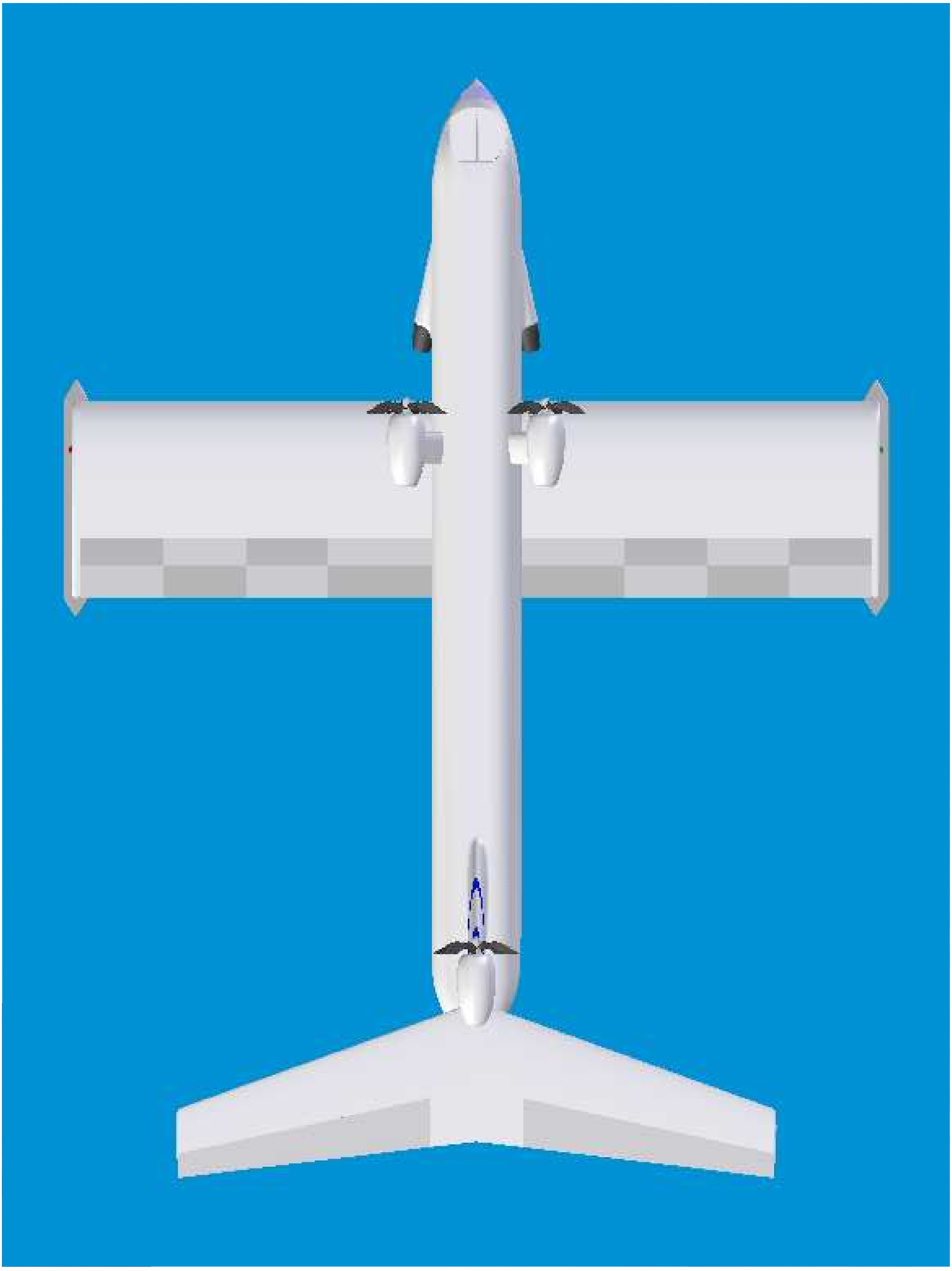
Cargo door design



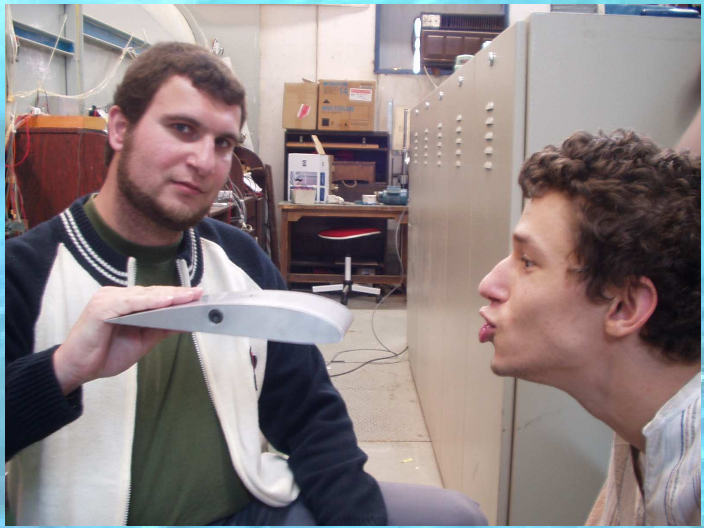
Final configuration





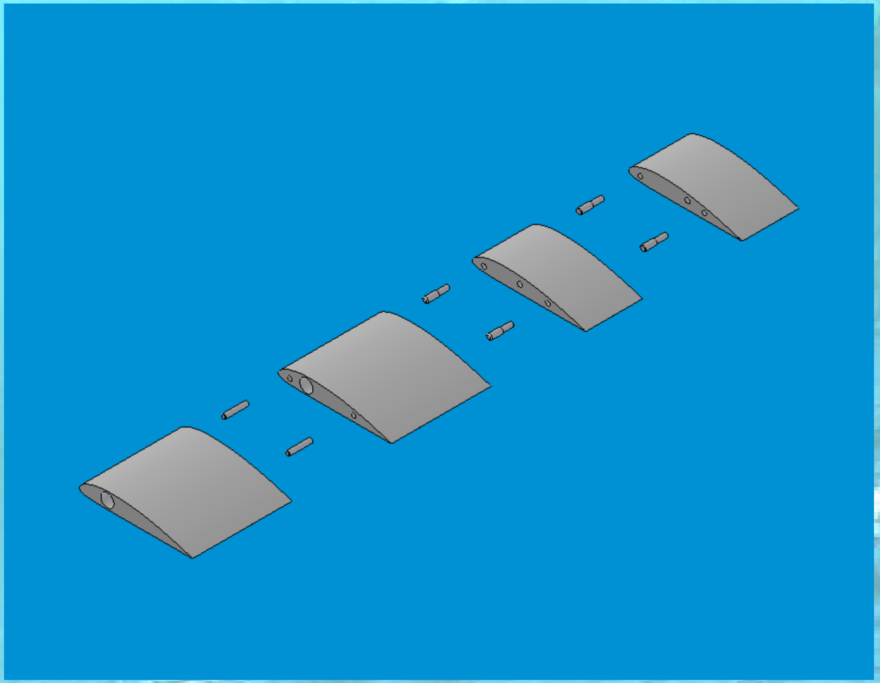


Wind Tunnel Test

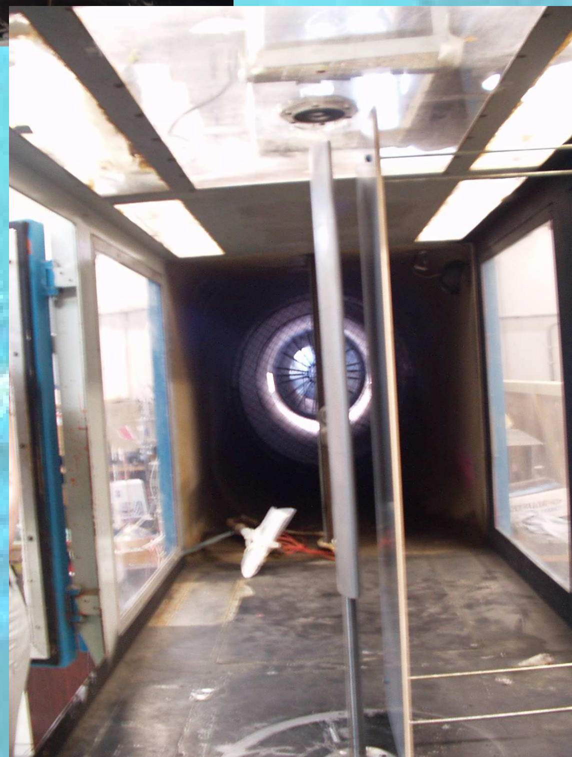


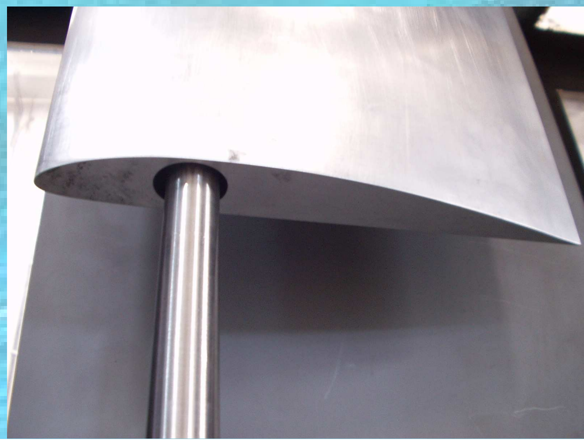
Wind Tunnel Test

- Test model
  - Rectangular wind with Clark-Y 14 section
  - Board for ground simulation
- Test parameters
  - AR
  - α (aoa)
  - h (distance above the board)

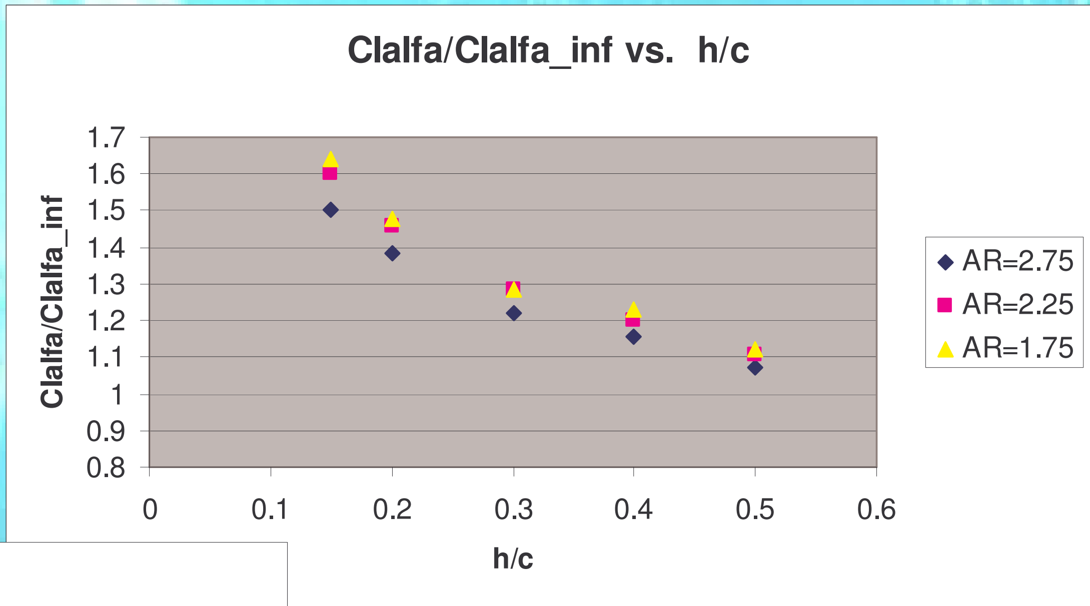


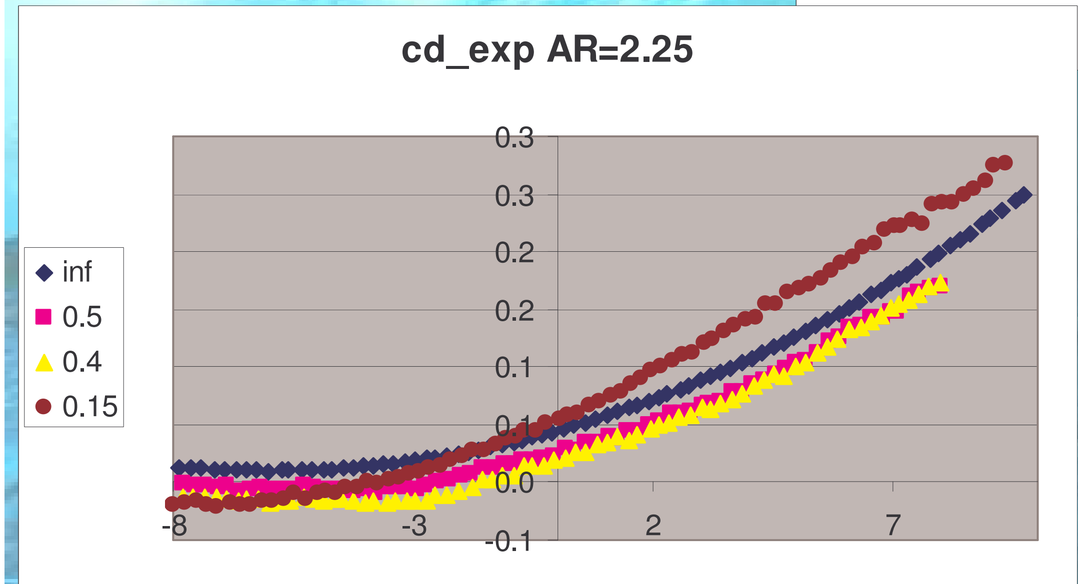
Wind Tunnel Test





Wind Tunnel Test Results:

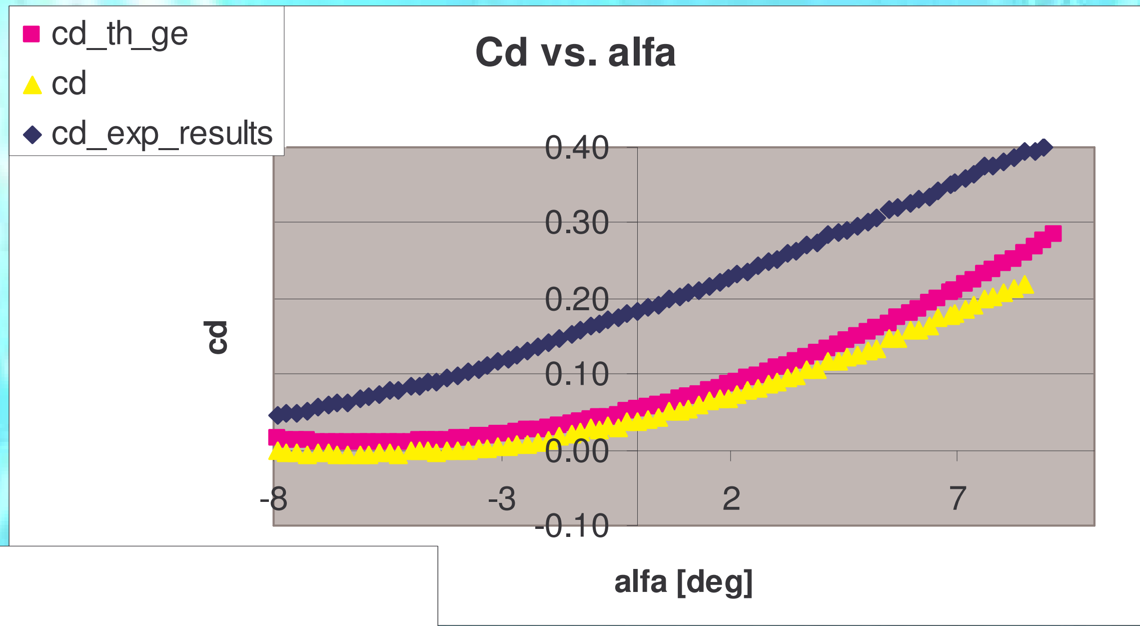


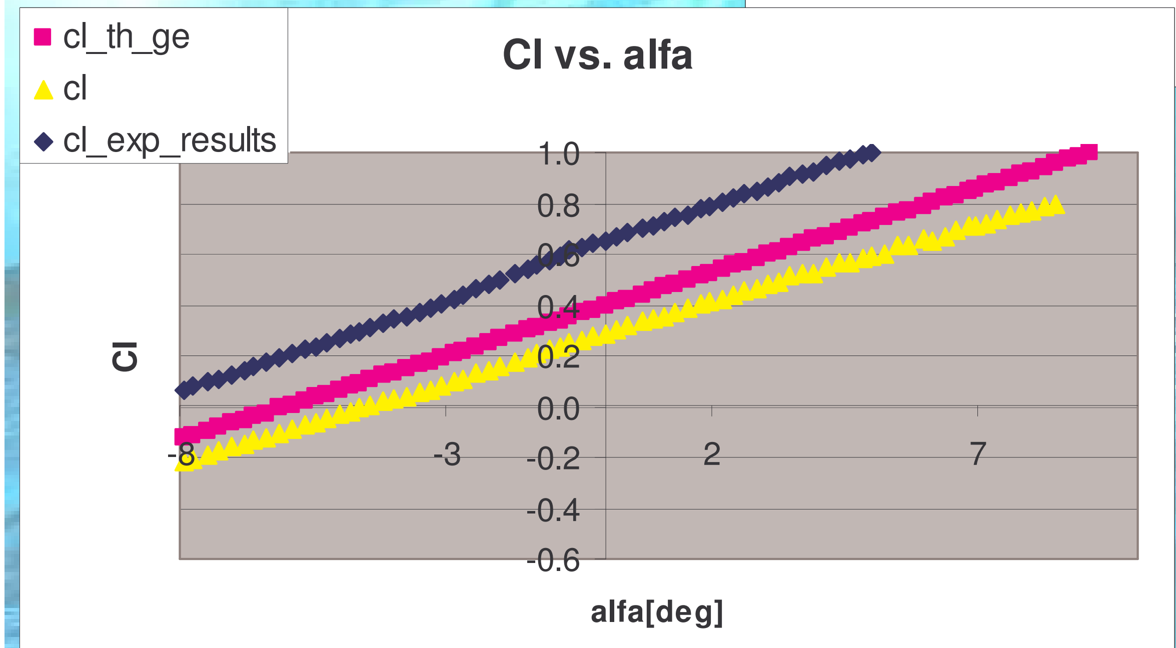


Wind Tunnel Test Results:

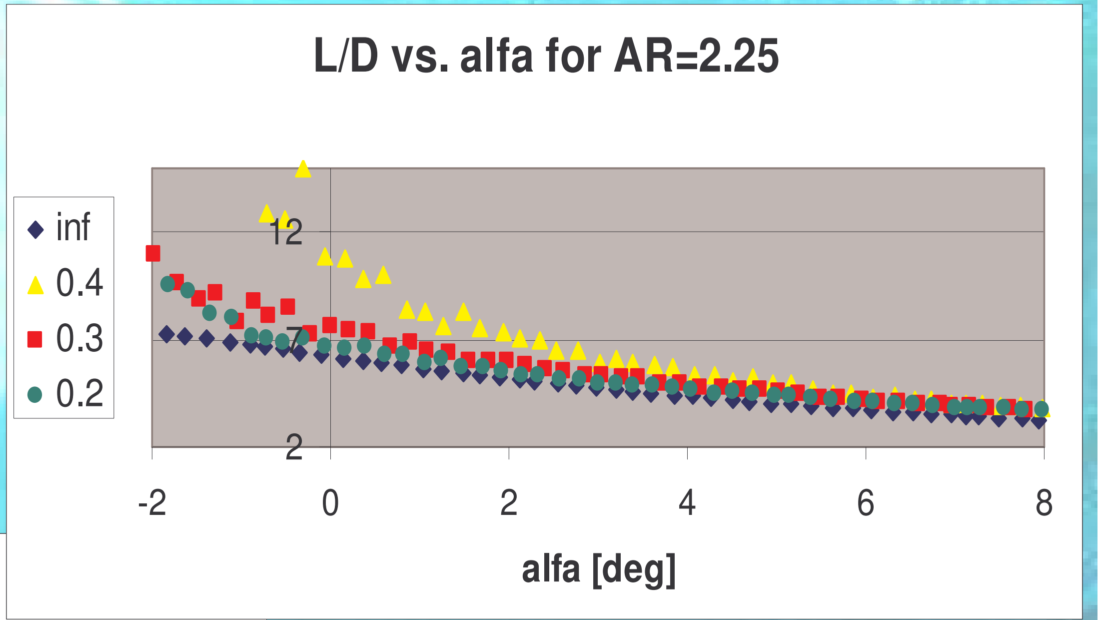
AR=2.75;

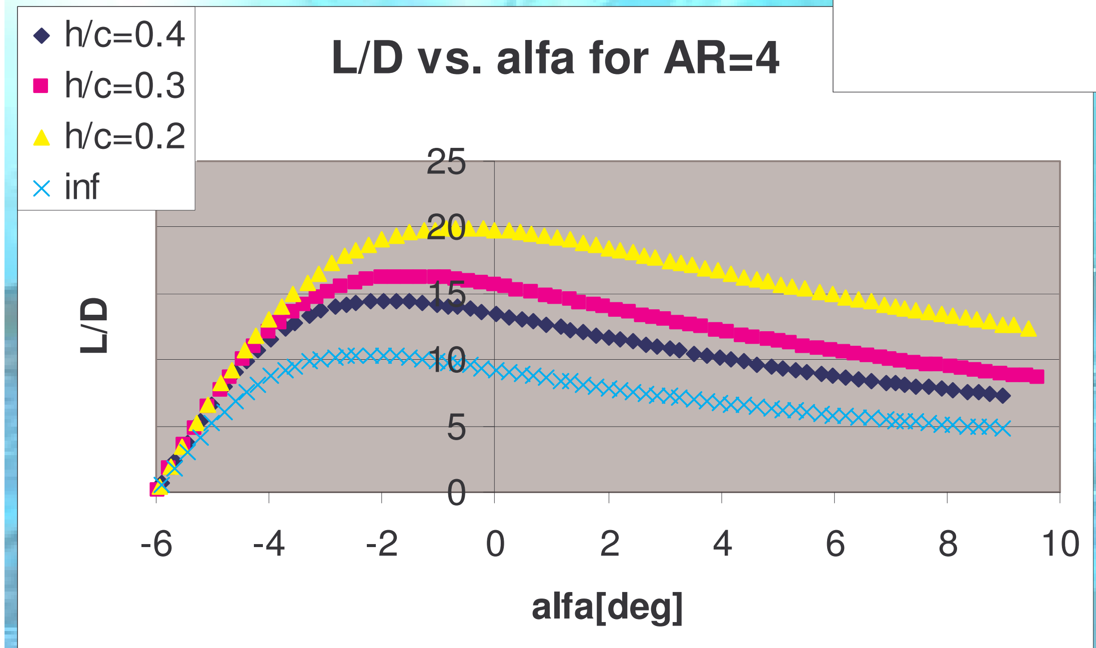
h/c=0.3





Wind Tunnel Test Results:





Cost estimation

Cost estimation

Cost estimation		50 planes (+5 prototype)	100 planes (+5 prototype)
Roskam	RDT&E	1563 M$	
	manufacture	11513 M$	16968 M$
	Cost per plane	285 M$	203 M$
Raimer	Cost per plane	217.5 M$	175.5 M$

Boeing 747-400 Freighter	187.5 - 214.5 M$

Comparison to other aircrafts

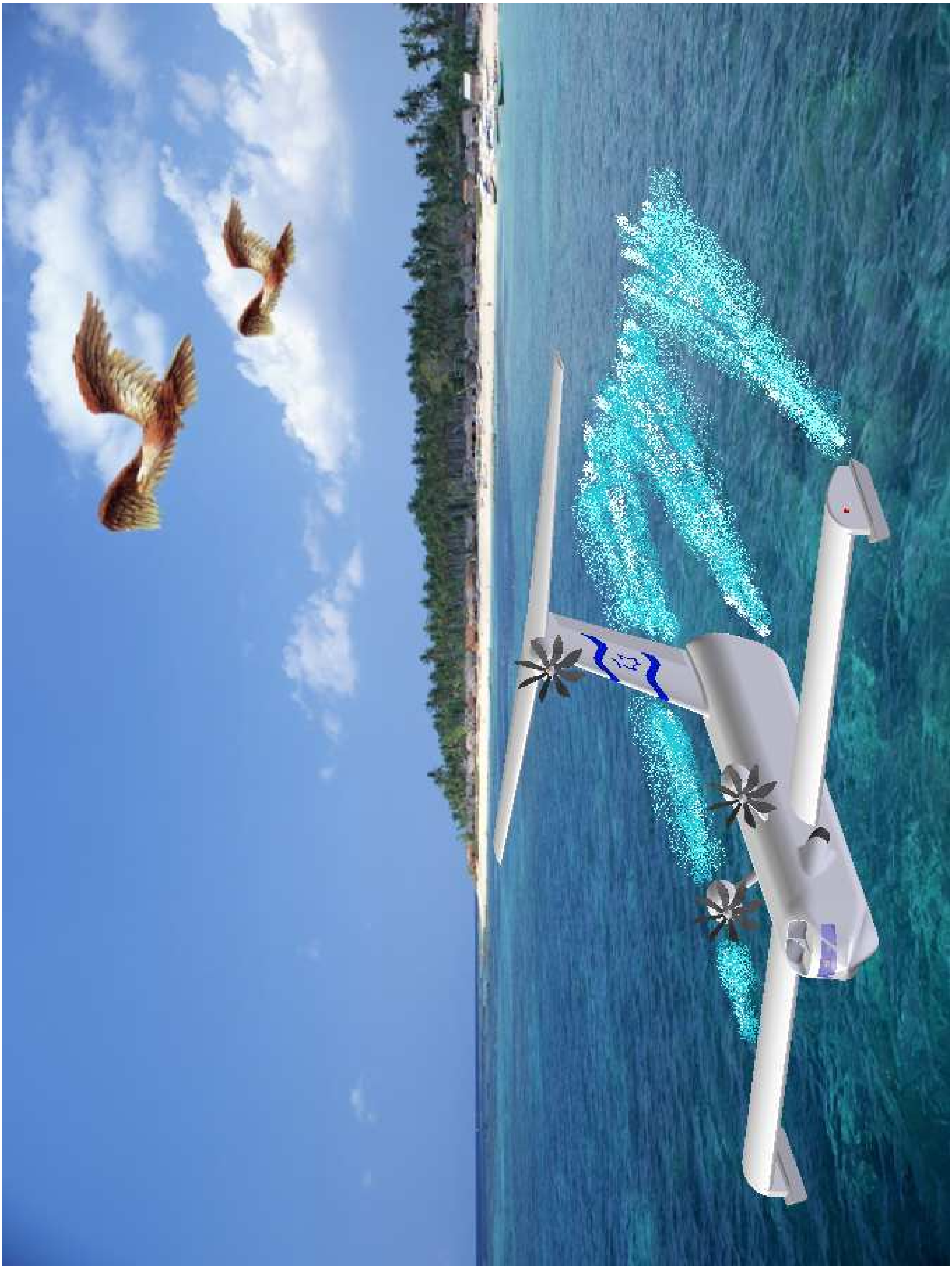
Comparison to other aircrafts

	Full payload configuration	*Max fuel configuration*	Boeing C17	ANTONOV	ANTONOV	Boeing
	SAMSON	***SAMSON***	GLOBMASTER	An-124 A	An-124 B	747-400GB
Max payload [kg]	***120000***	***70000***	72576	150000	120000	67175
Range [km]	***5880***	***12225***	4444	4500	4800	11455
Fuel [kg]	***60000***	***110000***	82125	214000	214000	162580

- Samson's performances are better than the performances of it's rivals
- Another iteration of drag calculations might narrow the difference

Points for future development

- A door to close the inlets above the cockpit
- A detailed structural design
- Detailed stability analysis
- Control



Special thanks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Moti Ringel

Questions