טכניון – מכון טכנולוגי לישראל
הפקולטה להנדסת אווירונאוטיקה וחלל

MONGUARD

Multi Operational National Guard

Critical Design Review
05.07.06

Content

1. Introduction

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Intro

<u>Operational need</u>

- The need for accurate, fast and online information is rapidly growing.

1. Controlling sensitive areas.
2. Controlling areas that are hard to reach.
3. Security and intelligence need.

Out of this need emerged the solution :

The MONGUARD (Multi Operational National Guard).

What‵ve been done

Requirements

Selection and design of components

Canister

Cameras

Engine

Avionics

Rocket engine (Booster)

Market survey

Preliminary sizes estimation

Review of existing solutions according to system requirements

Comparison

Folding wings

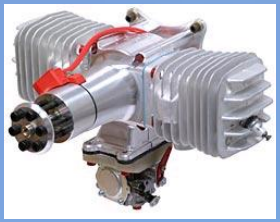
Inflatable wings

Comparison

The chosen configuration - Folding wings

Preliminary design

PDR



What`ve been done
This semester

- Structural design and analysis of aerodynamic surfaces.
- Aerodynamic analysis of wings/canard.
- Fuselage detailed design :
  - Wings joint
  - Sensors doors opening mechanism
  - Service panels
  - Cowling + NACA Scoop
  - Reinforcements

What‛ve been done
This semester

- Specific Issues :
  - Engine noise reduction
  - Alternatives for GPS
  - Thrown Appliances

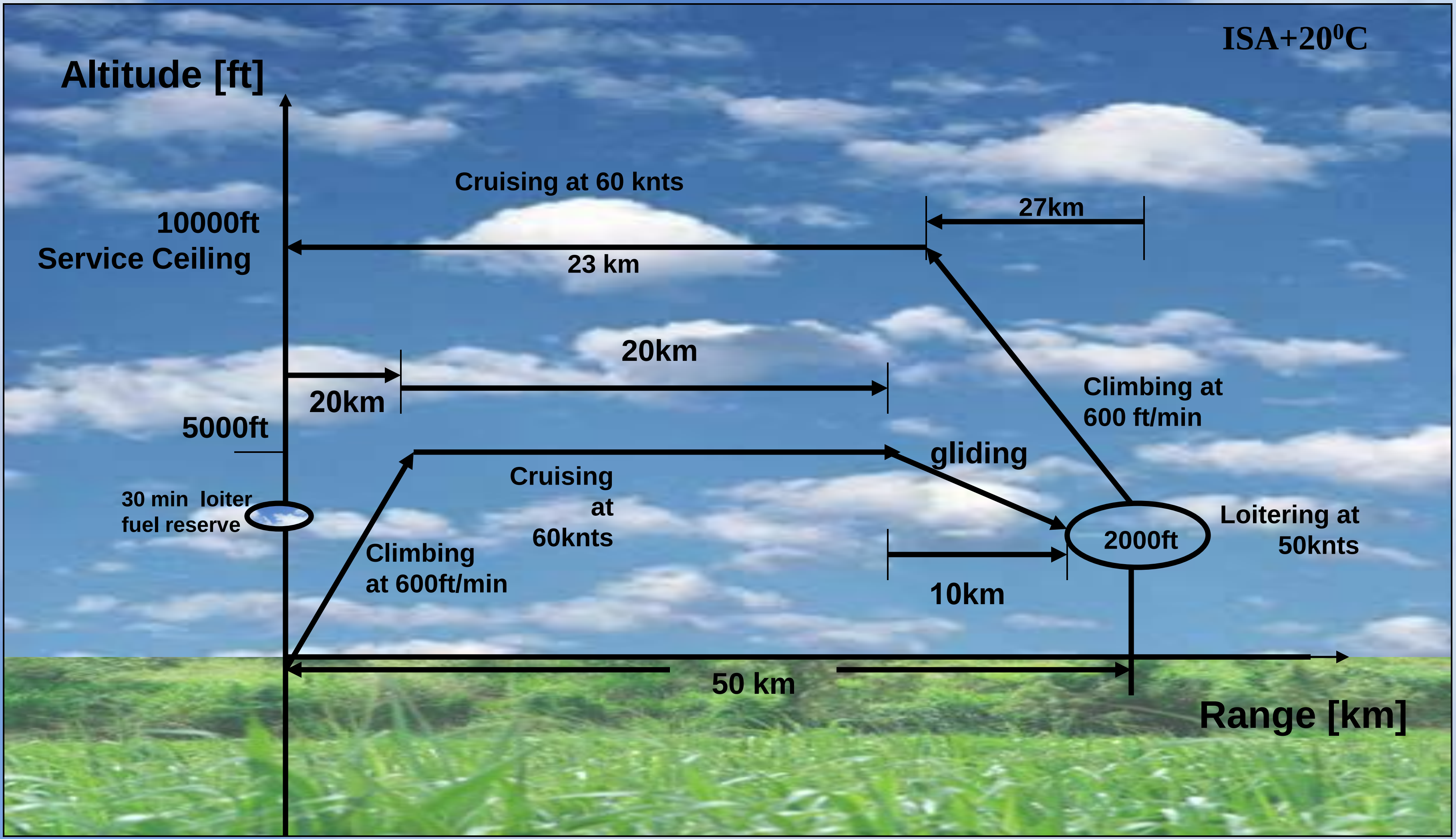
- Design and Building of a flying Model
  - Examination of building a wind tunnel model.

2. Specs and Customer Requirements

UAV specification

- Max. Take Off Weight – 50 kg
- Payload Weight - 20 kg
- Operational Endurance – 10 hr
- Max. Flight Level – 10,000 ft
- Canister Launched Capability
- Precision Para foil Recovery
- Day and Night monitoring capabilities
- velocity: Min. 40 Kt ;Cruise 60 Kt ;Max. 90 Kt
- Low acoustic signature
- Multi-functional component

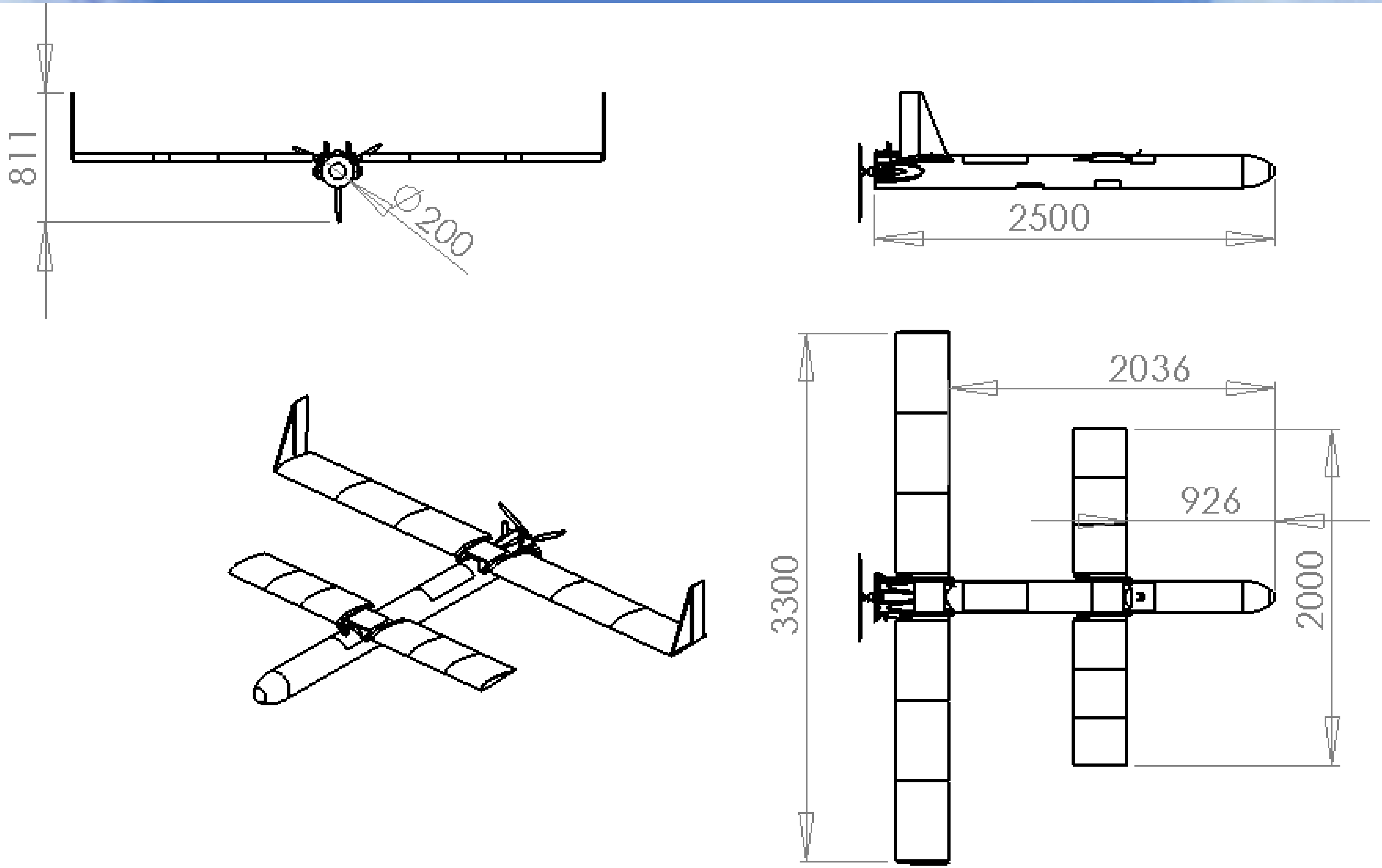
Mission Profile



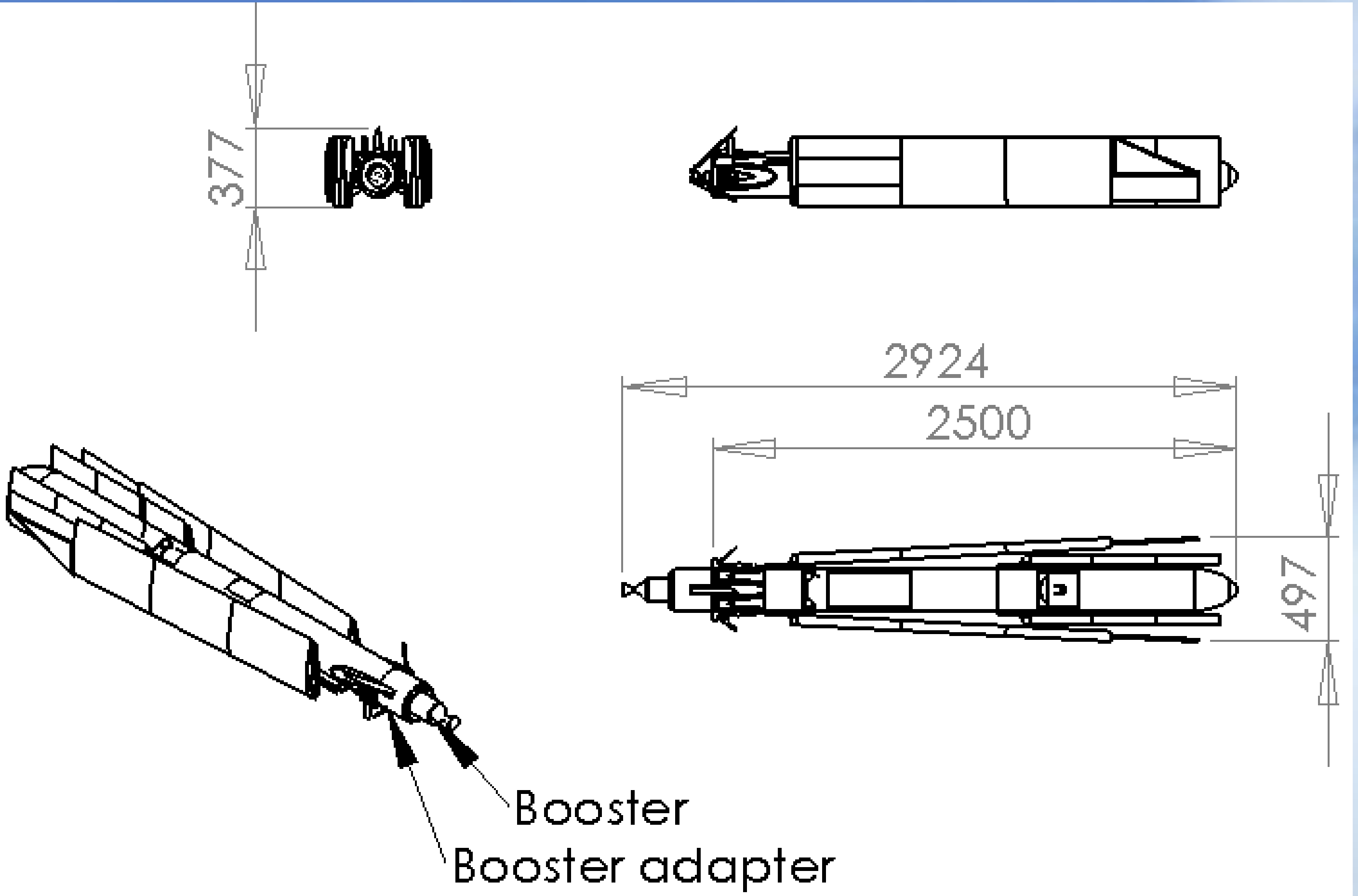
Our solution:

- Our solution is UAV with canard configuration
- The specifications: Endurance: 6.5 hr
  Weight: 50 kg
- The UAV will be equipped with 2 cameras
- Person identification capability from 2500ft
- Vehicle identification capability from 5000ft
- Fit for various ground and aerial vehicles.

ICD-Unfolded



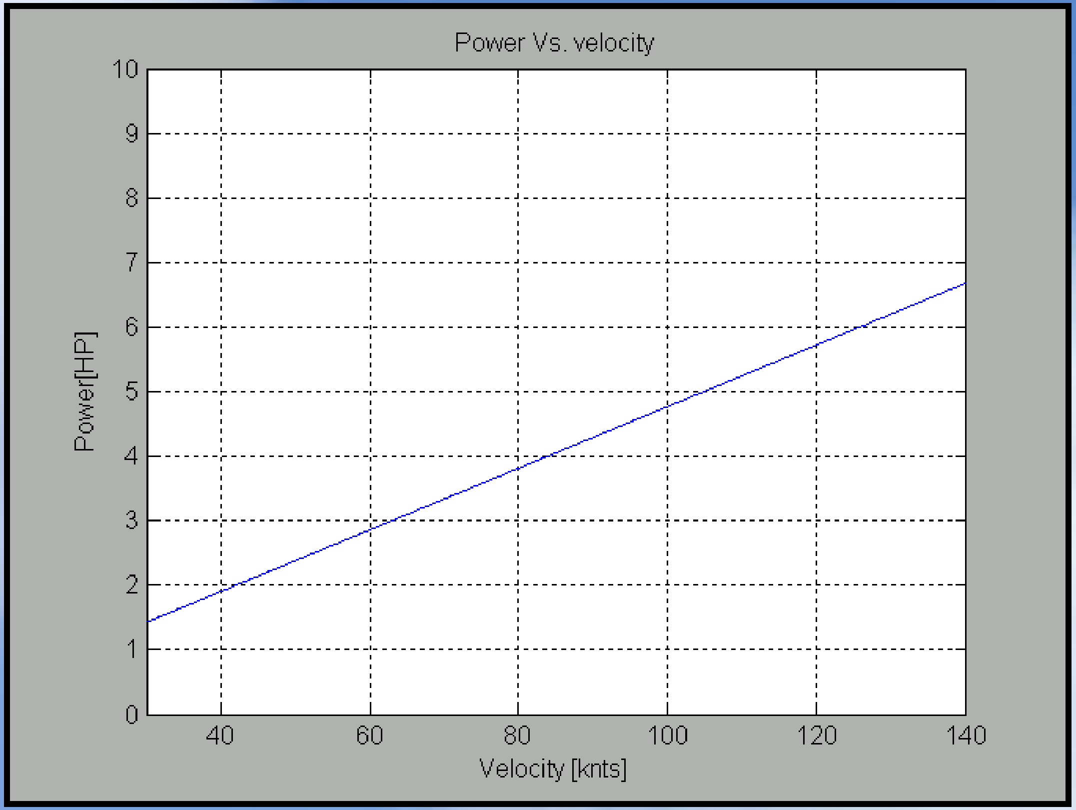
ICD-Folded



3. Flight Performance

Power Requirements

Required Power



Assumptions :

L/D=10

Propeller efficiency 0.7

Climb Rate

Climbing rate 1000ft/min -SL

$$\eta = 0.7 \Rightarrow P_{eng} = 6076.6_{watt} = 8.15_{HP}$$

Climbing rate 600ft/min

$$P_{eng}\eta = 3258 \quad (SL)$$

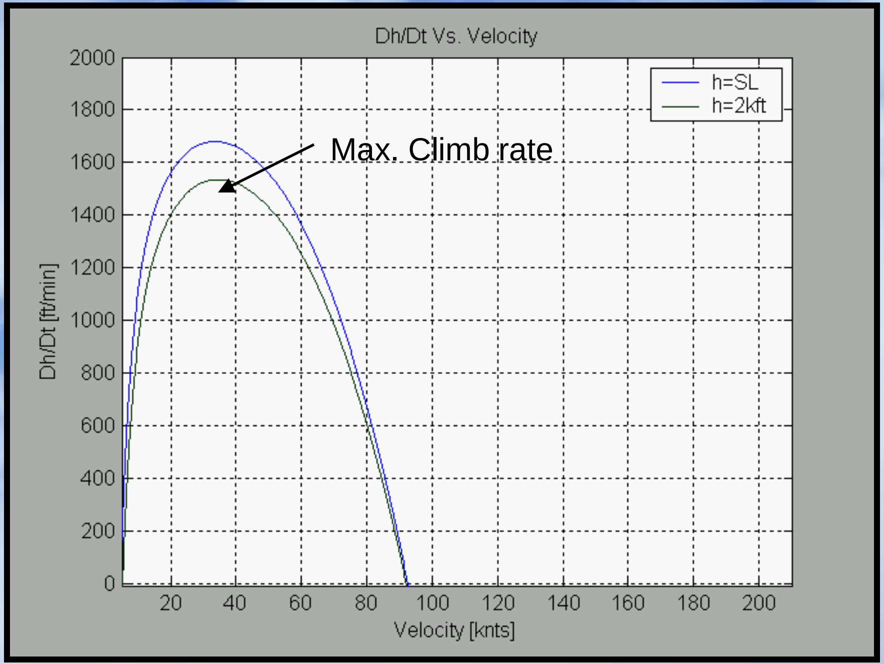
$$\frac{\rho}{\rho_0} = 0.9151 \ (3000\ ft)$$

$$P_{rated} = 5106.5_{watt} = 6.84_{HP}$$

$$\frac{\rho}{\rho_0} = 0.8107 \qquad (6000\ ft)$$

$$P_{eng} = 5826_{watt} = 7.8_{HP}$$

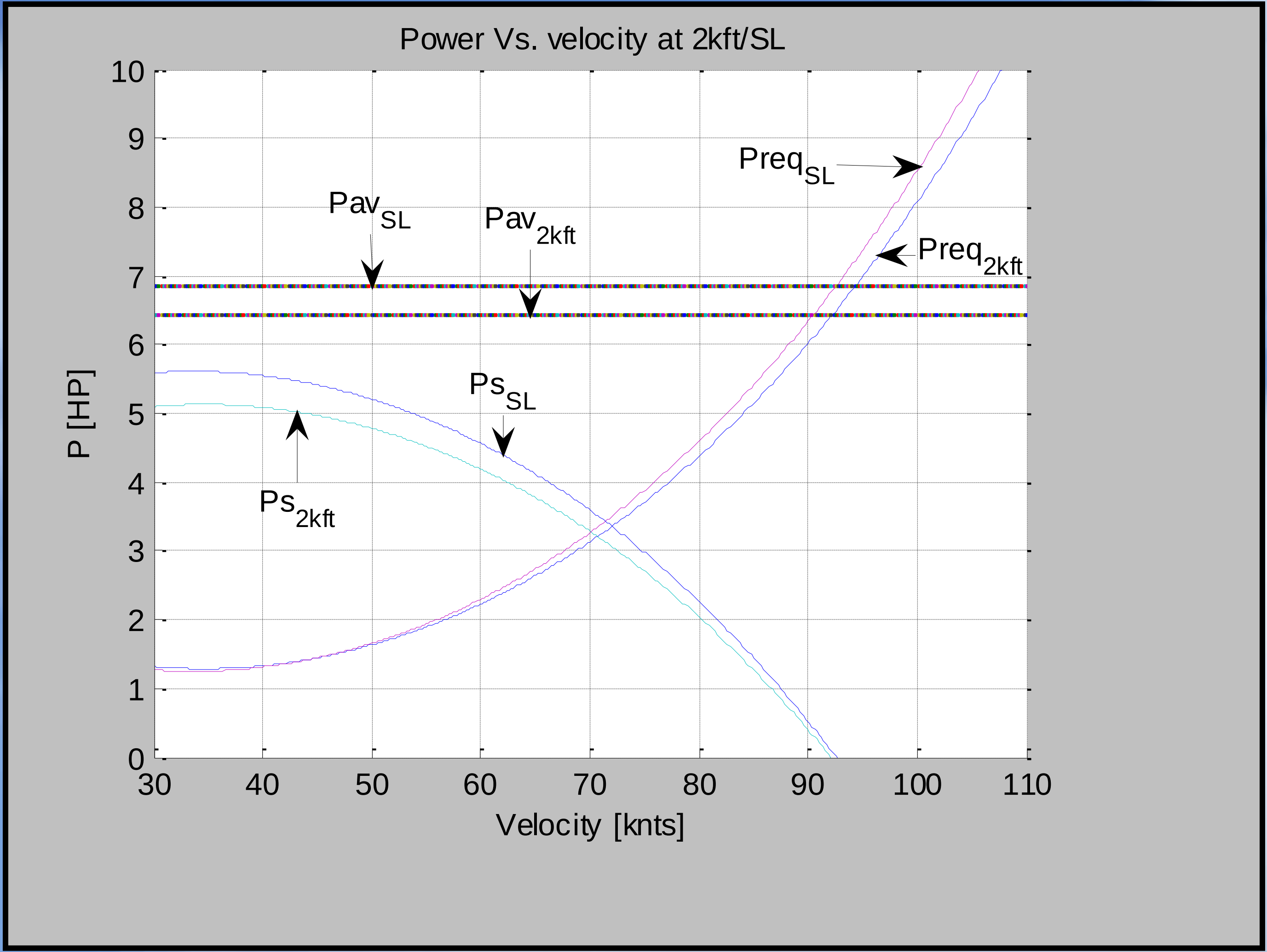
Climb rate at sea level & 2,000 ft



Horizontal velocity of 70 knts
Propeller eff.=0.7

AR=11
Cd0=0.05

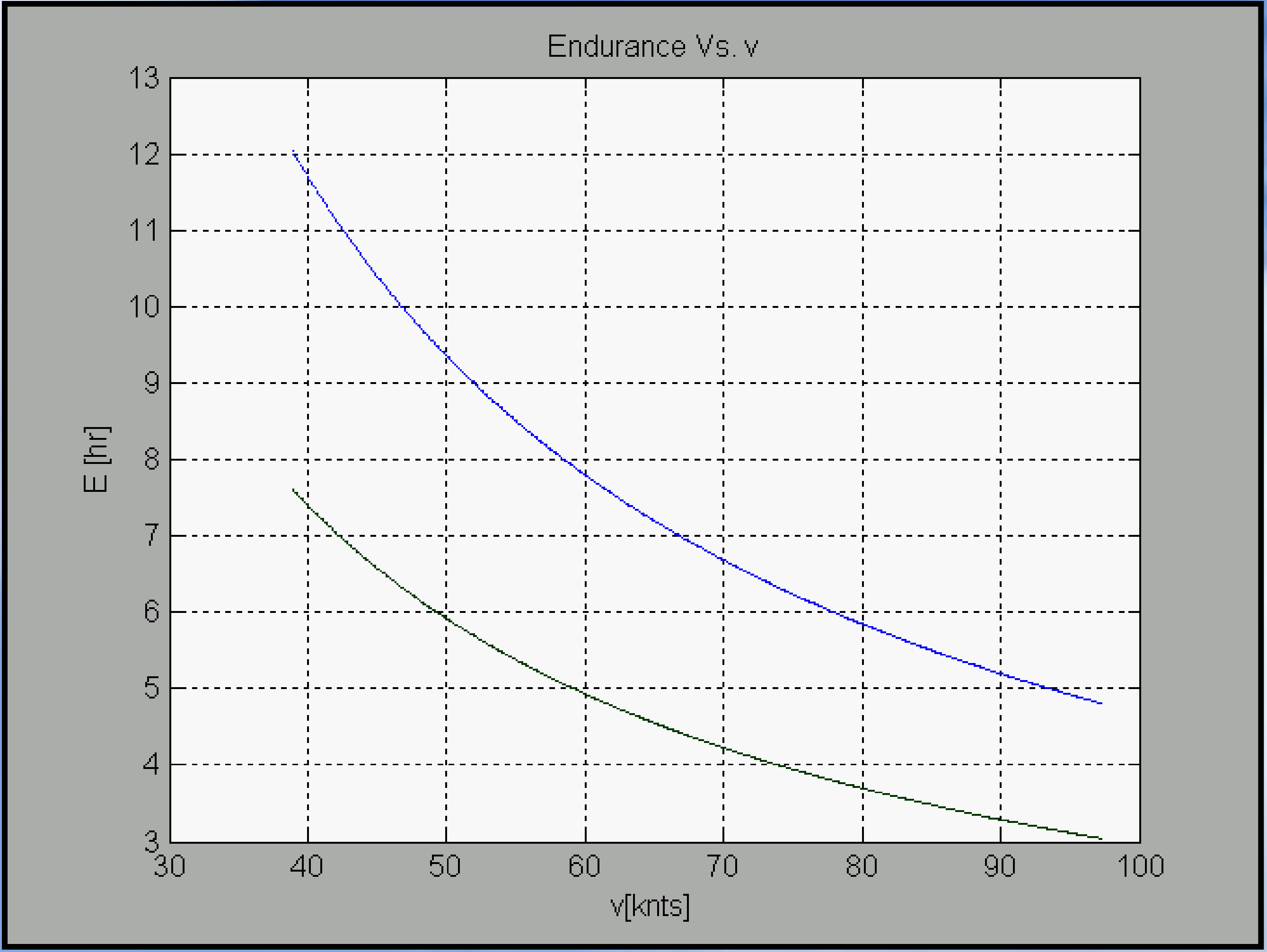
Available, Required and Excess Power Vs. Velocity



(at sea level and 2,000 ft)

Loiter Performance

Engine efficiency is 0.7
Beginning of the endurance at 48 kg and ending at 37 kg (**11 kg were consumed**)

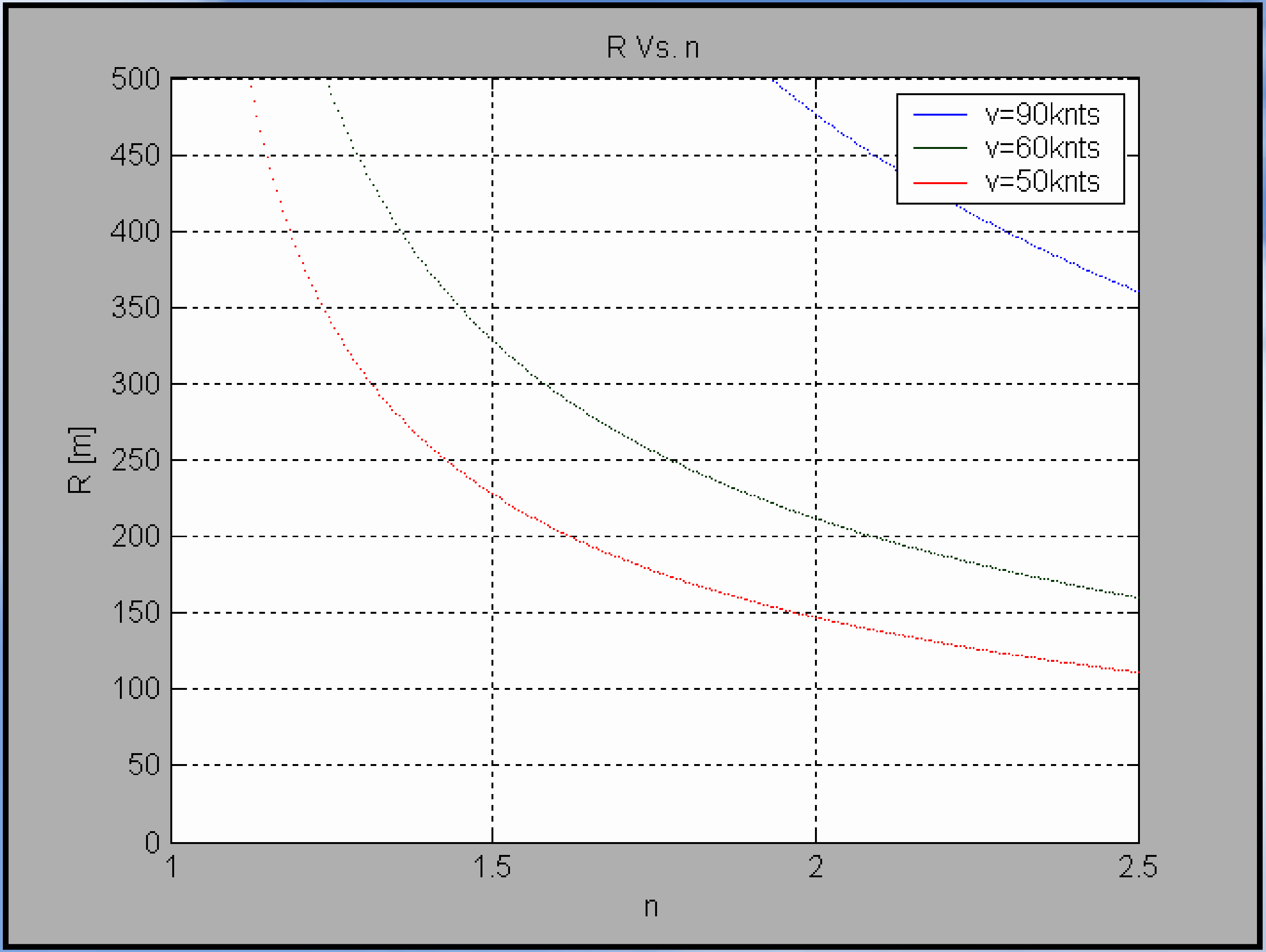


SFC =0.673 kg/hr/HP
SFC =1 kg/hr/HP
Safety factor = 1.5

Horizontal Turn Performance

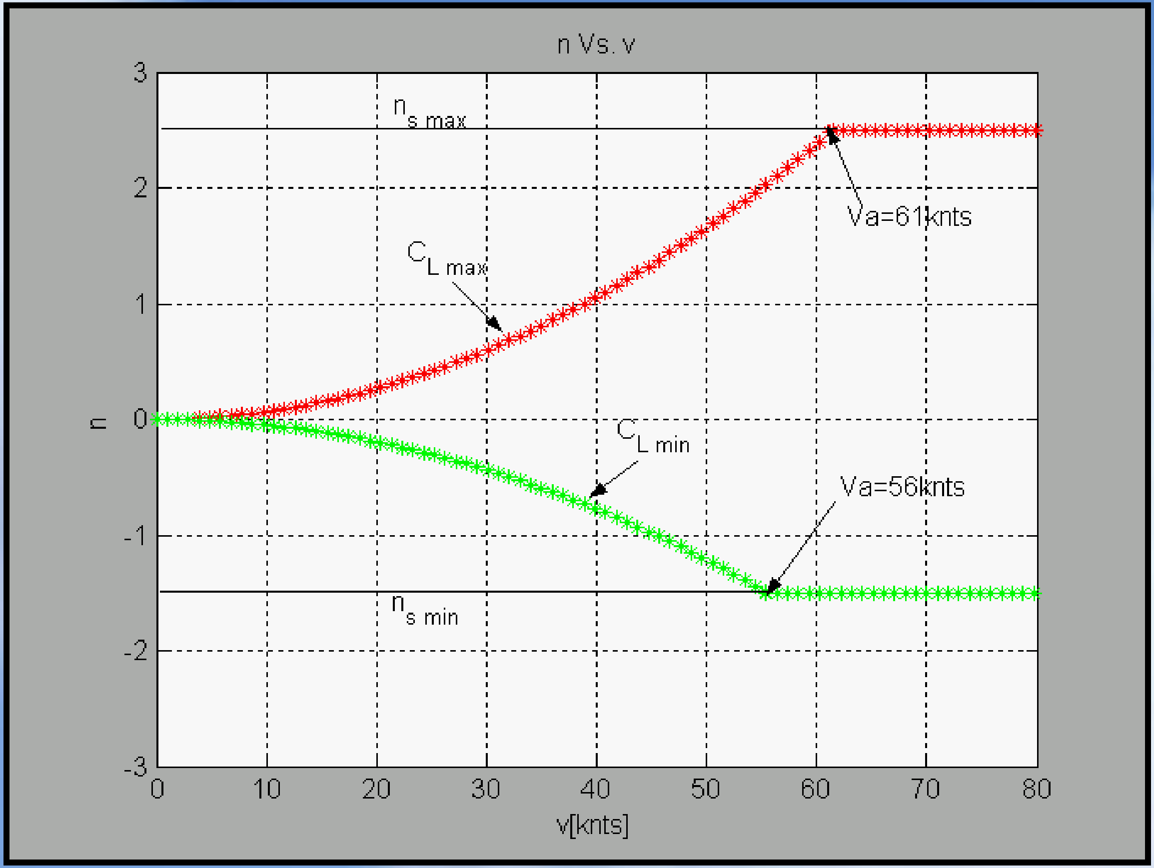
Radius of turn vs. load factor

We can obtain radius of 150[m] at n=2, at velocity of 50knts (loitering).
At cruise velocity ,n has to be 2.5 , so the radius will remain 150m.



$$R = \frac{V^2}{g}\sqrt{n^2 - 1}$$

V-N Diagram



<u>Load factor:</u>

Nmax= 2.5

Nmin= -1.5

$$n = \frac{\rho_0 S V^2 C_{L\max}}{2W_0}$$

$$C_{L\max} = 1.36$$

$$C_{L\min} = -1$$

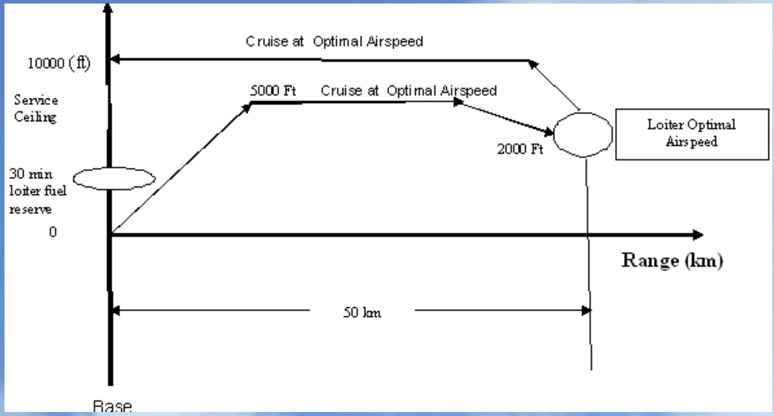
Mission Profile Calculations

Endurance ,at constant velocity

$$E = \frac{\eta}{SFC}\frac{1}{V}\frac{C_L}{C_D}\ln\left(\frac{W_0}{W_1}\right)$$

$$SFC = SFC_{manufacturer} \cdot n = 0.673 \cdot 1.5 = 1\frac{kg/hr}{HP} \qquad (n - safety\ factor)$$

$$Fuel\ \ Reserve\ \ at\ \ the\ \ end = 0.5kg$$



State	Time [min]	Peng [HP]	FF [kg/hr]	Fuel Weight [kg]	Horizontal Velocity [knts]	Climb Rate [ft/min]	Range [km]
Climbing	9	6.8	6.8	1	70	600	19
Cruising 1	11	3.4	3.4	0.7	60	☺	21
Gliding	8	0	0	0.01	60	☺	10
Loitering	330 (5.5 hr)	2.3	2.3	11	50	☺	☺
Climbing	13	6.5	6.7	1.4	70	600	27
Cruising 2	13	2.8	2.8	0.5	60	☺	23
Total	6.5[hr]			14. 5[kg]			100[km]

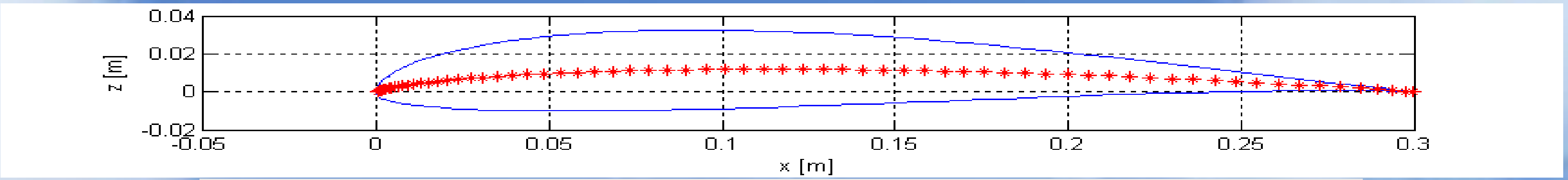
Airfoil Selection

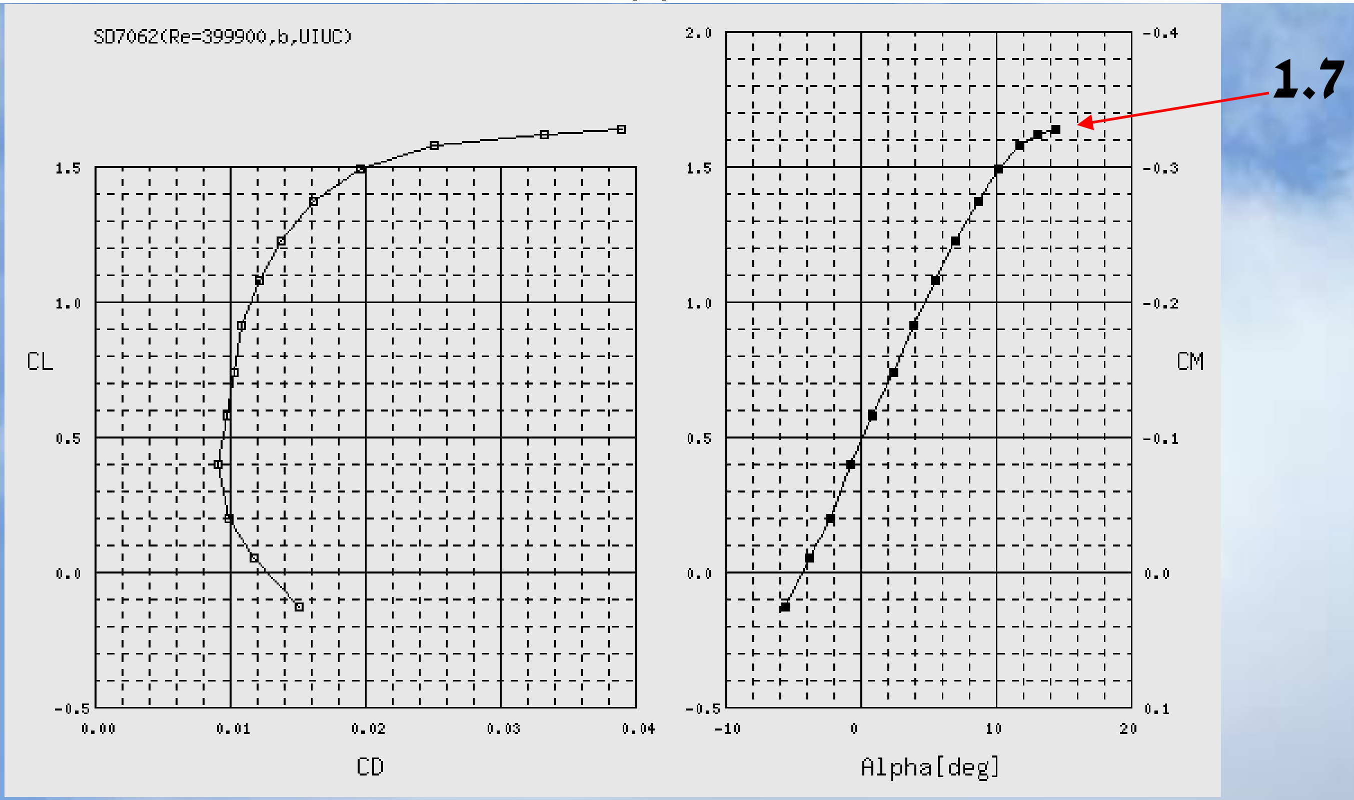
Requirements:

- Minimal drag
- Low Reynolds numbers $(Re = 4 \cdot 10^5 \div 6 \cdot 10^5)$
- Thick profile
- Big camber
- Low speed

Airfoil	Cd min	Cl max	Alpha max [deg]	Thickness	Camber	Reynolds
S8052	0.008	1.2	10	0.12	0.016	402000
Selig S8037	0.01	1.3	13	0.16	0.026	502000
SD 7062	0.012	1.7	10	0.14	0.04	401000
S8036	0.009	1.2	13	0.16	0.018	503000
E472	0.009	1.3	14	0.12	0	510000
FX63137	0.011	1.6	10	0.14	0.06	308600
FX76 MP140	0.01	1.7	10	0.1411	0.0707	500000
SG6040	0.014	1.05	10	0.16	0.025	500300

The Chosen Airfoil For The Wing And The Canard is SD7062





Aerodynamic Numeric Calculation

- Lift distribution on wing – canard configuration using VLM - Vortex Lattice Method.

- Airfoil lift calculation using Vortex Distribution method.

Theoretical Lift Coefficient

- Assuming flat aerodynamic surfaces and neglecting mutual wing-canard interferences.

$$C_L = C_{L\ canard} + C_{L\ wing} = \left(C_{L\alpha\ canard} + C_{L\alpha\ wing}\right)\alpha$$

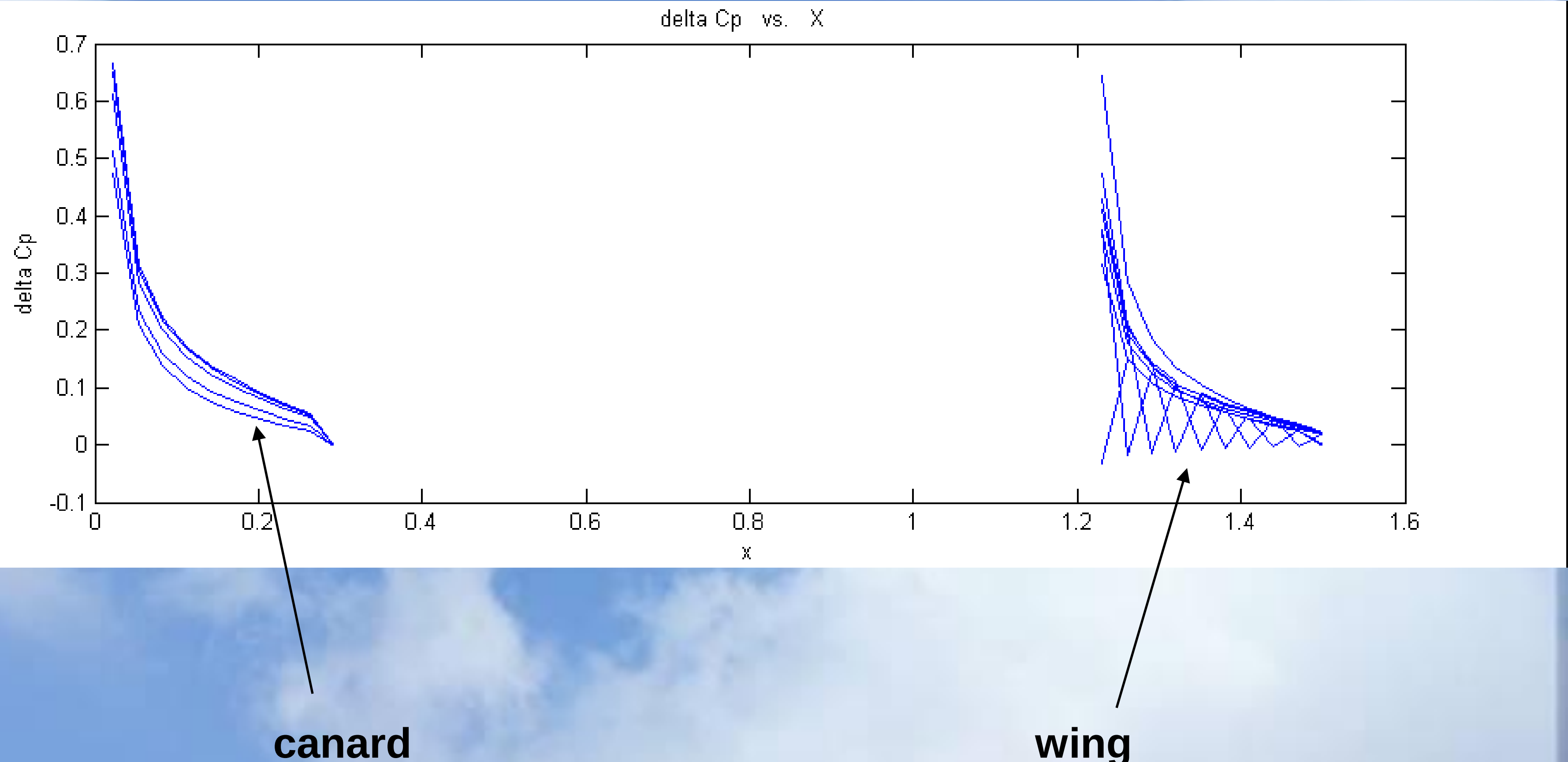
$$C_{L\alpha\ Theory} = C_{L\alpha\ canard} + C_{L\alpha\ wing} = \frac{2\pi}{1+\frac{2}{AR_{canard}}} + \frac{2\pi}{1+\frac{2}{AR_{wing}}}$$

$$AR = \frac{b^2}{s} = \frac{b}{c} \qquad AR_{canard} = \frac{2}{0.3} = 6.667 \qquad AR_{wing} = \frac{3.3}{0.3} = 11$$

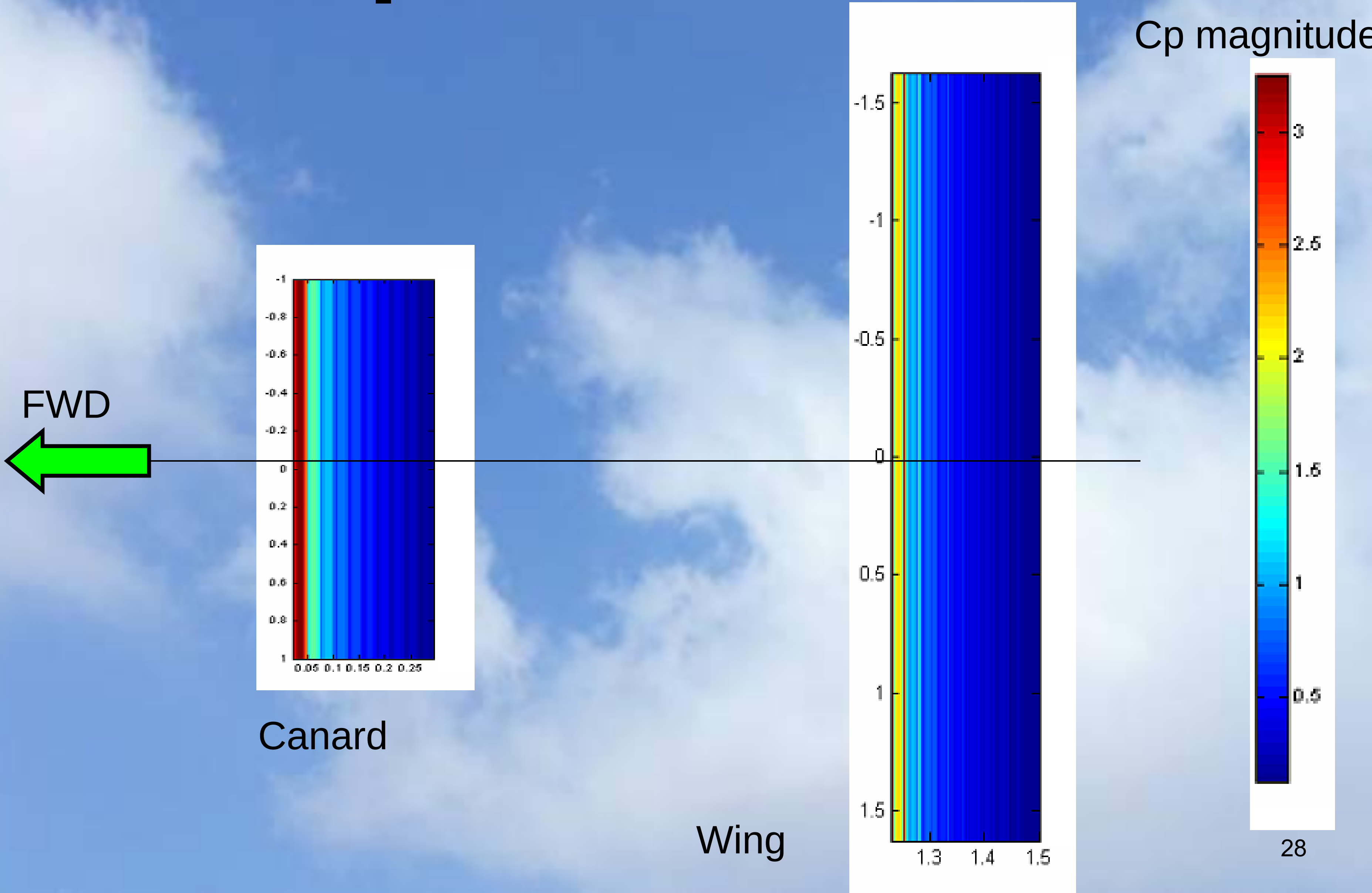
$$\boxed{C_{L\alpha\ Theory} = 10.15} \qquad \boxed{C_{L\alpha\ VLM} = 6.026 = 0.69 C_{L\alpha\ Theory}}$$

- The canard decreases wing lift by 30%!

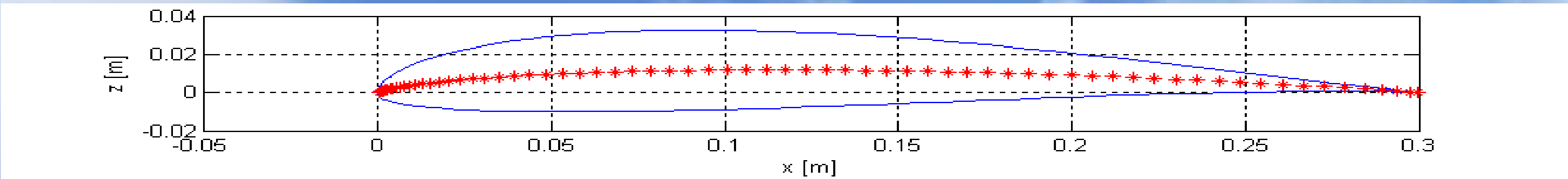
Cp Distribution



Cp Distribution

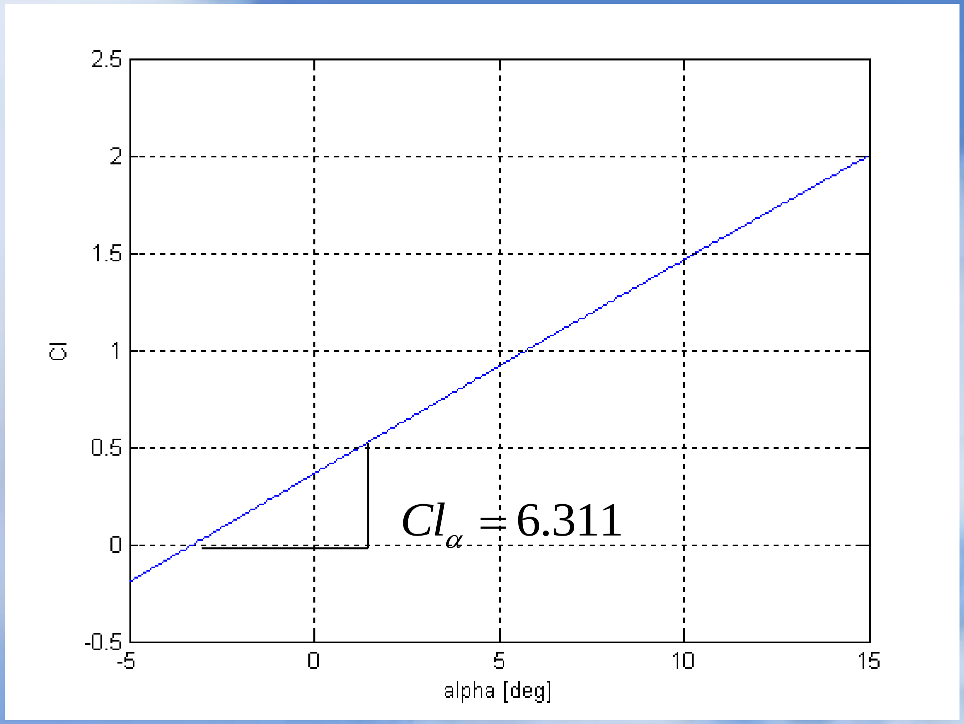


SD 7062 Airfoil Calculations

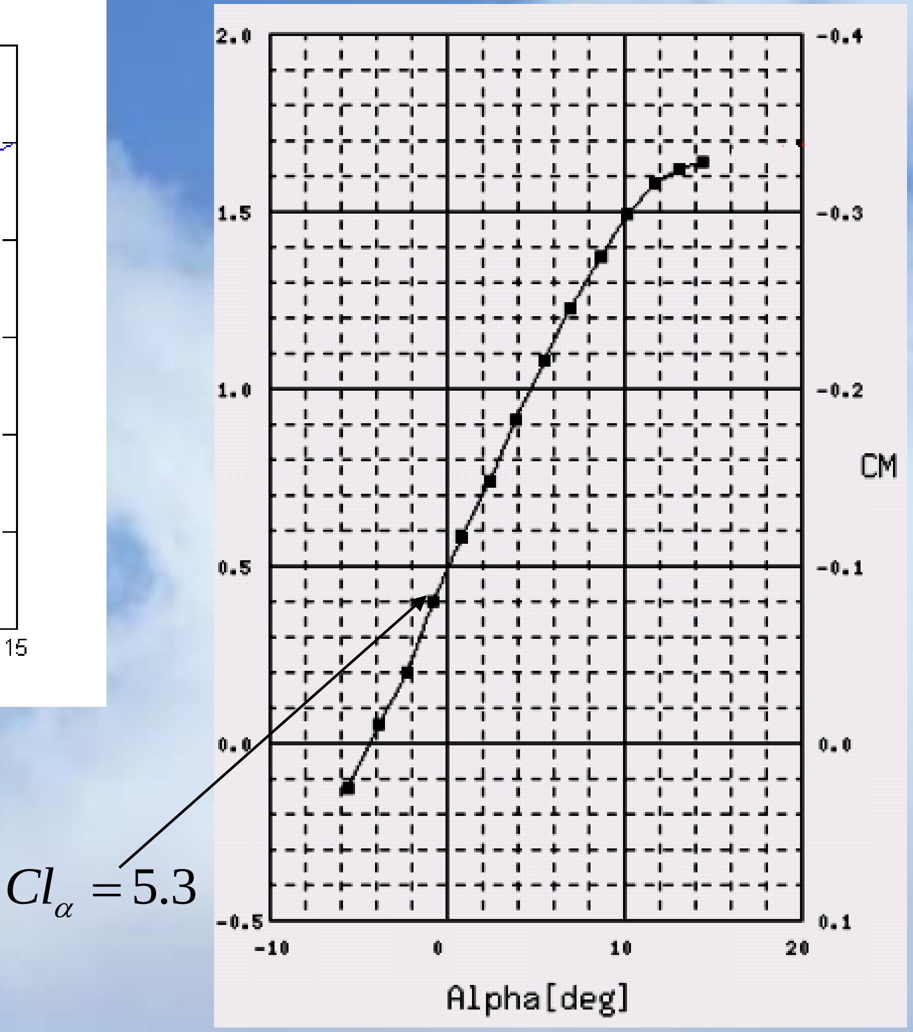


Lift Line Of SD7062

Calculated

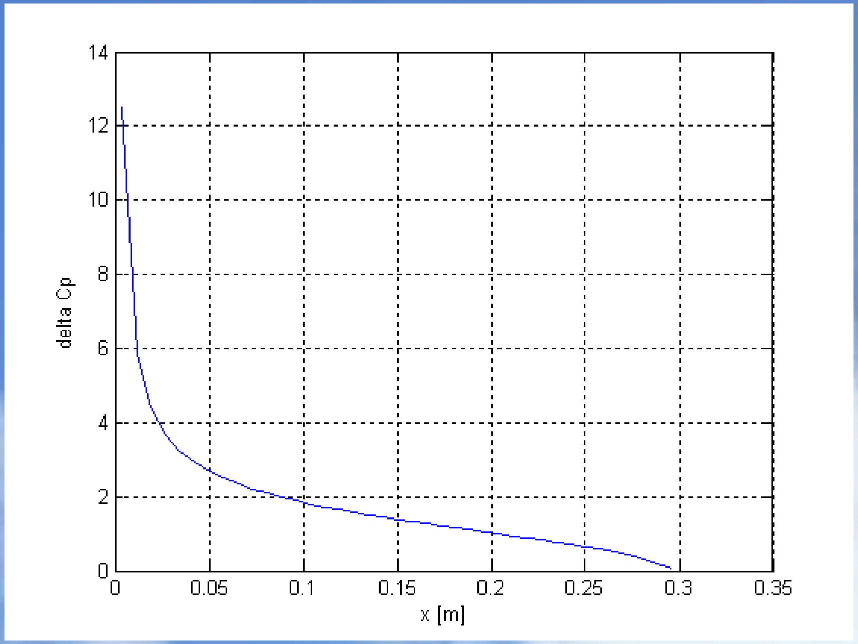


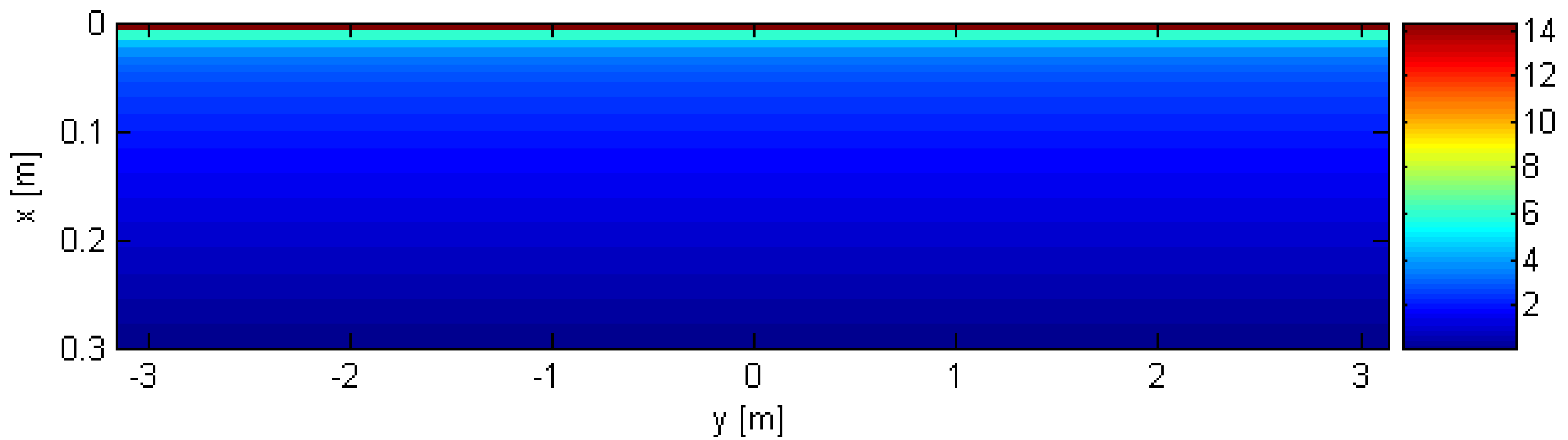
Experimental



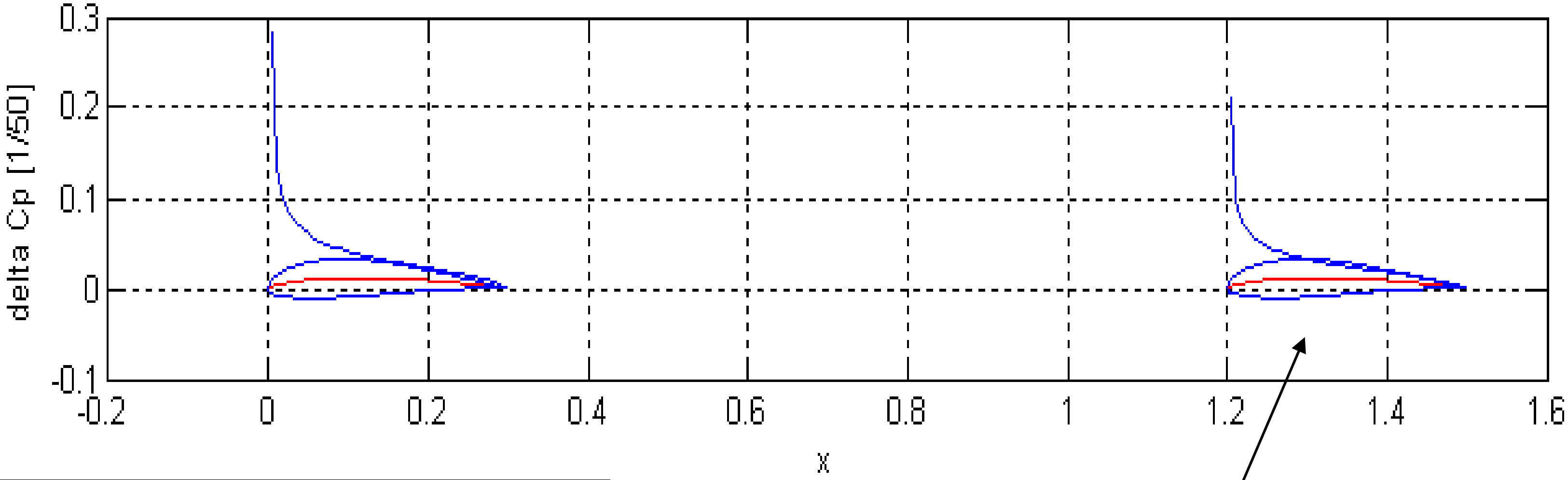
Pressure Distribution On SD7062

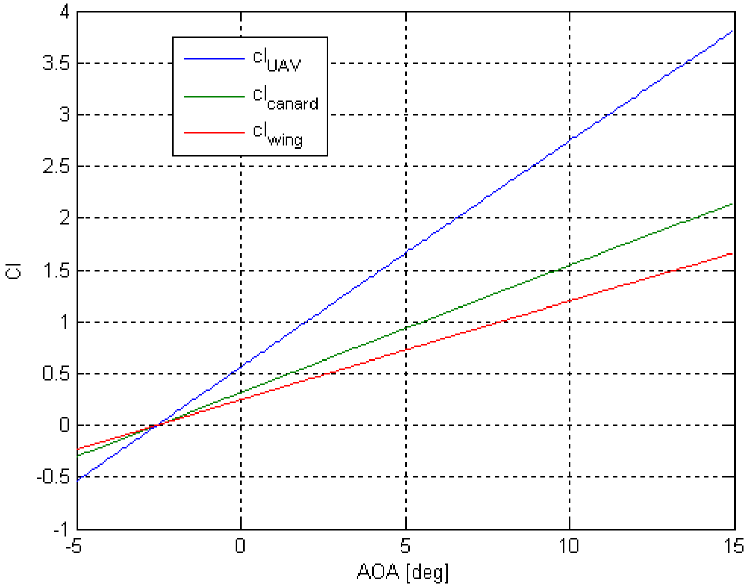
$$\alpha = 11^o$$





Effect Of Another Airfoil On Lift Line Calculation





$$Cl_{\alpha\ wing} = 5.51 = 87\% Cl_{SD7062}$$

For infinite canard and wing

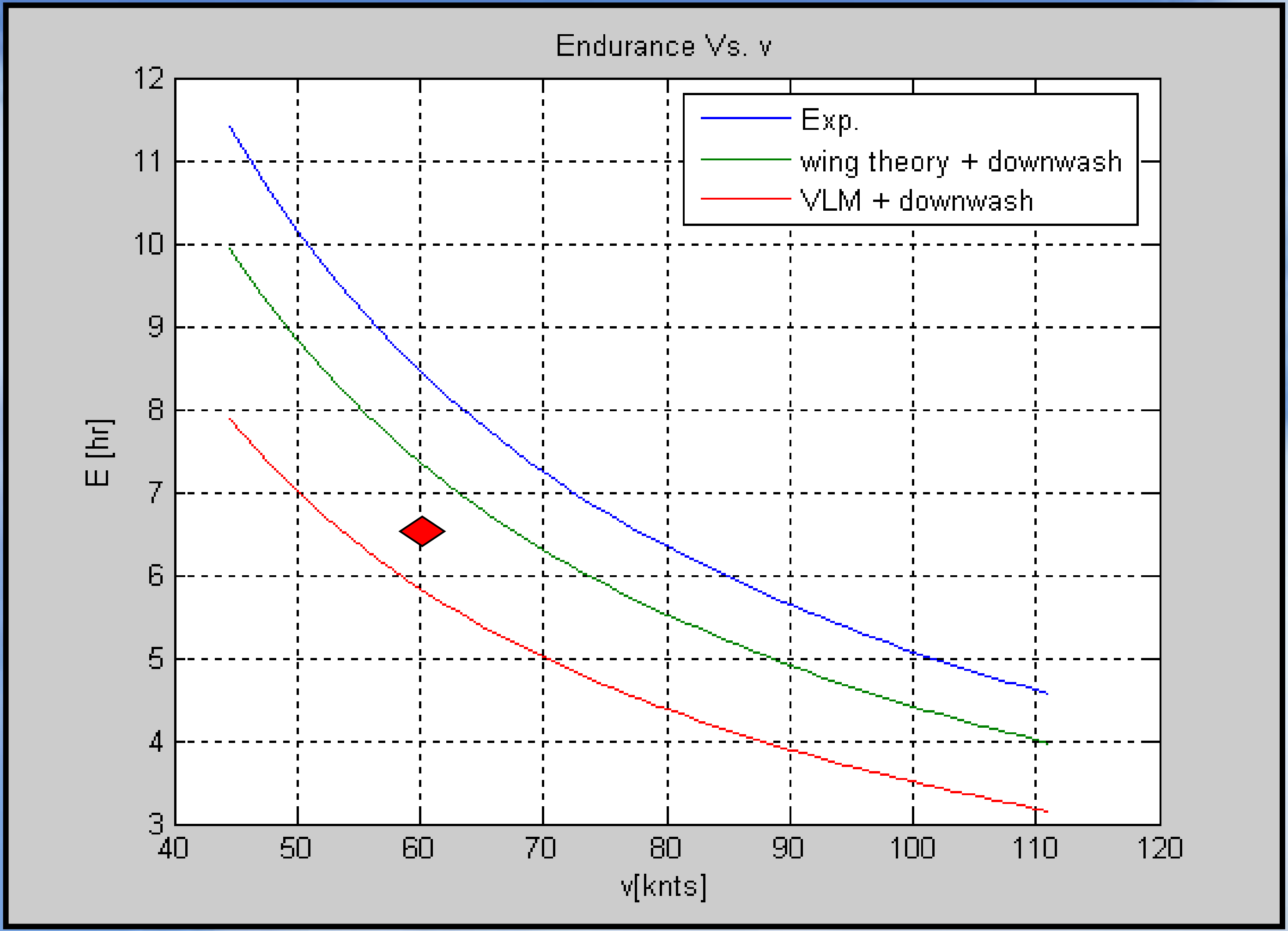
The canard decreases wing lift by 13%

Updated Flight Performance

According To New Lift Coefficients

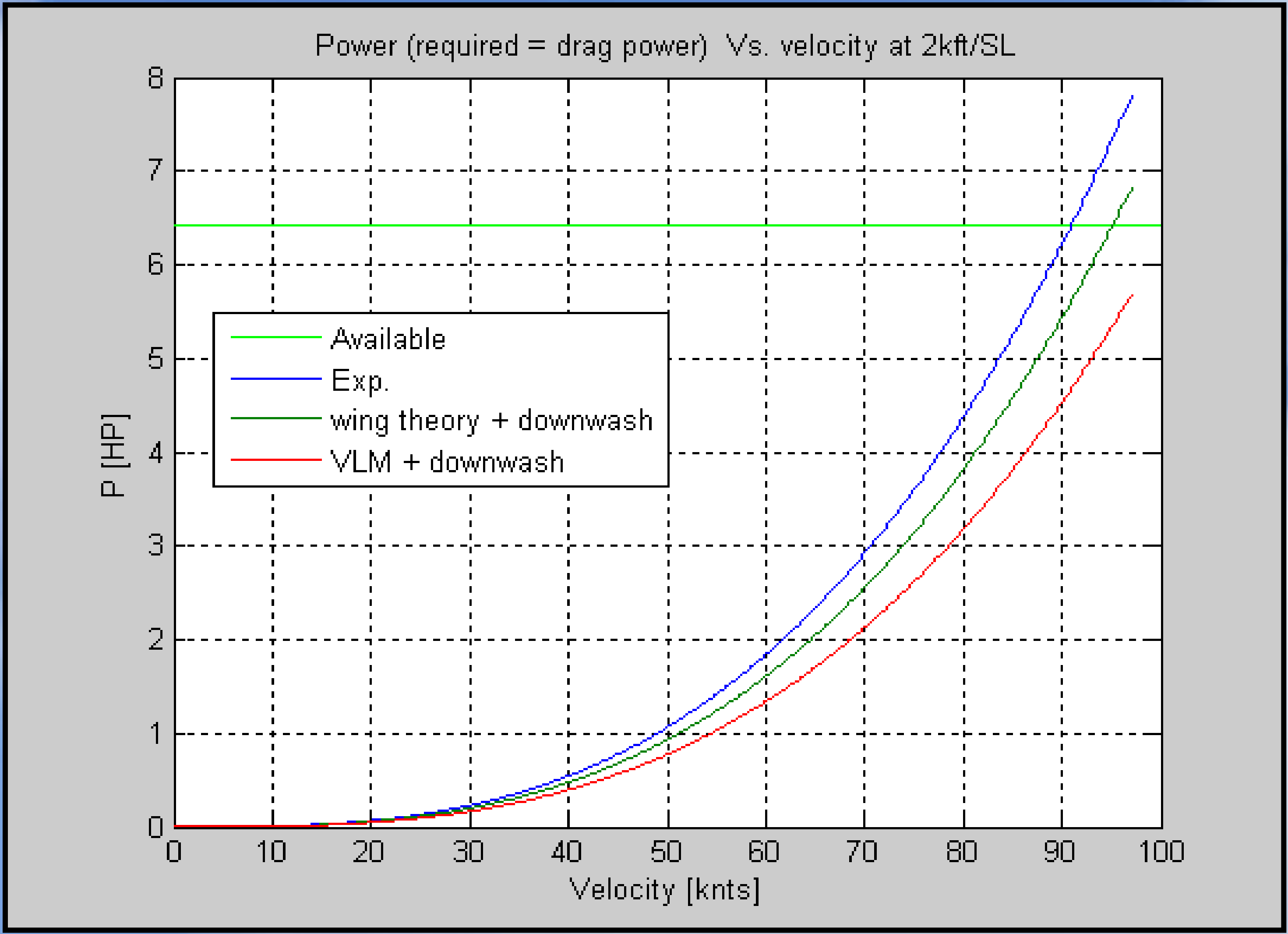
- Airfoil experimental Cl.
- Finite wing VLM calculated Cl. (with canard effect)
- Airfoil ‘Wing theory’ calculation. (with canard effect)

Endurance



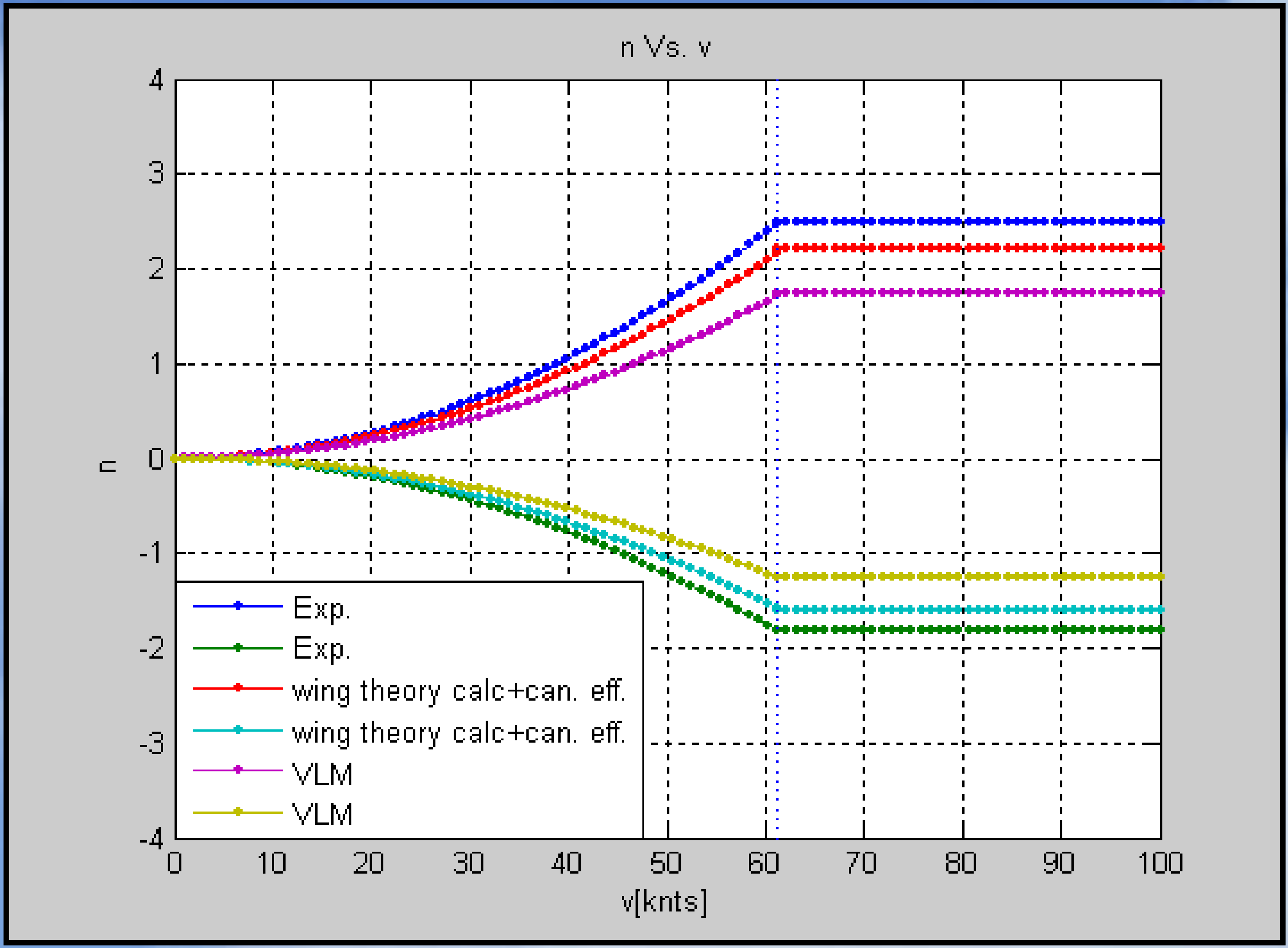
Endurance Vs. v
Exp.
wing theory + downwash
VLM + downwash
E [hr]
v[knts]
12
11
10
9
8
7
6
5
4
3
40
50
60
70
80
90
100
110
120

Power



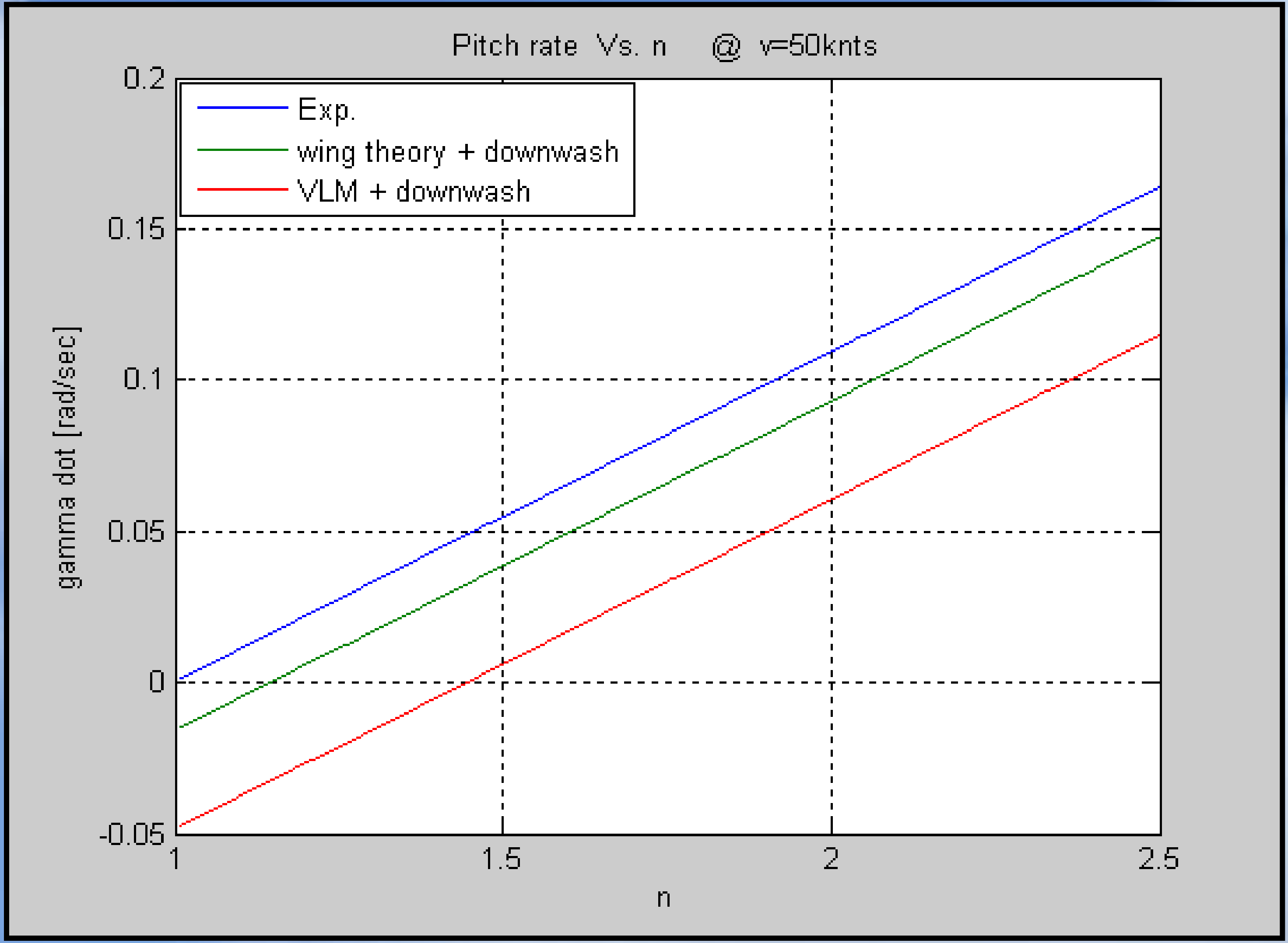
Power (required = drag power) Vs. velocity at 2kft/SL
Available
Exp.
wing theory + downwash
VLM + downwash
P [HP]
0
1
2
3
4
5
6
7
8
0
10
20
30
40
50
60
70
80
90
100
Velocity [knts]

V-N Diagram



n Vs. v
4
3
2
1
0
-1
-2
-3
-4
n
0
10
20
30
40
50
60
70
80
90
100
v[knts]
Exp.
Exp.
wing theory calc+can. eff.
wing theory calc+can. eff.
VLM
VLM

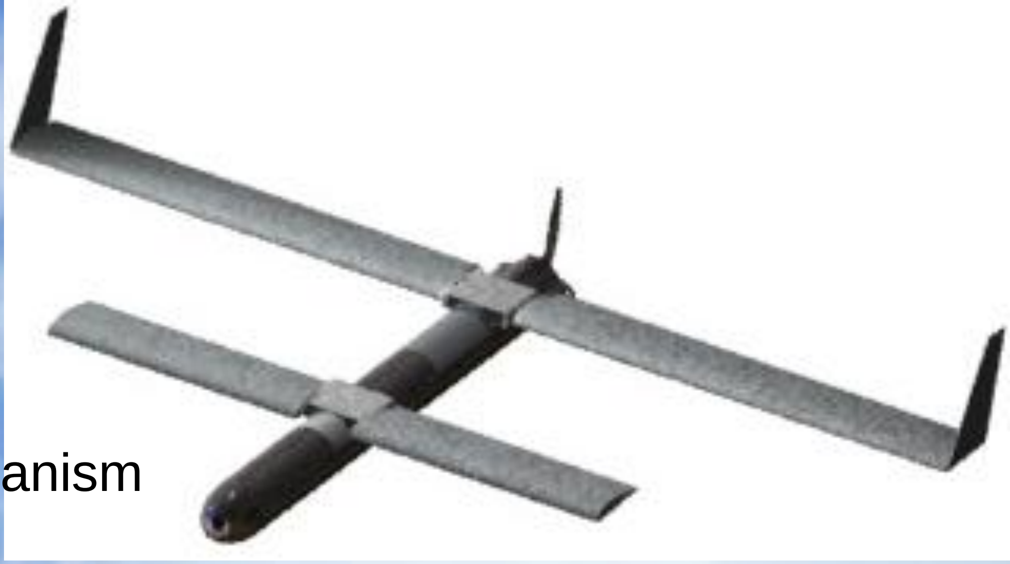
Pitch Rate ($\dot{\gamma}$)



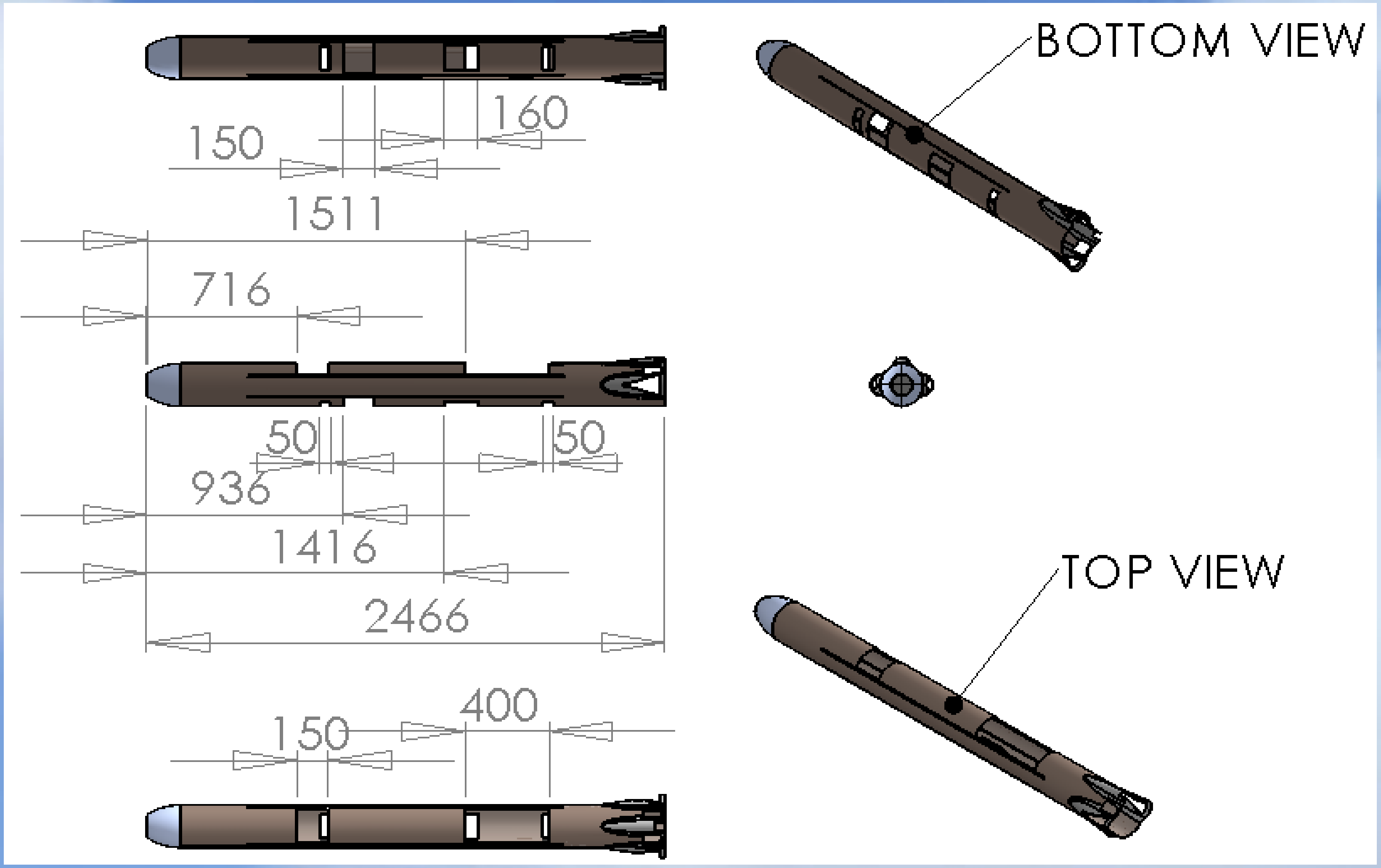
4. UAV Component Detailed Design

The components

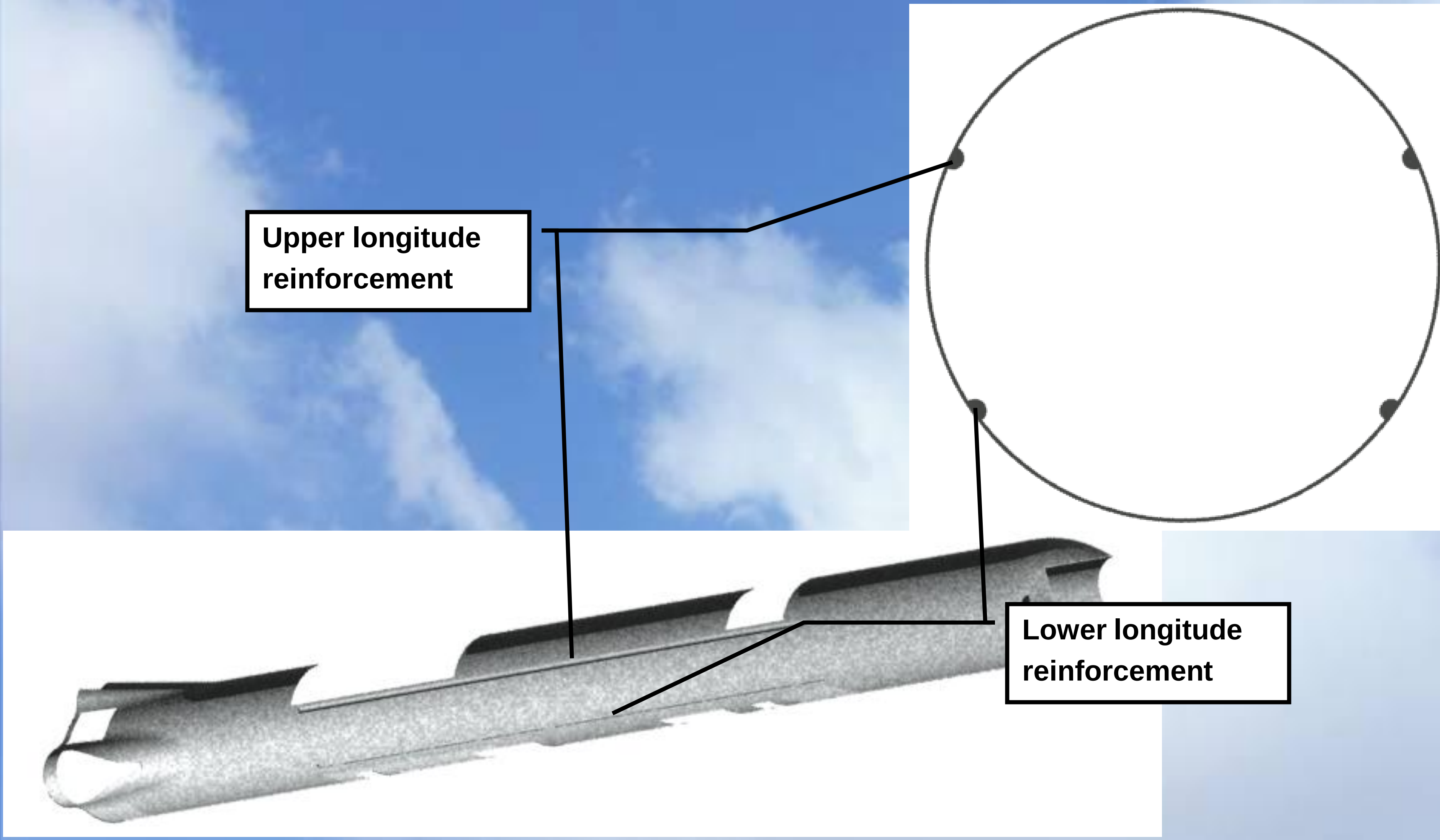
- Fuselage
  - Camera door opening mechanism
  - Service panels
  - Cowling + NACA Scoop
  - Reinforcements
- Wing structure
- Wing / Canard opening mechanism
- Canister



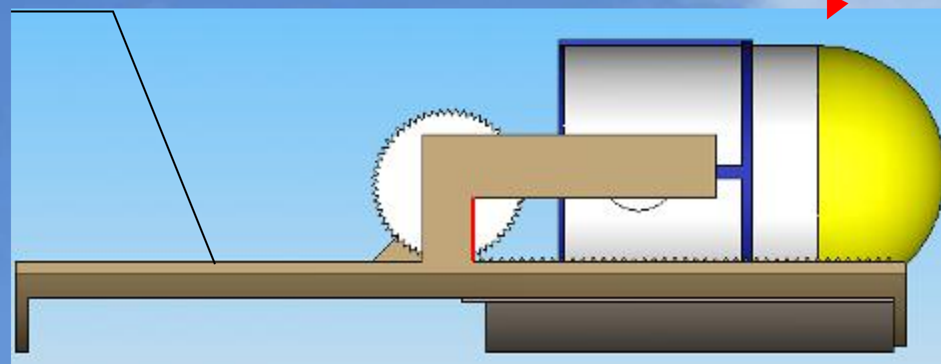
The Fuselage

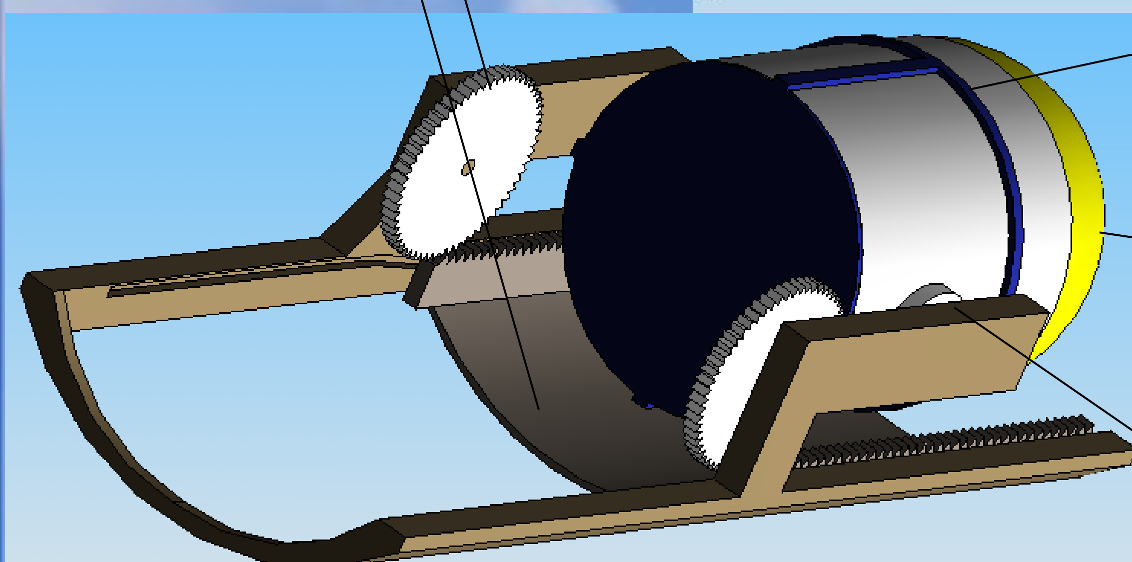


The Fuselage



Camera withdrawal mechanism





COG Wheel+ engine

Door frame

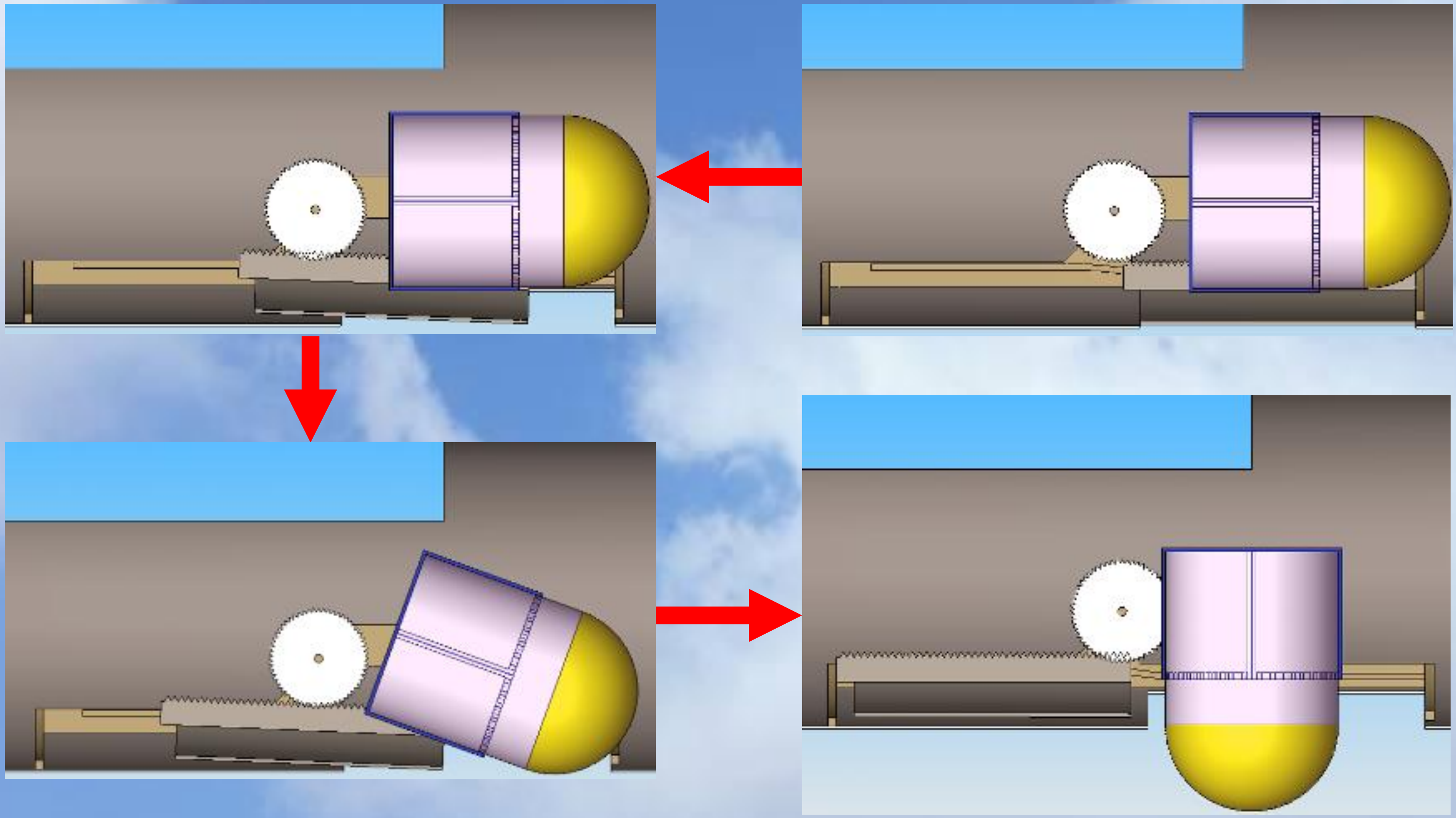
Sliding door

Camera holder

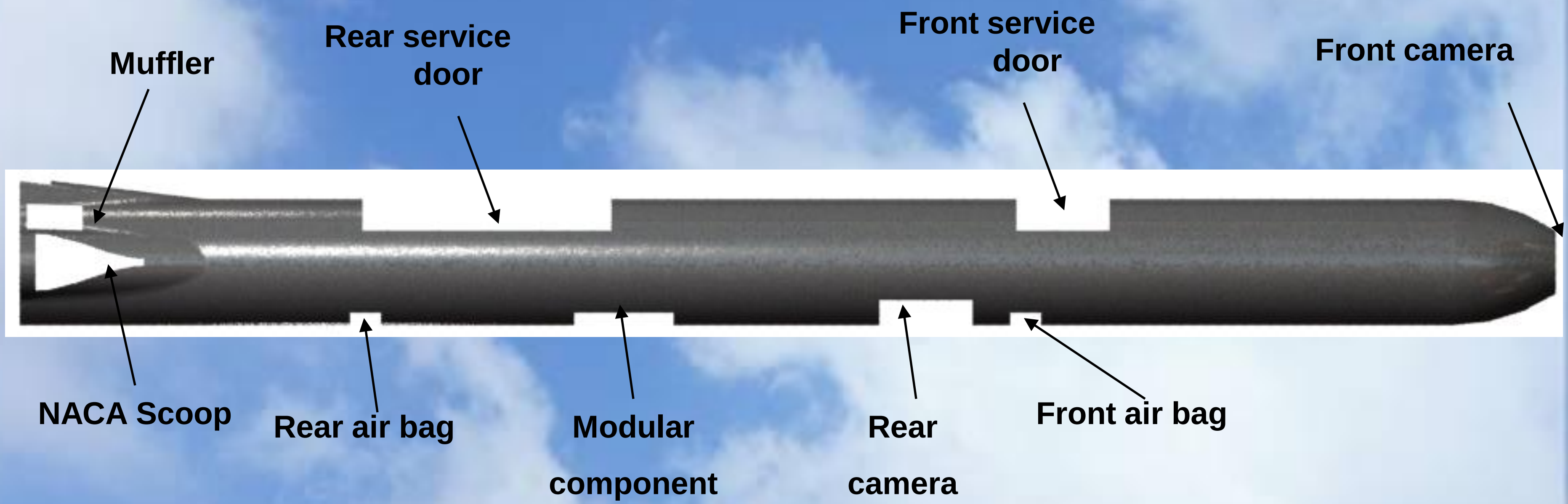
Rear camera

Camera engine

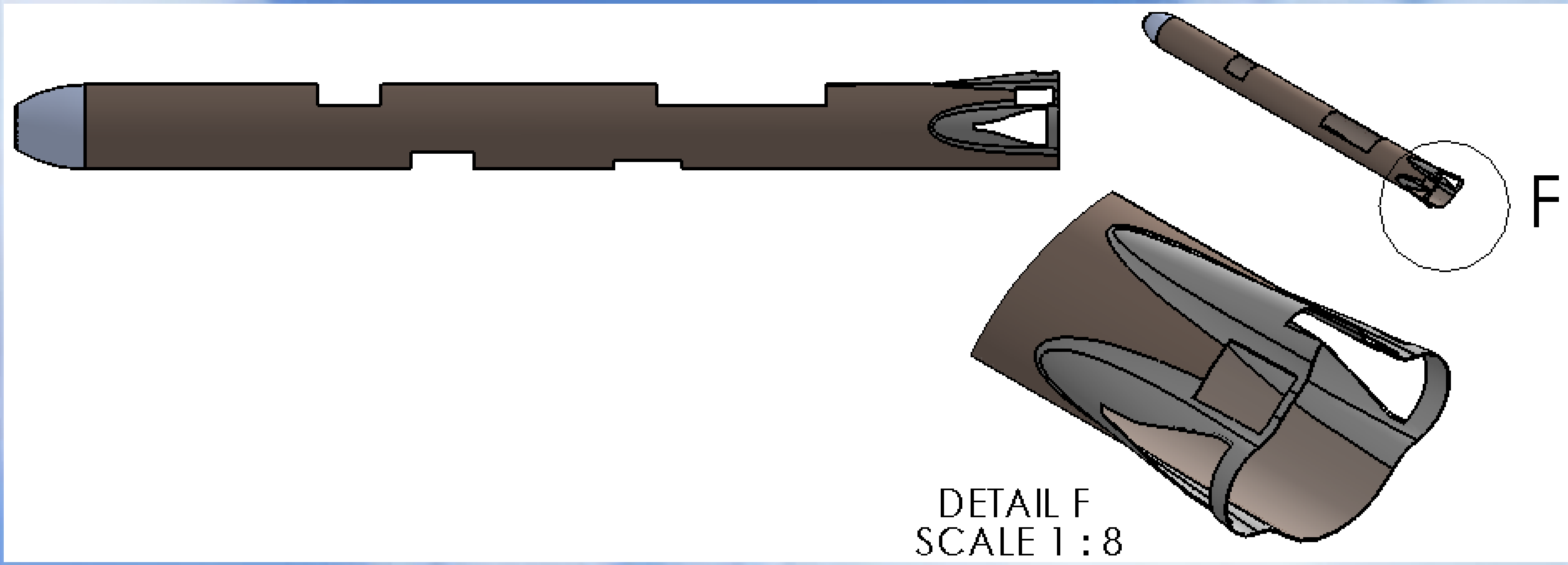
Camera and door withdrawal mechanism



Service Panels

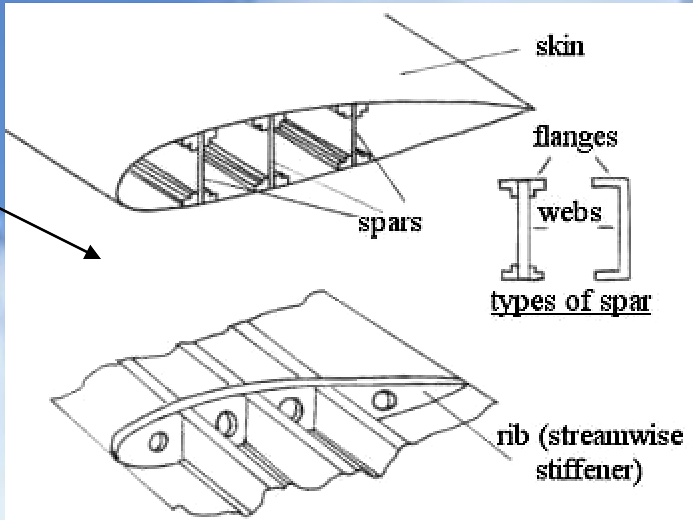


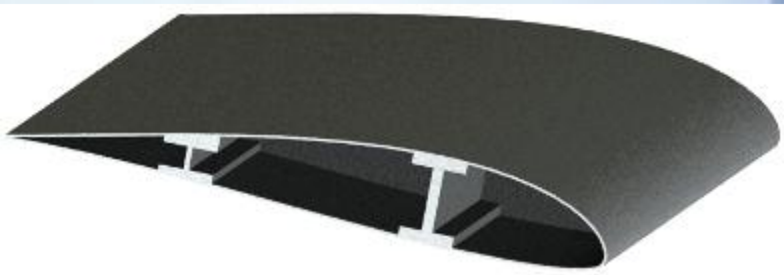
Cowling With NACA Scoop



Wing Structural Design

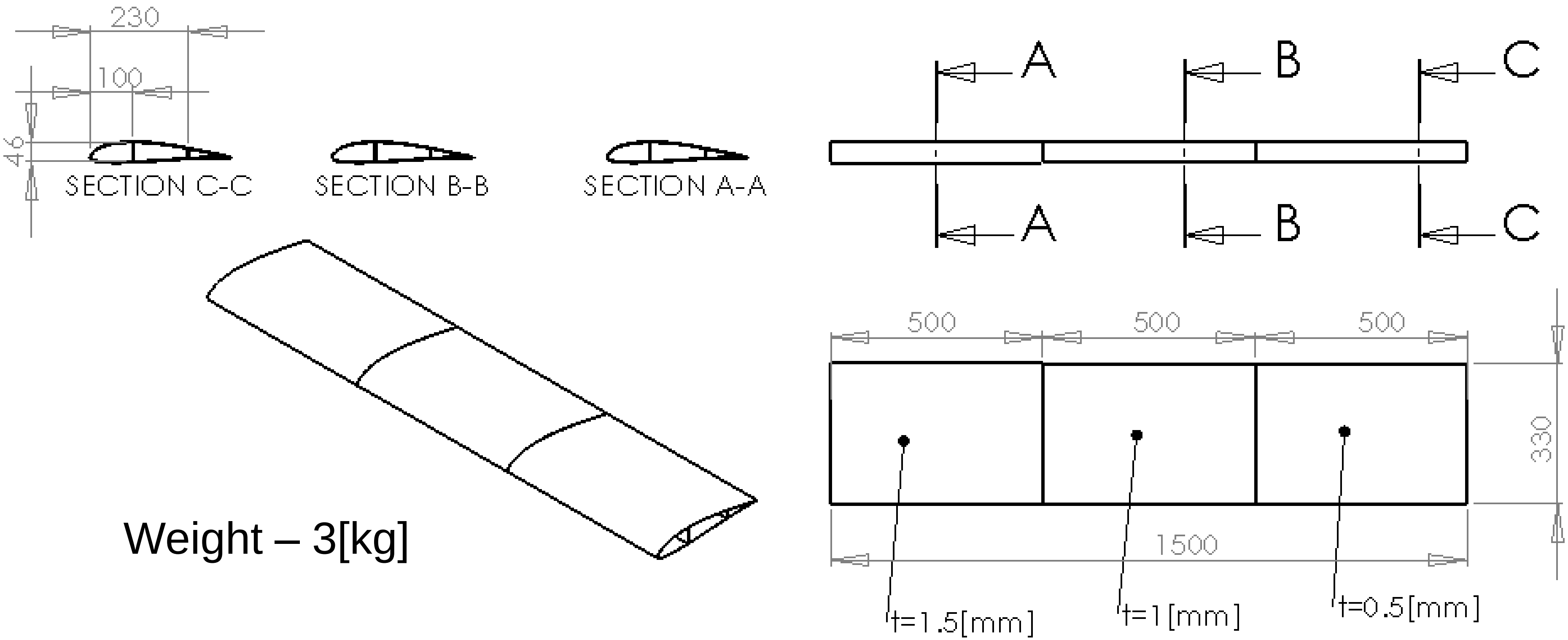
- First, a conventional design was performed.
- The result was a heavy wing (8.5 kg) which could bear greater loads than the maximum load applied on the UAV.





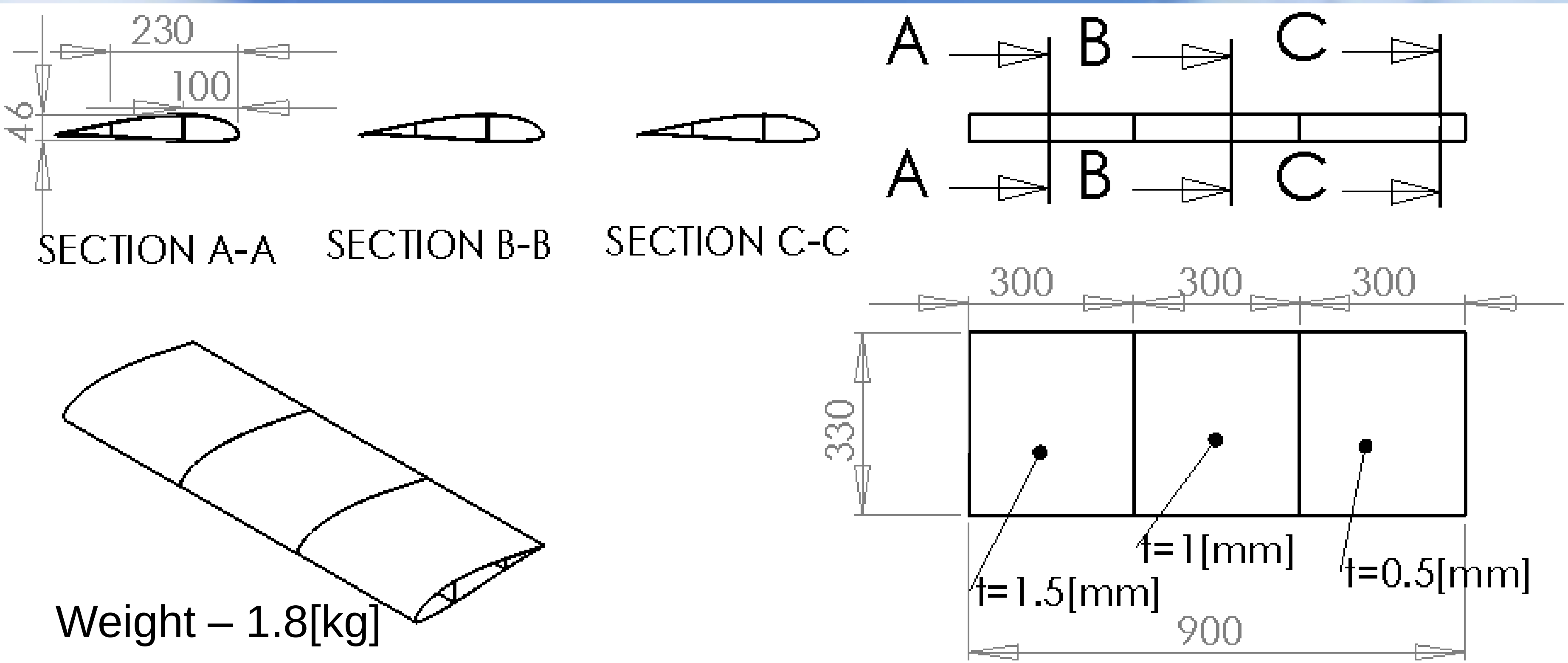
- It was decided to build aluminum extruded surfaces with thin spars.

Wing – half span



Weight – 3[kg]

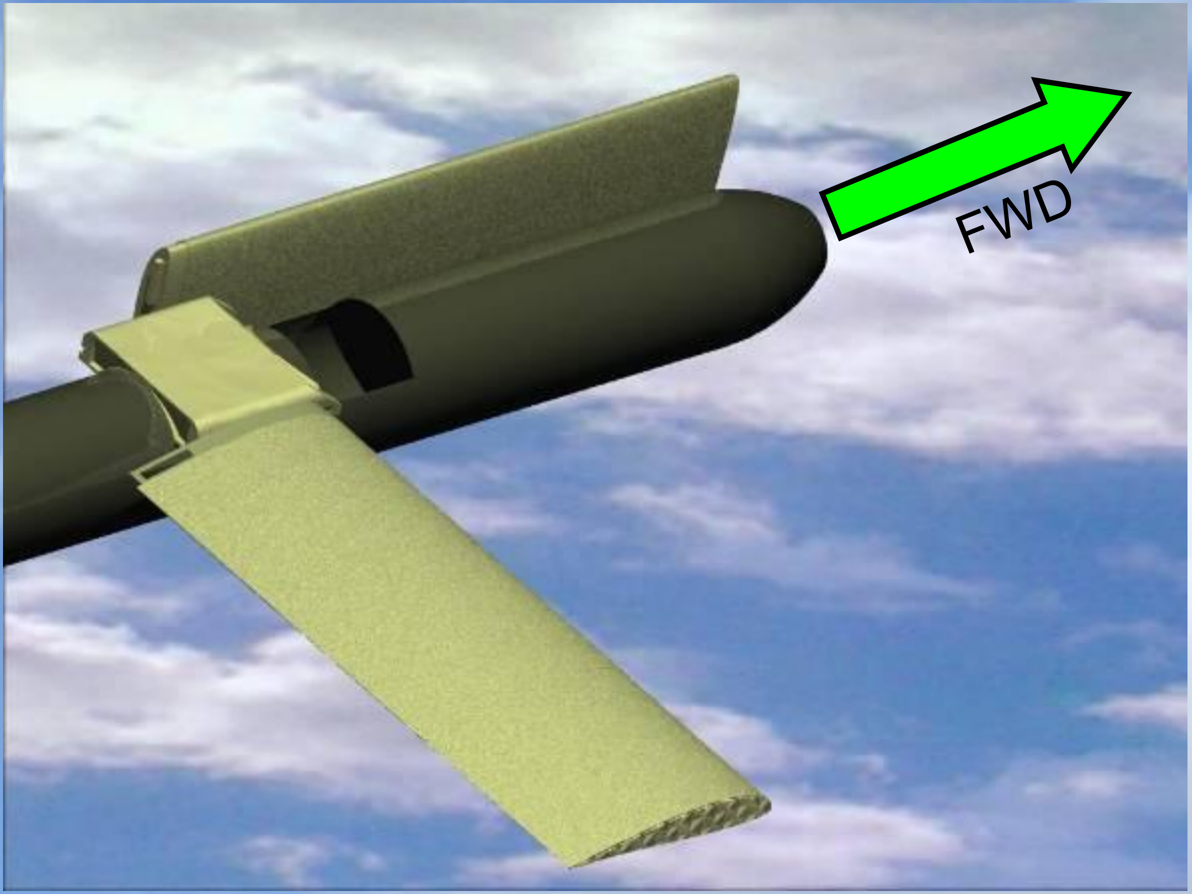
Canarad – half span



Weight – 1.8[kg]

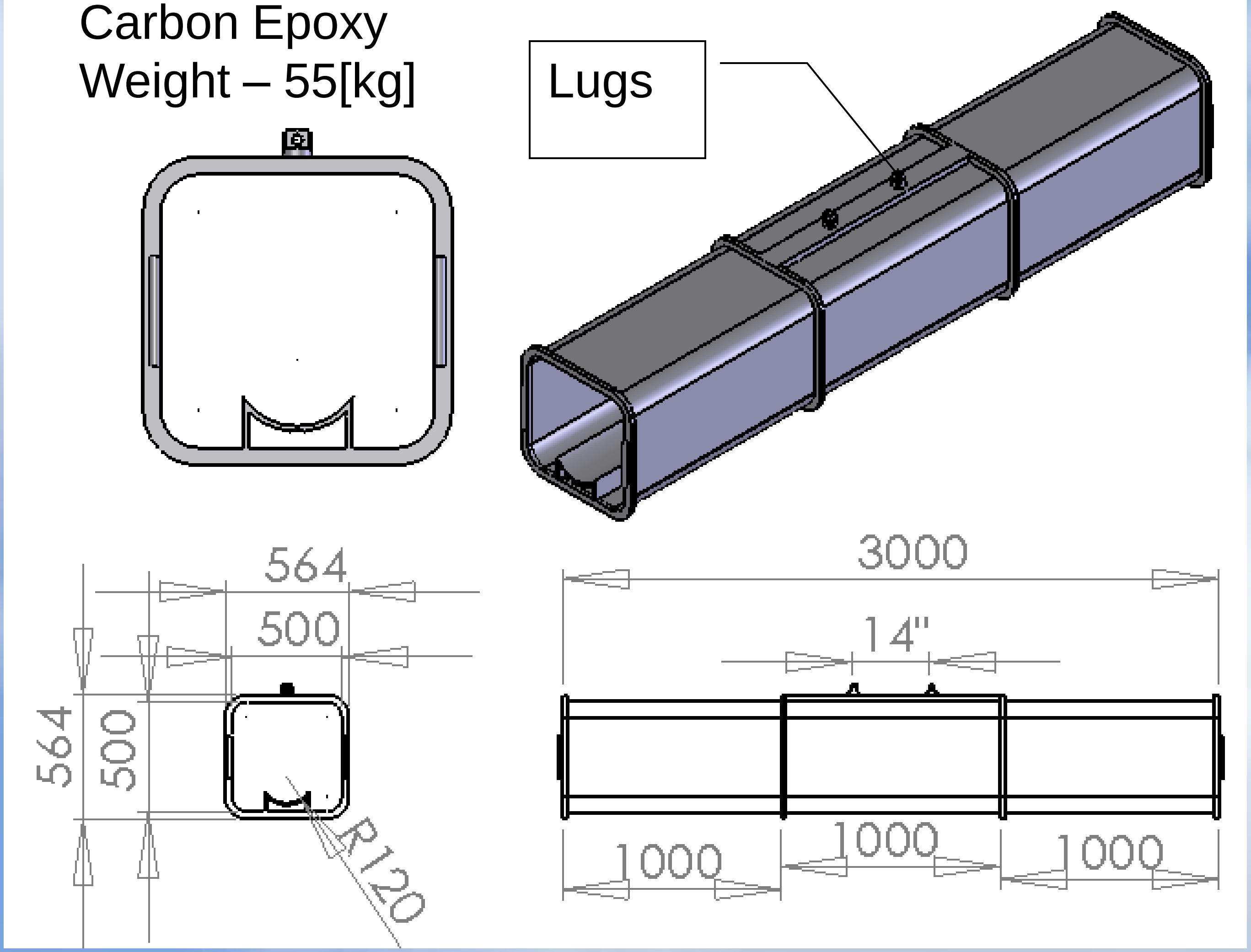
Wing/Canard Opening Mechanism

- It is necessary to design a pivot for this mechanism.

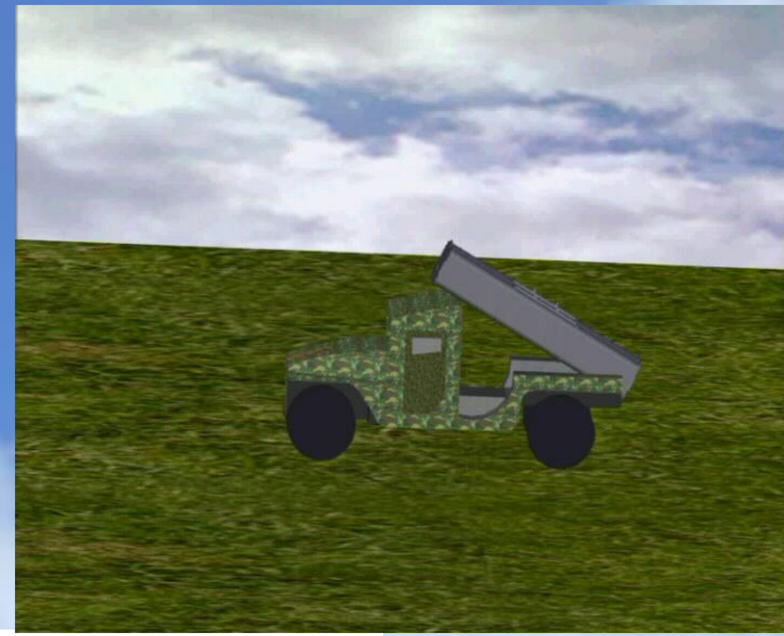


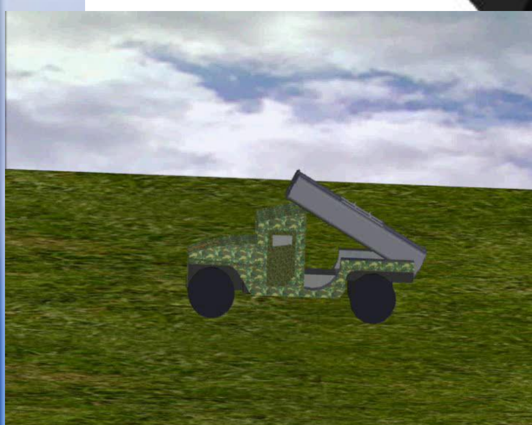
The Canister

Carbon Epoxy
Weight – 55[kg]



Movie



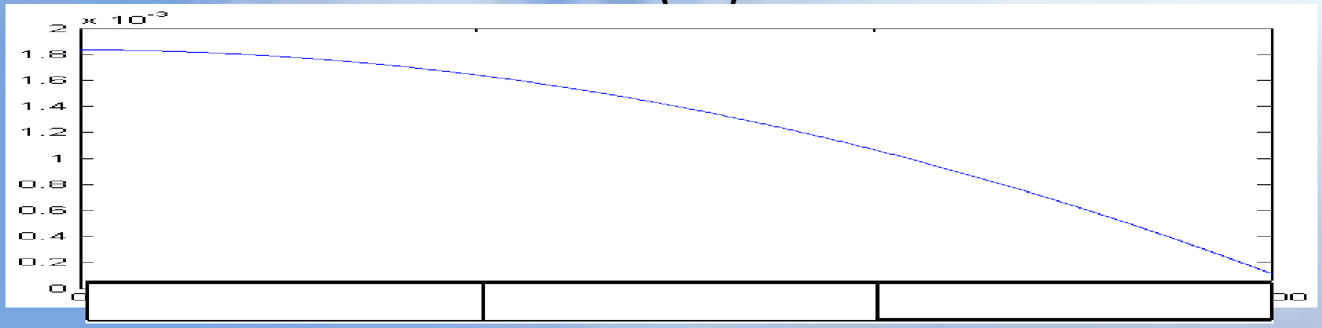


5. Load and Stress Analysis

Wing Structural Analysis

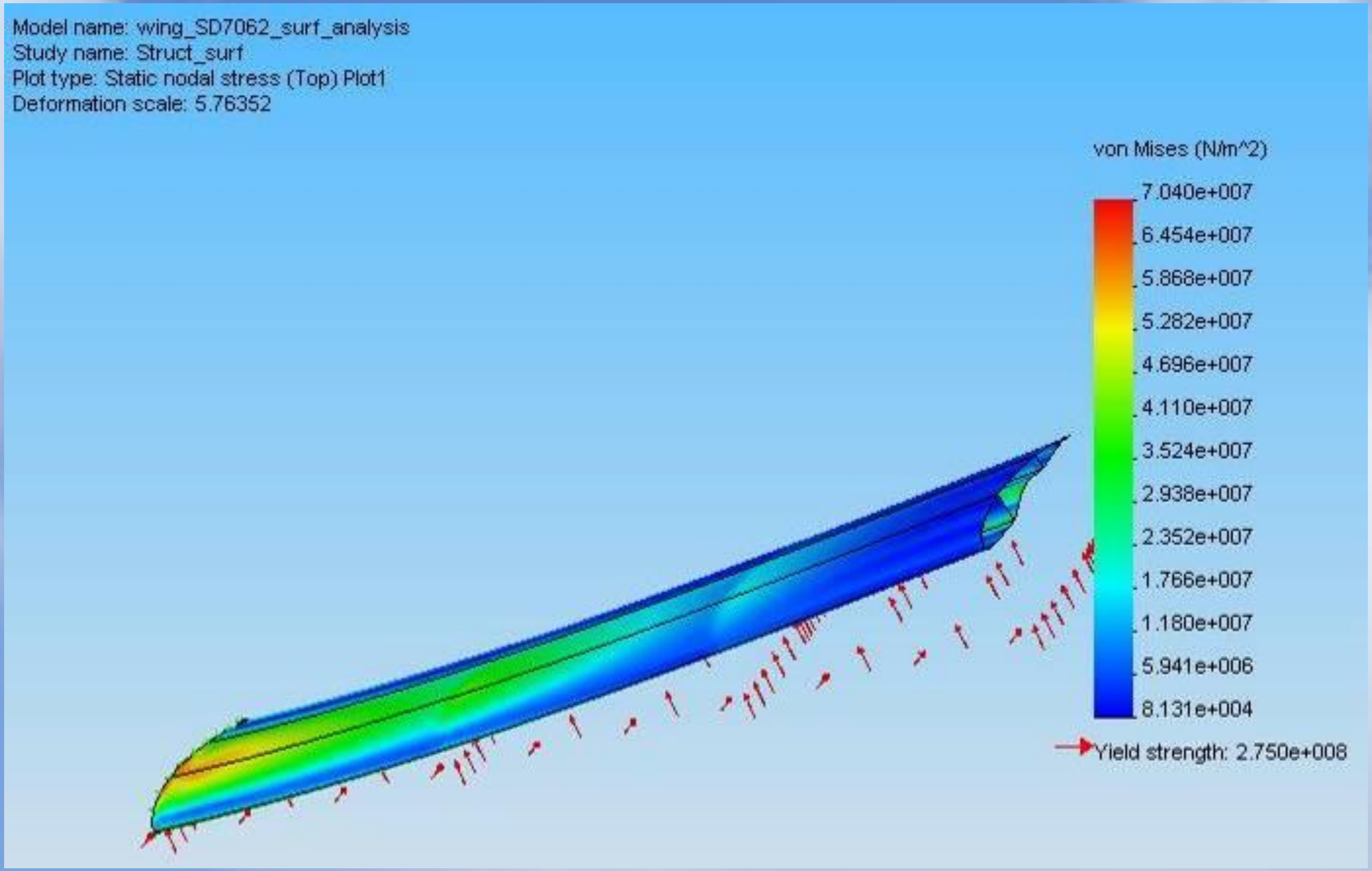
- The analysis was performed using FEM (Finite Elements Method) program, called COSMOS.
- Shell modeled wing. (more accurate for thin bodies than 3D elements)
- The wing is fixed at the root with 6 DOF.
- It is subjected to explicit pressure with the spatial shape of a second degree polynomial :

$$P(x) = -7.6289 \cdot 10^{-10} x^2 + 0.001833$$

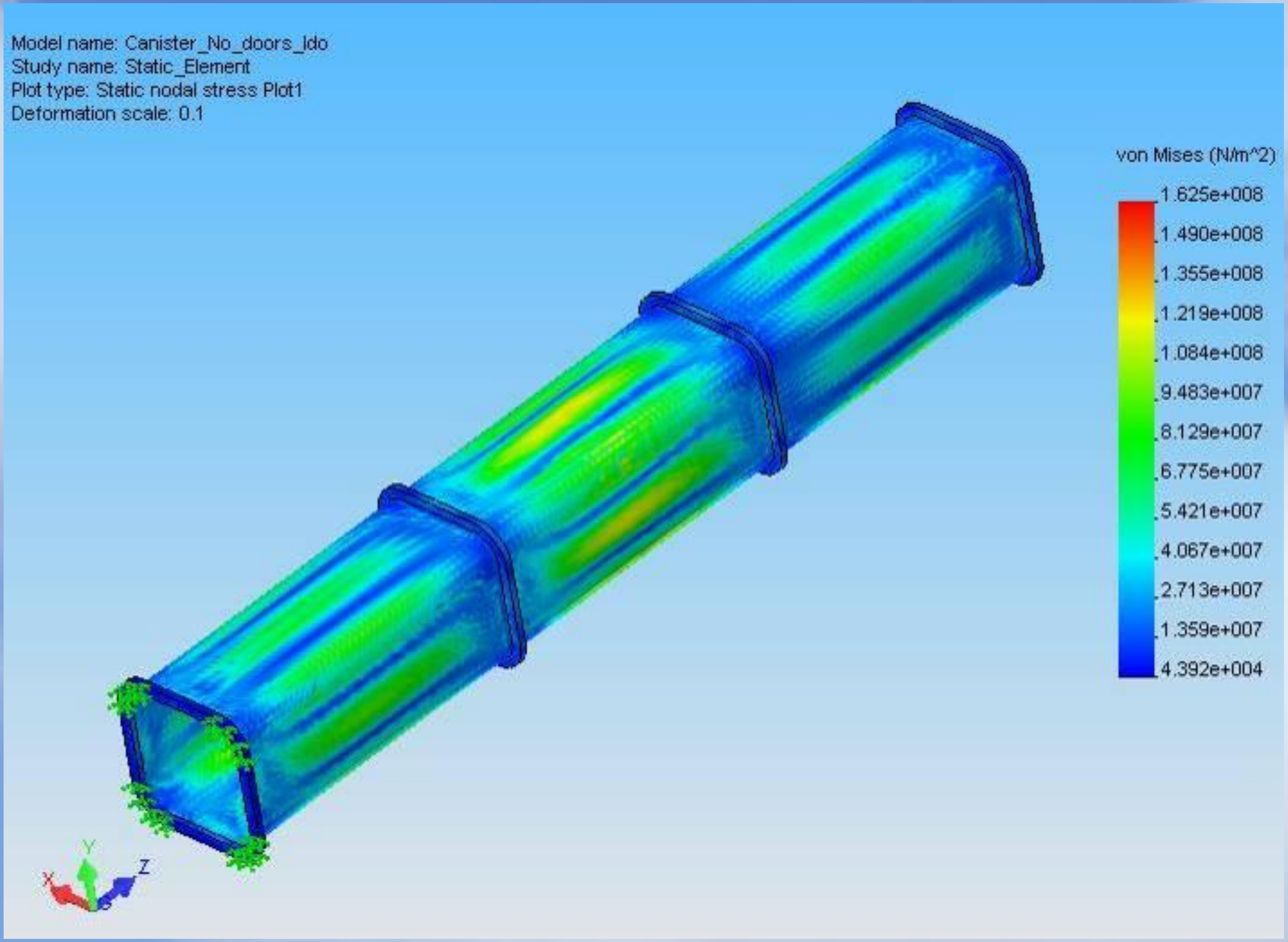


FEM Analysis

Stress

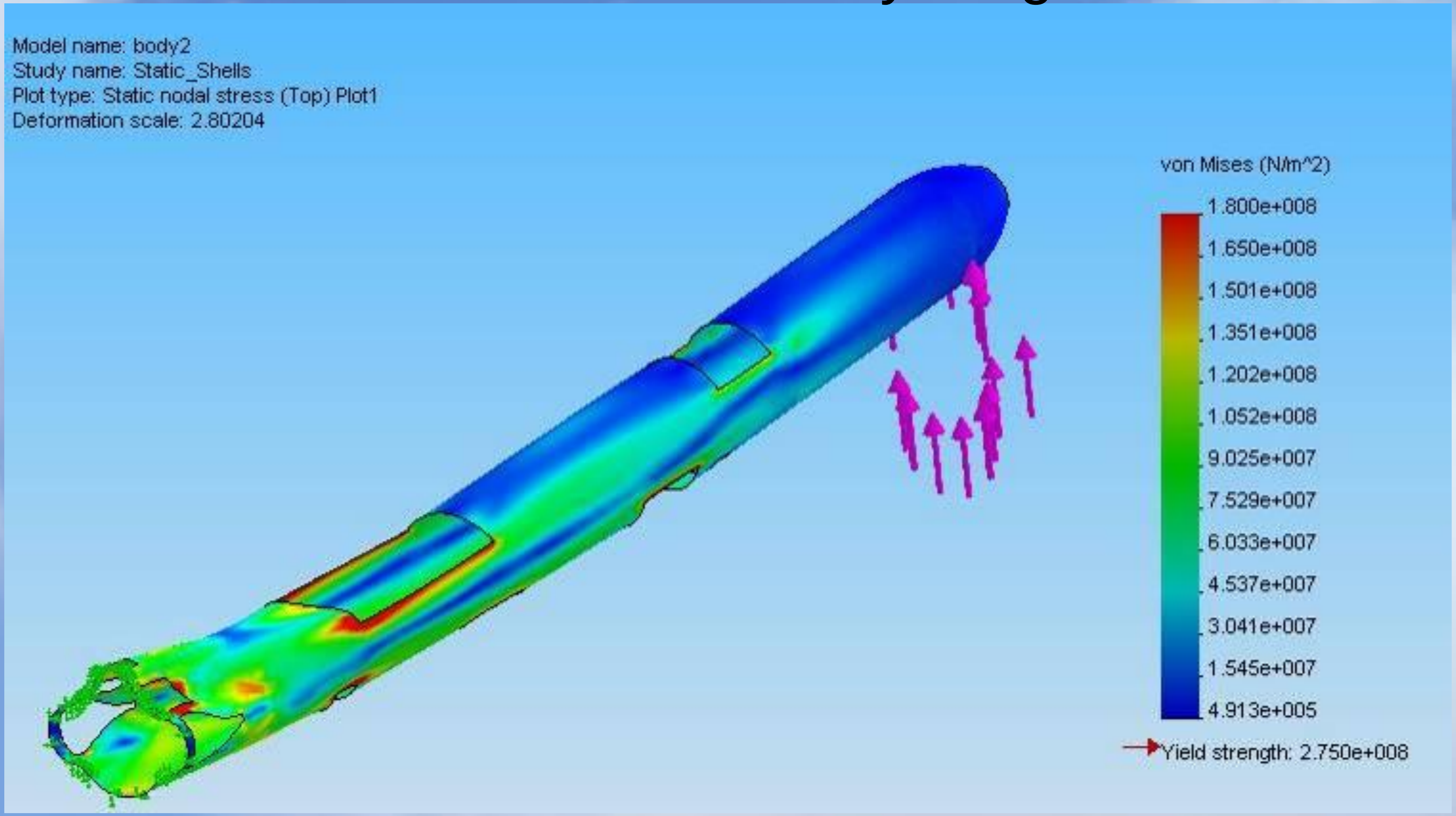


Canister Structural Analysis



Body Structural Analysis

- Fixed at engine
- concentrated force at nose = body weight X 2.5



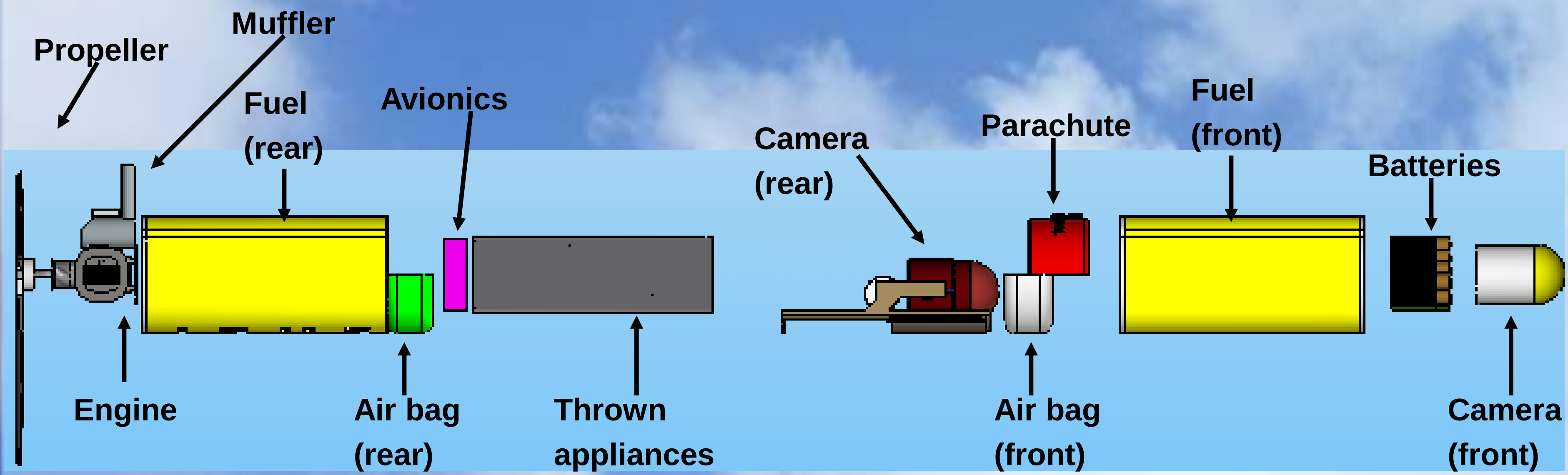
6. Systems General Arrangement

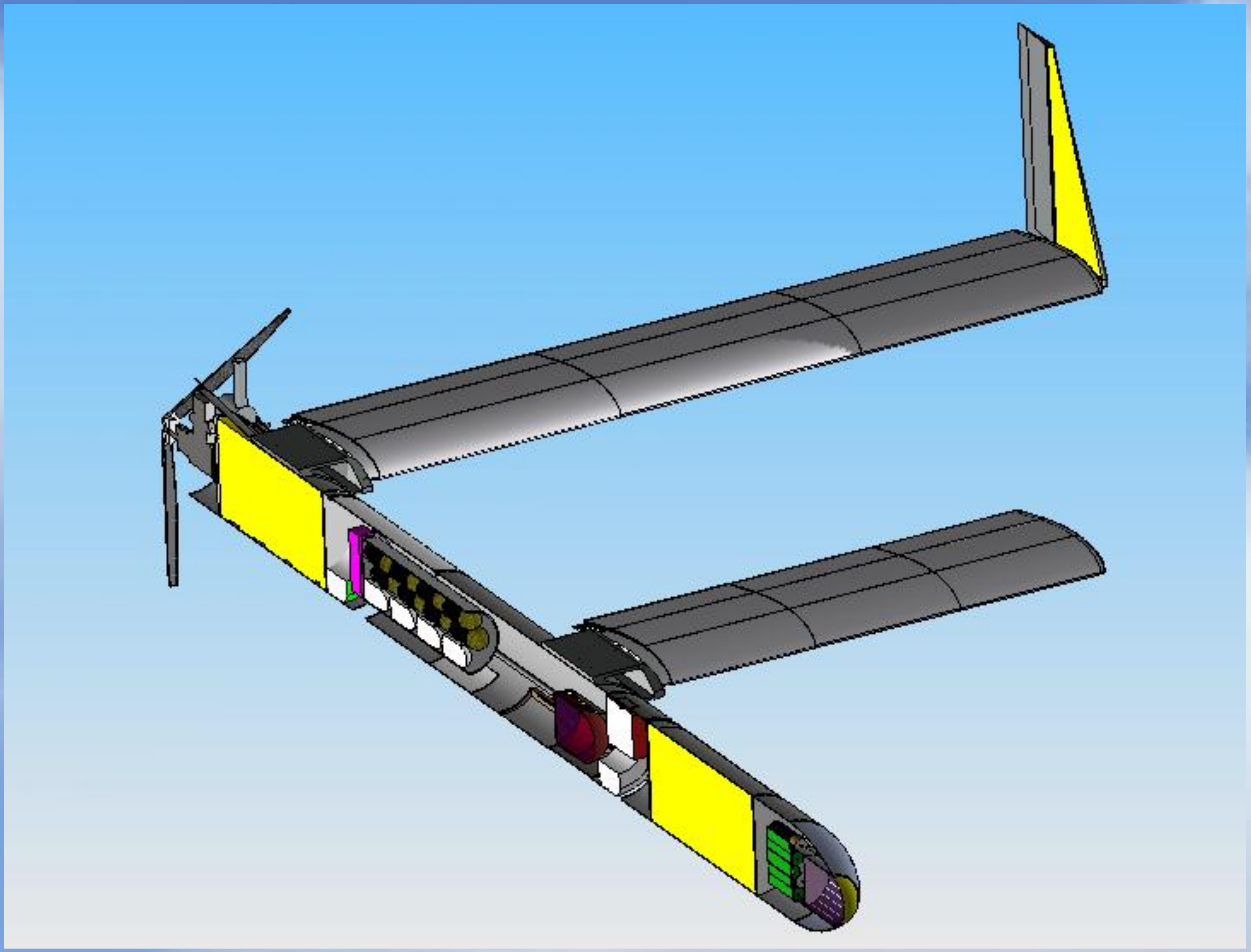
Component Integration

Folded UAV

Wing opened UAV section

System Arrangement





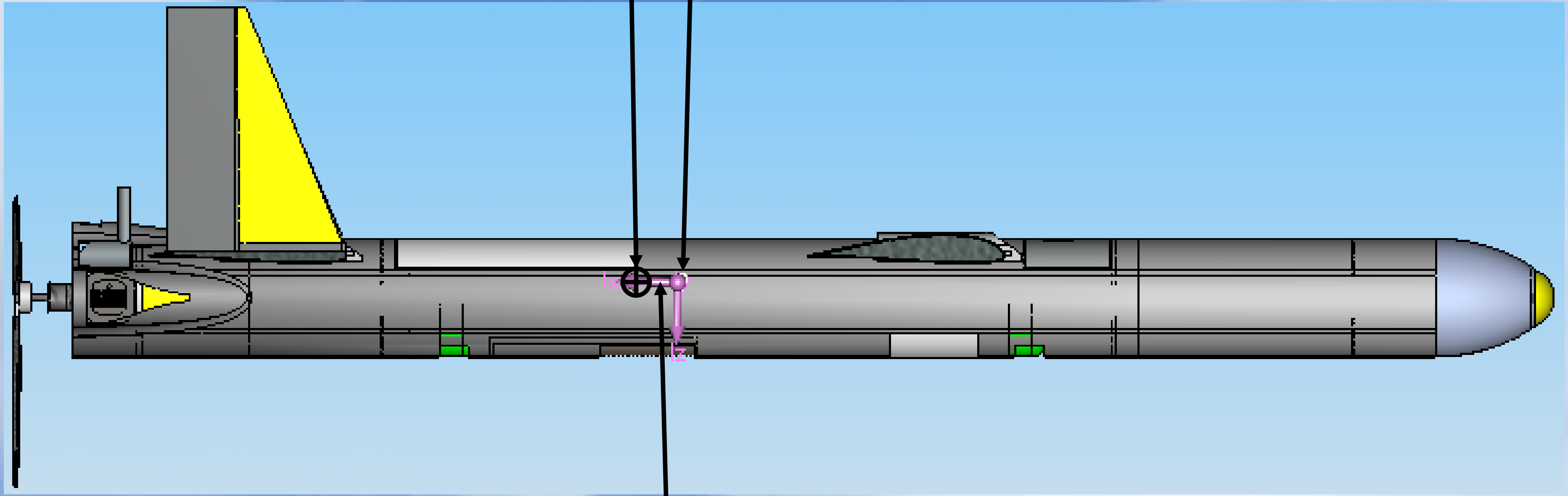
Components weights

item	Weight [gr]	position [mm]
body	3629	1209
fwd camera	1256	82
battery pack	2635	241
fwd fuel	8059	541
fwd air bag	78	900
parashoot	214	850
canard saddle	1160	1031
canard	3882	1077
wing saddle	1128	2144
wing	5546	2190
wing tips	863	2211
rear camera	1519	1044
appliances	6607	1639
avionics	218	1860
rear air bag	78	1940
rear fuel	8245	2183
engine	2870	2454
Contingency	2000	cg

Total weight

50 [kg]

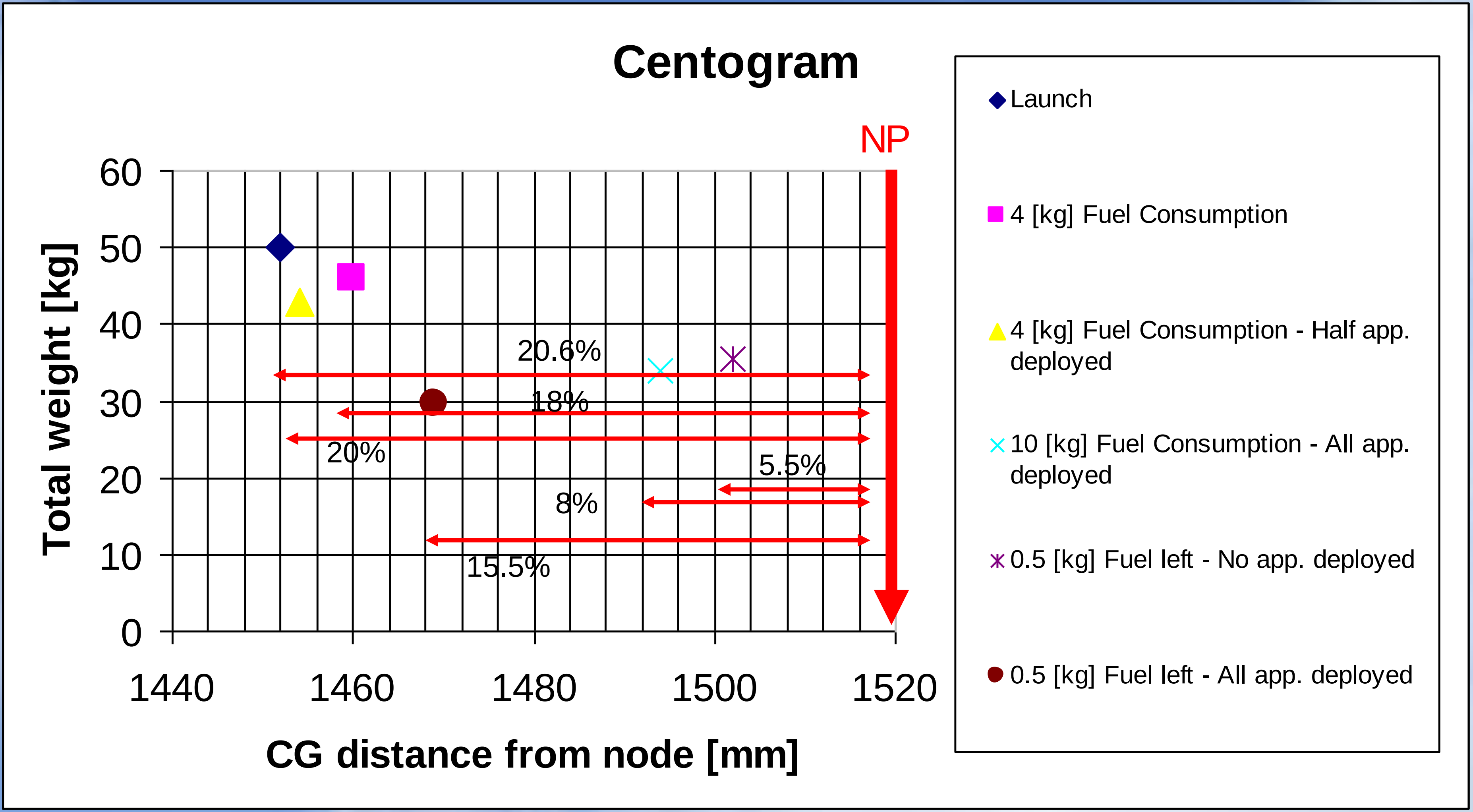
Stability margin



NP – 1521 [mm] from nose

CG – 1452 [mm] from nose

Stability margin 20%



Centogram
NP
60
50
40
30
20
10
0
Total weight [kg]
1440
1460
1480
1500
1520
CG distance from node [mm]
20.6%
18%
20%
5.5%
8%
15.5%
Launch
4 [kg] Fuel Consumption
4 [kg] Fuel Consumption - Half app. deployed
10 [kg] Fuel Consumption - All app. deployed
0.5 [kg] Fuel left - No app. deployed
0.5 [kg] Fuel left - All app. deployed

Purchased Components

- Cameras
- Batteries
- Air bag
- Parachute
- Avionics
- Engine

D-Stamp

Piccolo II


DA-100

The engine: DA-100

DA-100 Specifications:

- **Displacement**: 6.1 ci. (100cc)
- **Output**: 9.8 hp
- **Recommended Props**:
  2-blade: 26x12, 27x10, 28x10.
  3-blade: 24x12, 25x12, 26x12.
- **Weight**: 5.8 lbs (2.63 kilos)
- **Length**: 6.5" (162.5mm)
- **Width**: 11.45" (290.8mm) (w/ plug caps)
- **Bore**: 1.6771" (42.6mm)
- **Stroke**: 1.3779" (35mm)
- **Typical RPM**: 1,000 to 6,700
  8,500 max RPM
- **Fuel Draw**: 2.5 oz/min at 6,000 RPM.

- Provides the needed Power.
- Light weighted.
- Known as reliable.

The Autopilot: Piccolo II

- Complete integrated avionics system for small UAVs.
- Includes avionics hardware and software and ground-station hardware and software.
- A secondary payload serial port.
- Volume: 4.8” x 2.4” x1.5”
  Weight: 212 gr (max)

Figure 3. Piccolo II Front Panel

The cameras: D-Stamp (d/n) (CONTROP)

	D-stamp night	D-stamp day
weight	950 gr	750 gr
dimensions	125x160(l)	125x160(l)
pitch	+70 to -40°	+70 to -40°
zoom		X10
Field of view	14x10.5 °	5.2x4.2 ° 38x48 °
Altitude	<3000 ft	3,000 ft

7. Specific Issues

- **UAV noise reduction**
- **Alternatives for GPS**
- **Thrown appliances**

Noise in UAVs and its reduction

The sources of noise in an airplane?

- The propeller
- The engine
- Aerodynamic noise

Why should noise bother us?

- Alerts the enemy and draws attention.
- Interferes with the work of equipment placed on the UAV.

Noise reducing techniques

- Fitting the propeller to suite our mission exactly
  (Geometrical and physical properties):
  prop's speed, Number of blades, Blades thickness and length, Sweeping blades tip
- Mufflers
- Engine's power
- Quiet engine (electrical)
- Two engines: first for climbing second for loitering
- Fuselage adjustment
- Flying at high altitudes

The chosen solution for MonGuard: Reactive Muffler

- Very good attenuation of sound.
- Relatively easy to implement.
- Simple installation.

Our Muffler

- The information was taken from BME 105cc engine which is quite similar to our DA-100 engine. (9.2 HP, weights 4.4 lb, …)

Exhaust tubes
7/8" O.D.
3 1/2" long
261 gr per set
9.2 oz Per set

Alternatives for GPS

The basic idea

- Finding out where you are when you don’t have GPS or access to it.

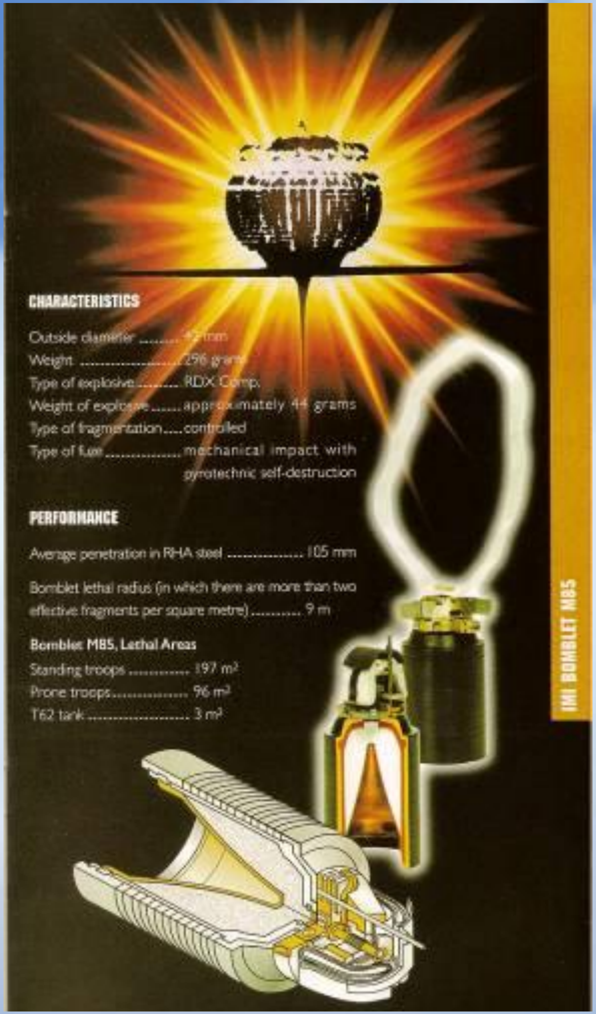
The options

1. Cellular tracking
2. Wi-Fi positioning system
3. Photo recognition system
4. Using other satellites
5. Radio navigation (LORAN-C stations)
6. Using accelerometers

Thrown appliances

SCOUT – Lockheed Martin

IMI - Bomblets



Available ammunition

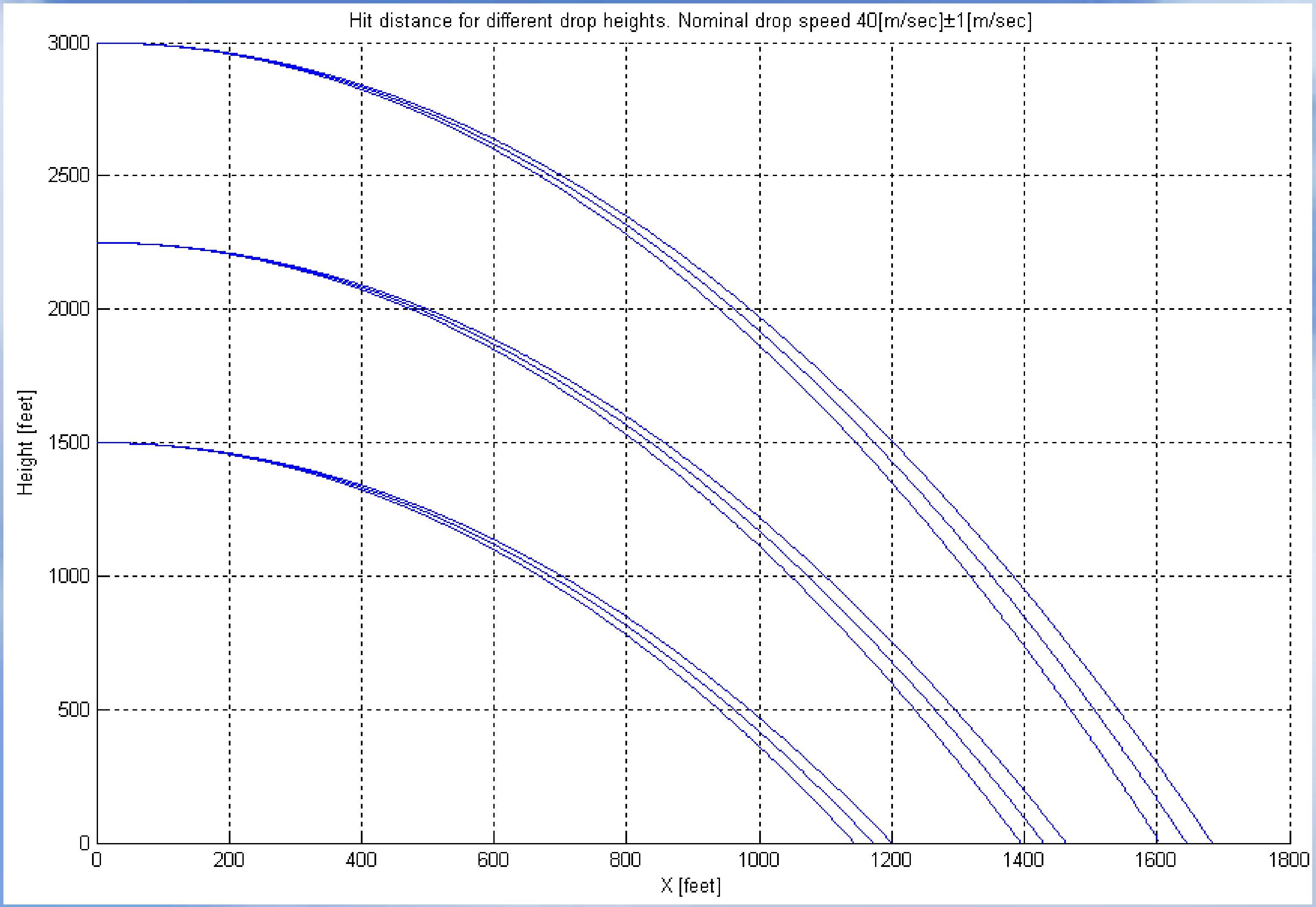
- For our needs there is no of-shelf product that can be used in the MonGuard UAV.

- The most promising candidates are the explosives, (TNT or other) tear gas, pepper gas and toxic gas, stun.

- It may be possible to use existing bomblets

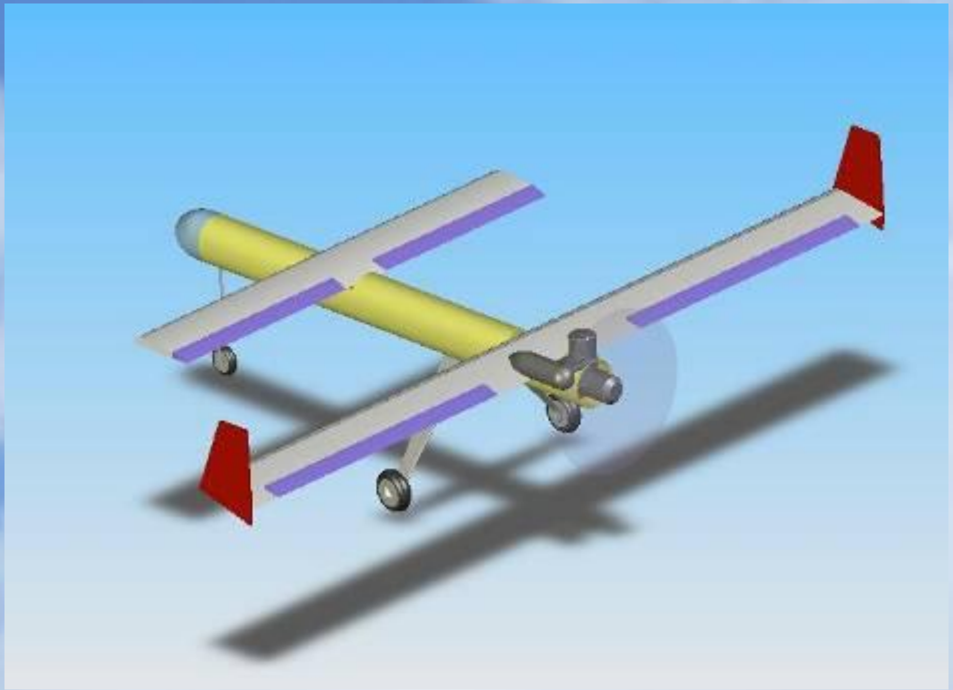
  (IMI M85/M87) as carried ammunition – demonstrated in CAD model.

Thrown appliances trajectory plot



8. Airborne Model

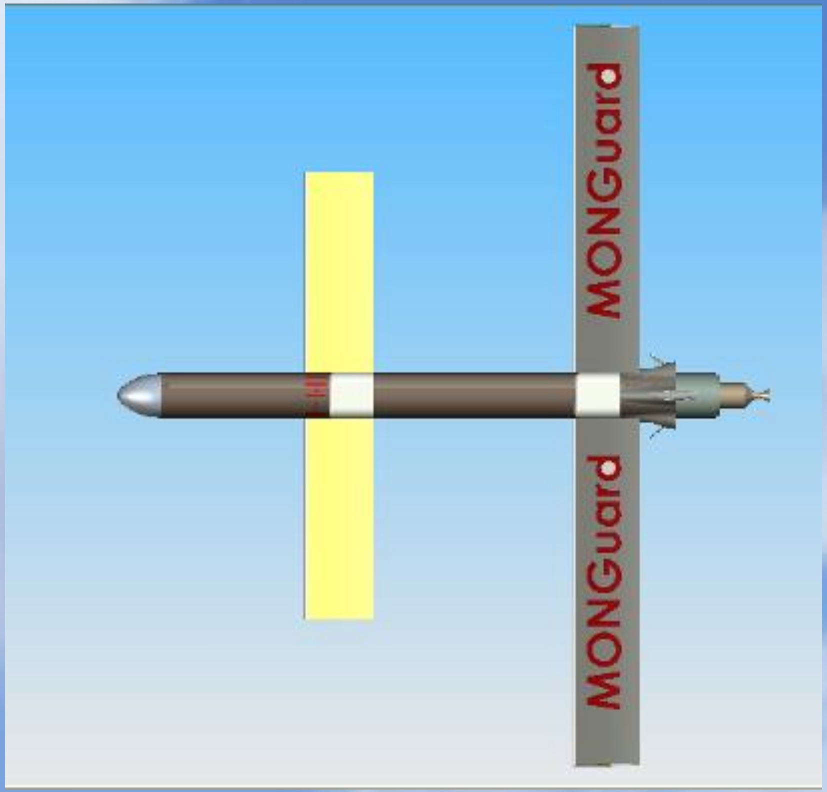
Monguard Airborne Scaled Model

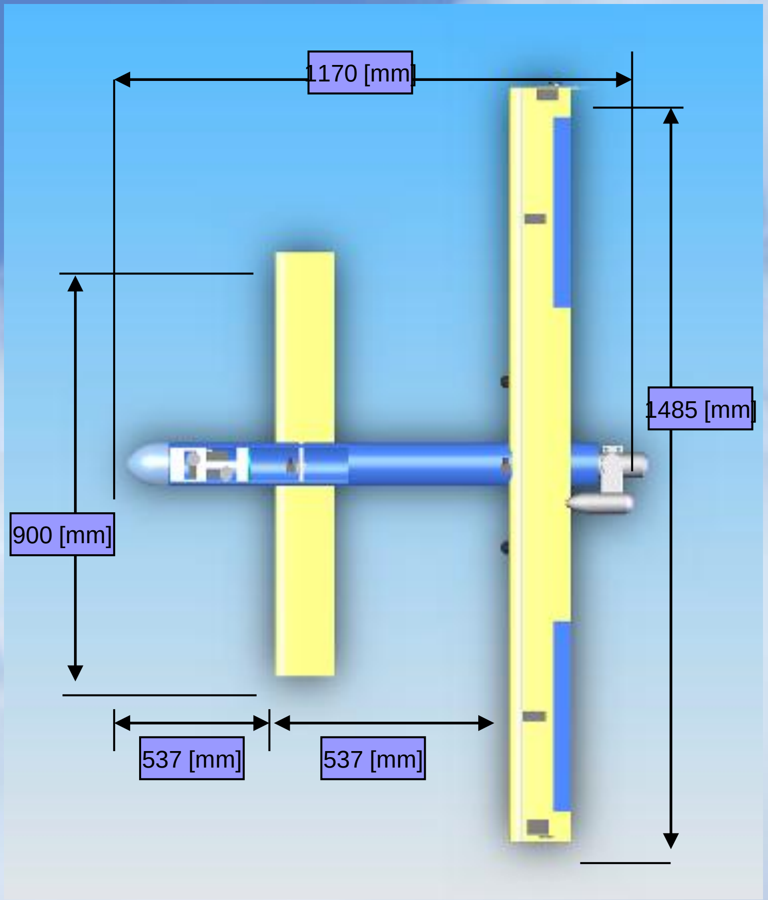


Monguard Airborne Scaled Model

- The goal of the scaled airborne model is to demonstrate and prove the design.
- It is important to show that a heavy forward canard configuration is possible and flying.
- When building we emphasized low cost and self production as much as possible.
- The scaled model does not include folding surfaces and canister launch, but focus on the aerodynamics of the body.

UAV model design





UAV

50 [kg]

Scale factor – 0.45

Scaled model

4.7 [kg]

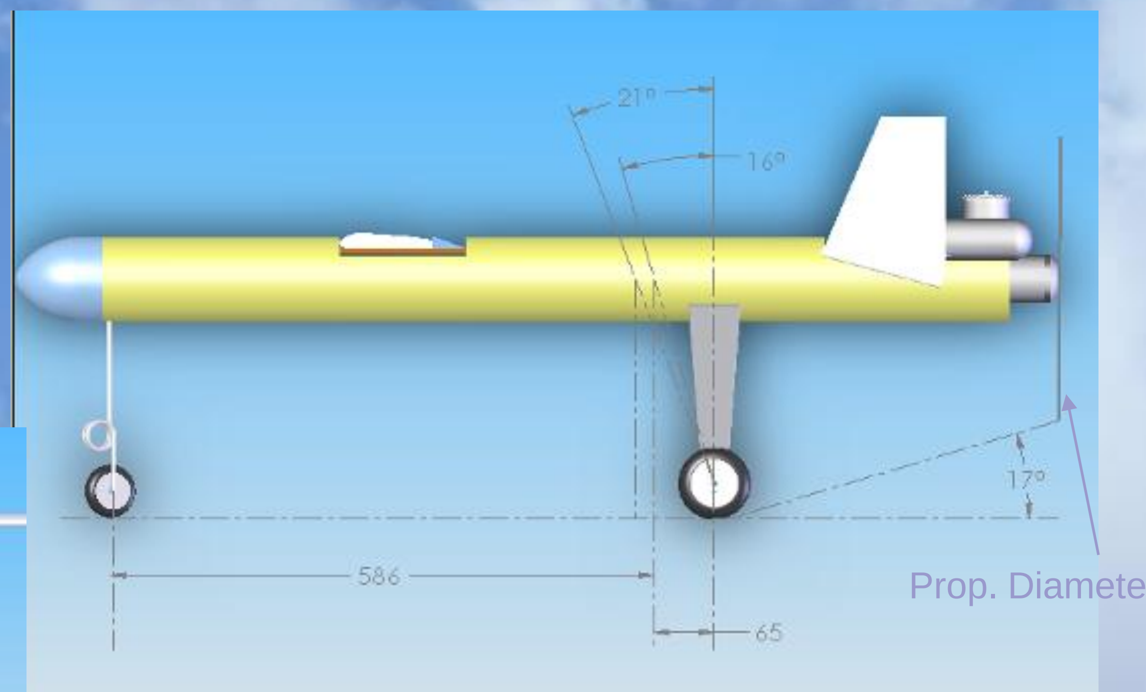
Landing gear design

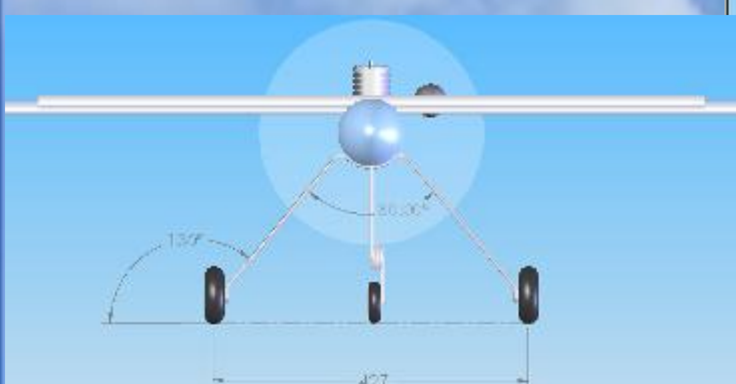
- **Optimum dimensioning for tricycle gear design (Raymer):**
  - 10-15 deg. Tip-back Clearance for takeoff
  - Front wheel takes 10% of the load
  - Main gear takes 90% of the load

$$front\ wheel\ MAX\ static\ load = W \cdot \frac{L}{L+l}$$

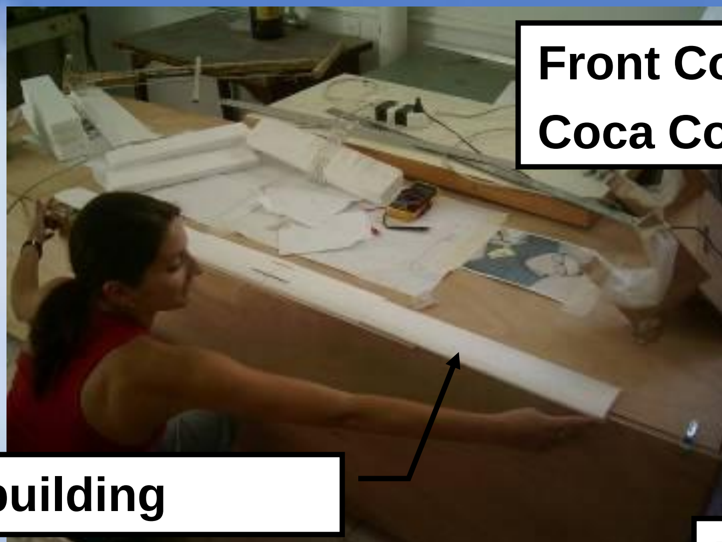
$$main\ gear\ MAX\ static\ load = W \cdot \frac{l}{L+l}$$

- **Static moment equilibrium:**
- **Design iterations**
  - Load distribution
  - Size of main gear
- **Results:**
  - 76% / 24% load on main/front wheel

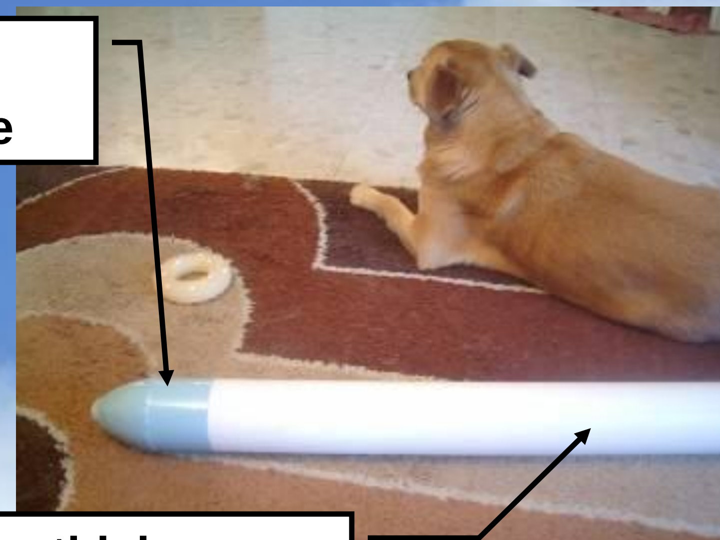




UAV Model building

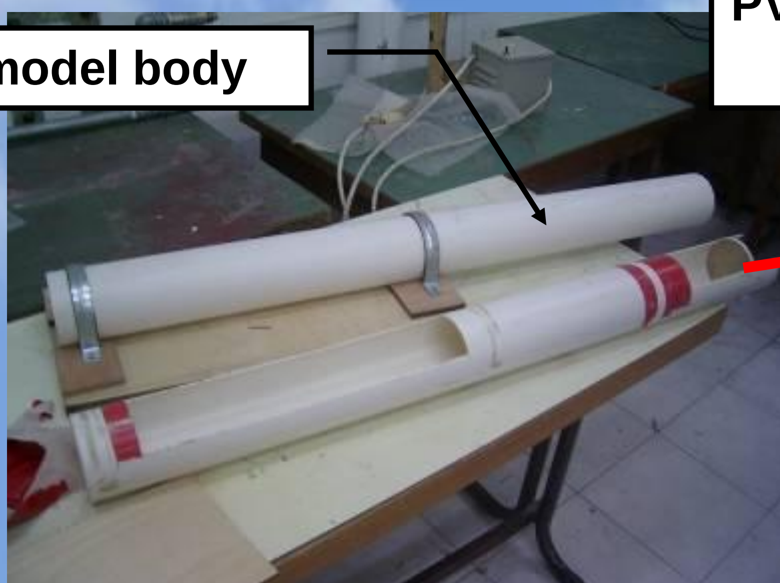


Wing building



Front Cover –
Coca Cola bottle

PVC tube, thickness 2.2[mm]

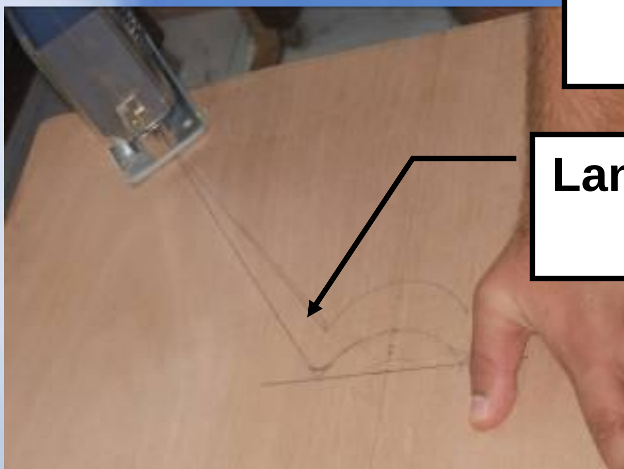


New model body

Crack in fire wall

UAV Model Building

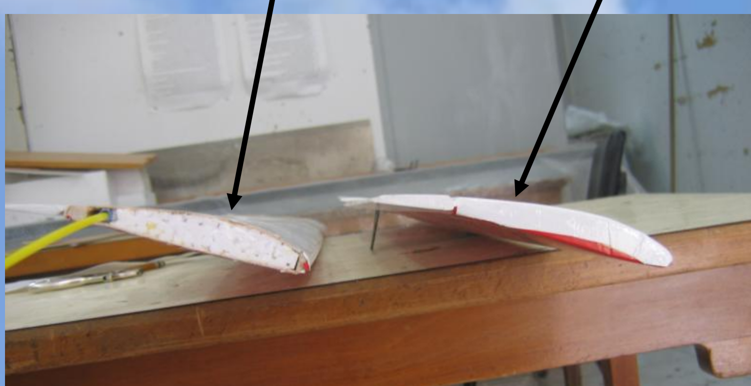
Landing gear form



Fire wall

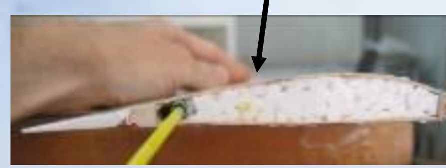
Wing

Canard



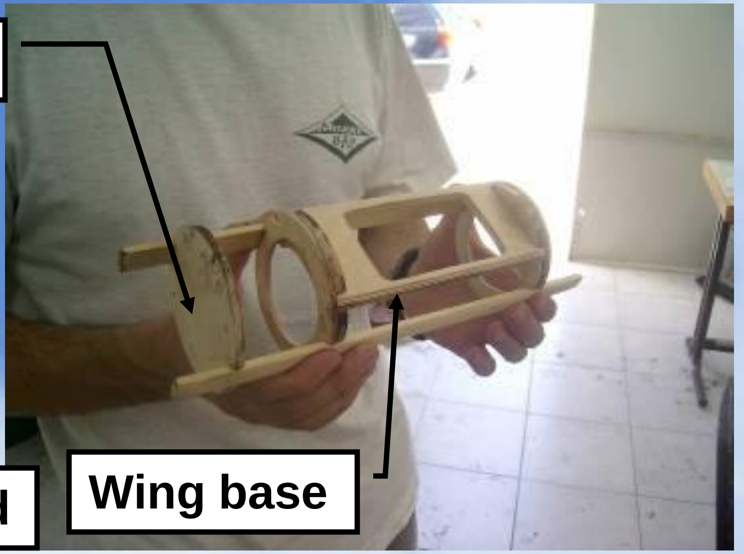
Wing

Canard



UAV Model building

Fire wall



Placing wing and canard

Wing base

Wingtip servo soldering

Cutting fuel service door

Landing gear form

UAV Model building

Model schedule and budget

- The budget we received for building the scaled model was 3800 NIS. So far our expenses did not exceed 2600 NIS.
- Less than 8 weeks building time

9. Summary

Based on client requirements of the system, our thinking process and deliberations the following was accomplished:

- Market survey and preliminary design.

- Configuration selection and detailed design of the following:
  - Wing / Canard
  - Fuselage
  - Wing / Canard opening mechanism
  - Camera withdrawal mechanism
  - Canister

- Detailed analysis:
  - Aerodynamics of wing / canard surfaces
  - Fuselage load and stress
  - Wing / Canard load and stress

- The explored topics were:
  - Engine
  - Camera
  - Avionics
  - Alternatives for GPS
  - Noise reduction
  - Thrown appliances

- A scaled (1:0.45) flying model was designed, built and flown.

- Subjects for further exploration:
  - Fitting the propeller to the mission profile.
  - Adjustment of the aerodynamic surfaces to fit the mission profile.
  - Design, building, experimentation and analysis of Wind tunnel model.
  - Launching Booster detailed design.

Questions…