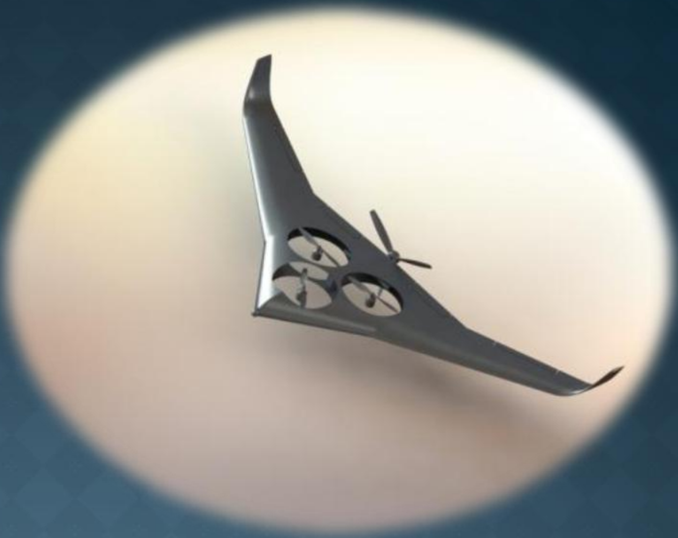


LO-DEÁ
Low altitude Observation Delta wing Electric Aircraft

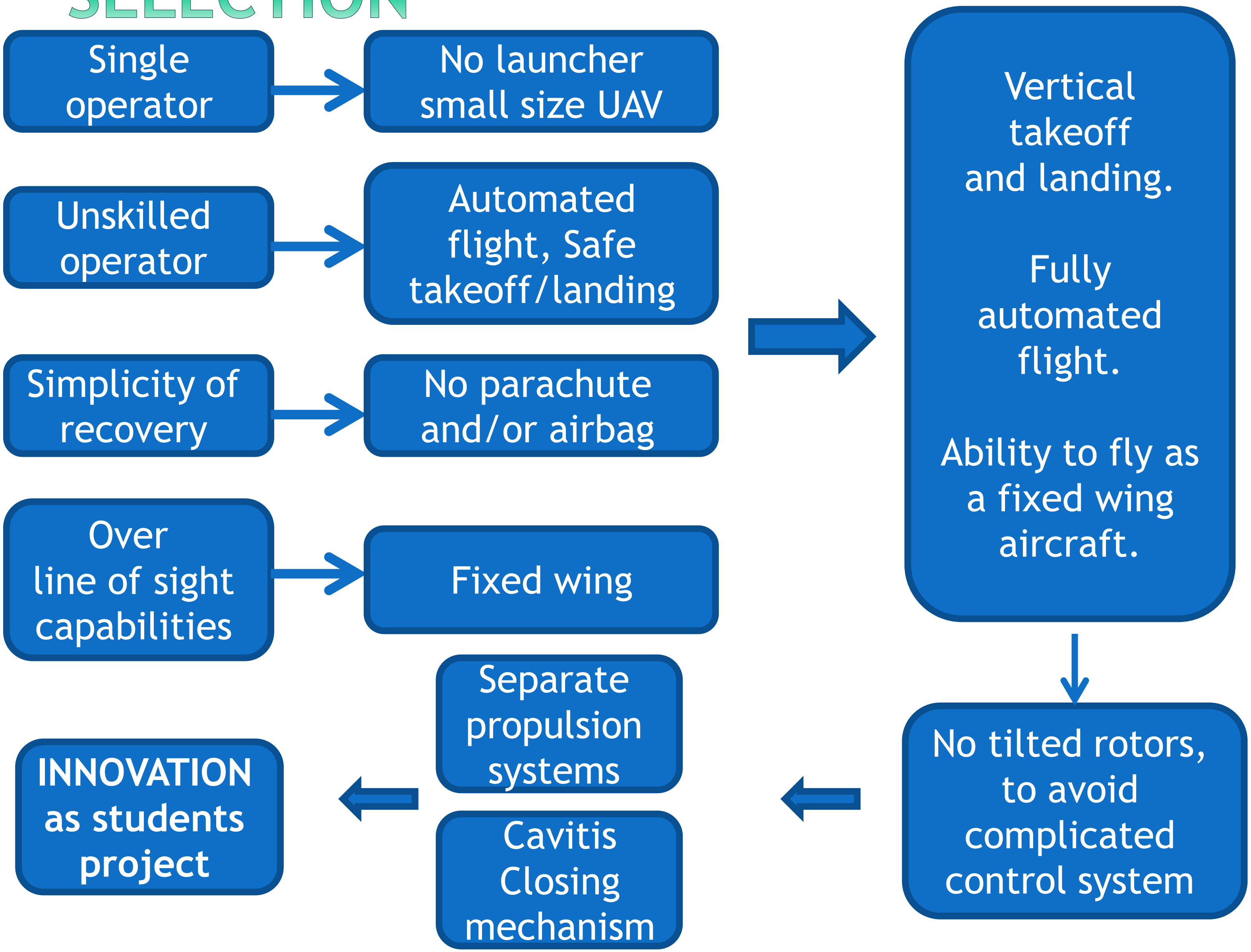
Critical **D**esign **R**eview

Almog Dov
Assaf Aloush
Bar Ovadia
Dafna Lavi
Orad Eldar
Supervisor: Dror Artzi

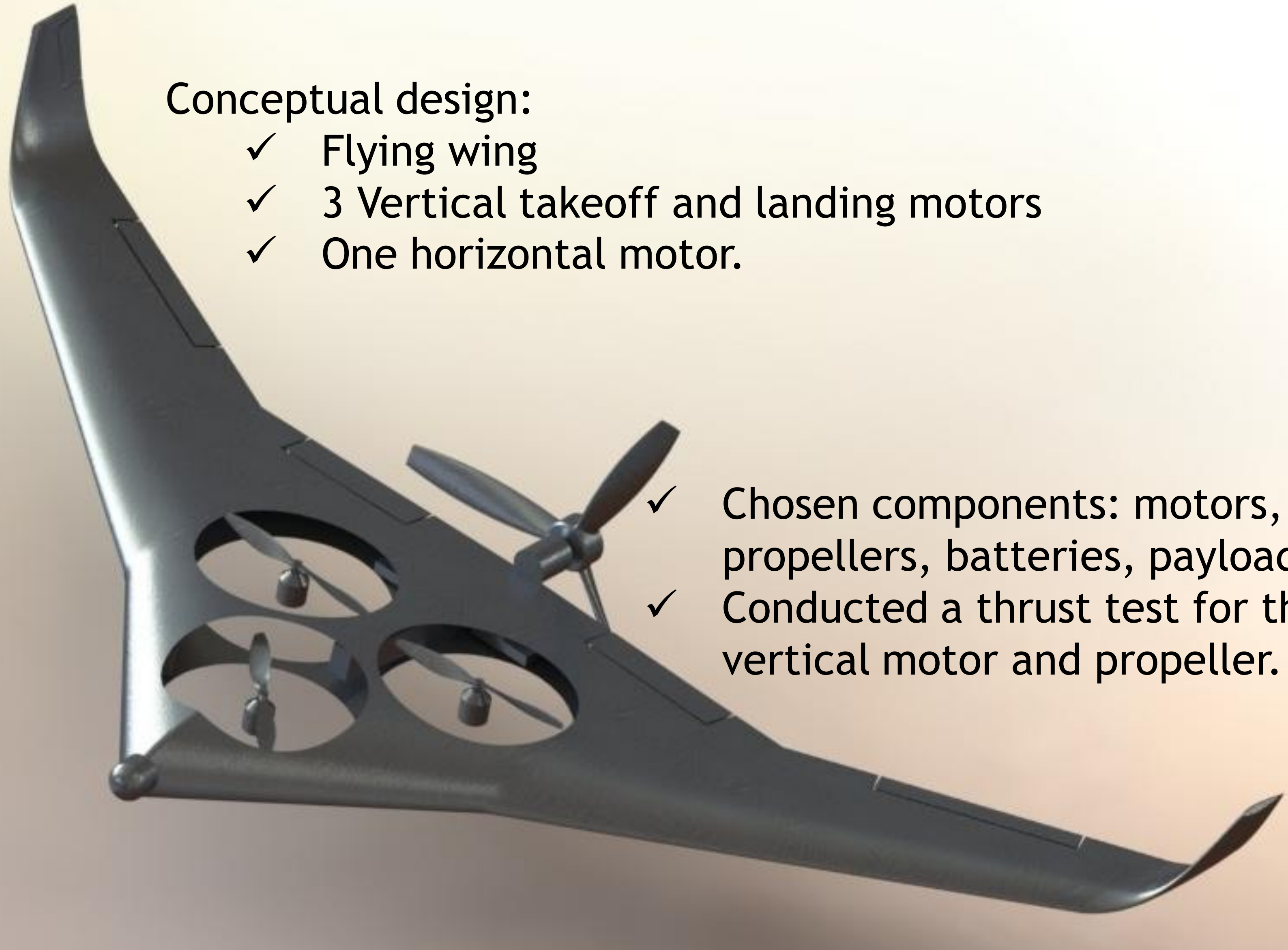
Review - Customer Specification and Requirements

- Man-portable UAV
- Over the hill / Urban surveillance
- Fast field deployment
- Endurance: 30 min
- Simple to operated by one man
- Real time video camera
- Quiet
- Portable Ground Control System (PGCS)
- Fully automated flight (including take-off and landing)

REVIEW- CONCEPTUAL APPROACH SELECTION



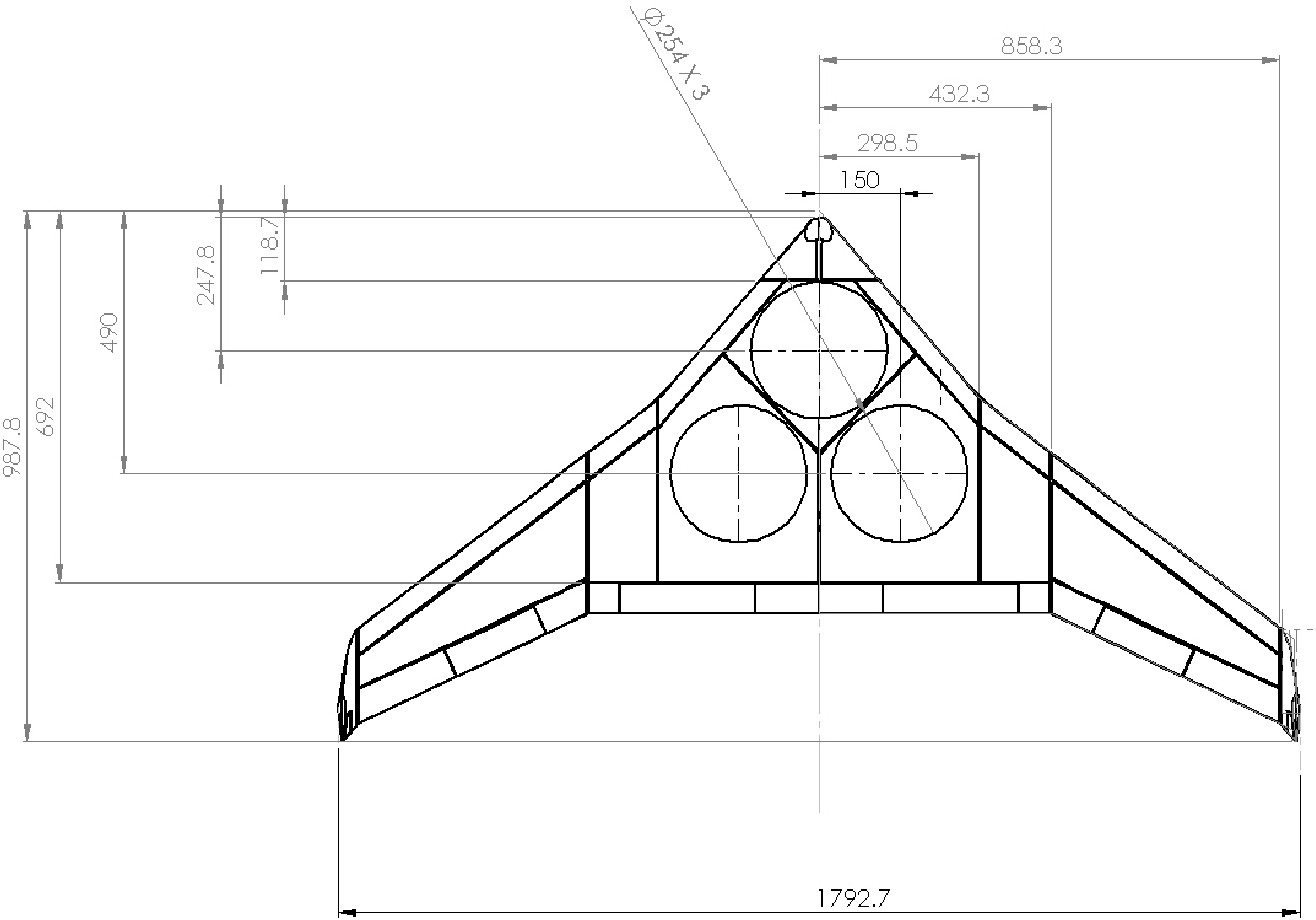
REVIEW



Conceptual design:

- ✓ Flying wing
- ✓ 3 Vertical takeoff and landing motors
- ✓ One horizontal motor.

- ✓ Chosen components: motors, propellers, batteries, payload.
- ✓ Conducted a thrust test for the vertical motor and propeller.

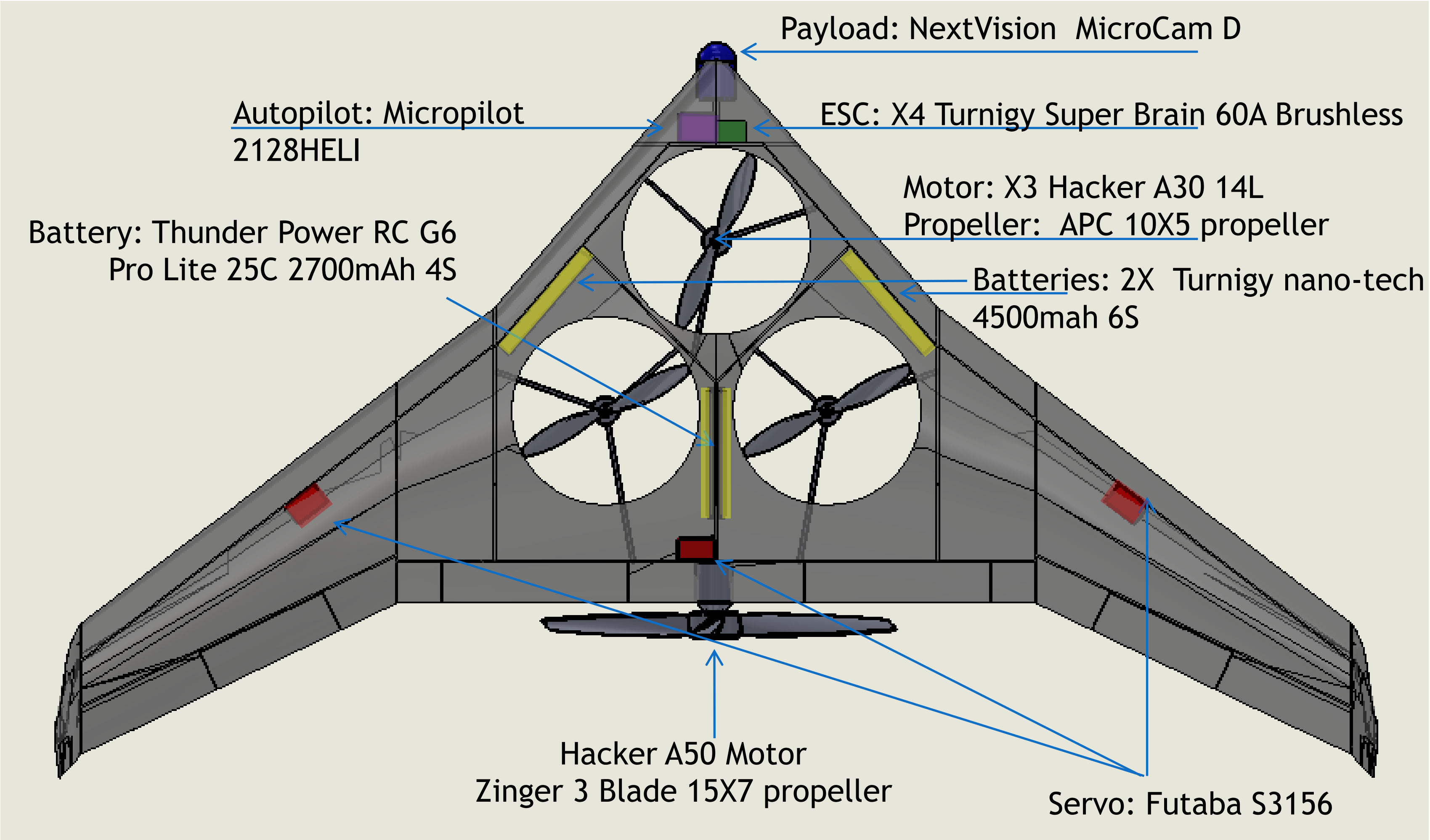


Ø254 X 3
858.3
432.3
298.5
150
118.7
247.8
490
692
987.8
1792.7

SYSTEMS/COMPONENTS INSTALLATION ARRANGEMENT

- Components:
  - 1 payload
  - 3 ‘Vertical’ motors
  - 1 ‘Horizontal’ motor
  - 4 electronic speed controllers
  - 3 Batteries
  - 1 Autopilot
- Installation principles:
  - Weight and balance – Keep CG. In place.
  - Accessibility – maintenance.

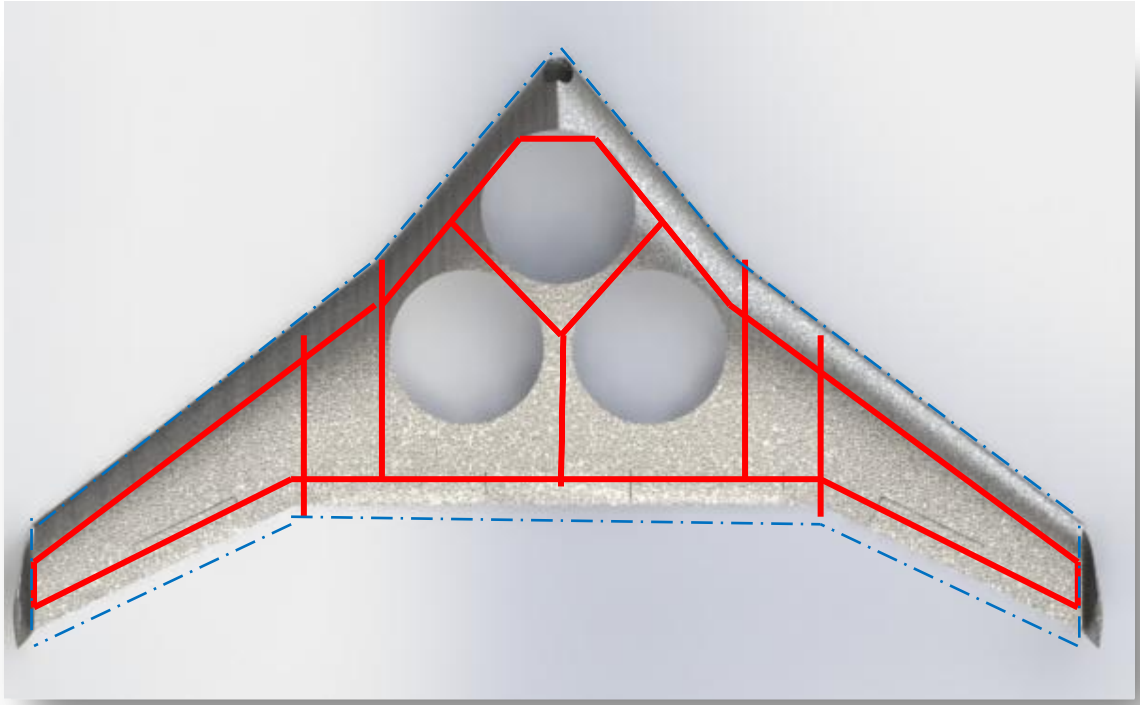
INSTALLATION SKETCH



SPLIT LIPO BATTERY

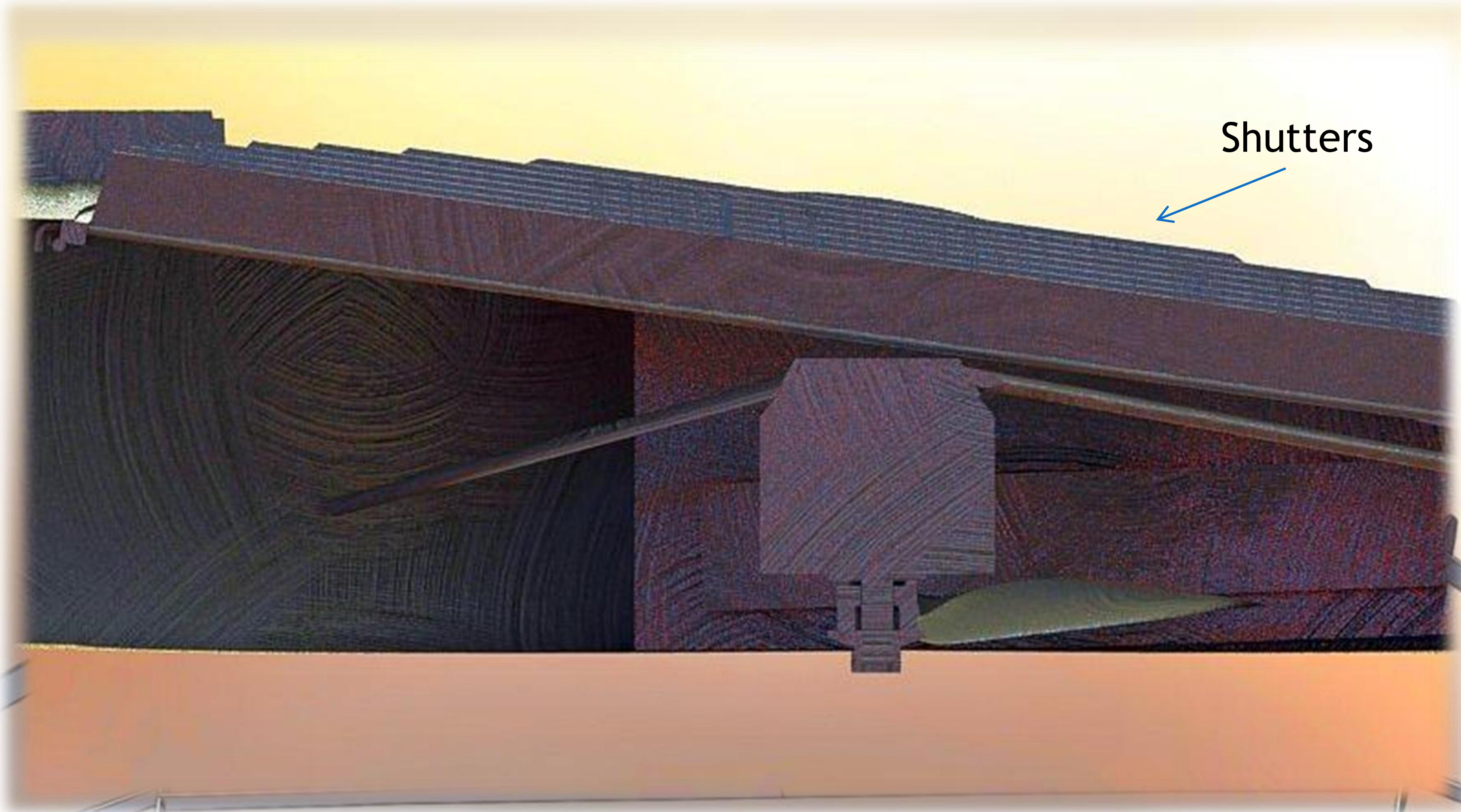
CONCEPTUAL DESIGN OF WING STRUCTURE

- Leading edge spars.
- Trailing edge spars.
- Ribs.
- Mid fuselage reinforcement.

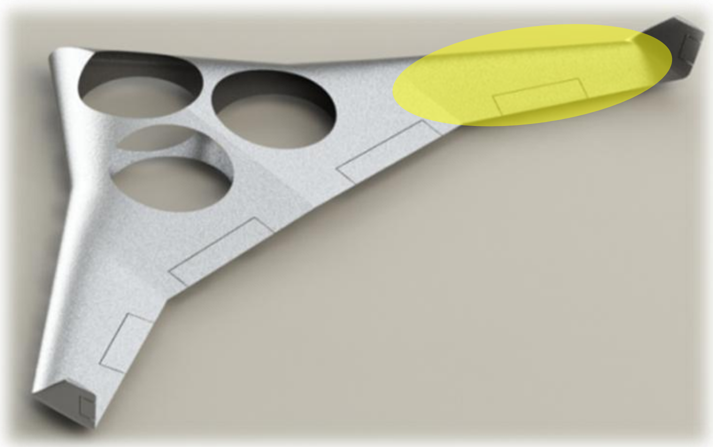


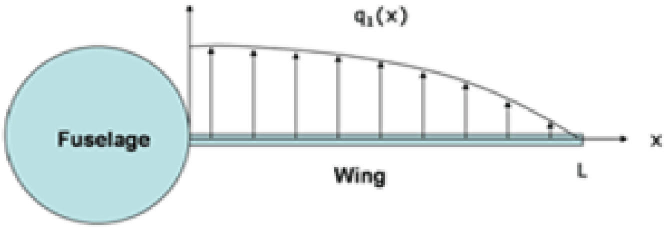
CONCEPTUAL DESIGN OF WING STRUCTURE

- Motor mount structure:
  - Upside down vertical motors



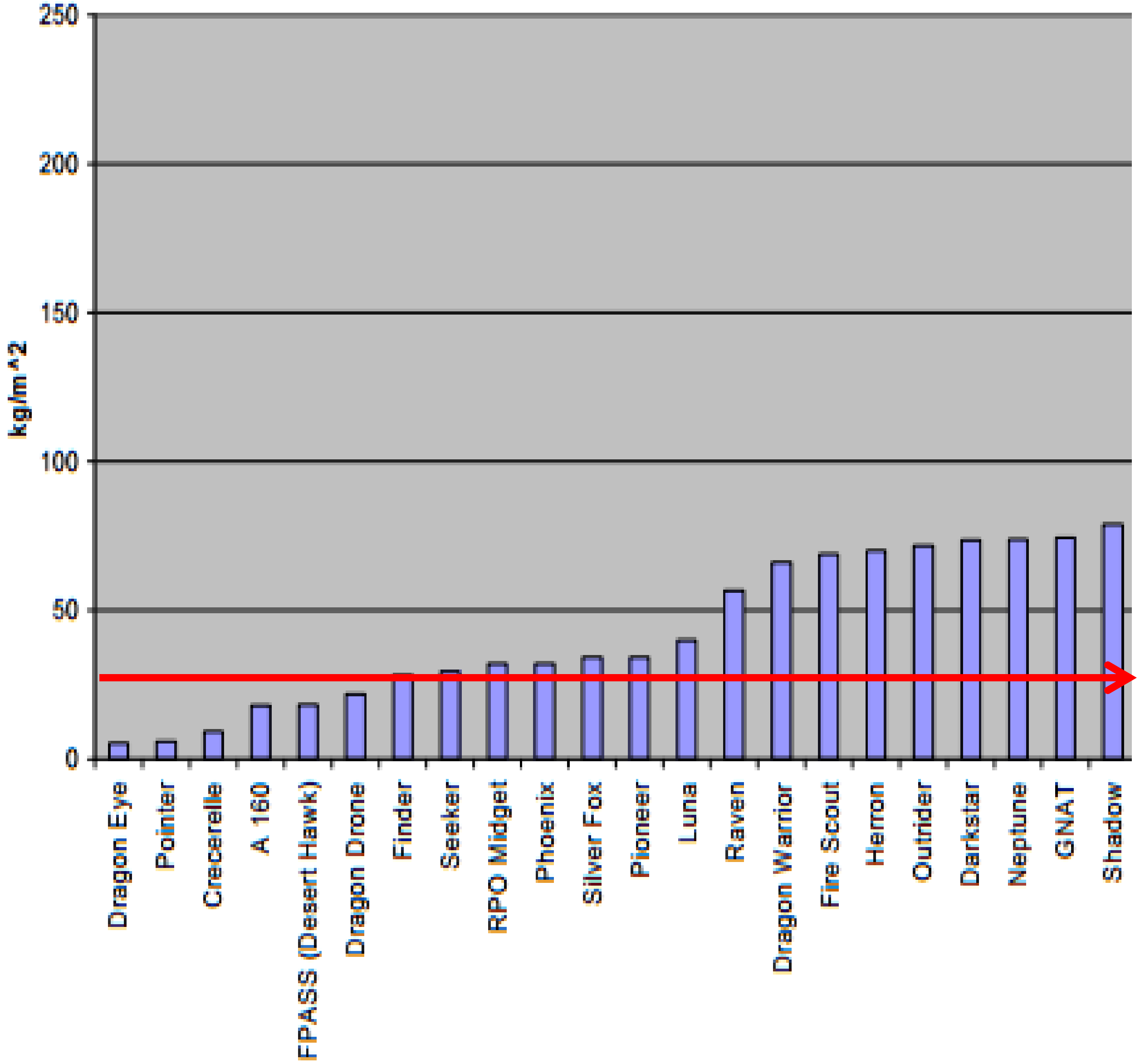
OUTER WING DESIGN





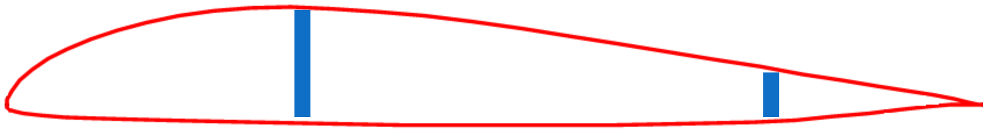
- Work under bending load.
- Wing area is 0.09[m^2]
- The 0.45[m] span wing is subject to 2.25[kg] force.
- Wing load is 25[Kg/m^2].
- Under 3.8G (Normal category) the wing load equals to 95[Kg/m^2].

WING LOADING

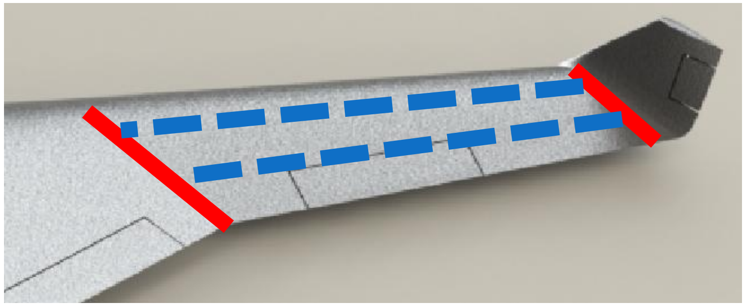


OUTER WING DESIGN (CONT.)

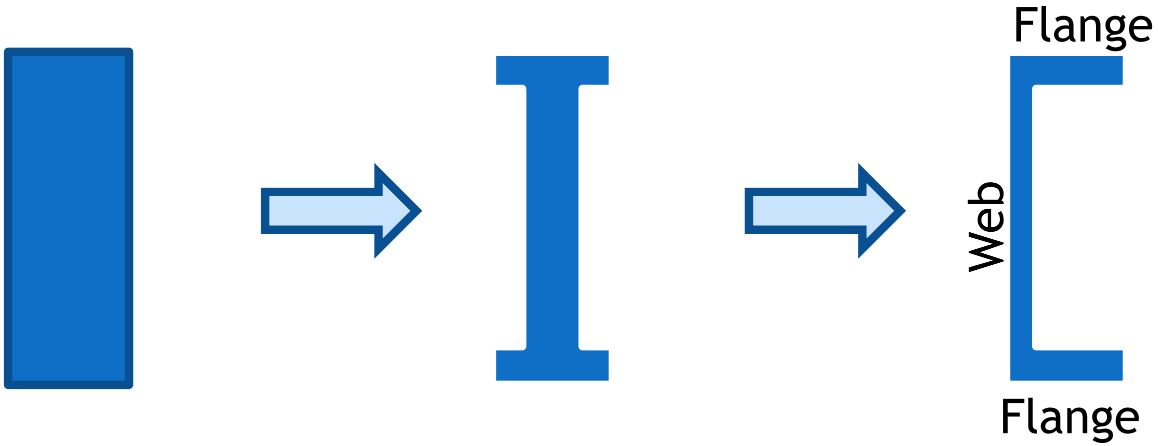
- 2 Spars: One main **spar** and one trailing edge **spar**.



- Tip and root **ribs**

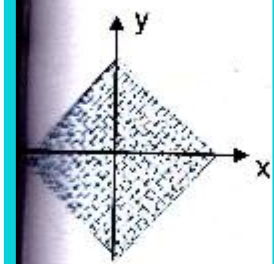
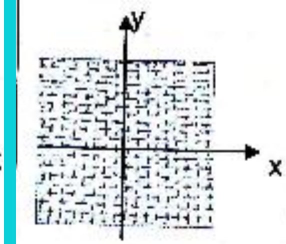


- Main spar cross-section:



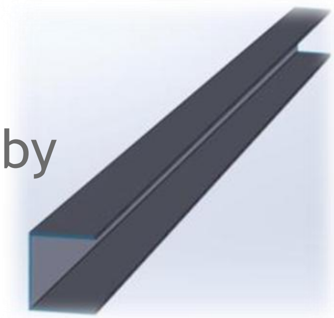
OUTER WING DESIGN (CONT.)

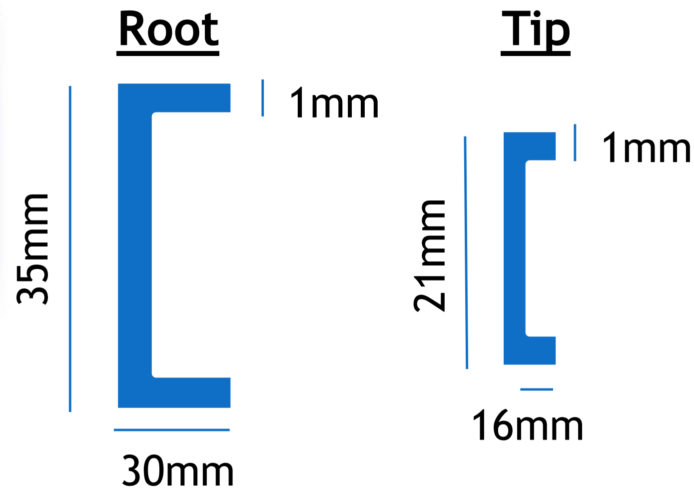
- Web and flange material
  - Carbon Fabric (45deg)
- Flange support
  - Carbon unidirectional (UD)

Carbon Fabric		Carbon UD	
 45°	 0-90º	 U.D.	תאור
$E_X = E_Y = 1200$	$E_X = E_Y = 6000$	12000	$E = [Kg/mm^2]$
$G_{XY} = 3000$	600 -300	600 -300	$G = [Kg/mm^2]$
$\tau_{XY} = 6$	$\sigma_X = \sigma_Y = 6$ $\tau_{XY} = 6$	$\sigma = 120$	חוזק לשבר Kg/mm^2
$\gamma = 2000\ \mu S$	$E = 1000\ \mu S$	$E = 10000\ \mu S$	התארכות לשבר

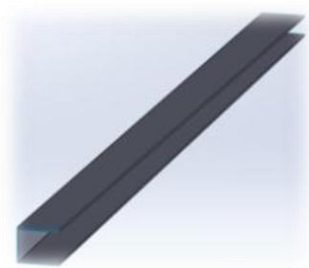
SPAR DIMENSIONS

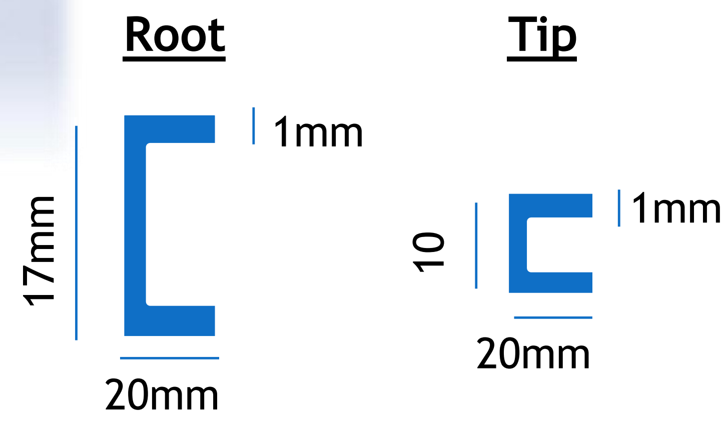
- Main spar:
  - Web height – forced by
  - wing geometry
  - Flange Width- Calculated by bending load analysis under the assumption of constant thickness of 1mm





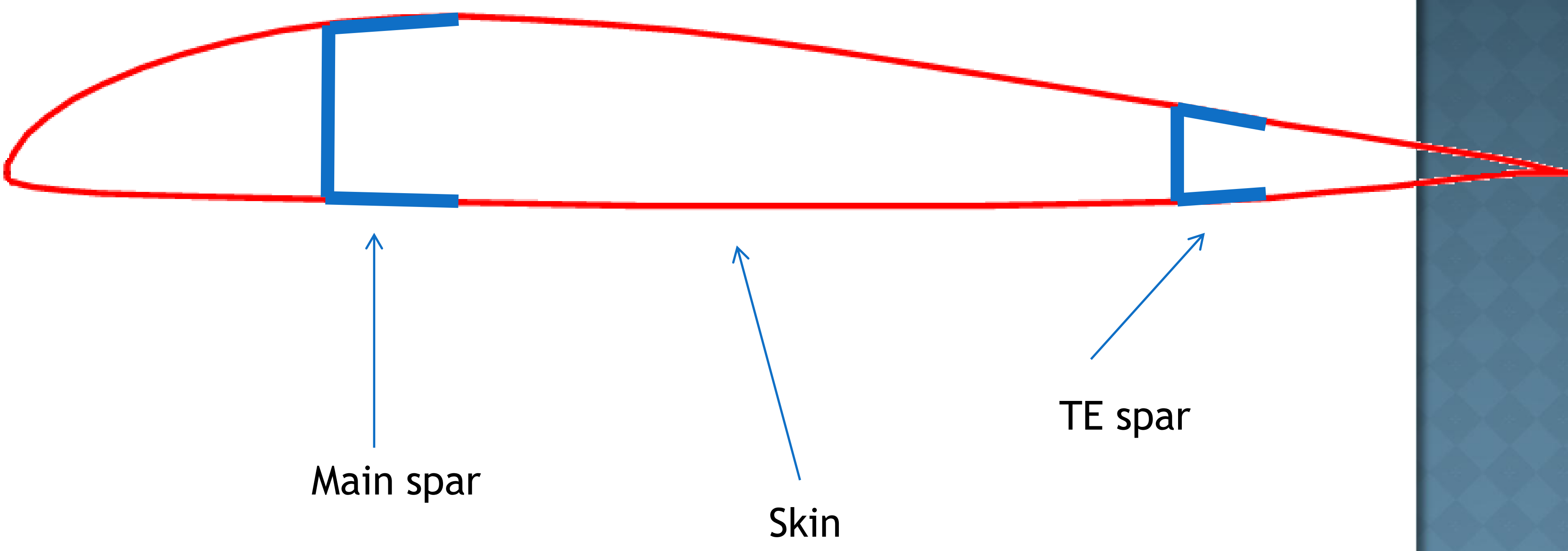
- Trailing edge spar:
  - Web height – forced by wing geometry
  - Flange Width- Designed for smooth operation of the aileron control system





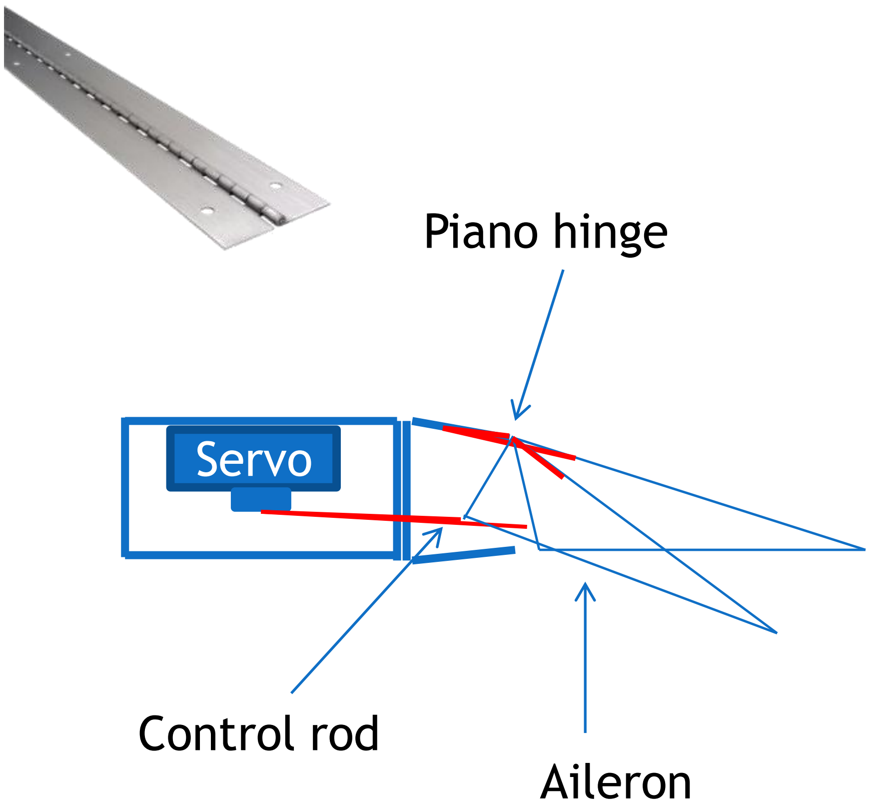
OUTER WING DESIGN (CONT.)

- Main spar at 25% chord.
- Trailing edge spar parallel to the ailerons hinges line.



OUTER WING DESIGN (CONT.)

- To minimize drag, ailerons control system is located inside the wing.



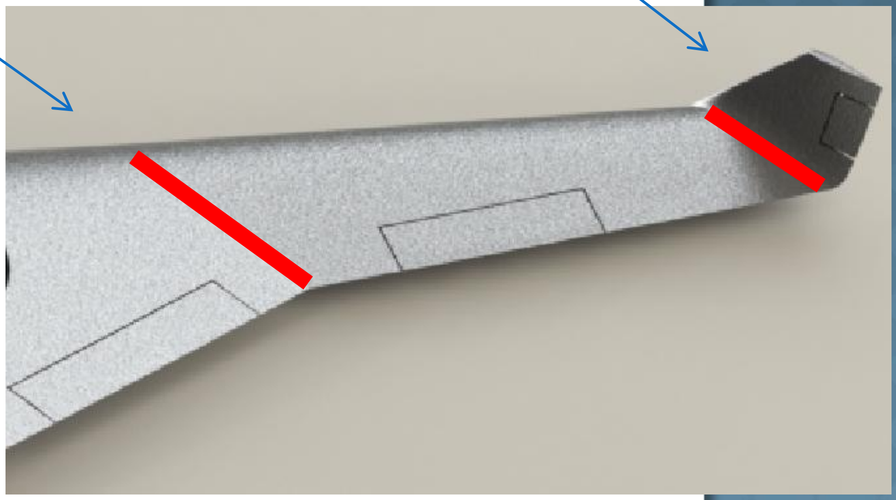
S3156 Micro		
FUTM0656		
Volts	Torque	Speed
4.8V	28 oz-in (2.0 kg-cm)	0.13 sec/60°
6.0V	33 oz-in (2.4 kg-cm)	0.11 sec/60°
Dimensions		Weight
7/8 x 7/16 x 7/8 in. (22 x 11 x 22 mm)		0.33 oz (9.3 g)
		3P, BB, MG

- Enough torque for our use
- Small weight
- Reliability

OUTER WING DESIGN (CONT.)

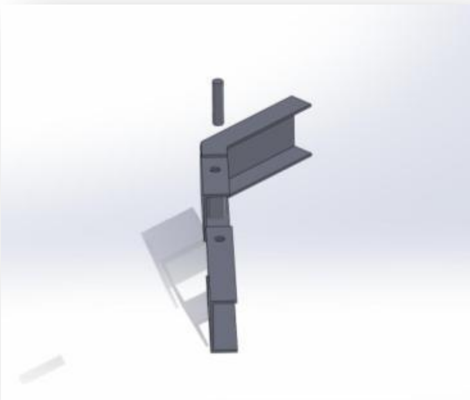
- Root and tip ribs
  - EPPLER 334 airfoil shaped
  - Tip is made of 1mm carbon fabric
    - Holes for electrical wires
    - Connection to the winglets

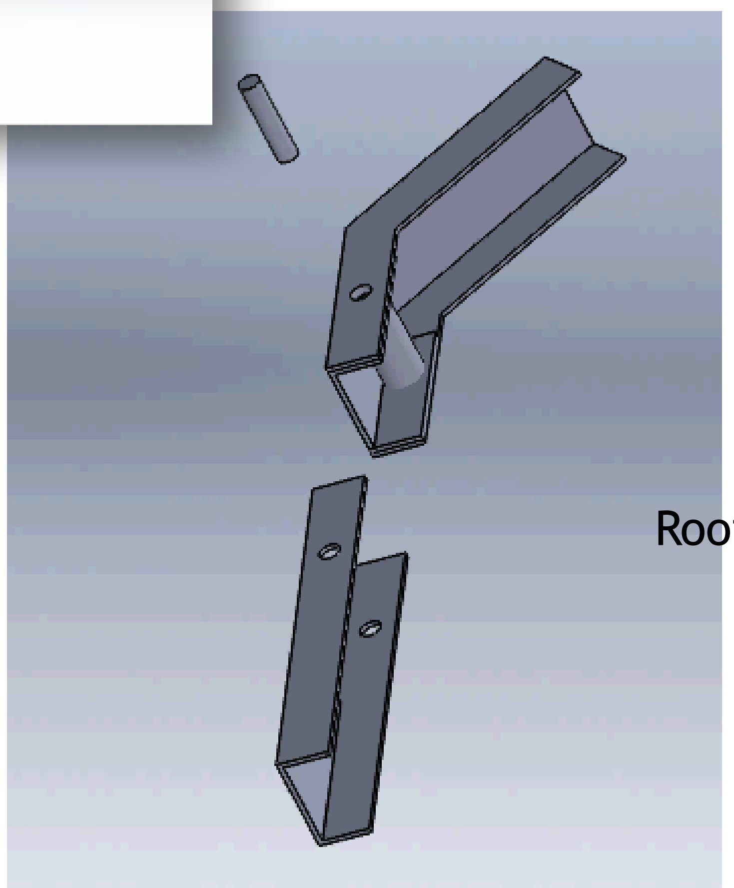
  - Root is made of 3mm carbon fabric
    - Holes for electrical wires
    - Supports the outer wing spars

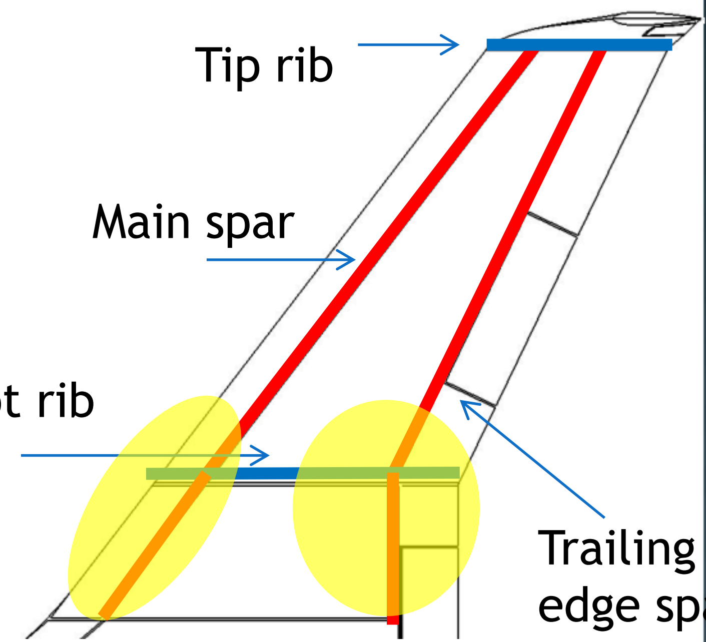


OUTER WING DESIGN (CONT.)

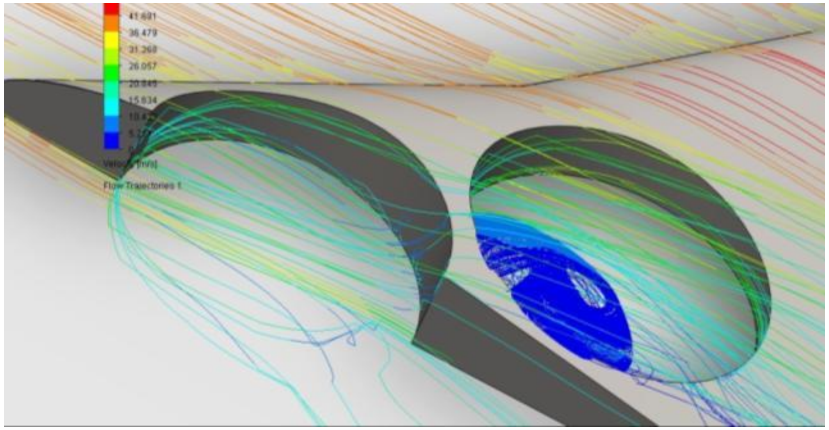
Connection to the main body is made by two spars

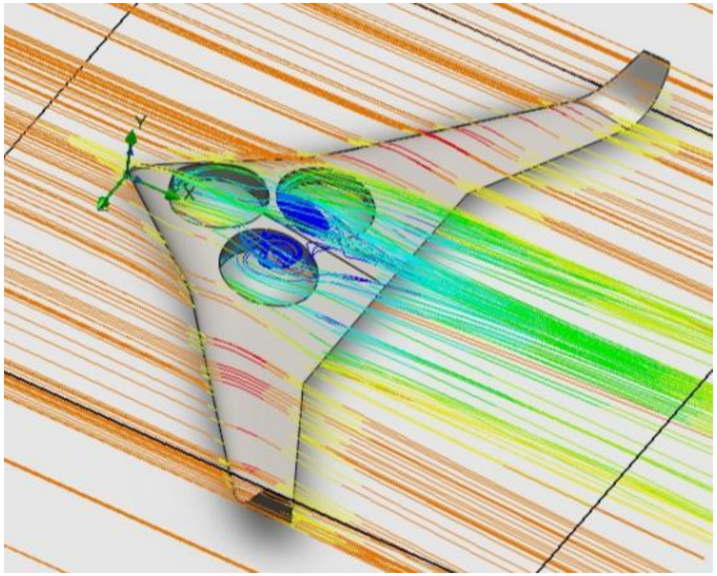




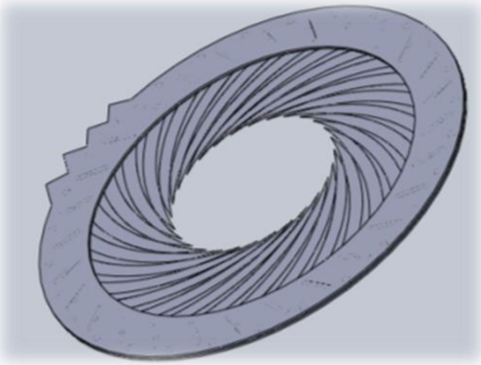


DETAIL DESIGN OF ROTORS CAVITY CLOSING MECHANISM

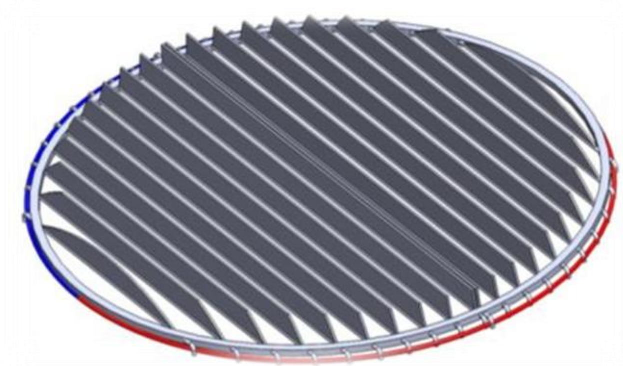




- Iris system:

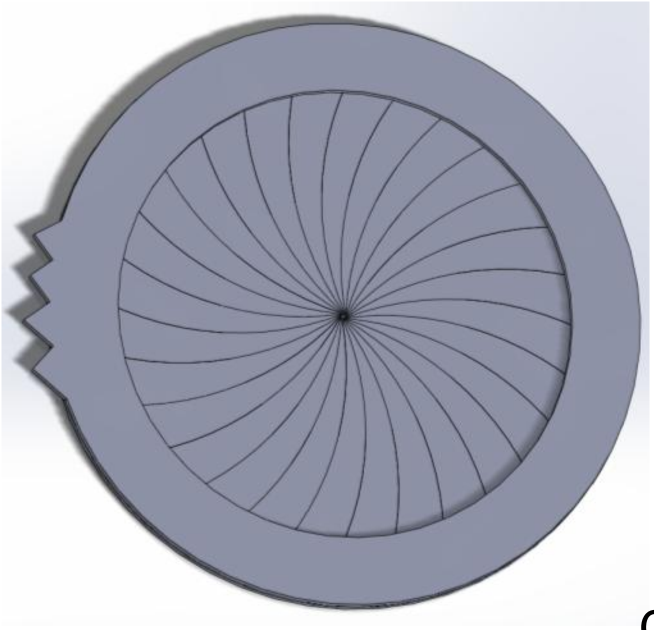


- Shutters system:

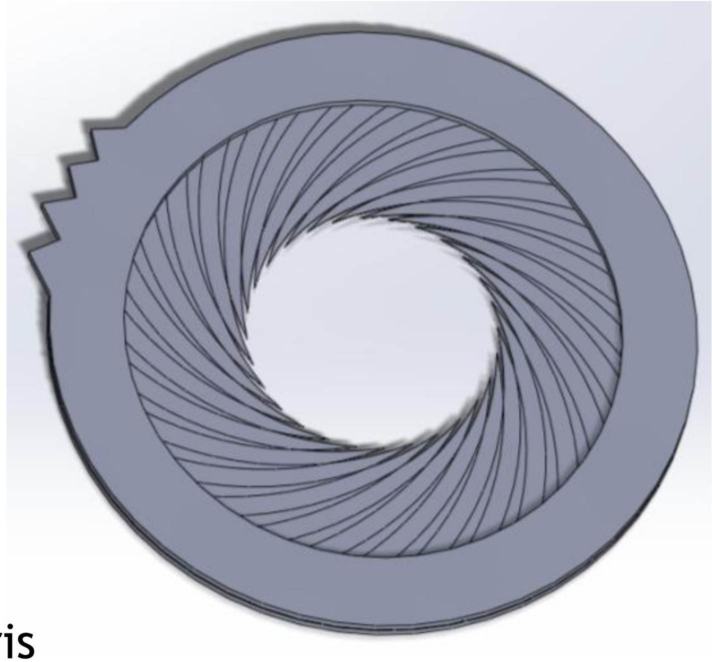


IRIS MECHANISM

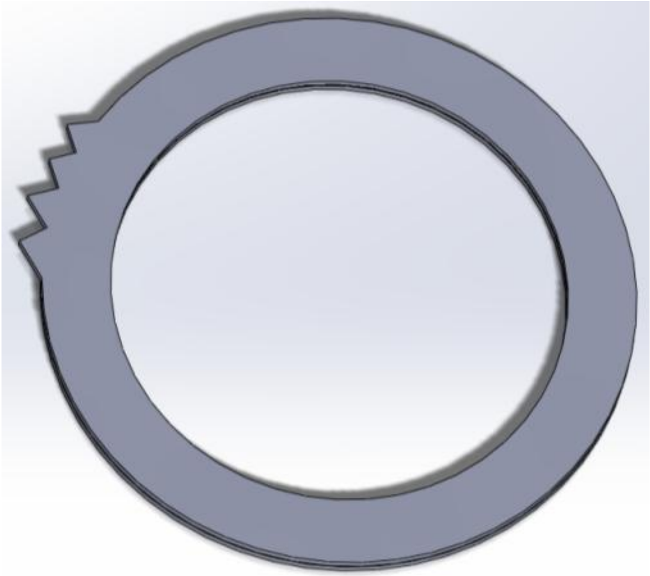
Closed iris



Half closed iris - Top ring rotates

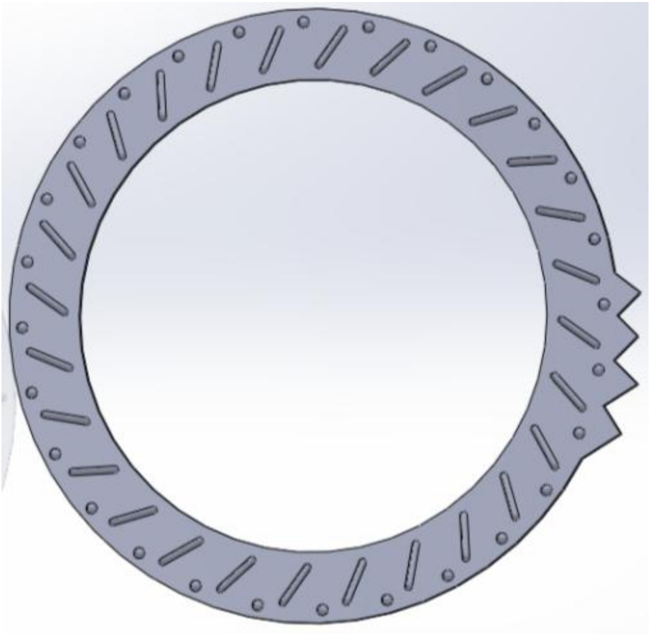


Opened iris

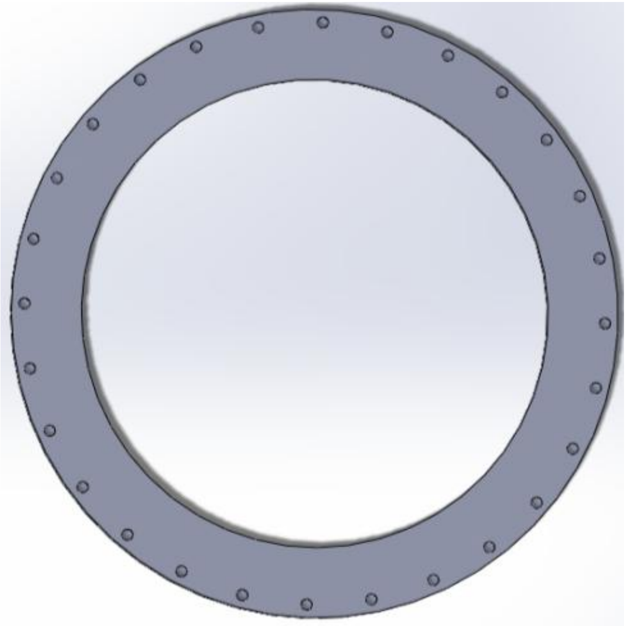


IRIS COMPONENTS

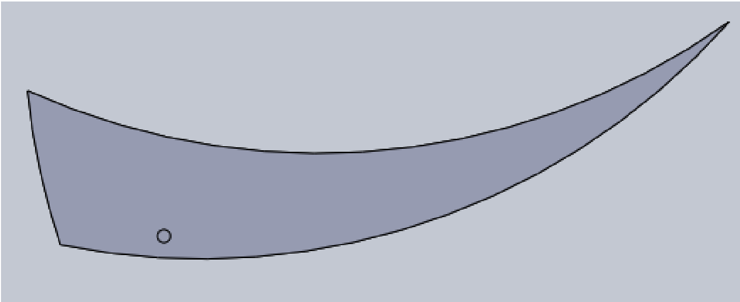
Top ring

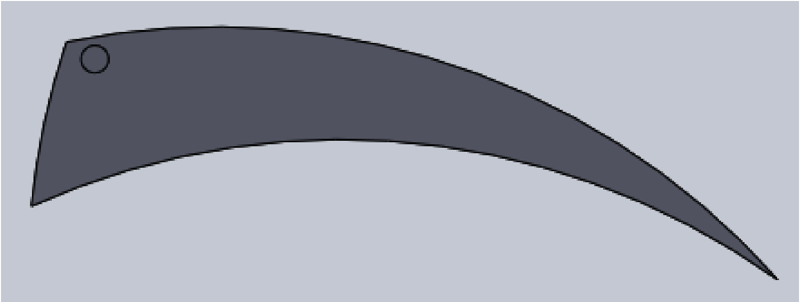


Base ring

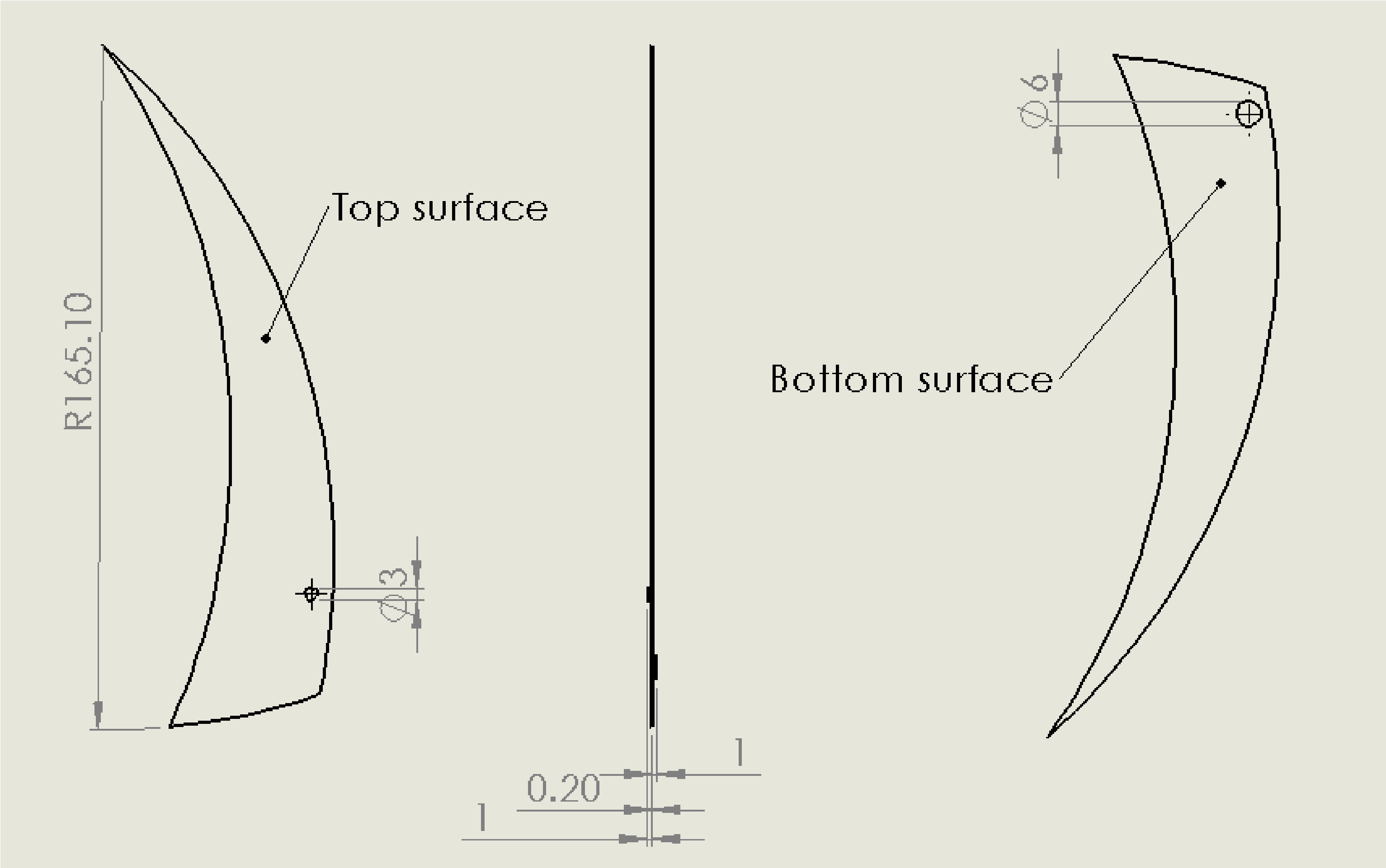


Iris segments – top and bottom view





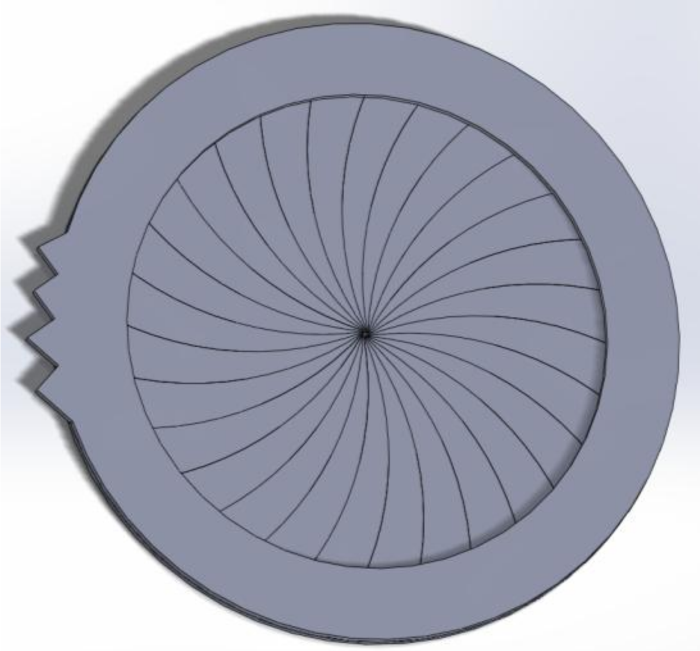
IRIS SEGMENTS



IRIS COVER DETAILED DESIGN

- Dimensions:
  - Rings:
    - Inner dimension – 10”
    - Outer dimension – 13”
    - Thickness – 2mm
  - Segments:
    - Thickness – 0.2mm each
    - Total thickness - 1mm
    - 28 segments

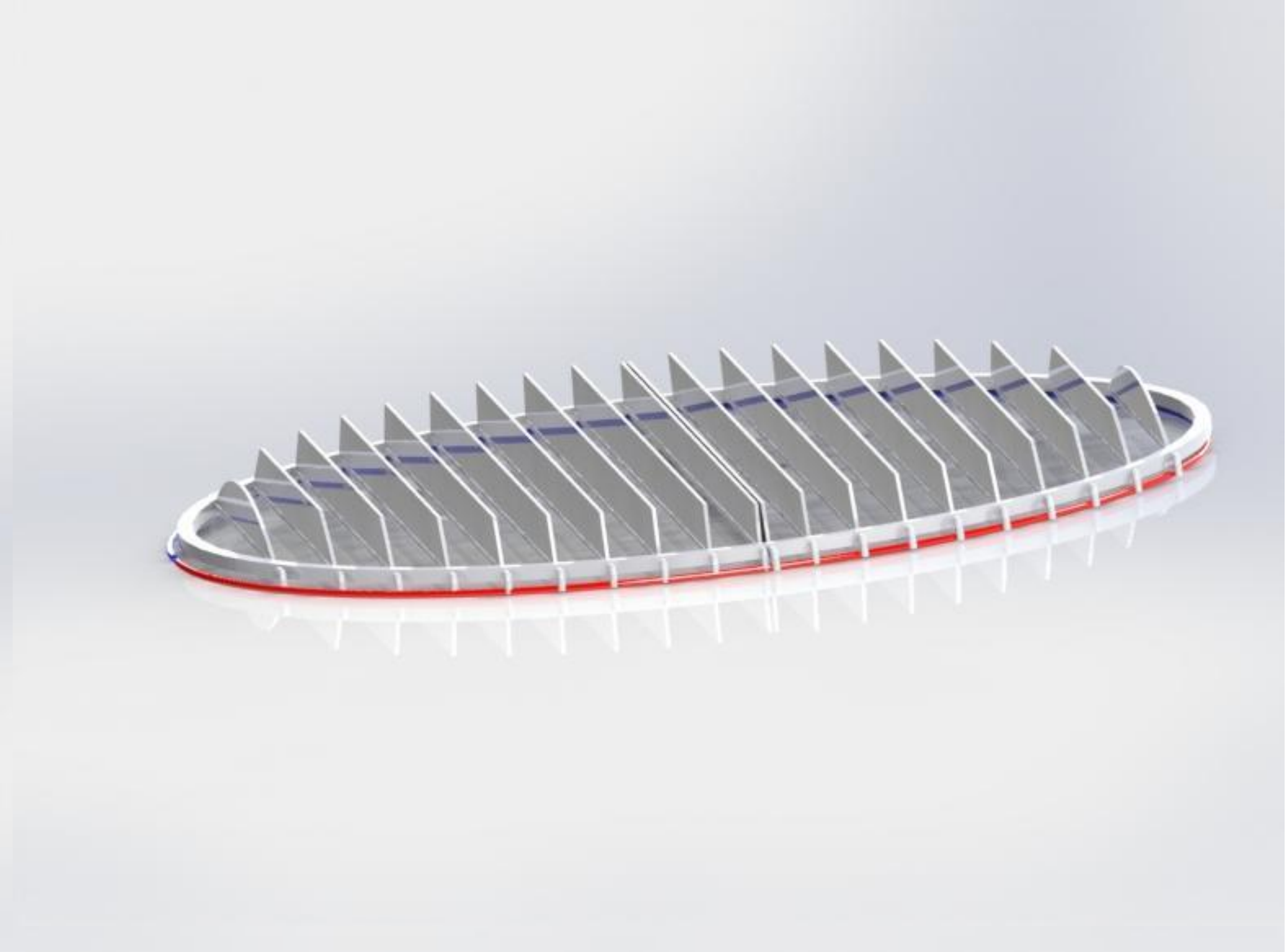
    (5 segments overlapping with 0.5 degrees angle)



Total thickness - 5mm

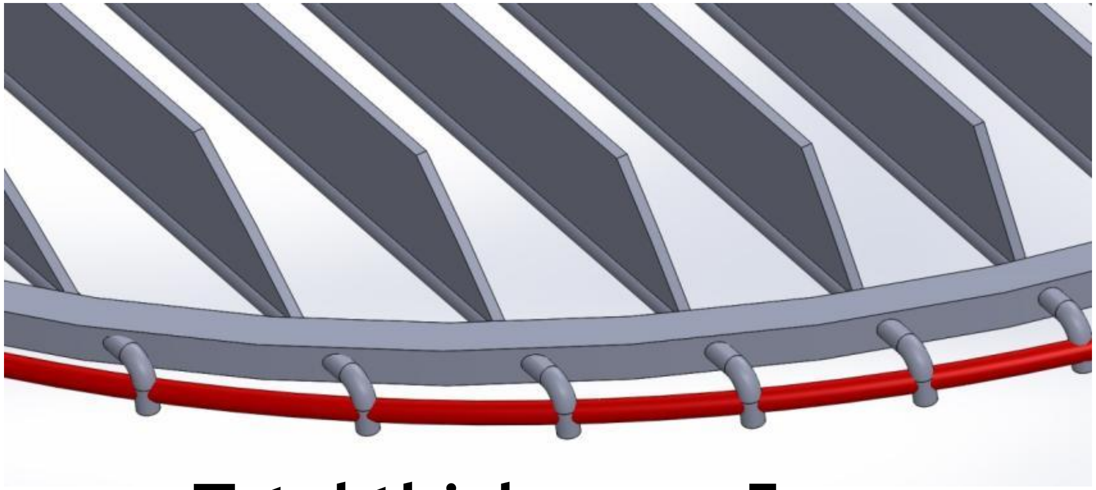
Max diameter - 13’’

SHUTTERS MECHANISM



SHUTTERS COVER DETAILED DESIGN

- Dimensions:
  - Ring:
    - Inner ring diameter – 10''
    - Outer ring diameter – 10.4''
    - Thickness – 5mm
  - Shutters:
    - Height – 3mm
    - Thickness – 1mm
  - Cable:
    - diameter – 2mm



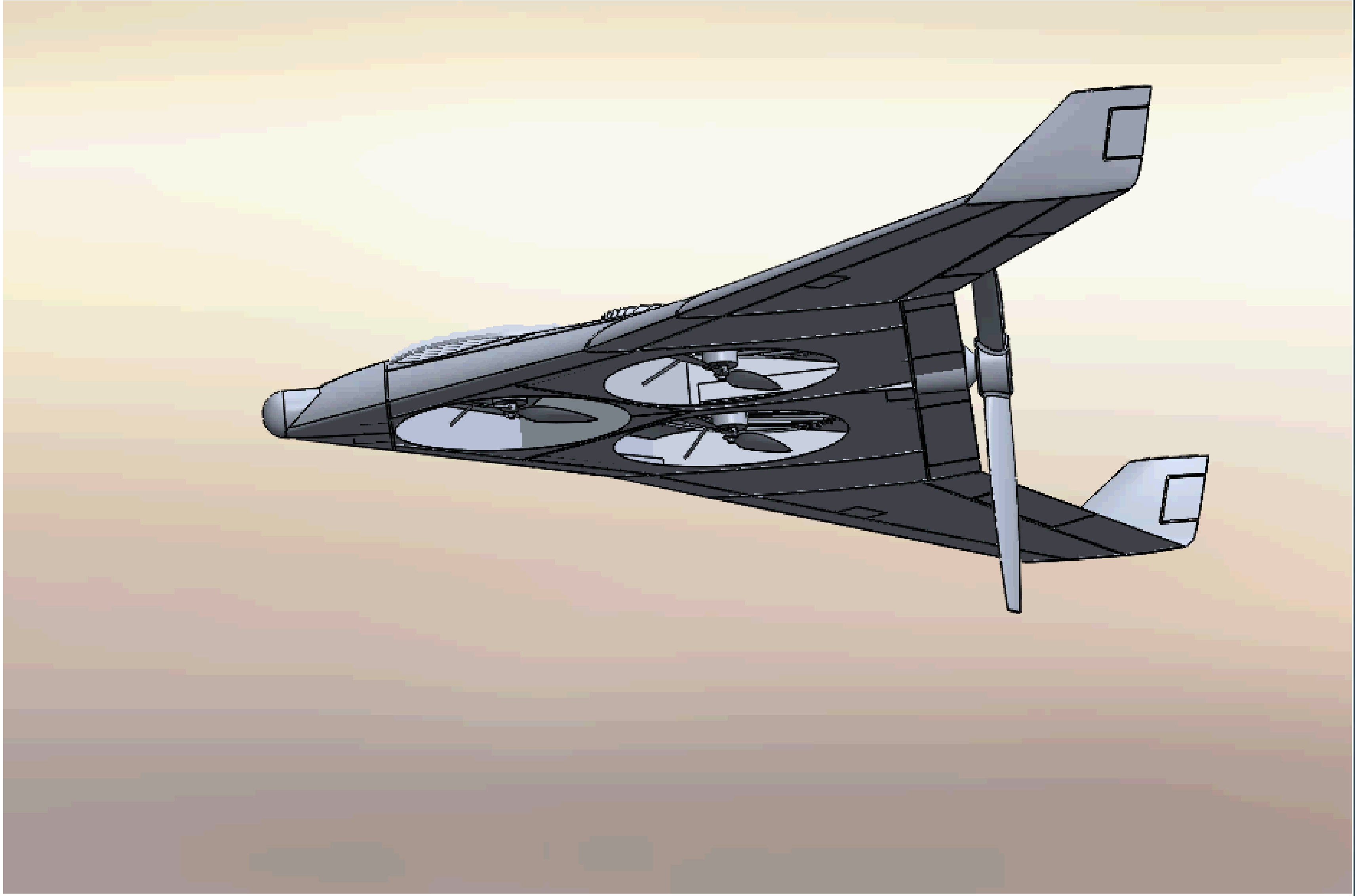
Total thickness - 5mm

Max diameter - 10.4''

COMPARISON

	Iris	Shutters
Mechanism	Simple	Simple
Max. diameter	13’’	10.4’’
Max. thickness	5mm	5mm
Flow interruption	None	During vertical flight
Effect on curved outer contour	Distinguished step	Minimal step

FLIGHT PATTERN

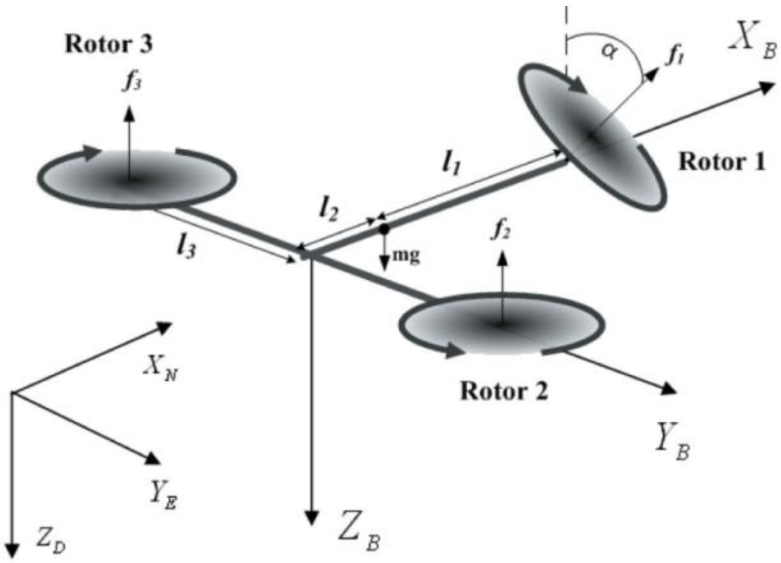


MODELING OF TRI ROTOR UAV

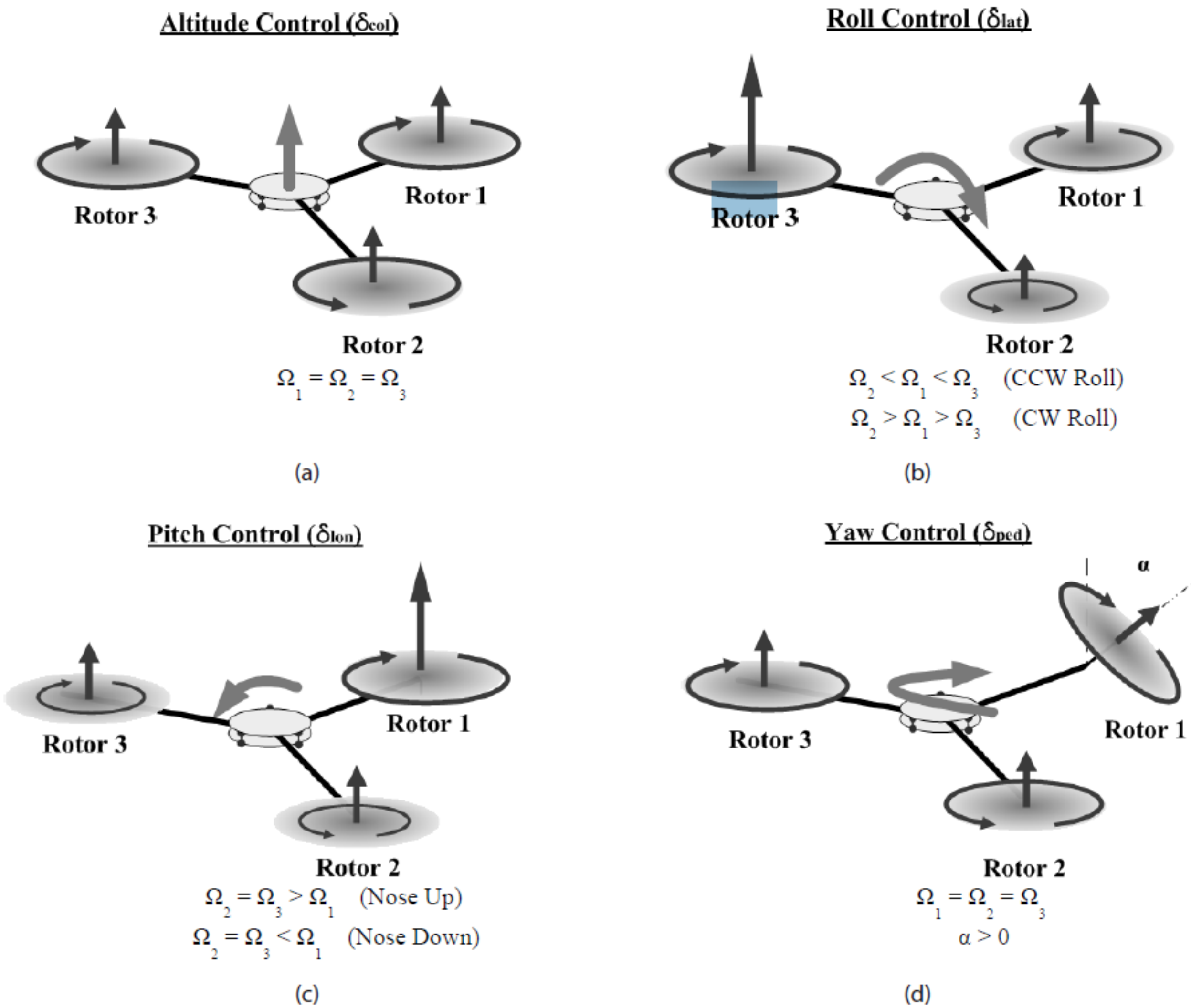
- The basic Tri Rotor UAV configuration:
  - Two parallel rotors with opposite rotation
  - Single tilted rotor
- Tilt angle α enables 3 degrees of freedom motion
- Force and moment equations:

$$\vec{F} = \begin{bmatrix} 0 \\ f_1 \sin\alpha \\ -f_2 - f_3 - f_1\cos\alpha \end{bmatrix}$$

$$\overrightarrow{M} = \begin{bmatrix} -l_3(f_2 - f_3) \\ -l_2(f_2 + f_3) + l_1 f_1 \cos\alpha \\ l_1 f_1 \sin\alpha - \tau_1\cos\alpha + \tau_2 - \tau_3 \end{bmatrix}$$



- 4 motion controls for the model
- Available by change in α or angular velocity Ω:



[1] Dynamic Modeling and Stabilization Techniques for Tri-Rotor Unmanned Aerial Vehicles

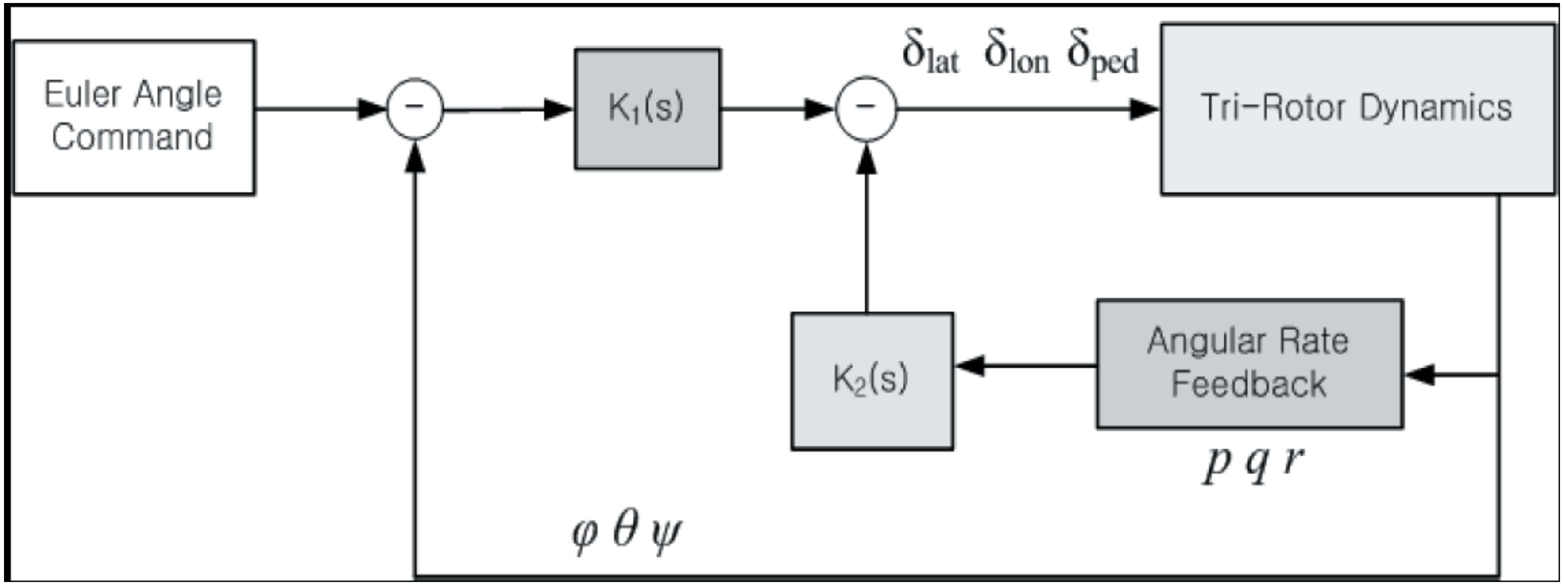
- Only altitude control – same motor's plane
- Movement equation:

$$m\ddot{z} = f_1 + f_2 + f_3 - mg$$

Where $f_i = k_t \cdot {\Omega_i}^2$

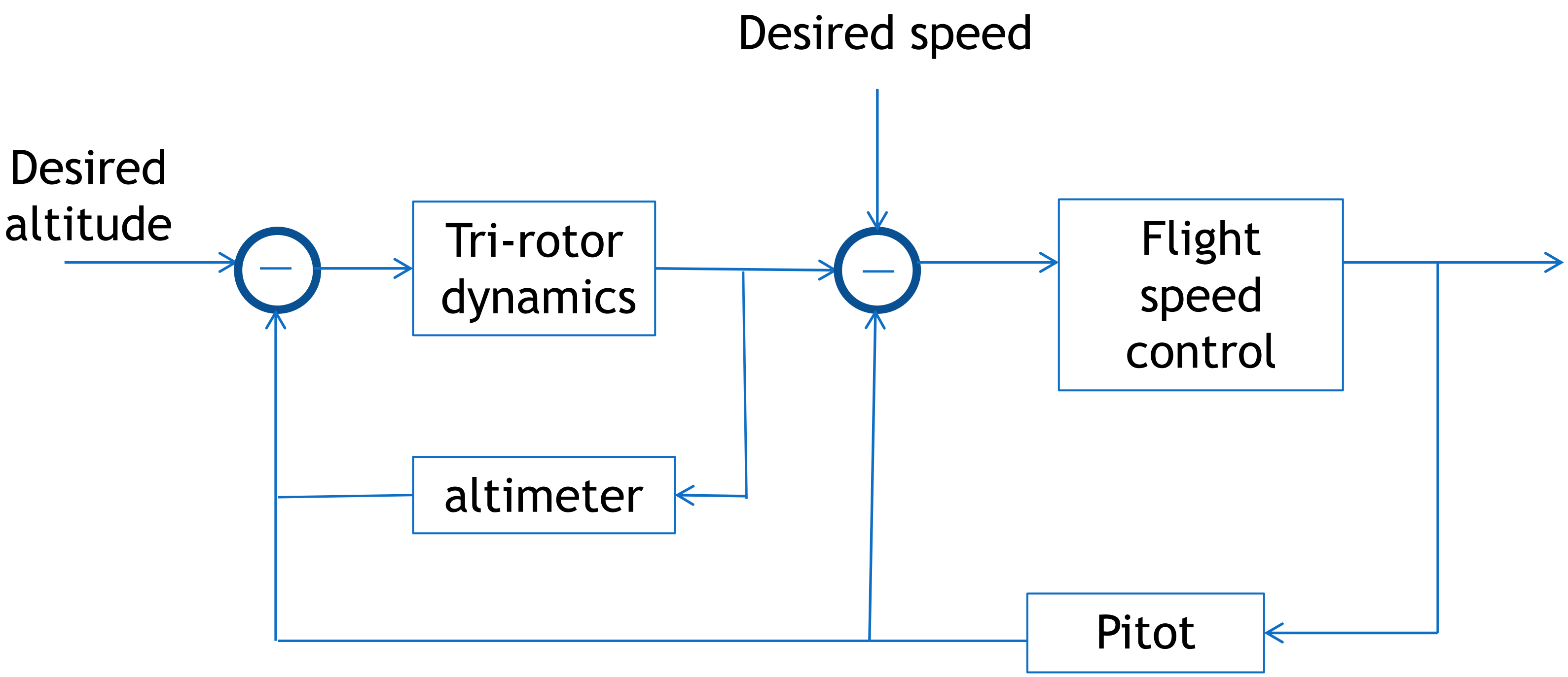
k_t - thrust coefficient of the rotor.

BLOCK DIAGRAM FOR ATTITUDE HOLD AUTOPILOT



- Inner loop – angular-rate feedback
- Outer-loop – attitude feedback

TRANSITION DIAGRAM



- Reaching desired altitude → horizontal motor powers up.
- Reaching desired flight speed → vertical motors shut down.
- Shutters – parallel with horizontal motors.

LINEAR MODEL OF THE LATERAL DYNAMICS

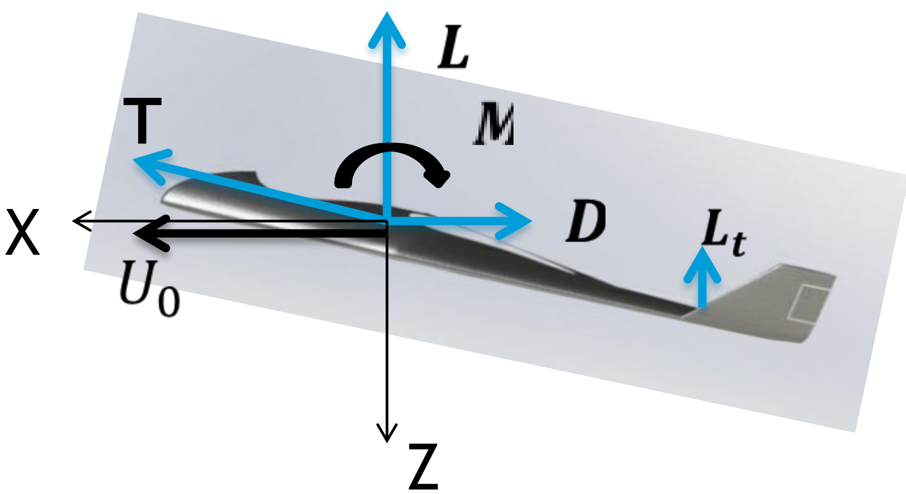
- Equations for transmission equation.
- Tunnel test did not yield all the required parameters.
- Need more experiments.

$$\begin{Bmatrix} \dot{\beta} \\ \dot{p} \\ \dot{r} \\ \dot{\phi} \end{Bmatrix} = \begin{bmatrix} Y_v & 0 & -1 & g/U_0 \\ L'_\beta & L'_p & L'_r & 0 \\ N'_\beta & N'_p & N'_r & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \begin{Bmatrix} \beta \\ p \\ r \\ \phi \end{Bmatrix} + \begin{bmatrix} Y^*_{\delta_a} & Y^*_{\delta_r} \\ L'_{\delta_a} & L'_{\delta_r} \\ N'_{\delta_a} & N'_{\delta_r} \\ 0 & 0 \end{bmatrix} \begin{Bmatrix} \delta_a \\ \delta_r \end{Bmatrix} - \begin{bmatrix} Y_v \\ L'_\beta \\ N'_\beta \\ 0 \end{bmatrix} \beta_g$$

$$\begin{aligned} \dot{\psi} &= r \\ \dot{y} &= U_0(\beta + \psi) \\ a_{y_{cg}}^{meas} &= U_0(\dot{\beta} + r) - g\phi \end{aligned}$$

LINEAR MODEL OF LONGITUDINAL DYNAMICS

$$\begin{Bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \end{Bmatrix} = \begin{bmatrix} X_u & X_w & 0 & -g \\ Z_u & Z_w & U_0 & 0 \\ \bar{M}_u & \bar{M}_w & \bar{M}_q & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{Bmatrix} u \\ w \\ q \\ \theta \end{Bmatrix} + \begin{bmatrix} X_{\delta_e} & T_{\delta_T} \\ Z_{\delta_e} & 0 \\ \bar{M}_{\delta_e} & 0 \\ 0 & 0 \end{bmatrix} \begin{Bmatrix} \delta_e \\ \delta_T \end{Bmatrix} - \begin{bmatrix} X_u & X_w \\ Z_u & Z_w \\ \bar{M}_u & \bar{M}_w \\ 0 & 0 \end{bmatrix} \begin{Bmatrix} u_g \\ w_g \end{Bmatrix}$$

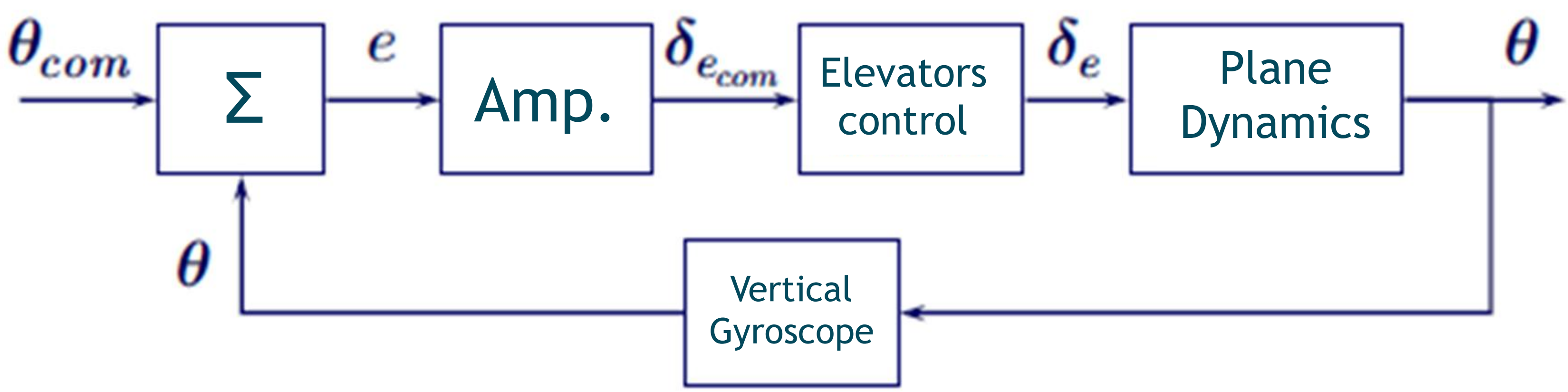


Aeronautical Equipment for Flight Control

- Inertial Sensors:
  - Linear and angular accelerometers.
  - Gyroscopes
- Air Data Sensors
  - Flow direction (α,β).
  - Flight speed sensor (Pitot)
  - Altimeter
- Optic sensors, GPS, etc.
- All Included in our controller – Micropilot 2128HELI

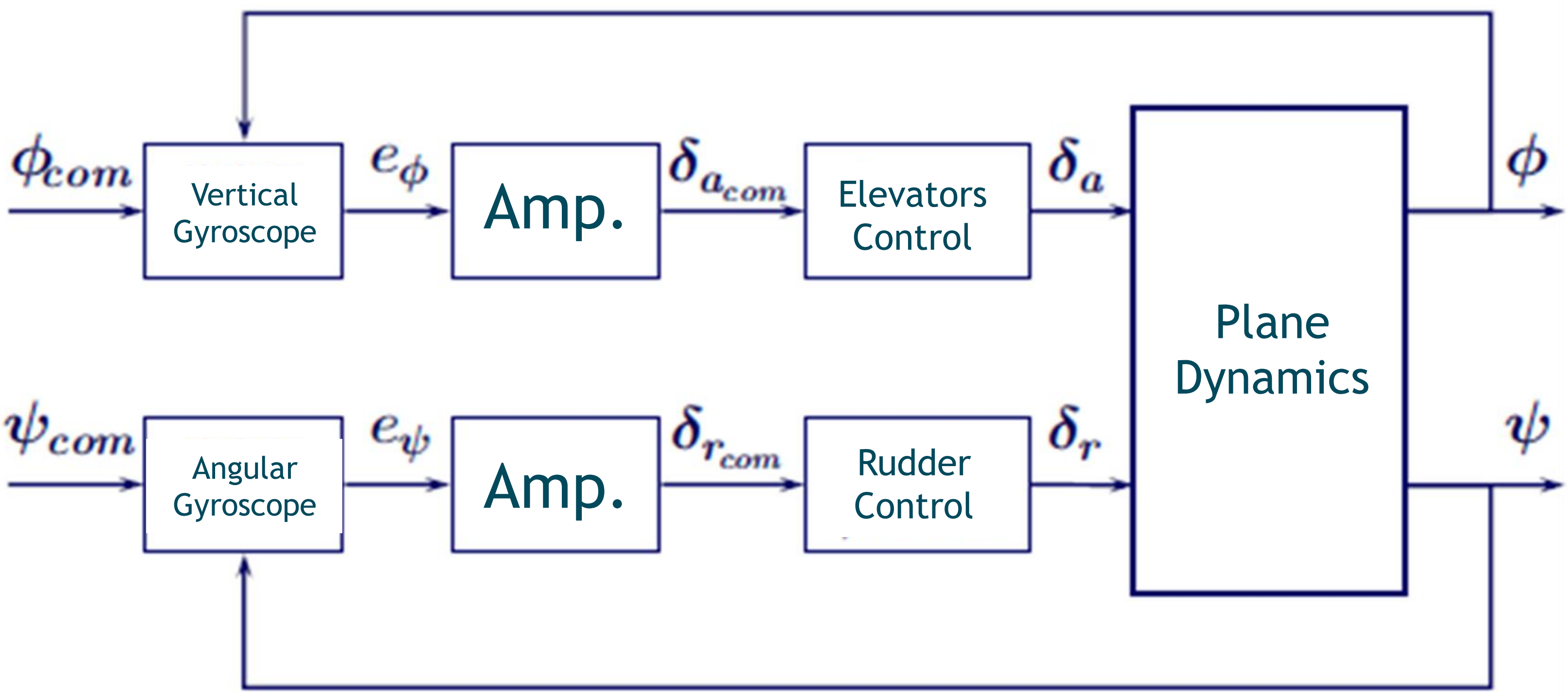
PITCH ANGLE CONTROL DIAGRAM

- Basic block diagram for pitch angle control:



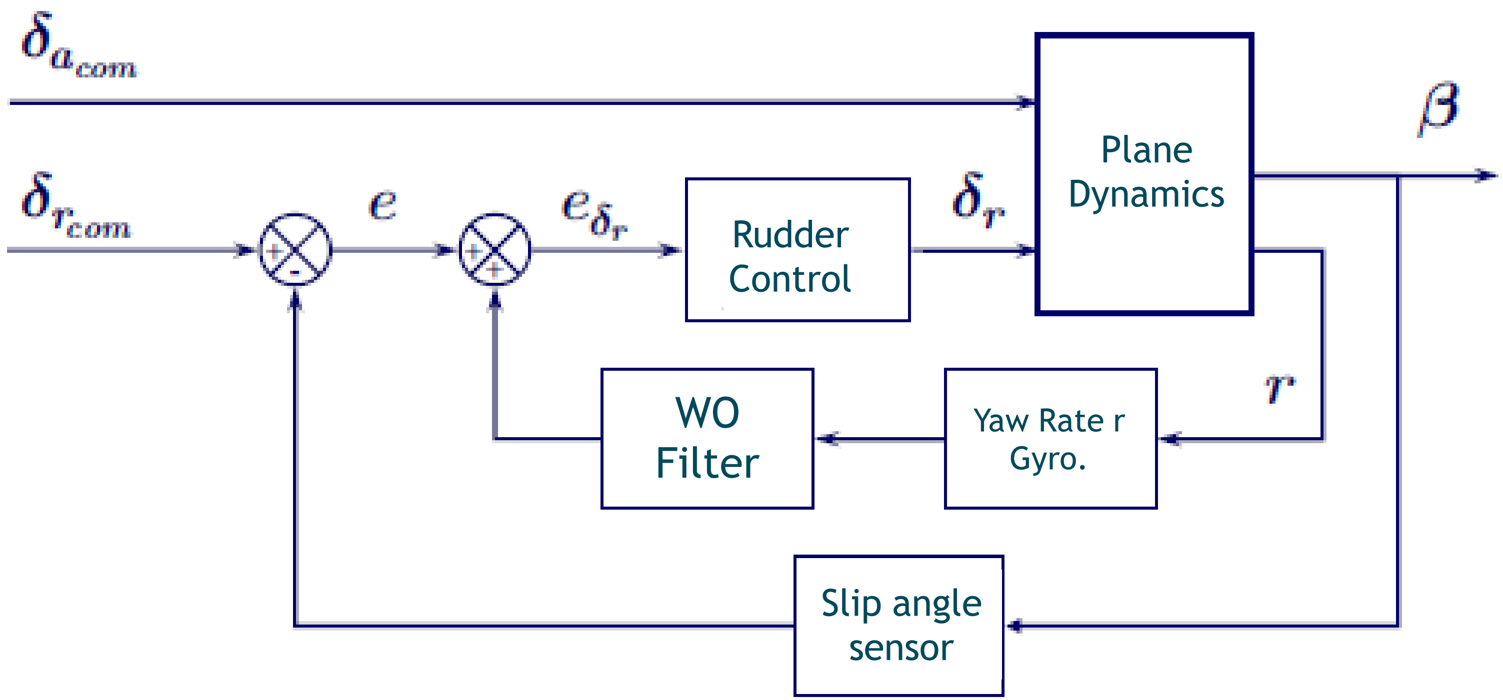
AUTOMATED LATERAL FLIGHT

Basic diagram - Automated pilot:



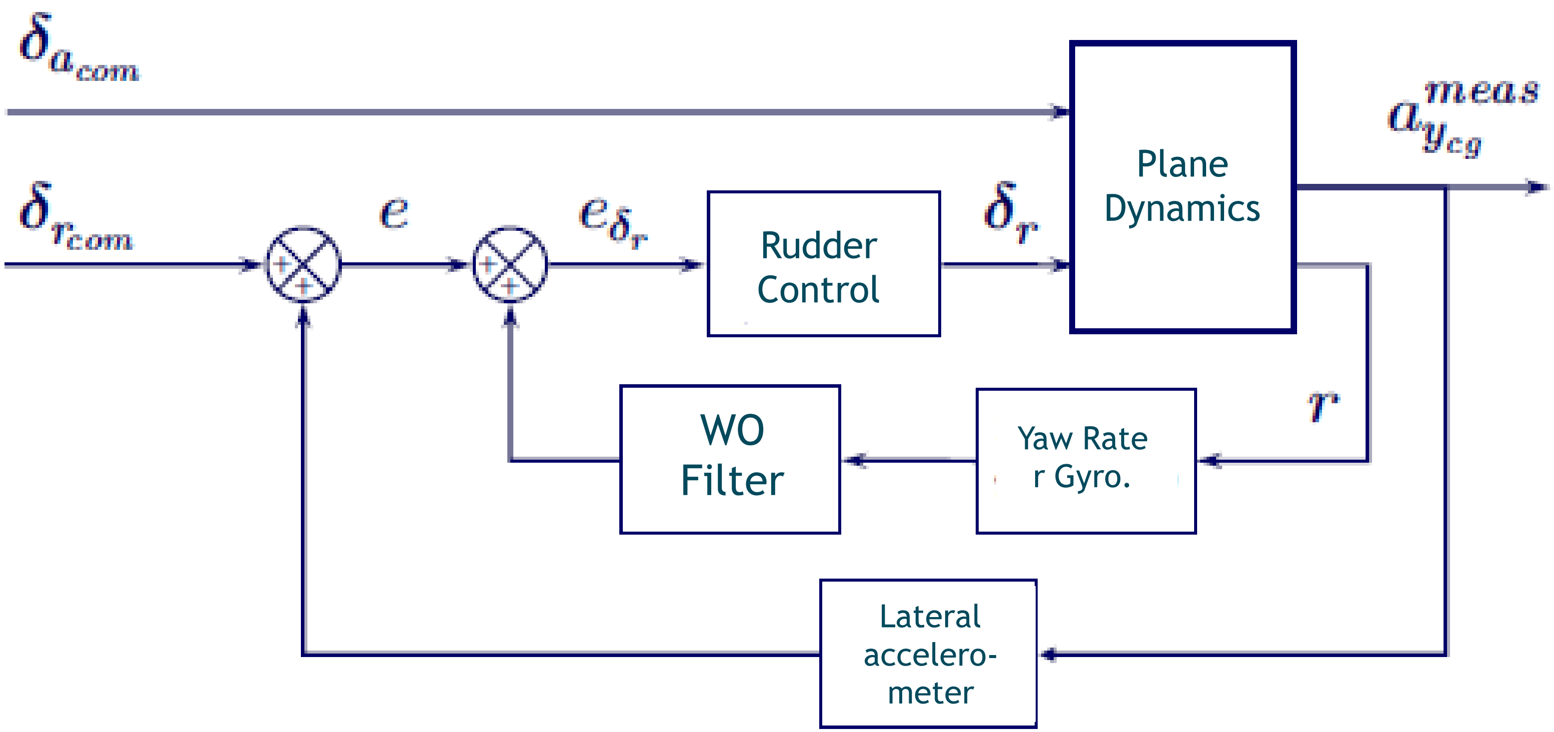
TURN COORDINATION

ß control with angle feedback:



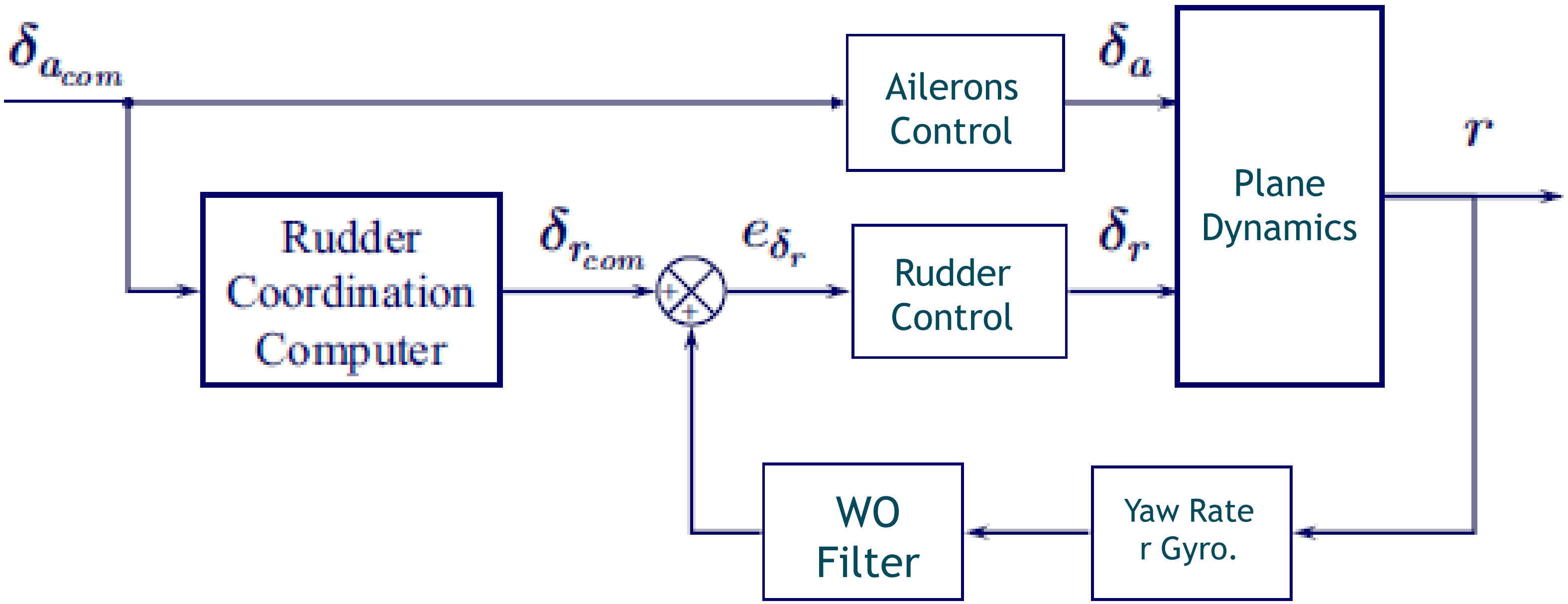
TURN COORDINATION

α control with lateral acceleration feedback:



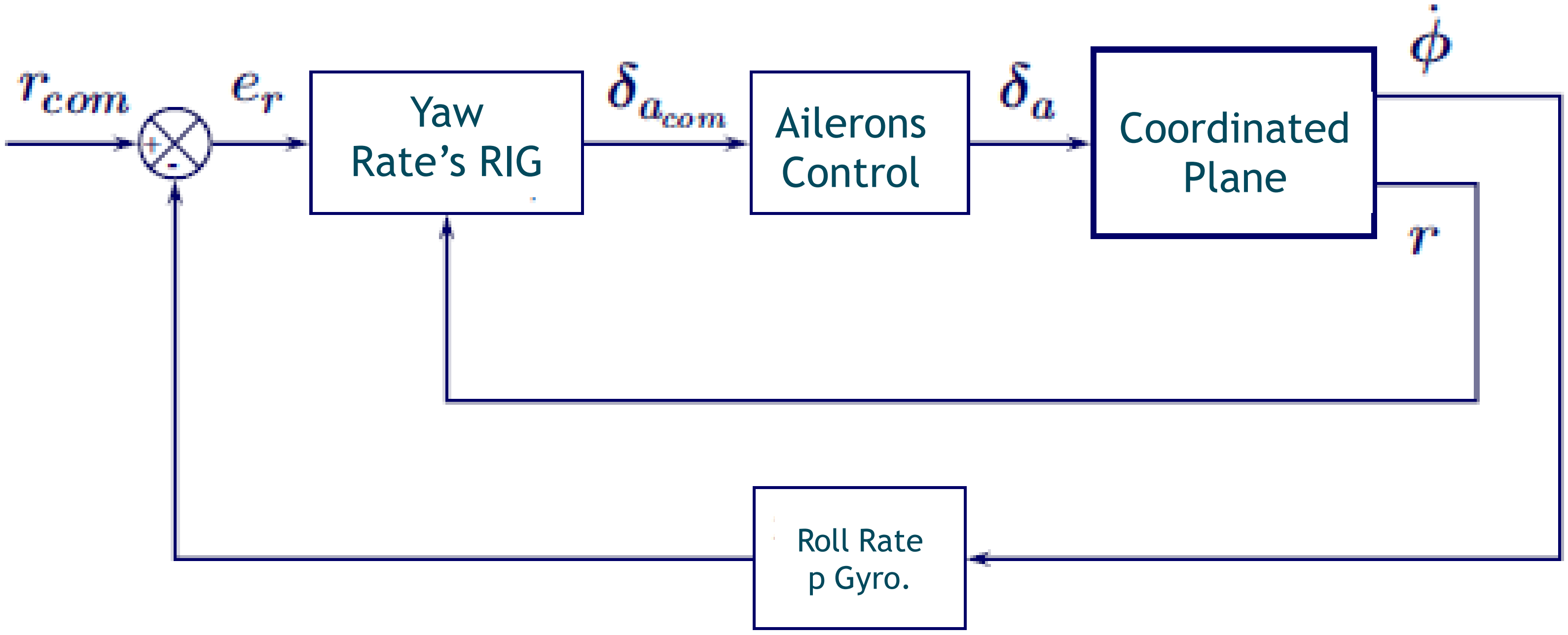
TURN COORDINATION

Rudder Control:



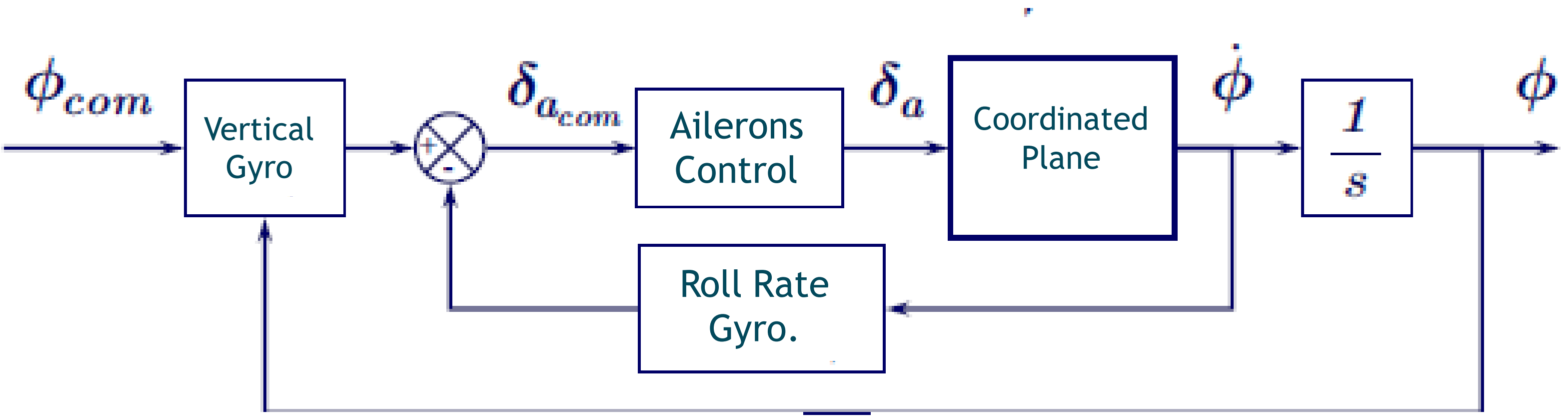
YAW RATE CONTROL

Basic diagram - Yaw rate control in a coordinated plane:

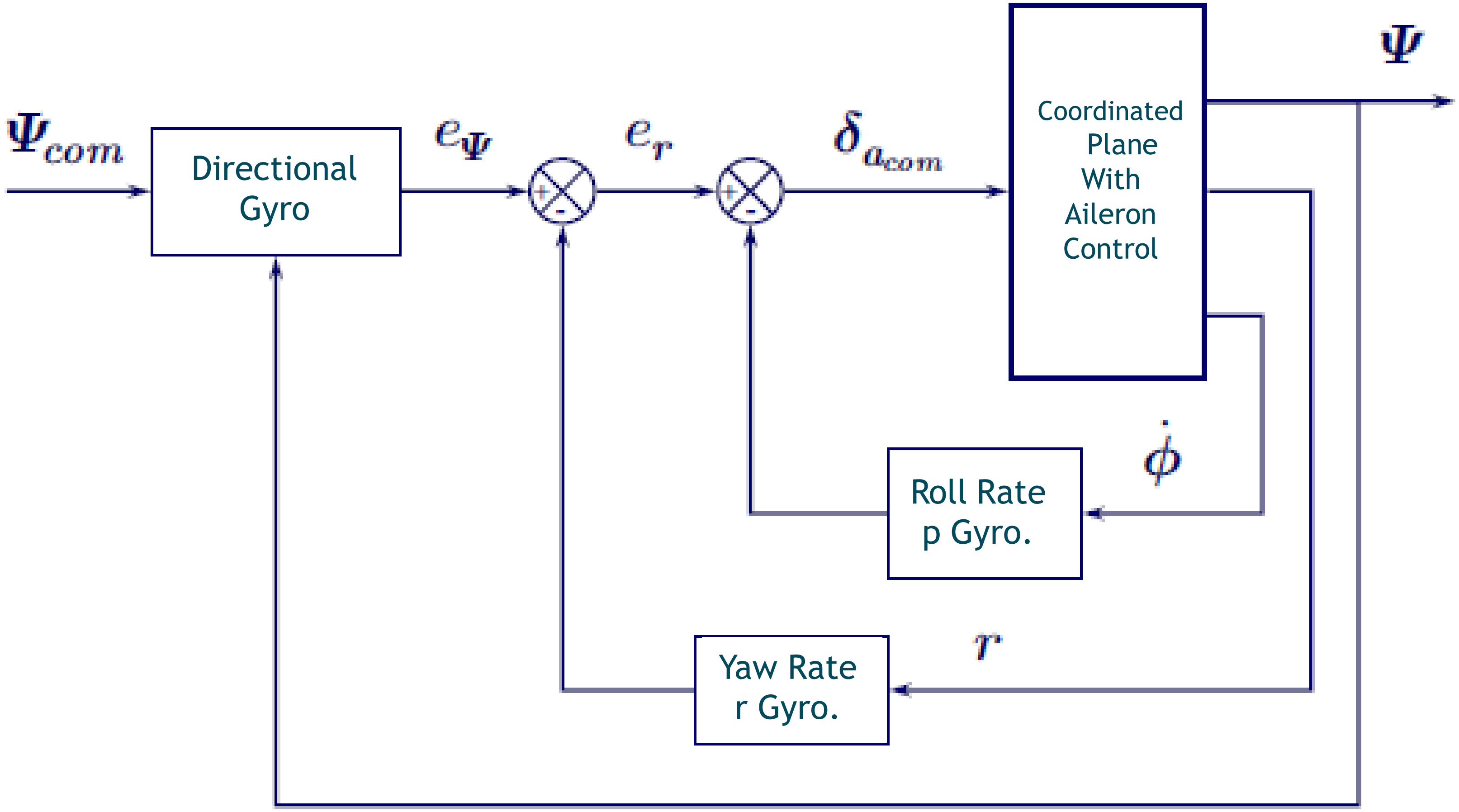


ROLL ANGLE CONTROL

Basic diagram - Roll angle control in a coordinated plane:



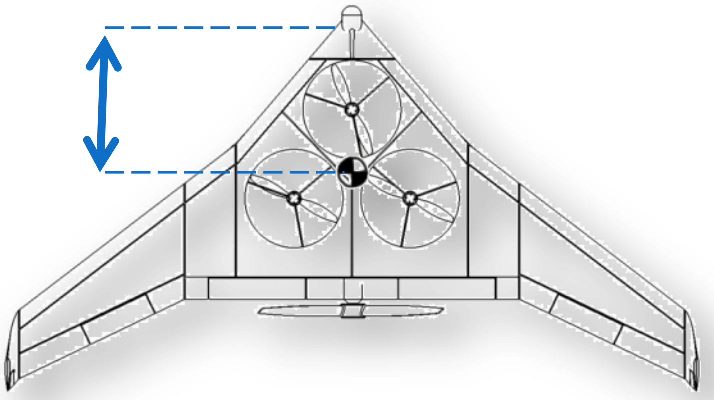
FLIGHT DIRECTION CONTROL



FINALIZED WEIGHT AND BALANCE ANALYSIS

*Reference datum - Payload

MTOW 4.5Kg
CG @ 390mm

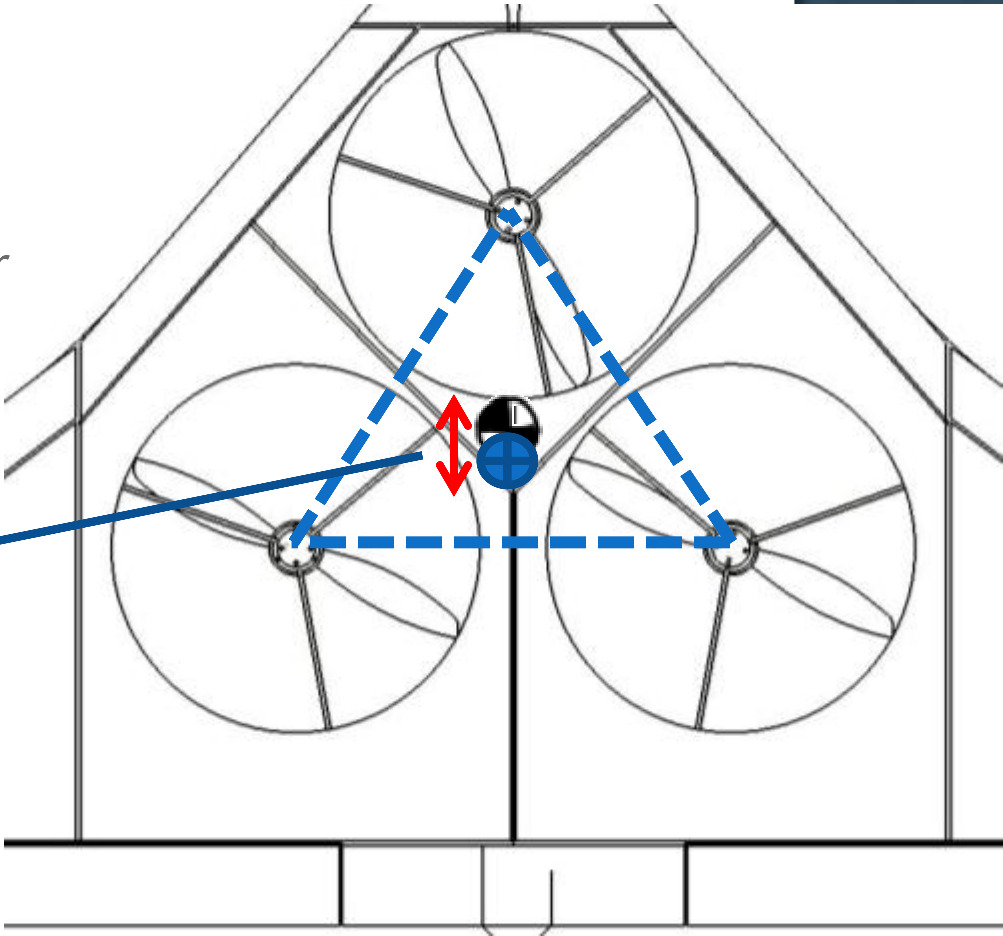


Station	Weight [Kg]	Arm [m]	Moment [Kg*m]
Fuselage	1.1	0.822	0.653
Motor V1	0.143	0.26	0.039
Motor V2	0.143	0.55	0.083
Motor V3	0.143	0.55	0.083
Motor H4	0.43	0.77	0.331
Battery 1	0.67	0.1	0.053
Battery 2	0.67	0.1	0.053
Battery 3	0.72	0.387	0.108
Controller 1	0.03	0.107	0.003
Controller 2	0.03	0.326	0.01
Controller 3	0.03	0.326	0.01
Controller 4	0.03	0.654	0.02
EL Servo	0.011	0.73	0.018
AL Servo	0.011	0.73	0.018
RU Servo 1	0.011	0.817	0.02
RU Servo 2	0.011	0.817	0.02
Tx\Rx	0.024	0.109	0.005
Payload	0.099	0	0
Contingency	0.194	0	0

CENTER OF GRAVITY LOCATION

Location	Distance from reference datum [mm]
Center of mass	390mm
Aerodynamic center	391.5mm

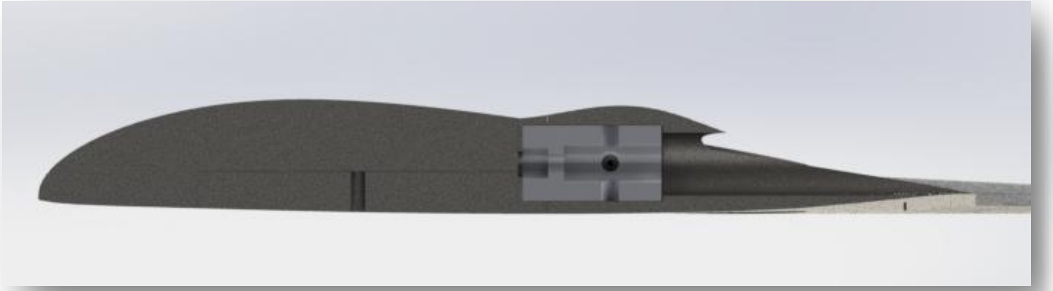
- Improving stability margin:
  - Move front motor and hole forward
  - Using control system for non-even power settings for forward and rear motors.

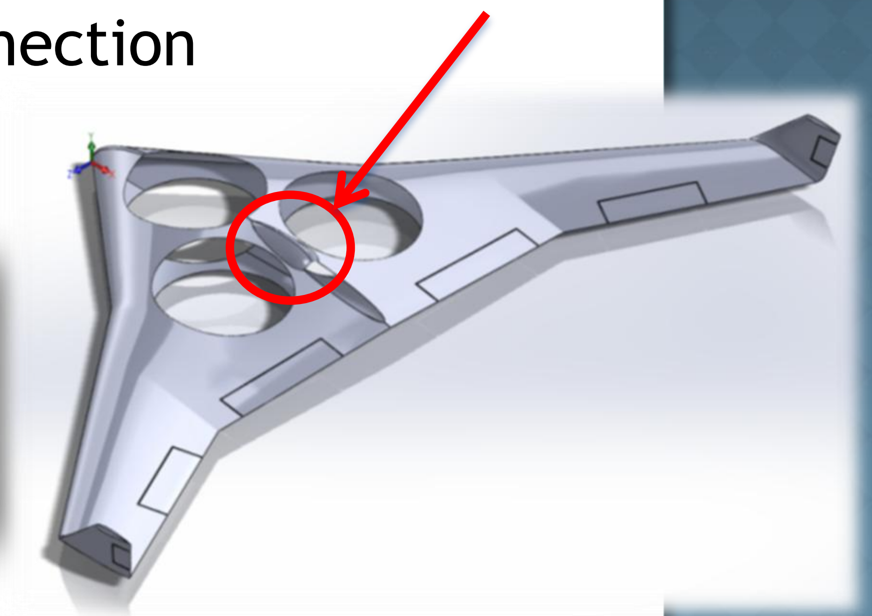


Stability margin 0.3%

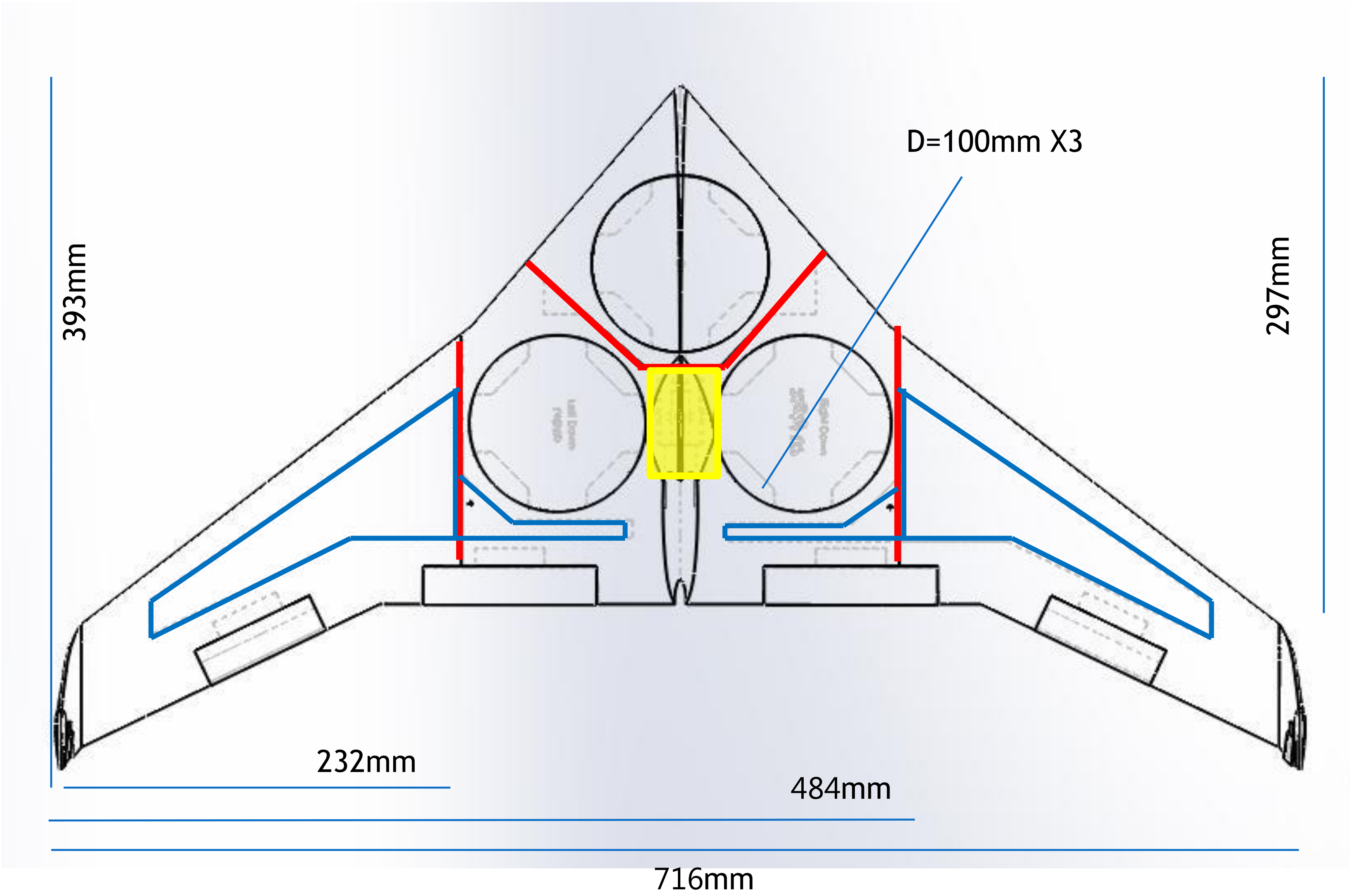
PREPARATIONS FOR WIND TUNNEL TEST

- Wind tunnel limitations: Blockage percentage 4%
- Scale: 1:2.5
- Modification – Connection to balancer
- 3D Printing of the fuselage and wings
- Split the model into 4 main parts
- Reinforcement of wing-body connection

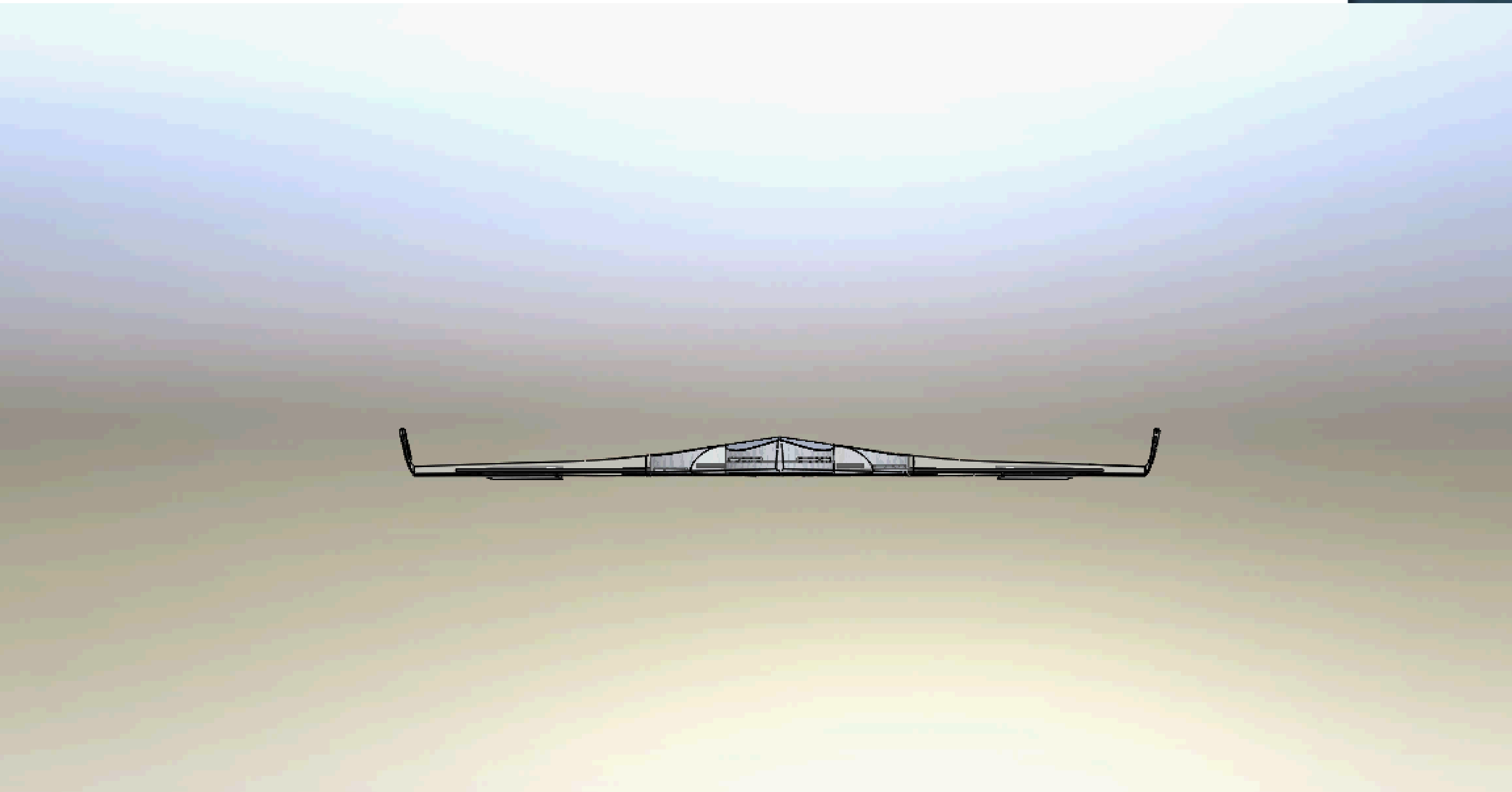




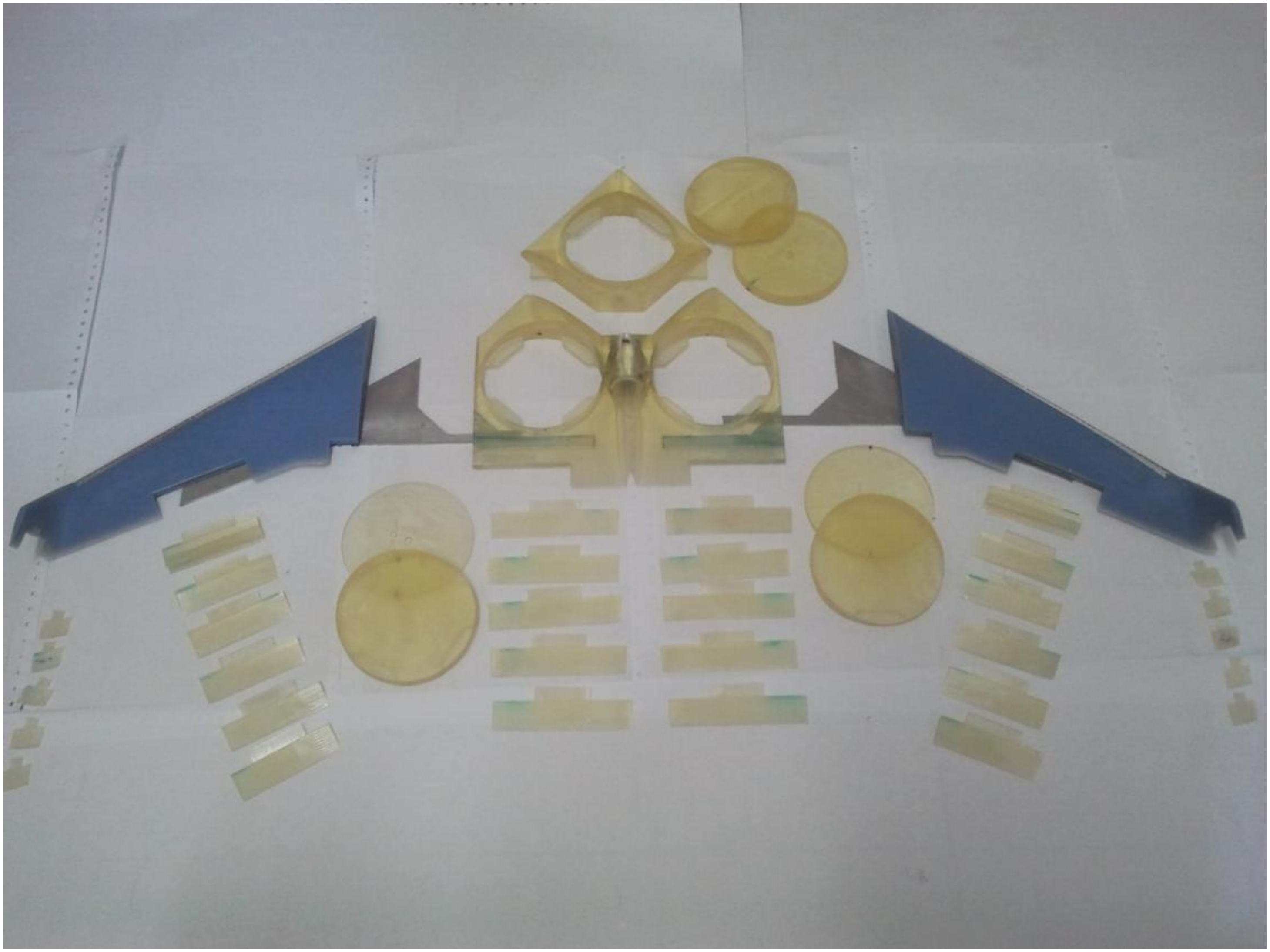
PREPARATIONS FOR WIND TUNNEL TEST



WIND TUNNEL MODEL - 3D ANIMATION

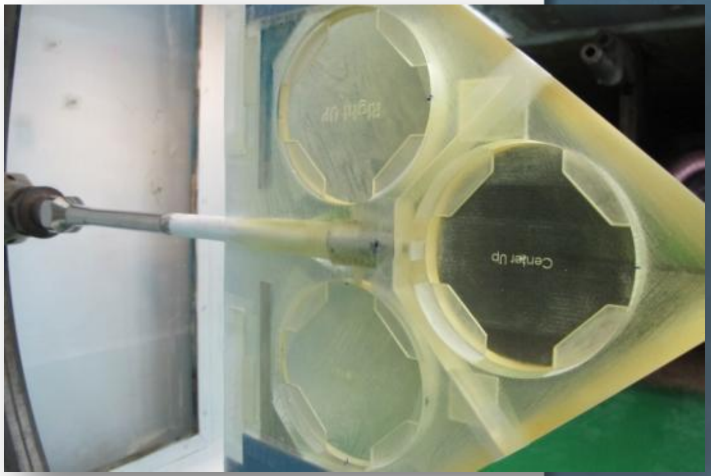


WIND TUNNEL MODEL



WIND TUNNEL TEST

- Calibration run
- Clean aircraft configuration:
  - Change elevators
  - Change ailerons including split aileron
  - Change rudders
- Top covers only configuration:
  - Change elevators
  - Change ailerons
  - Change rudders
- No covers configuration:
  - Change elevators
  - Change ailerons
  - Change rudders



35 runs

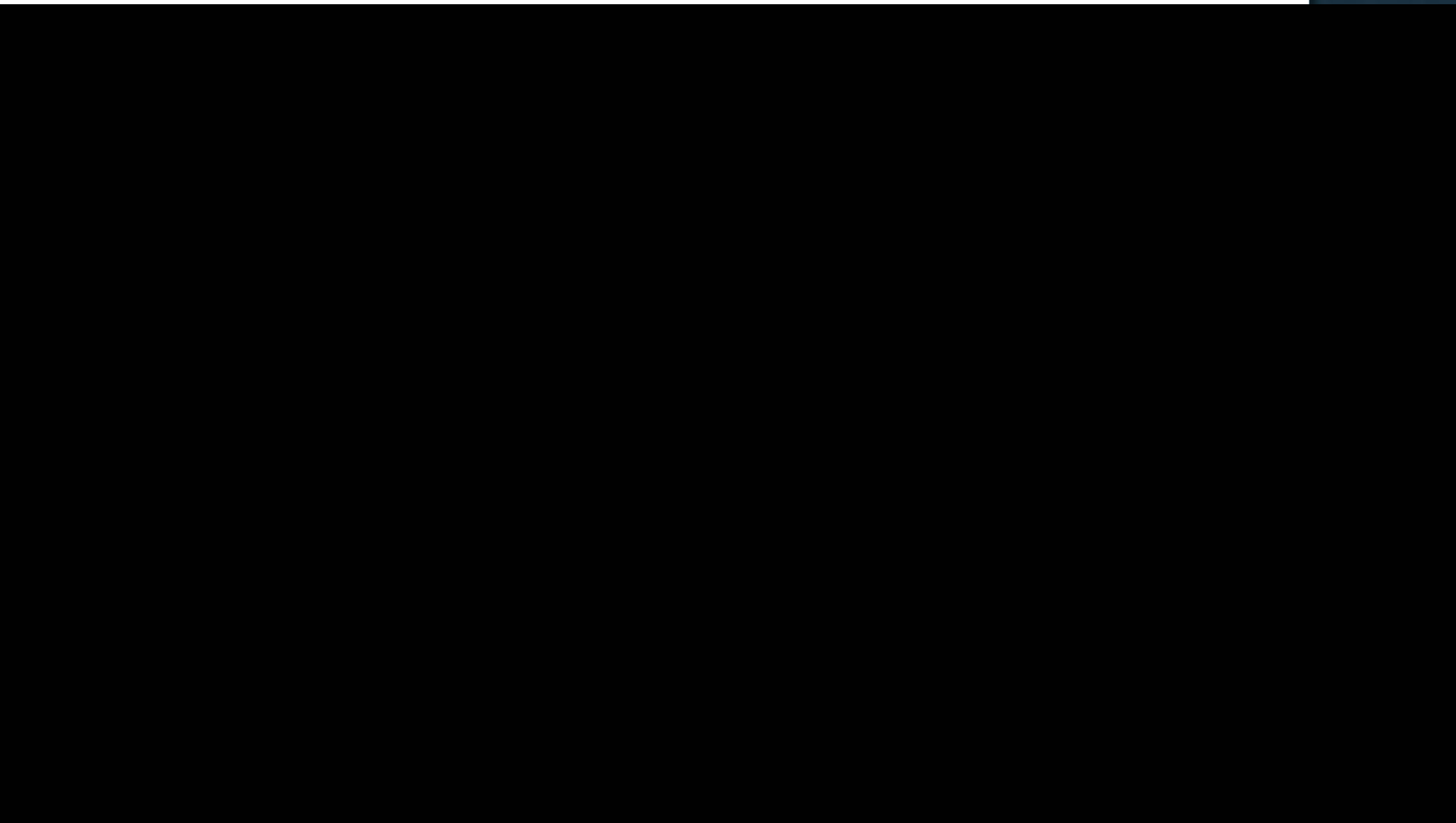
WIND TUNNEL TEST PLAN

Priority	Rudders	Elevators	Ailerons	Motor covers	Pitch Plane - α range	Air speed (m/s)	Test No.
1	0	0	0	top+bottom	15+ - 5-	30	1
1	0	0	0	top+bottom	15+ - 5-	40	2
1	0	0	0	top+bottom	15+ - 5-	50	3
1	0	0	7.5-+	top+bottom	15+ - 5-	optimal speed	4
1	0	0	15-+	top+bottom	15+ - 5-		5
1	0	7.5-	0	top+bottom	15+ - 5-		6
1	0	15-	0	top+bottom	15+ - 5-		7
1	0	7.5+	0	top+bottom	15+ - 5-		8
1	0	15+	0	top+bottom	15+ - 5-		9
1	5-	0	0	top+bottom	15+ - 5-		10
1	10-	0	0	top+bottom	15+ - 5-		11
1	5+	0	0	top+bottom	15+ - 5-		12
1	10+	0	0	top+bottom	15+ - 5-		13
1	0	0	split aileron	top+bottom	15+ - 5-		14
1	0	0	7.5-+	top only	15+ - 5-	optimal speed	15
1	0	0	15-+	top only	15+ - 5-		16
0	0	7.5-	0	top only	15+ - 5-		17
0	0	15-	0	top only	15+ - 5-		18
1	0	7.5+	0	top only	15+ - 5-		19
1	0	15+	0	top only	15+ - 5-		20
0	5-	0	0	top only	15+ - 5-		21
0	10-	0	0	top only	15+ - 5-		22
1	5+	0	0	top only	15+ - 5-		23
1	10+	0	0	top only	15+ - 5-		24
1	0	0	split aileron	top only	15+ - 5-		25

WIND TUNNEL TEST PLAN

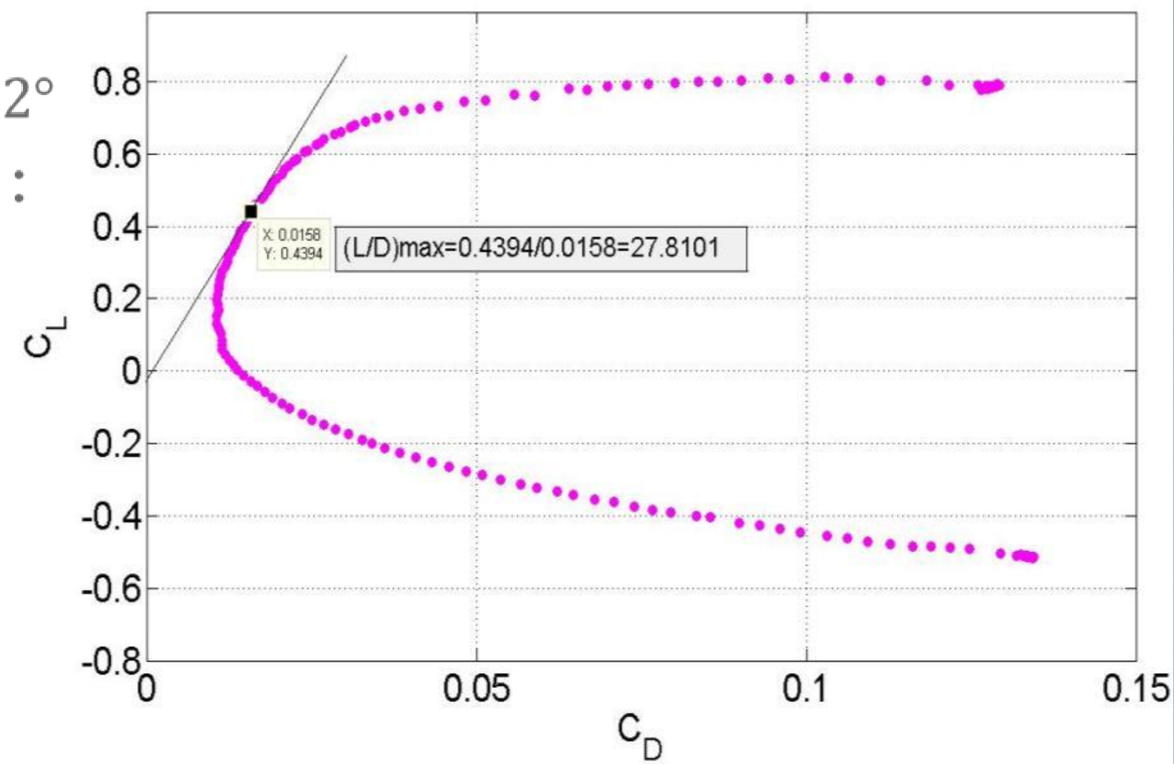
1	0	0	7.5-+	none	15+ - 5-		26
1	0	0	15-+	none	15+ - 5-		27
0	0	7.5-	0	none	15+ - 5-		28
0	0	15-	0	none	15+ - 5-		29
1	0	7.5+	0	none	15+ - 5-		30
1	0	15+	0	none	15+ - 5-	optimal speed	31
0	5-	0	0	none	15+ - 5-		32
0	10-	0	0	none	15+ - 5-		33
1	5+	0	0	none	15+ - 5-		34
1	10+	0	0	none	15+ - 5-		35
1	0	0	split aileron	none	15+ - 5-		36
Preference	Rudders	Elevators	Ailerons	Motor covers	Yaw Plane - ß range	Air speed (m/s)	Test No.
1	0	0	0	top+bottom	10+ - 10-	optimal speed	37
1	0	0	split aileron	top+bottom	10+ - 10-		38
1	5-	0	0	top+bottom	10+ - 10-		39
1	10-	0	0	top+bottom	10+ - 10-	optimal speed	40
1	5+	0	0	top+bottom	10+ - 10-		41
1	10+	0	0	top+bottom	10+ - 10-		42
0	5-	0	0	top only	10+ - 10-		43
0	10-	0	0	top only	10+ - 10-	optimal speed	44
1	5+	0	0	top only	10+ - 10-		45
1	10+	0	0	top only	10+ - 10-		46
0	5-	0	0	none	10+ - 10-		47
0	10-	0	0	none	10+ - 10-	optimal speed	48
1	5+	0	0	none	10+ - 10-		49
1	10+	0	0	none	11+ - 10-		50

WIND TUNNEL VIDEO

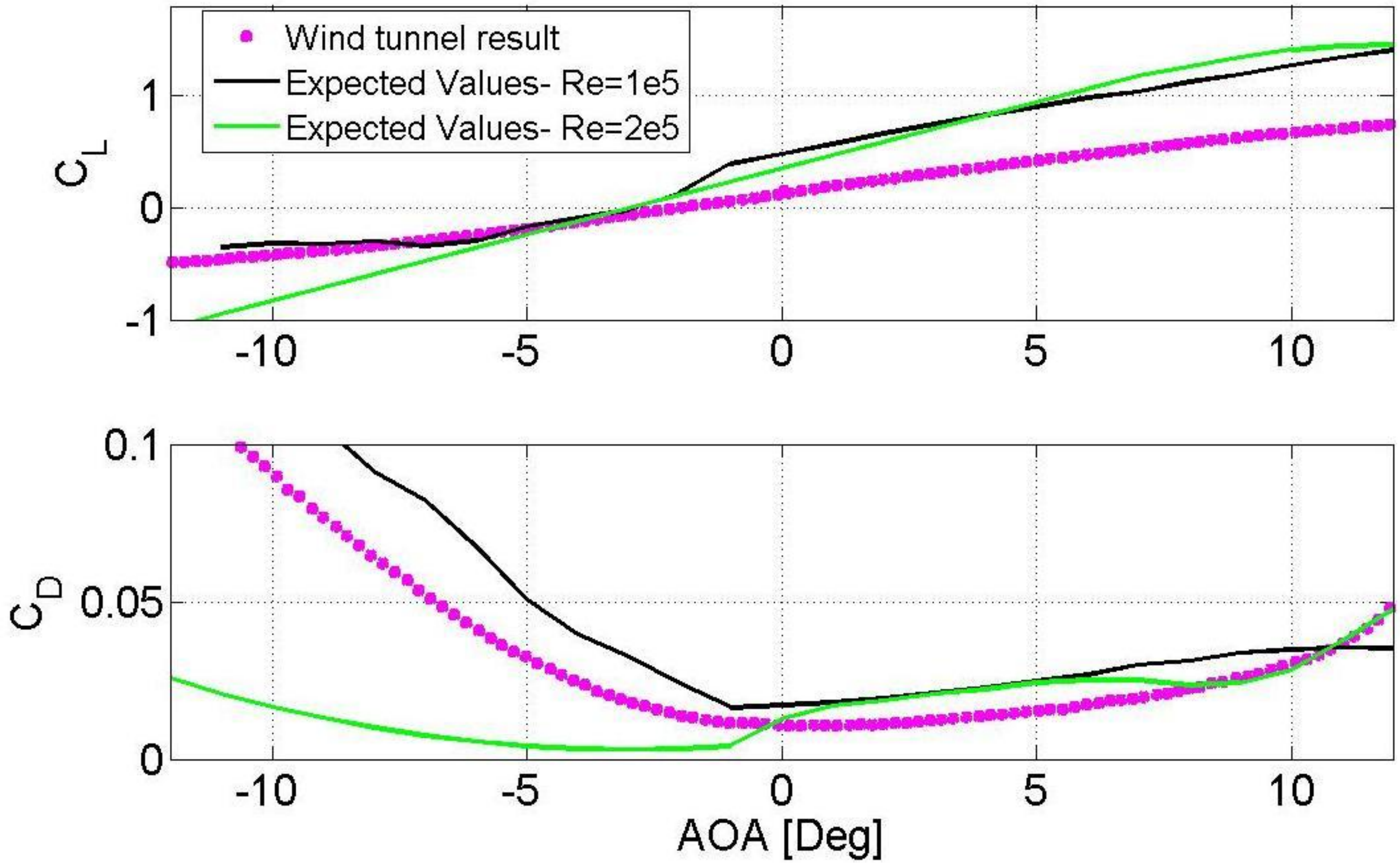


FIRST RUN- VERIFYING AND CALIBRATING:

- Running at V= $35 ^m/_s$, straight and level flight:
  - Expected values:
    - Stall at $\alpha = 13°$
    - $(^L/_D)max = 20.36$
- Results:
  - Vibration at $\alpha > 12°$
  - $(^L/_D)max = 27.81$:

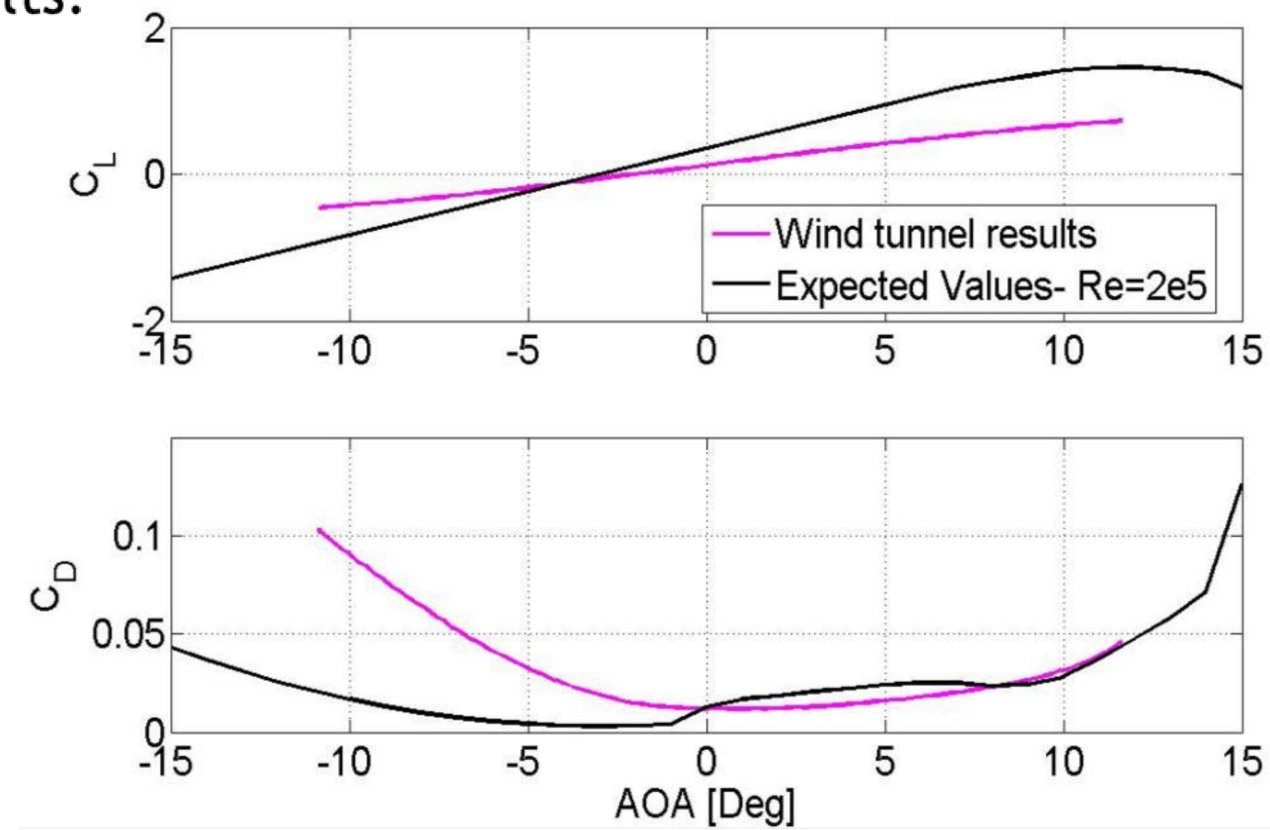


- More results:
  - Lift and drag coefficients matches predicted results for $Re = 1 \cdot 10^5$, actual flight Re is $2 \cdot 10^5$:

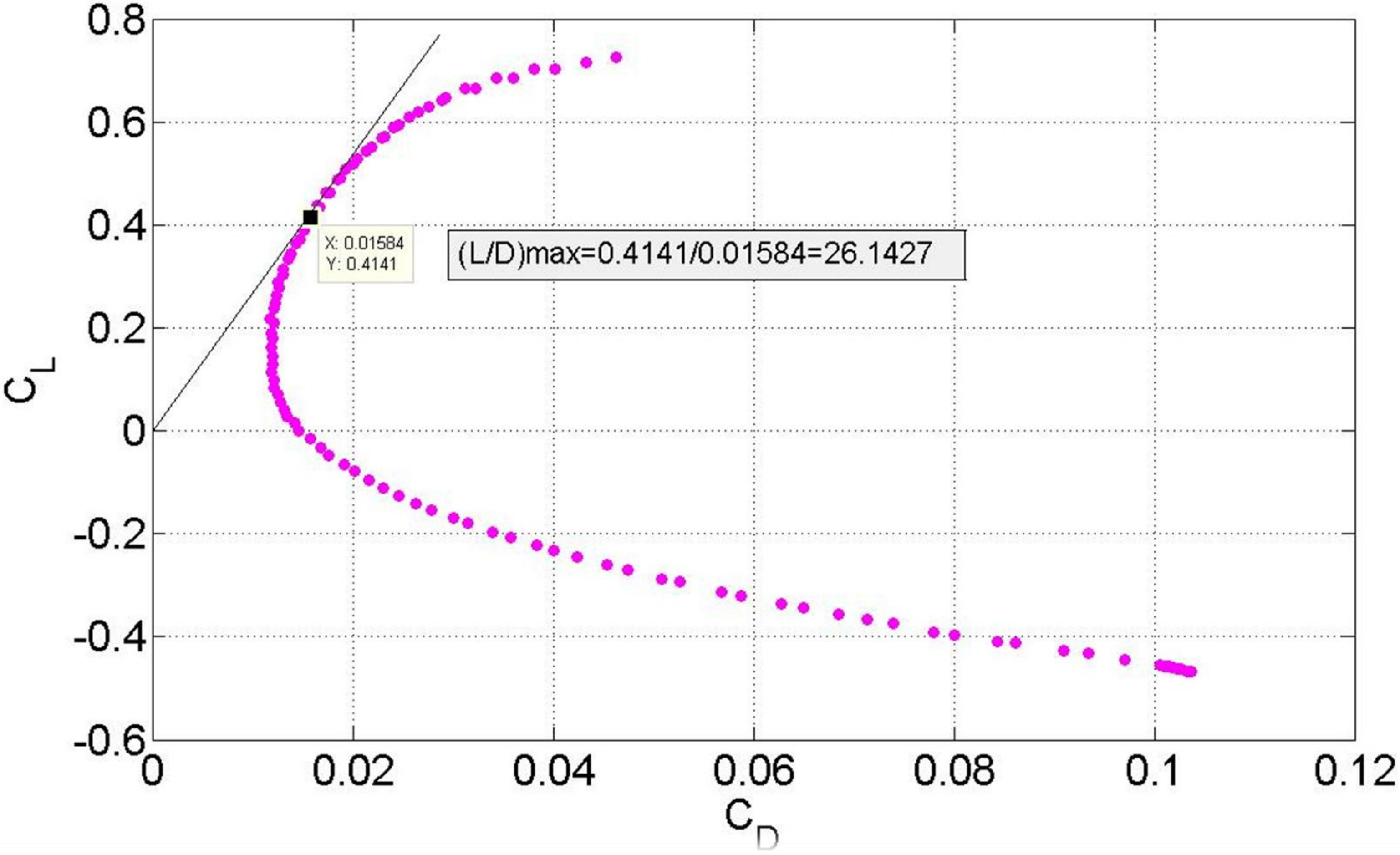


CALIBRATION:

- Minimum air speed value is $V = 45\,{}^{m}/_{s}$, In order to simulate real flight conditions ($Re = 2 \cdot 10^5$).
- Beyond $45\,{}^{m}/_{s}$ the model is in danger! Tunnel air speed was set at $45\,{}^{m}/_{s}$.
- New results:



- New <u>(L/D)max=26.14:</u>

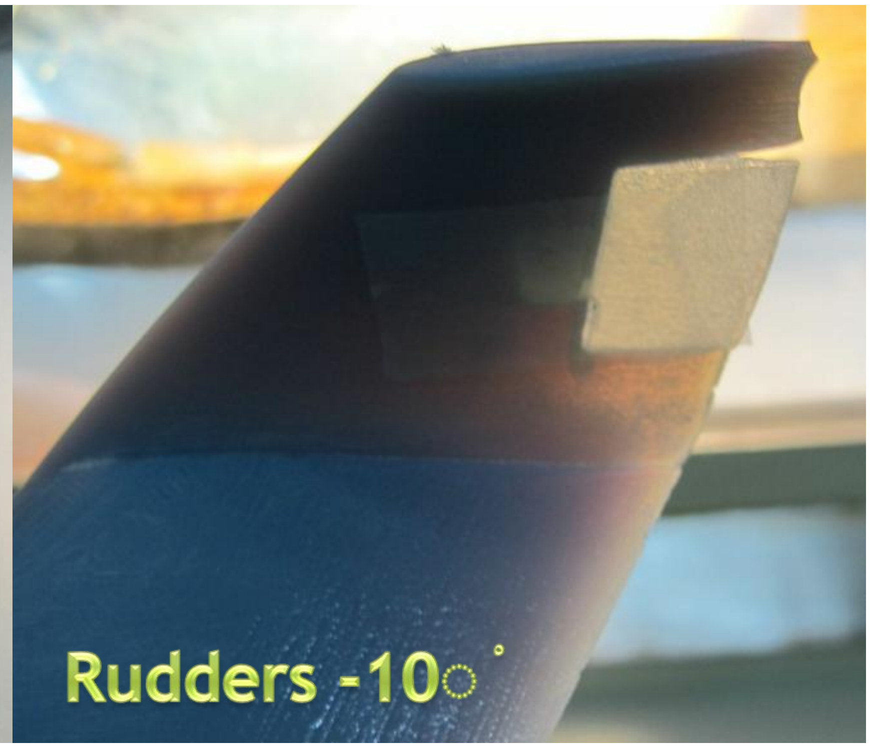


MID-CONCLUSIONS:

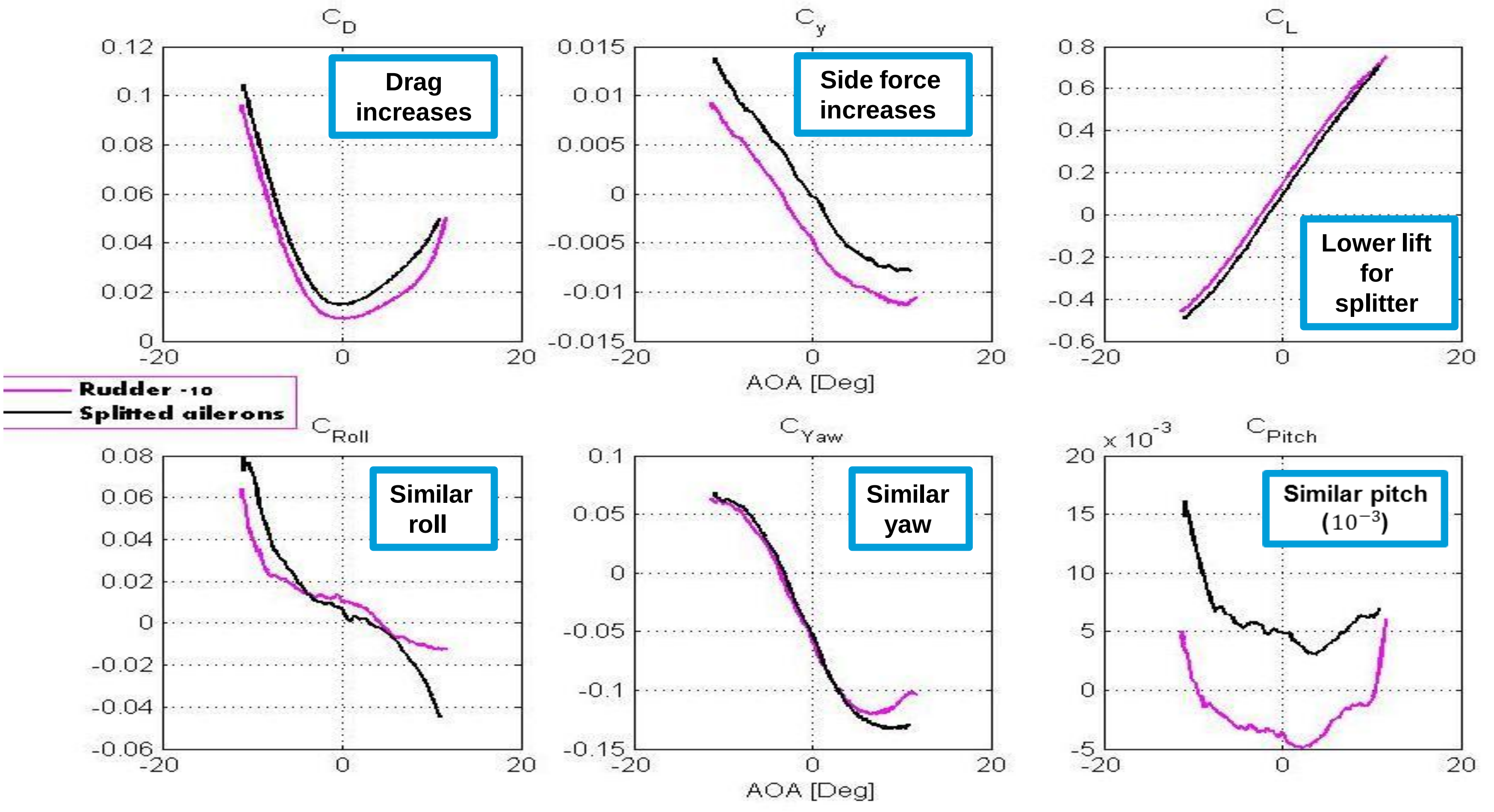
- In order to simulate real flight conditions:
  - Speed range - $45\,{}^{m}/_{s} - 67\,{}^{m}/_{s}$
- To ensure the safety of the model:
  - AOA range - $(-10°) \div (+10°)$
  - Speed was set to $45\,{}^{m}/_{s}$

SPLITTER OR RUDDERS?

- Two options were investigated for better yaw:
  - Rudders at $(-10°)$
  - Splitter ailerons

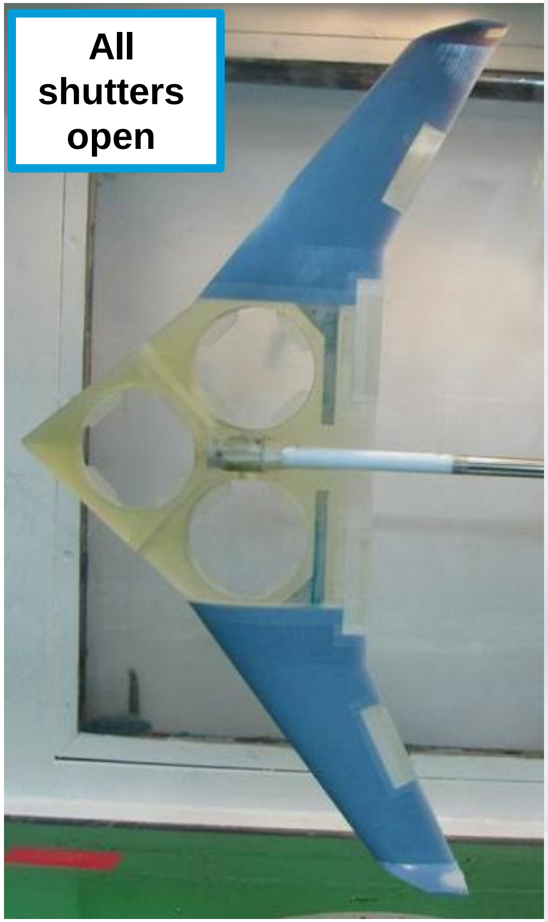


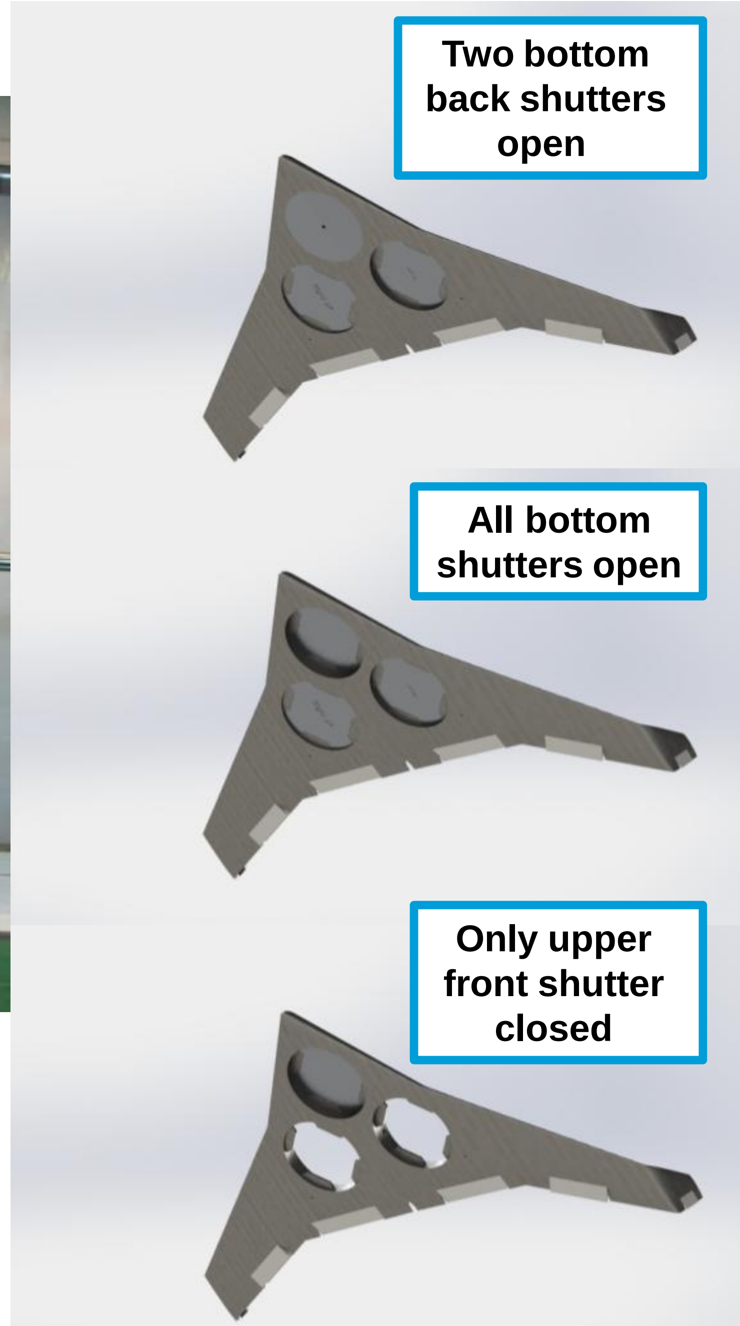
SPLITTER OR RUDDERS?

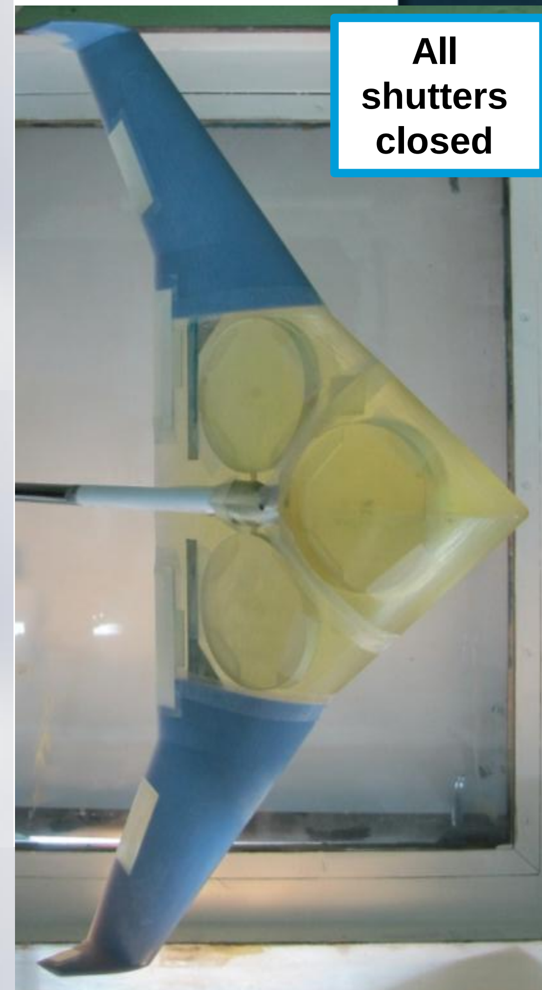


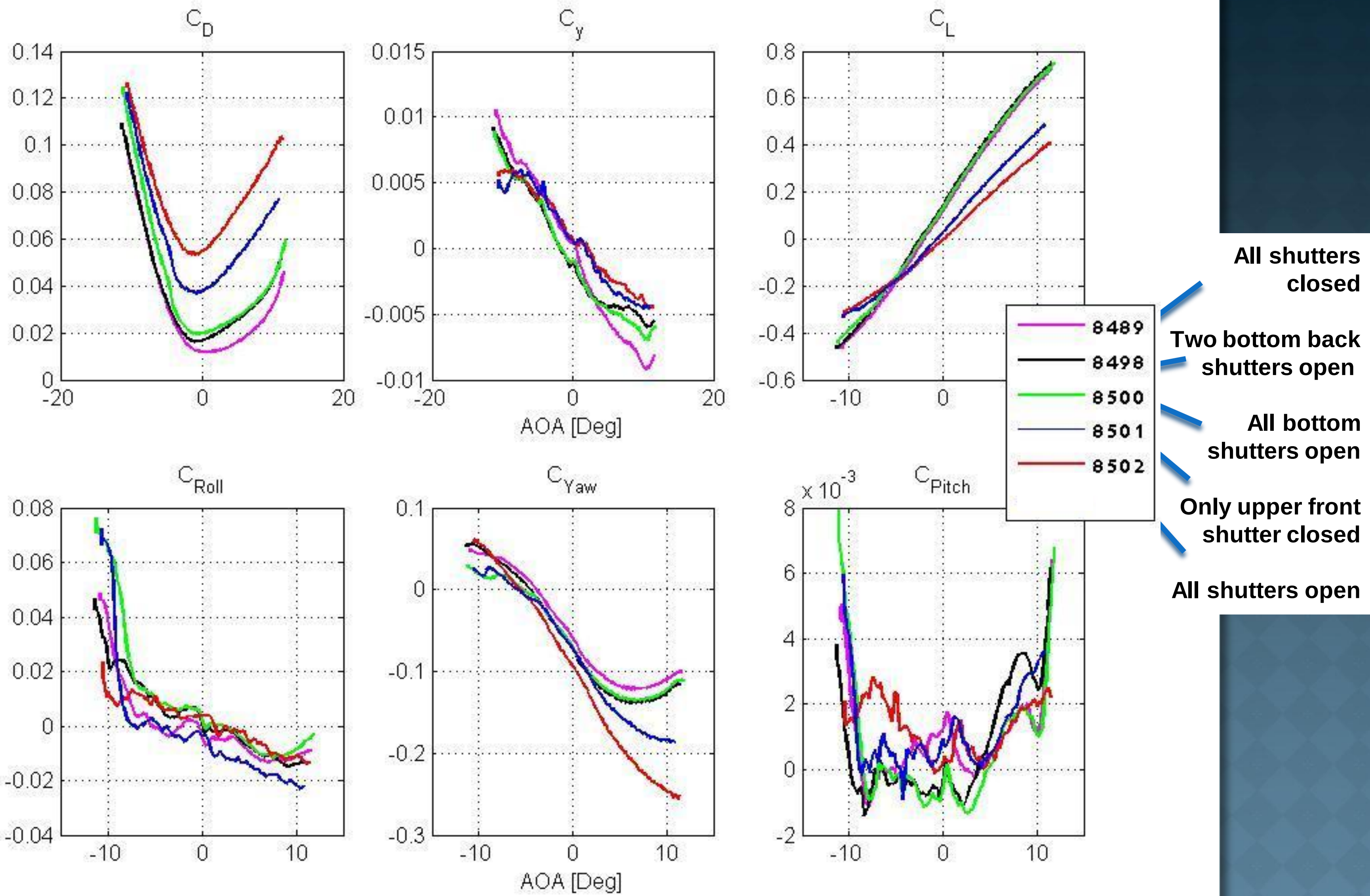
Using the splitter ailerons leaded to similar yaw, with great loses.

The conclusion- during the actual flight, the rudders will be in use.

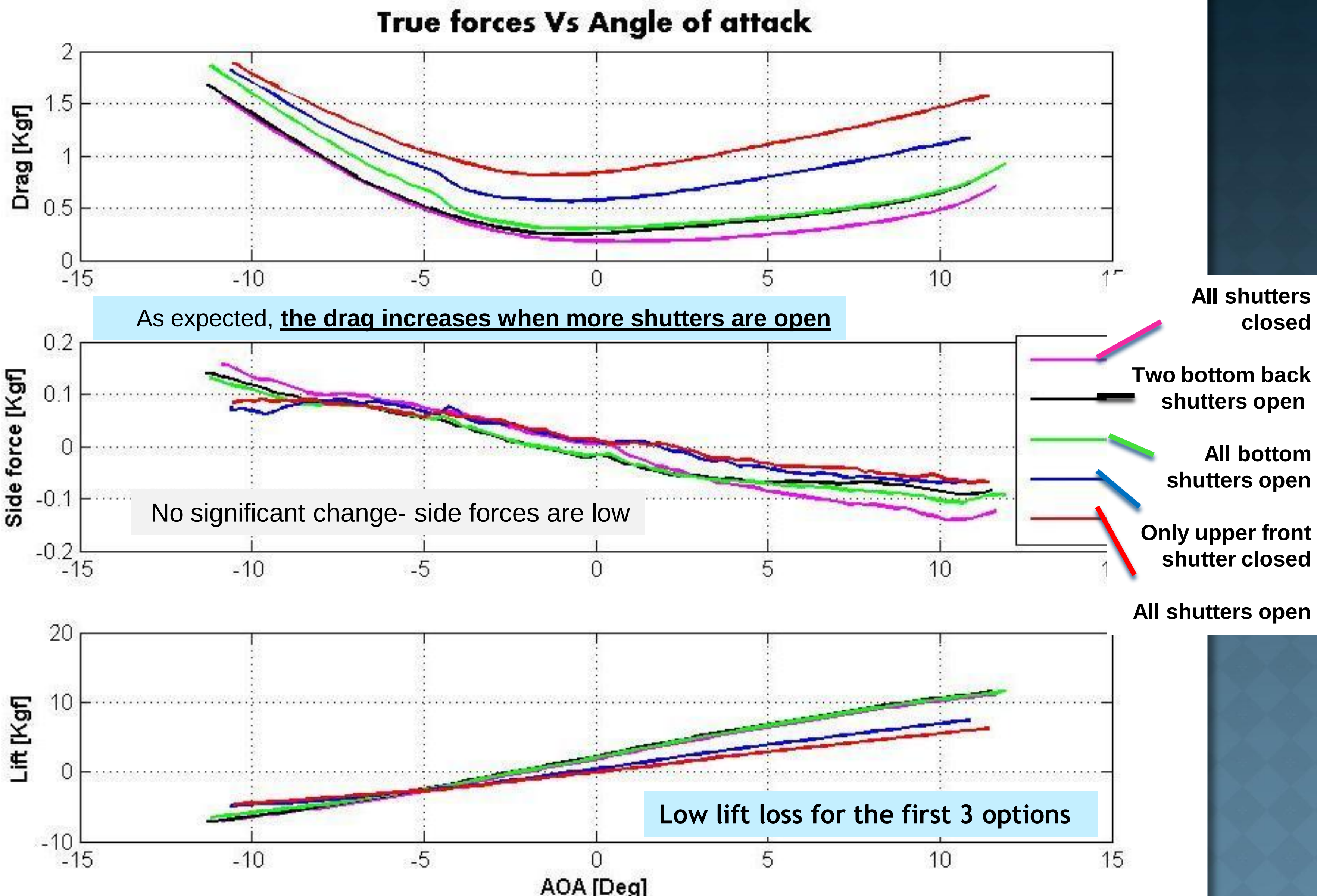

All shutters open


Two bottom back shutters open
All bottom shutters open
Only upper front shutter closed


All shutters closed



C_D
C_y
C_L
C_Roll
C_Yaw
C_Pitch
x 10^-3
AOA [Deg]
AOA [Deg]
8489
8498
8500
8501
8502
All shutters closed
Two bottom back shutters open
All bottom shutters open
Only upper front shutter closed
All shutters open

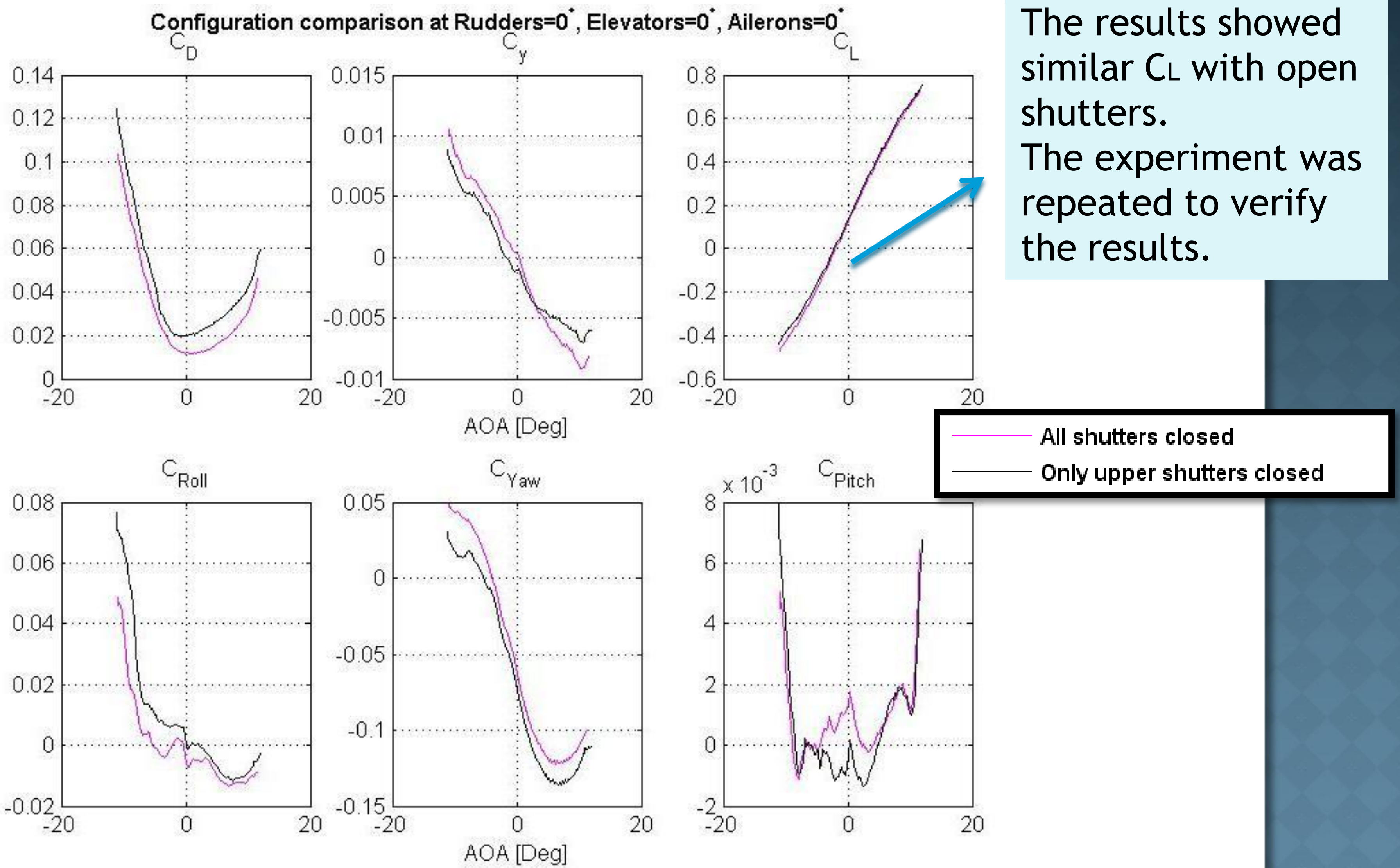

True forces Vs Angle of attack
Drag [Kgf]
As expected, the drag increases when more shutters are open
Side force [Kgf]
No significant change- side forces are low
Lift [Kgf]
Low lift loss for the first 3 options
AOA [Deg]
All shutters closed
Two bottom back shutters open
All bottom shutters open
Only upper front shutter closed
All shutters open

MORE MID-CONCLUSIONS

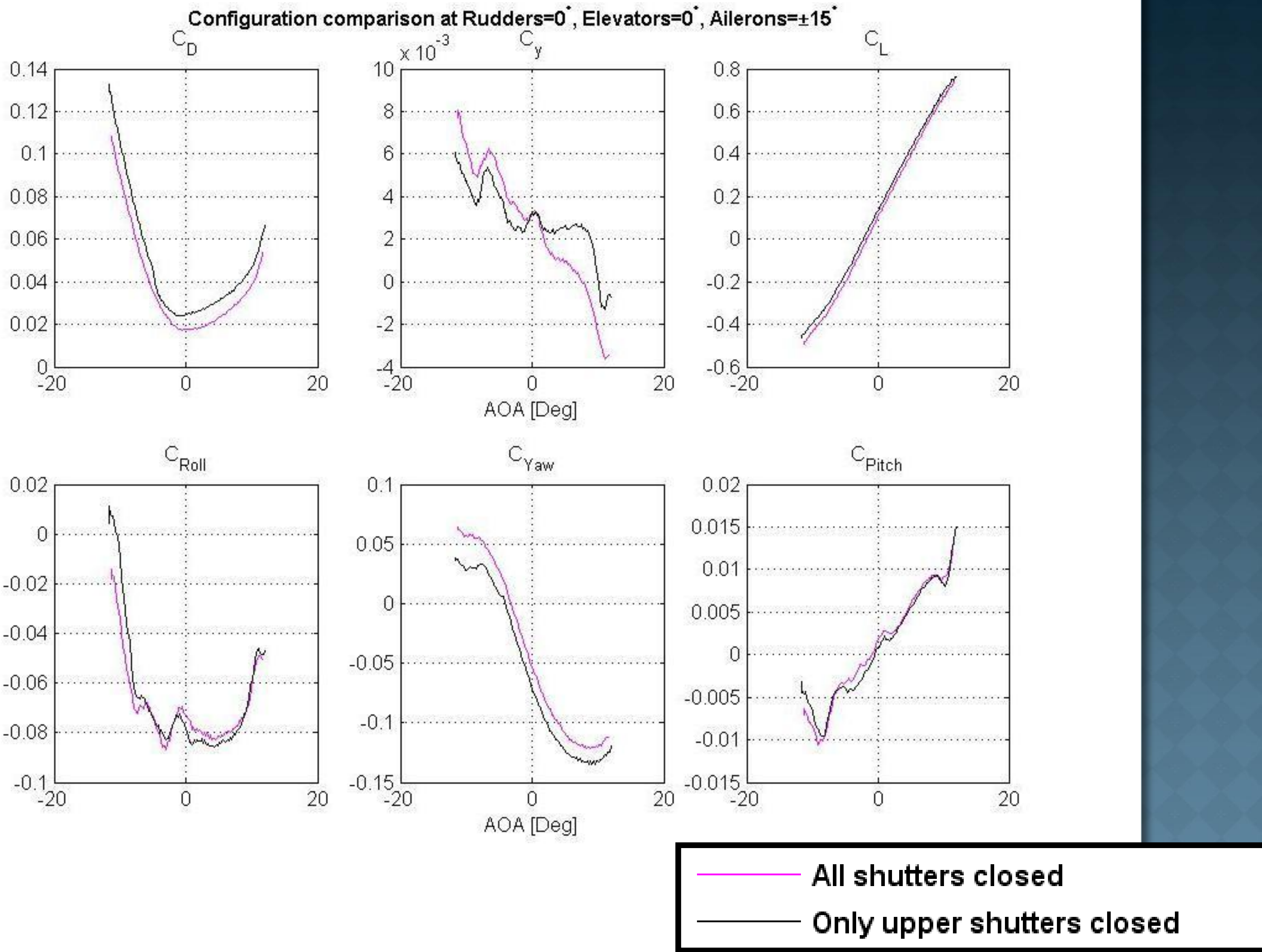
- Some of the shutters can stay open during the horizontal flight
- Two main options:
  - All bottom shutters remains open
  - Only two bottom back shutters open
    - The difference between the two is not significant

    → The option of bottom shutters open was chosen
- And now:
  - Confirming this choice by:
    - Comparing the configurations at maneuvering
    - Calculating the loses of range and endurance

DIFFERENT MANEUVERS COMPARISON

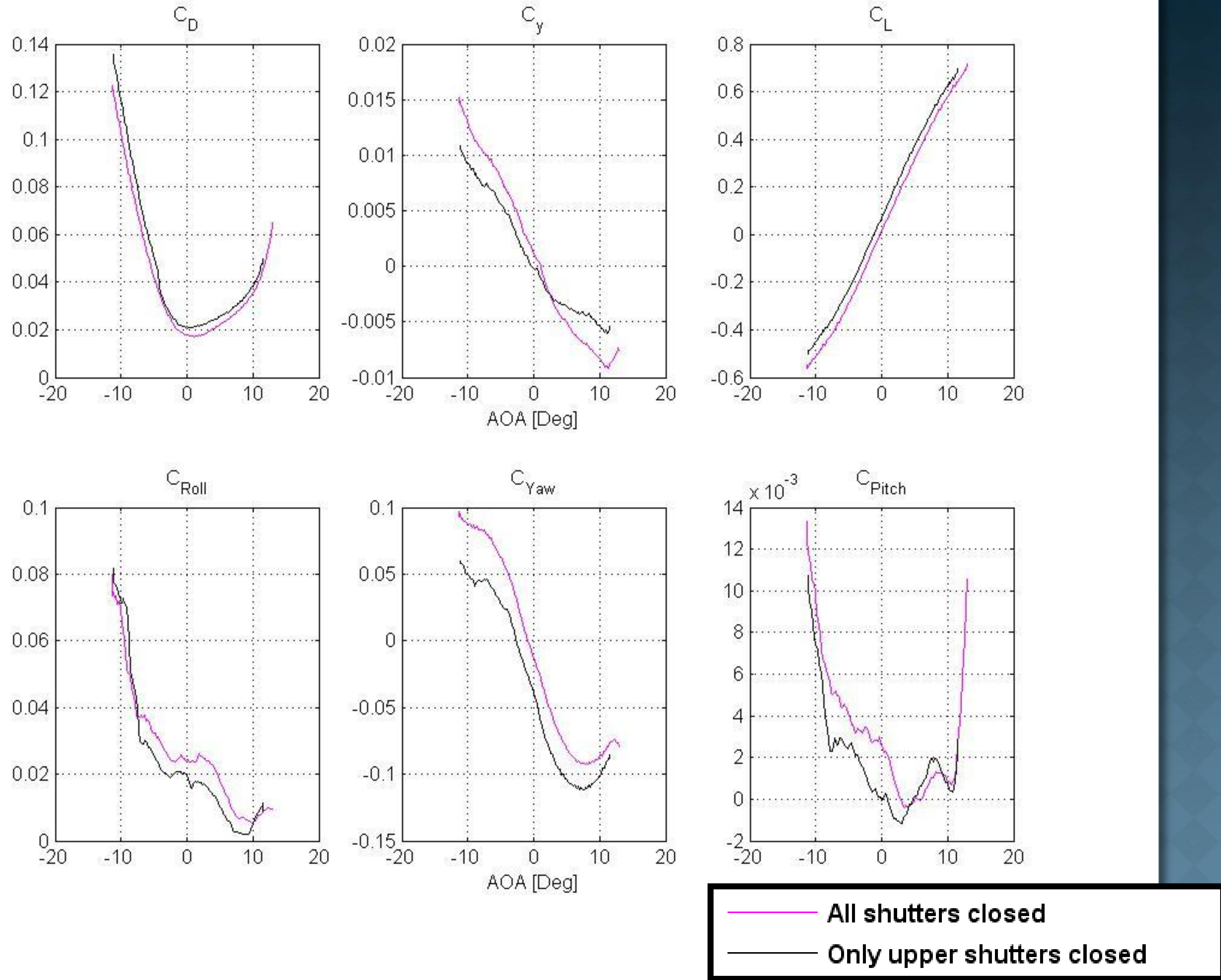


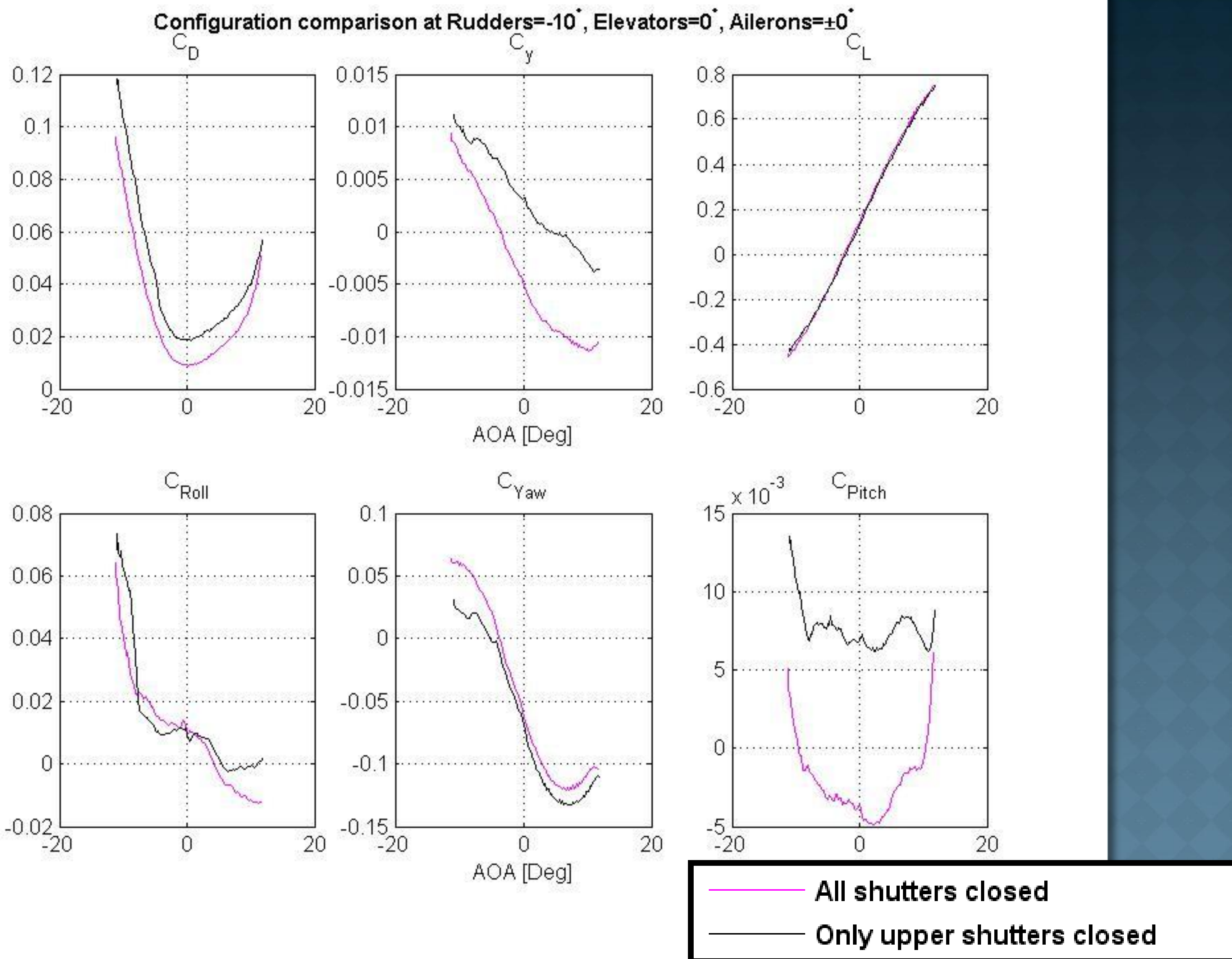
The results showed similar C_L with open shutters.
The experiment was repeated to verify the results.



Configuration comparison at Rudders=0°, Elevators=0°, Ailerons=±15°
C_D
C_y
x 10^-3
C_L
AOA [Deg]
C_{Roll}
C_{Yaw}
C_{Pitch}
AOA [Deg]
All shutters closed
Only upper shutters closed

Configuration comparison at Rudders=0°, Elevators=15°, Ailerons=±0°

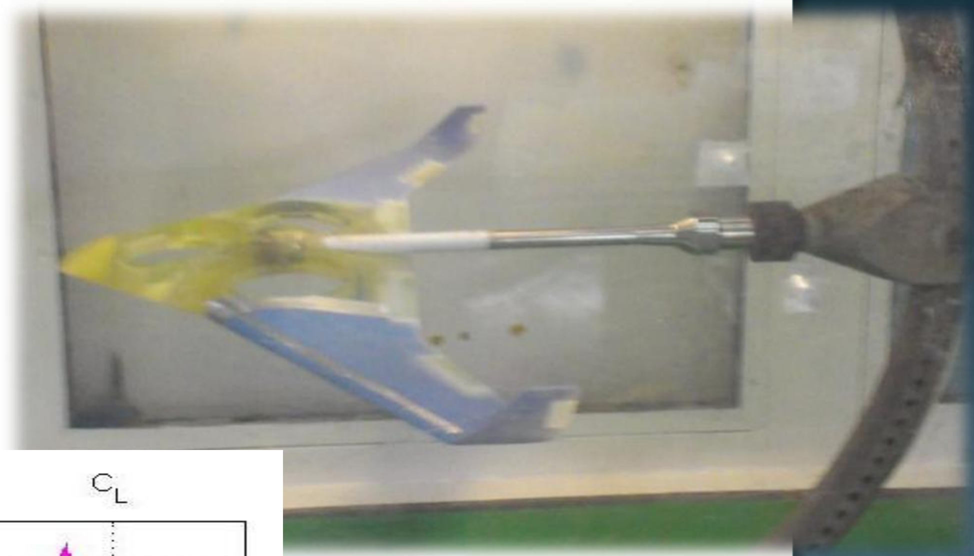


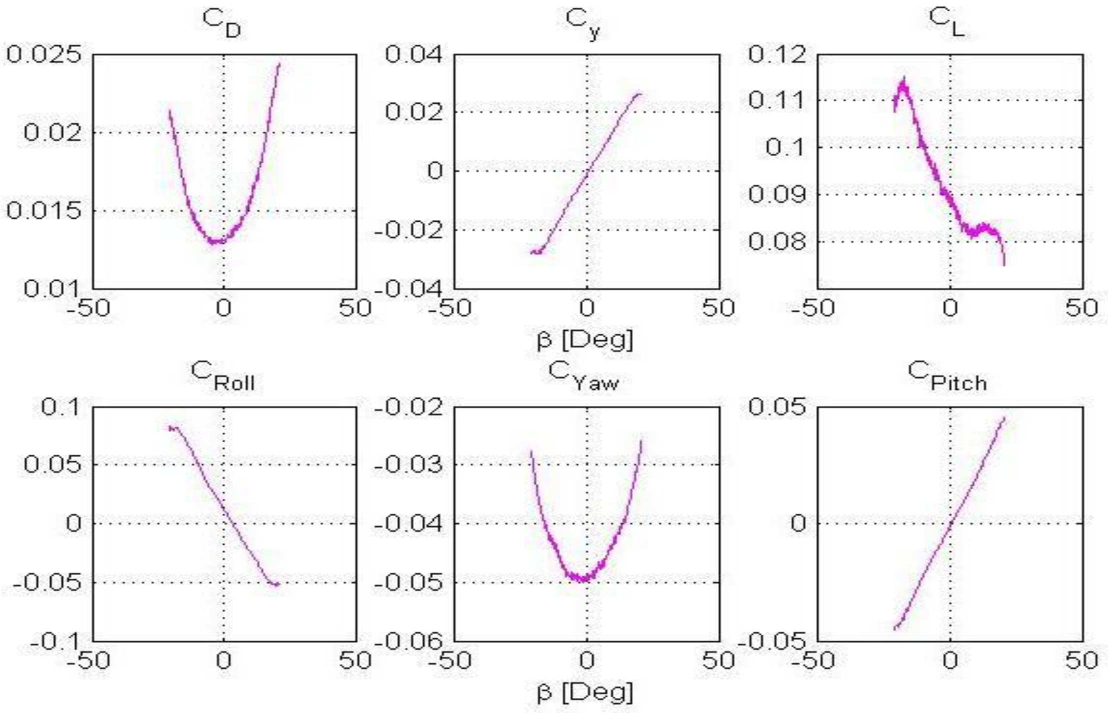


Configuration comparison at Rudders=-10°, Elevators=0°, Ailerons=±0°
C_D
C_y
C_L
AOA [Deg]
C_Roll
C_Yaw
x 10^-3
C_Pitch
AOA [Deg]
All shutters closed
Only upper shutters closed

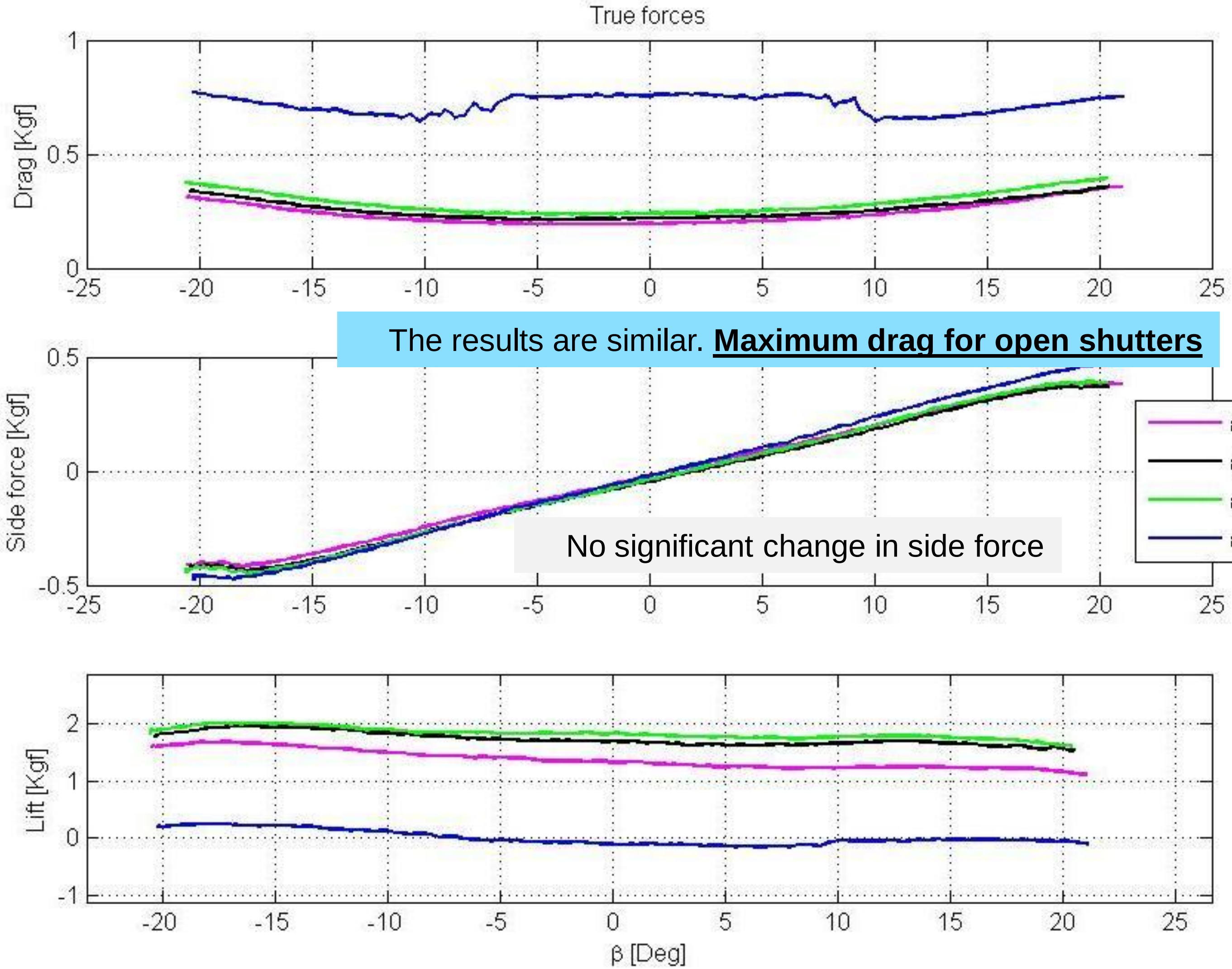
SECOND SET – CHANGING SLIP ANGLE

- Calibration run
  - Level flight, slip angle ß=(−20°) ÷ (+20°)
-





CONFIGURATION COMPARISON



The results are similar. **Maximum drag for open shutters**

No significant change in side force

All shutters closed

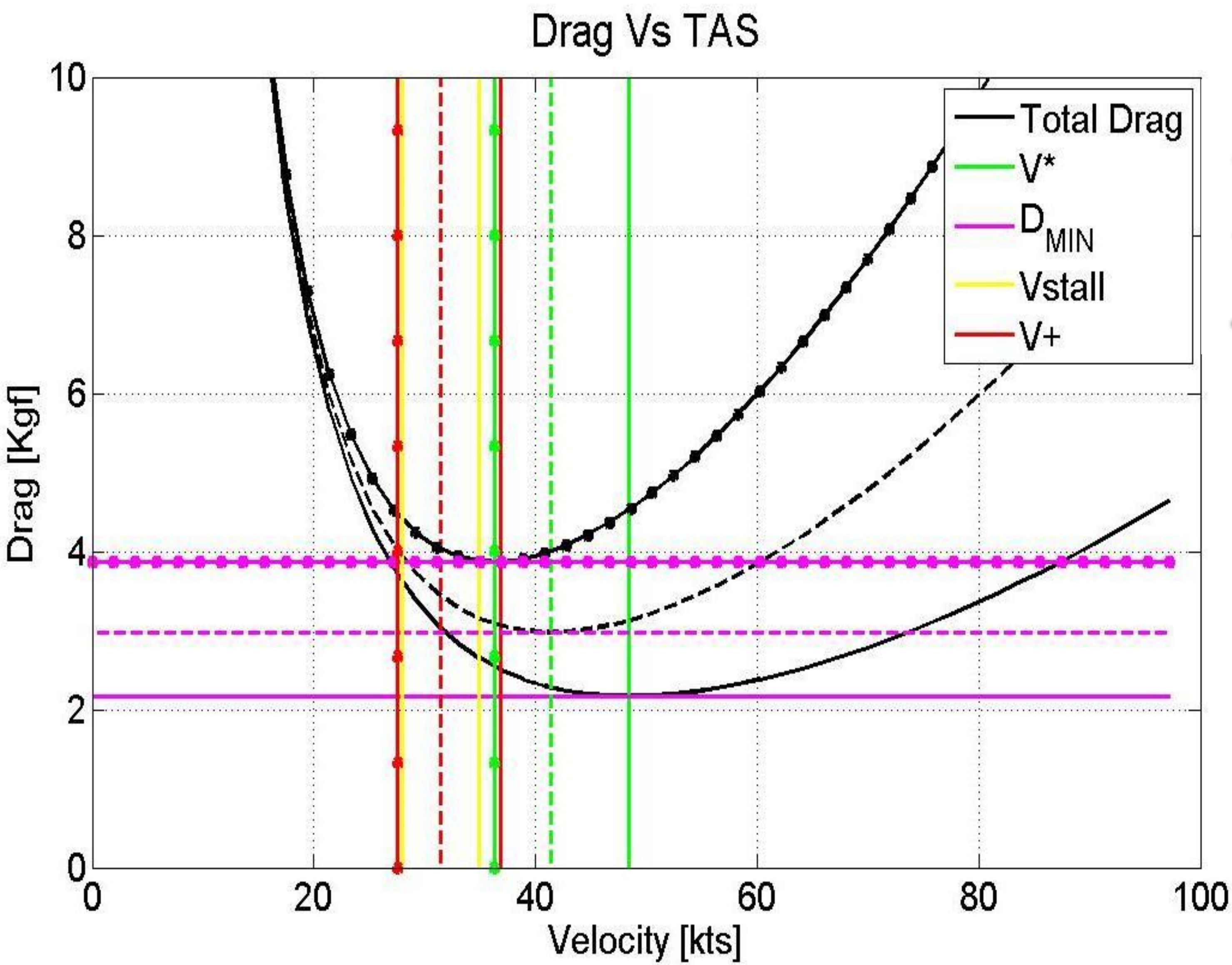
Two bottom back shutters open

All bottom shutters open

All shutters open

The lift decreases as the shutters open

PERFORMANCE COMPARISON

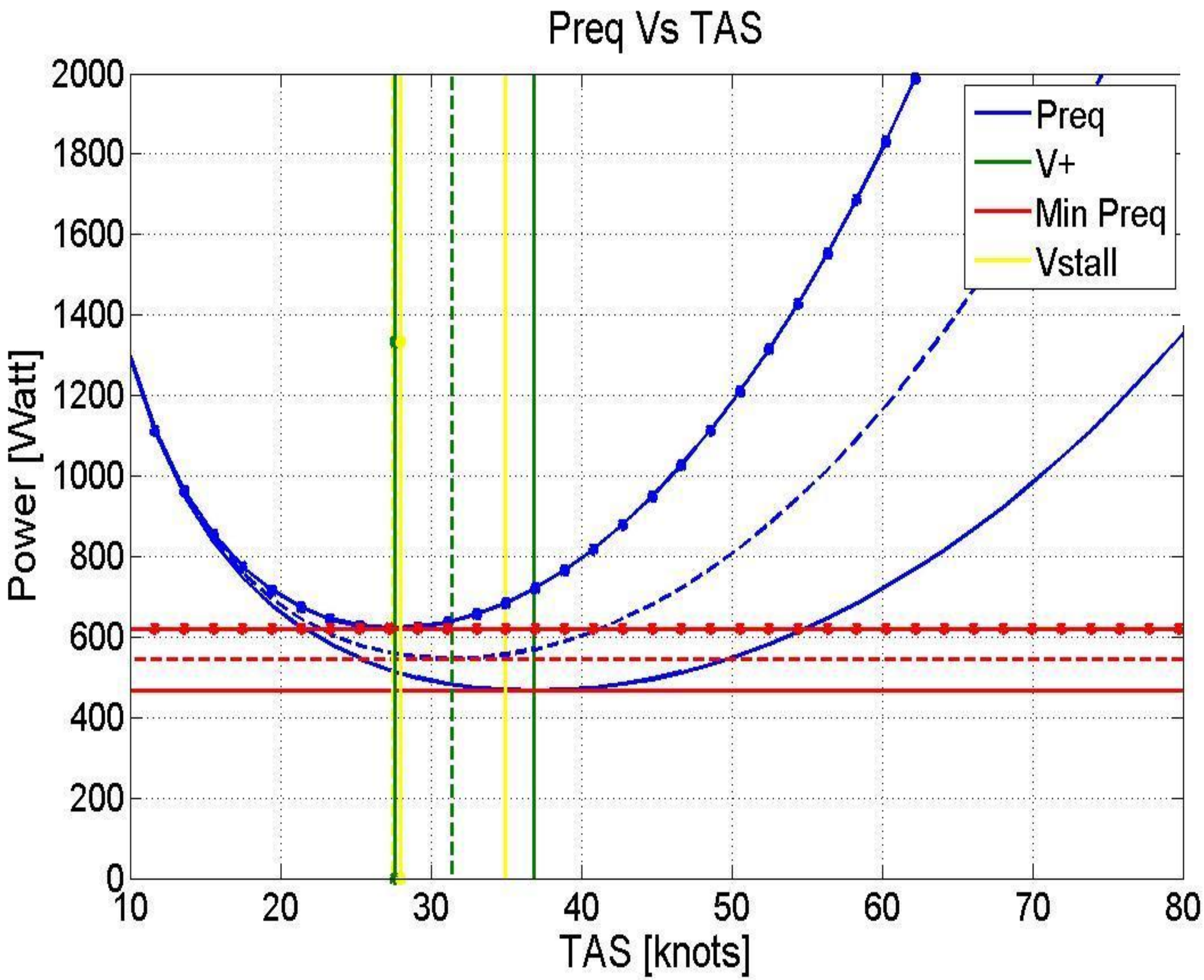


Shutters closed- expected

Shutters closed- results

Bottom shutters open- results

PERFORMANCE COMPARISON



Shutters closed- expected

Shutters closed- results

Bottom shutters open- results

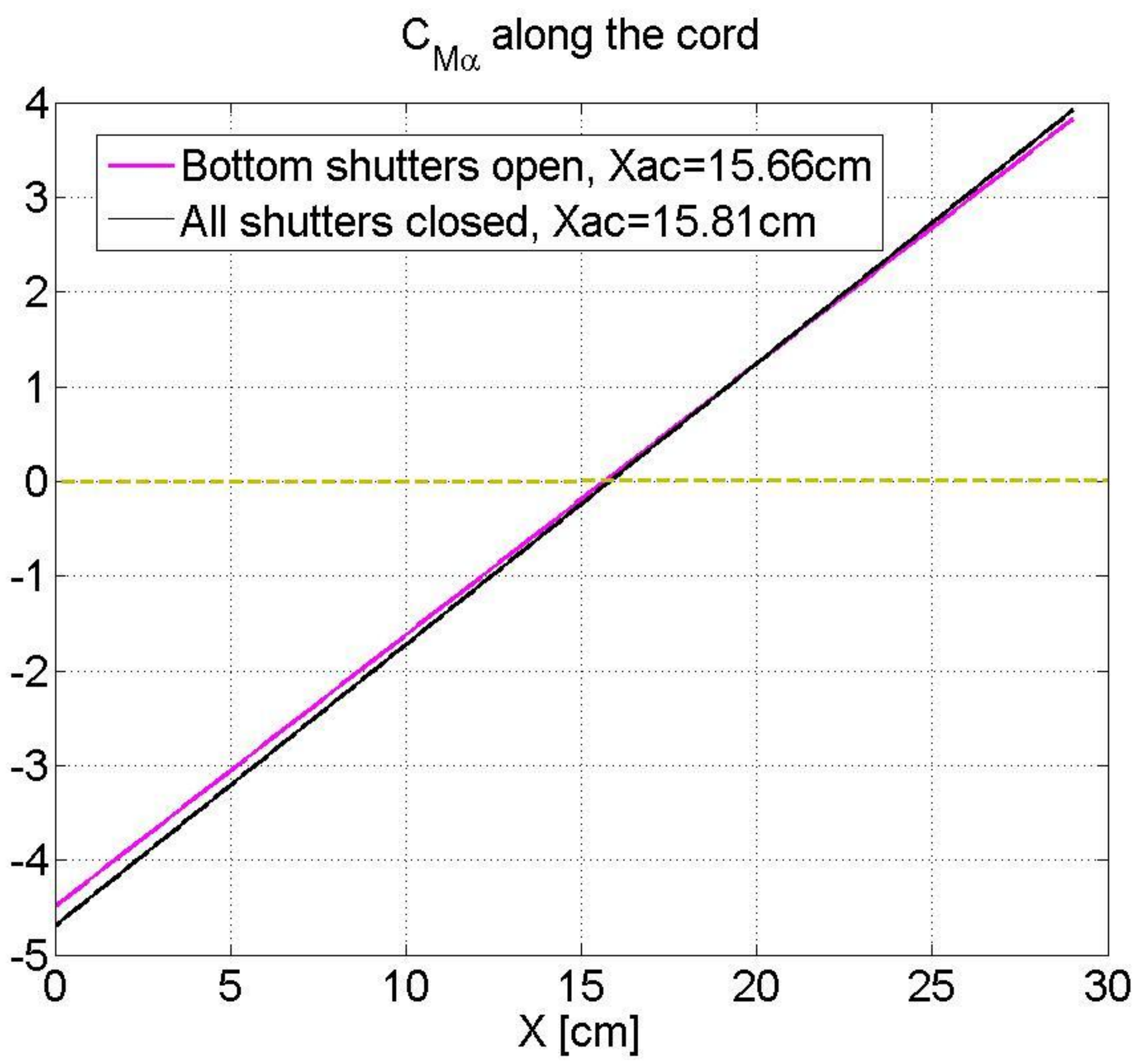
ENDURANCE AND RANGE RESULTS

		Analysis results	Experimental Results- All Shutters Closed	Experimental Results- Bottom Shutters Open
Stalling Speed	[Kts]	34.95	27.55	28.02
Minimum Drag	[Kgf]	2.17	2.97	3.86
At Speed Of	[Kts]	48.46	41.35	36.3
Minimum Required Power	[Watt]	465.24	545.2	621.05
At Speed Of	[Kts]	36.82	31.42	27.58
Maximum Cruise Range	[Km]	22.7	19.4	18.5 @30kts

COEFFICIENTS FROM THE EXPERIMENT

- $C_{L_\alpha} = 0.0537[{}^{1}/_{deg}]$
- $C_{L_0} = 0.138$
- $C_{D_0} = 0.0197$
- $Y'_\beta = 0.0237[{}^{Kgf}/_{deg}]$
- $L'_\beta = -0.006[{}^{Kgf}/_{deg}]$
- $R'_\beta = 0.7709[** {}^{Kgf}/_{deg}]$
- $N'_\beta = -0.401[** {}^{Kgf}/_{deg}]$

Aerodynamic Center



Wind Tunnel Test - Conclusions

- Rudders were chosen for yaw control after a comparison to the splitter aileron version.
- The forces and moments differences of the configurations were examined while changing the angle of attack.
  - The UAV cannot fly without motor covers.
  - Bottom shutters open - the results showed similar lift with greater drag
  - Bottom shutters open will lead to decreasing the UAV's range by 5% (1Km)
- The aerodynamics mentioned were examined for different maneuvering performances

  → Results were similar
- **Main conclusion-**

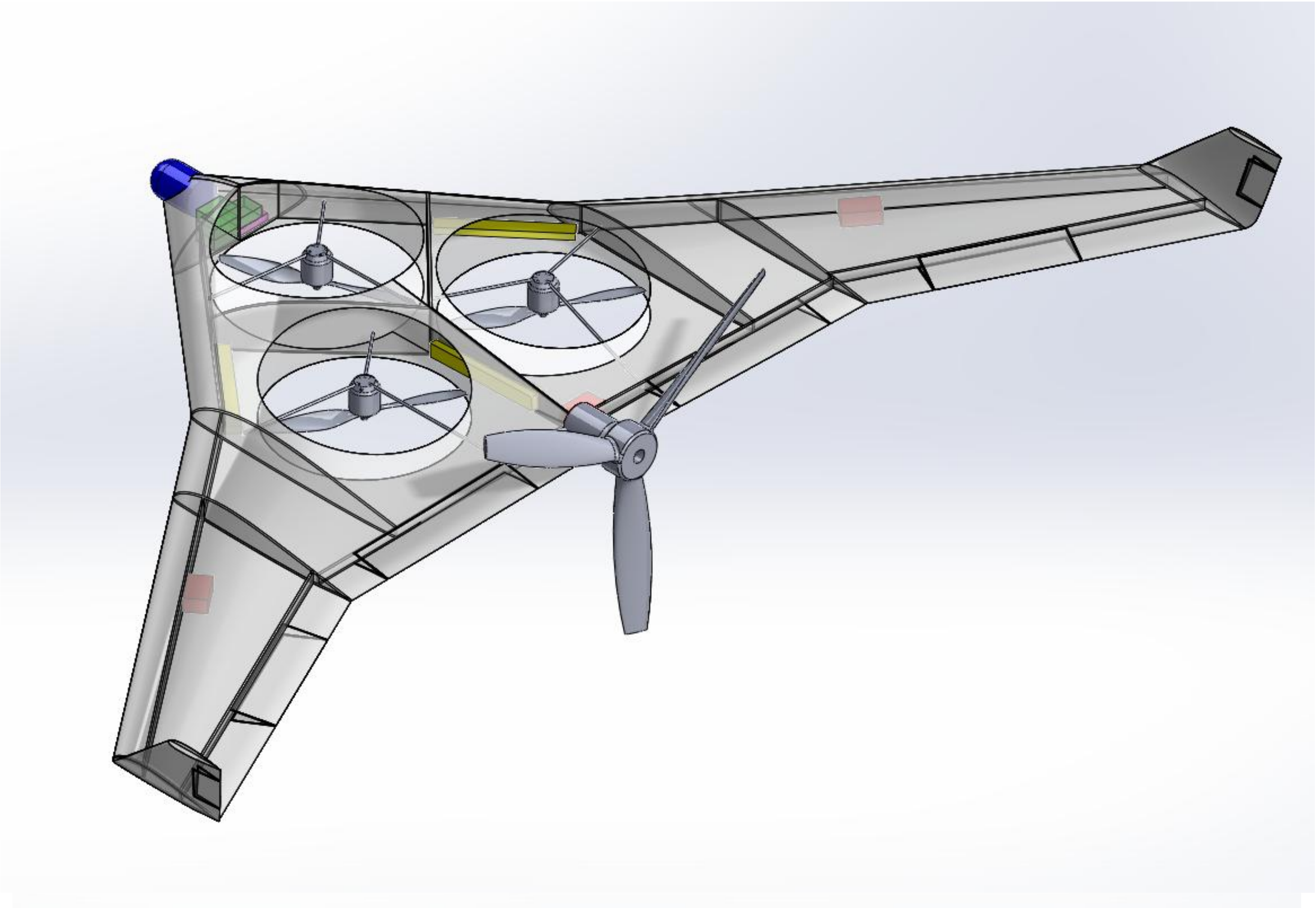
  There is no need for bottom covers

  → no need for extra mechanism

SUMMARY

- Systems/Components Installation Arrangement ✓
- Conceptual Design of Wing Structure ✓
- Detail Design of Outer Wing Segment ✓
- Detail Design of Rotors Cavity Closing Mechanism ✓
- Finalize Weight and Balance Analysis ✓
- Finalize Aircraft Performance Analysis ✓
- Flight Control System Design ✓
- Wind tunnel Test and Test Results Evaluation ✓

SUMMARY



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