בס"ד

טכניון – מכון טכנולוגי לישראל
הפקולטה להנדסת אווירונאוטיקה וחלל

SATLA-U

Search & Attack Loitering Autonomous UAV

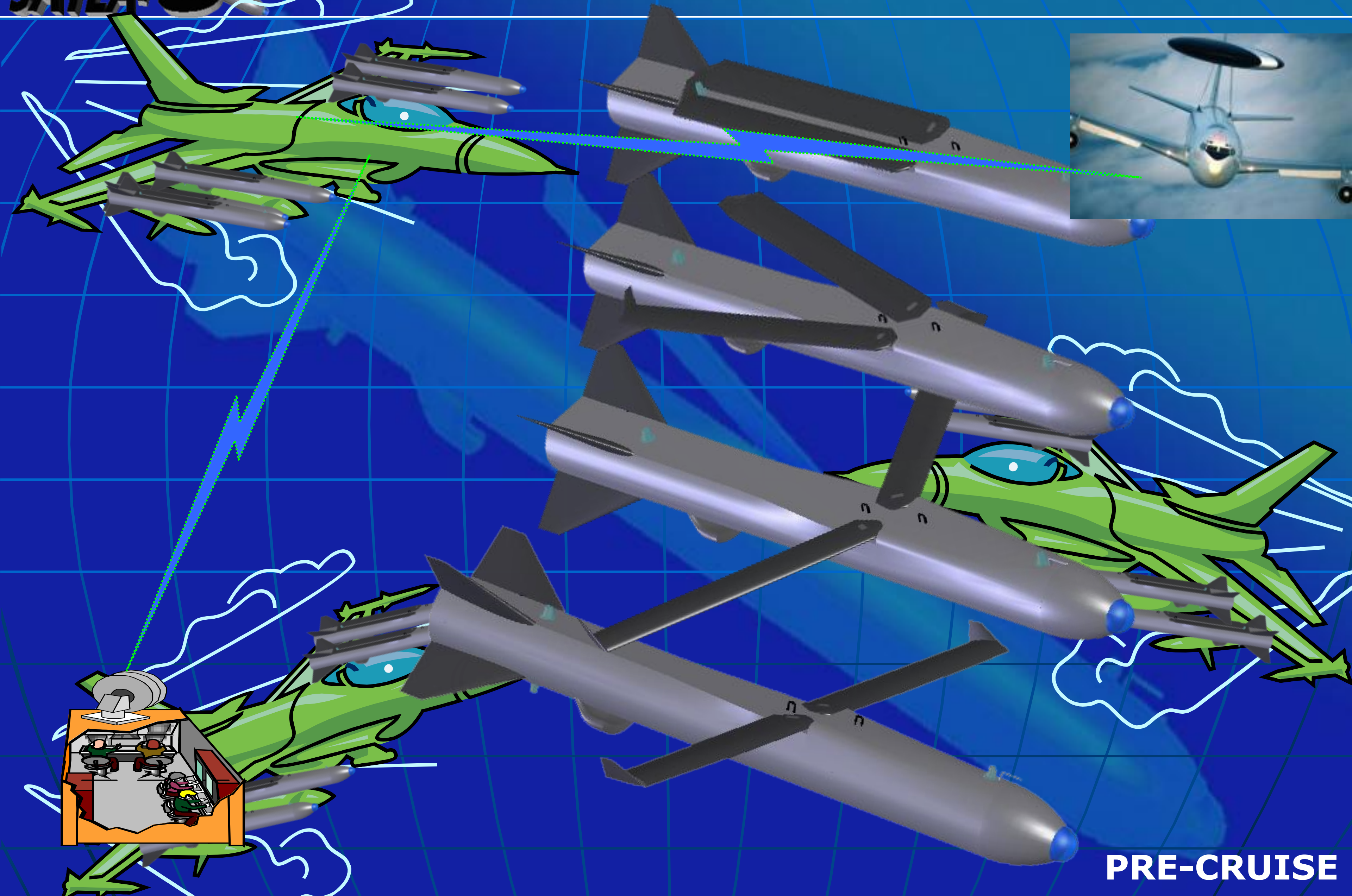
The SATLA-U Team

Group director: Dror Artzi

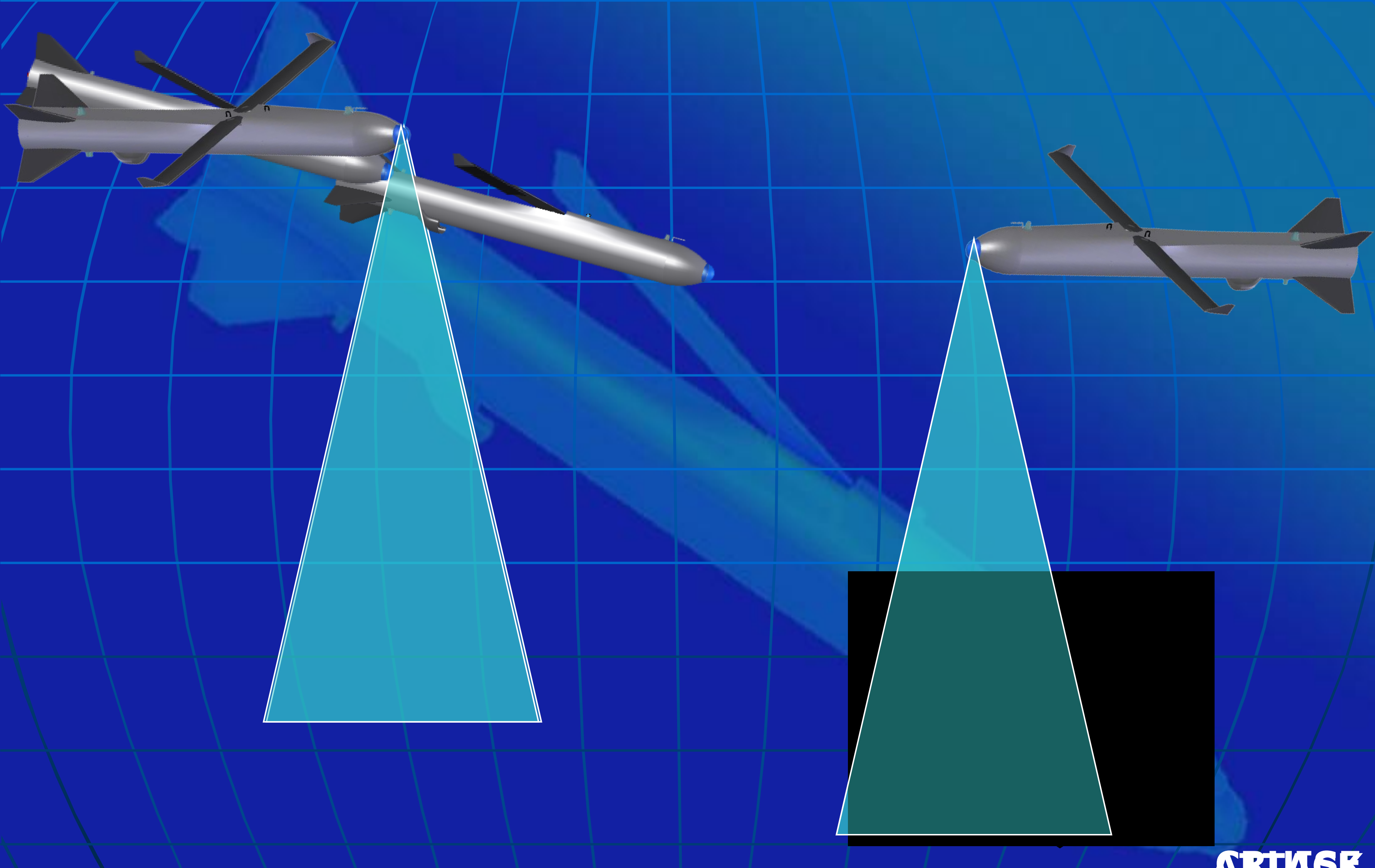
Us:

Avi Bitansky
Michael Iovnovich
Mor Ben-Ephraim
Maital Levy
Vladimir Stoliarevsky
Oren Zarnihchi
Dima Alekhin
Itzik Meyer
Shai Cohen
Tal Barak

Mission Profile



Mission Profile



Specifications

Performance

- Endurance: **3**[hr]
- Max. speed 230 [kts] @ cruise ,
  360 [kts] @ dive
- Designated target: Stationary, Precision: 2x2[m]

Technical Data

- Weight: **250** [kg]
- Payload weight (warhead) **45** [kg]
- Fuselage length **3.4** [m]
- Wing span **3.26** [m] (fully opened)

- Cost **$ 870,000**

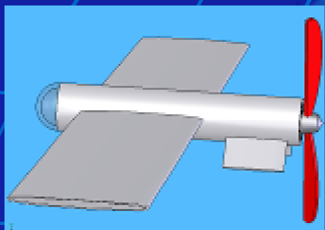
The S-U's Unique Capabilities and Design

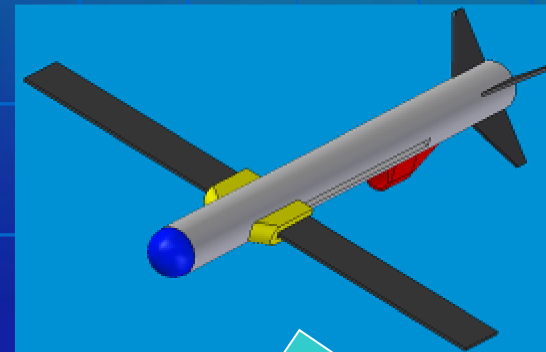
- Carriage Capability on two different fighter planes F15 and F16
- Endurance of 3hr – Scanning Time Neto
- Metamorphic Configuration – Wing Mechanisms
- Advanced Aerodynamic Configuration

Design

- Performance and Propulsion Model
- Aerodynamic Computational Model
- Aerodynamic Model for Store Separation
- 6 DOF Simulation for Store Separation
- 3 DOF Attack Simulation
- Dynamic Loads Analysis
- Impact Analysis at Separation

Design Process





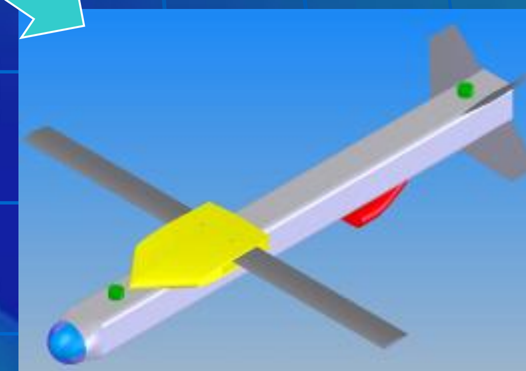
Primary Survey

F15,F16 Compatibility

Requirements

Jet/Electric Alternative Design

Piston/Fuel Cell Alternative Design



Alternative Selection

Propulsion

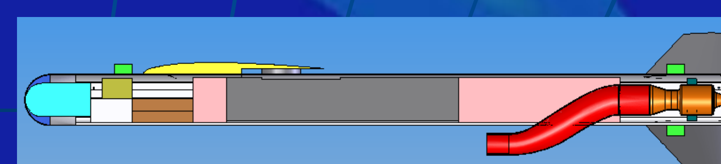
Aerodynamic Performances

Guidance and Control

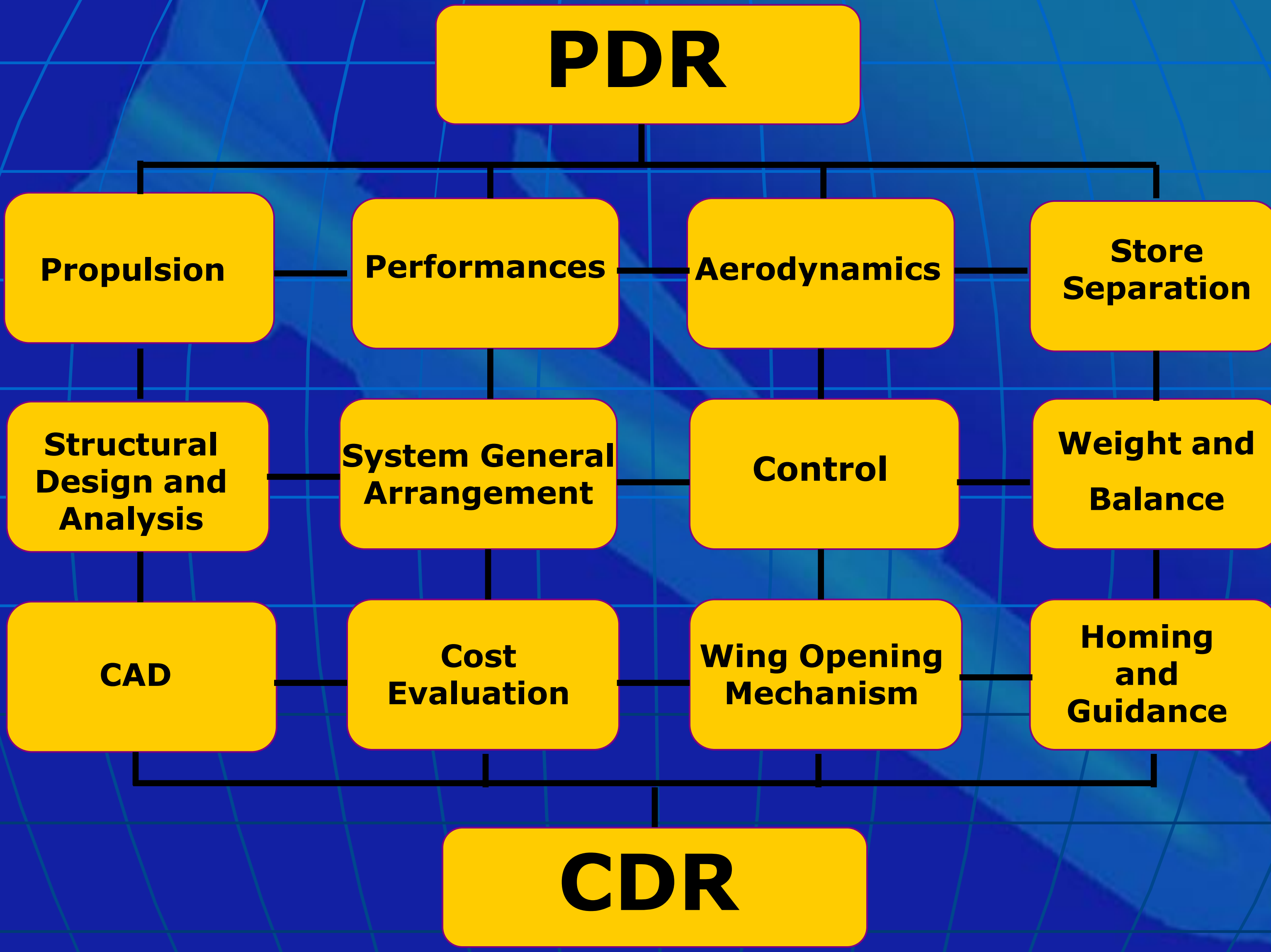
AV Systems

Layout, weights and structural design

PDR



Design Process Continued



SATLA-U Performance and Propulsion

- According to preliminary performance analysis, a small turbo-jet engine was chosen

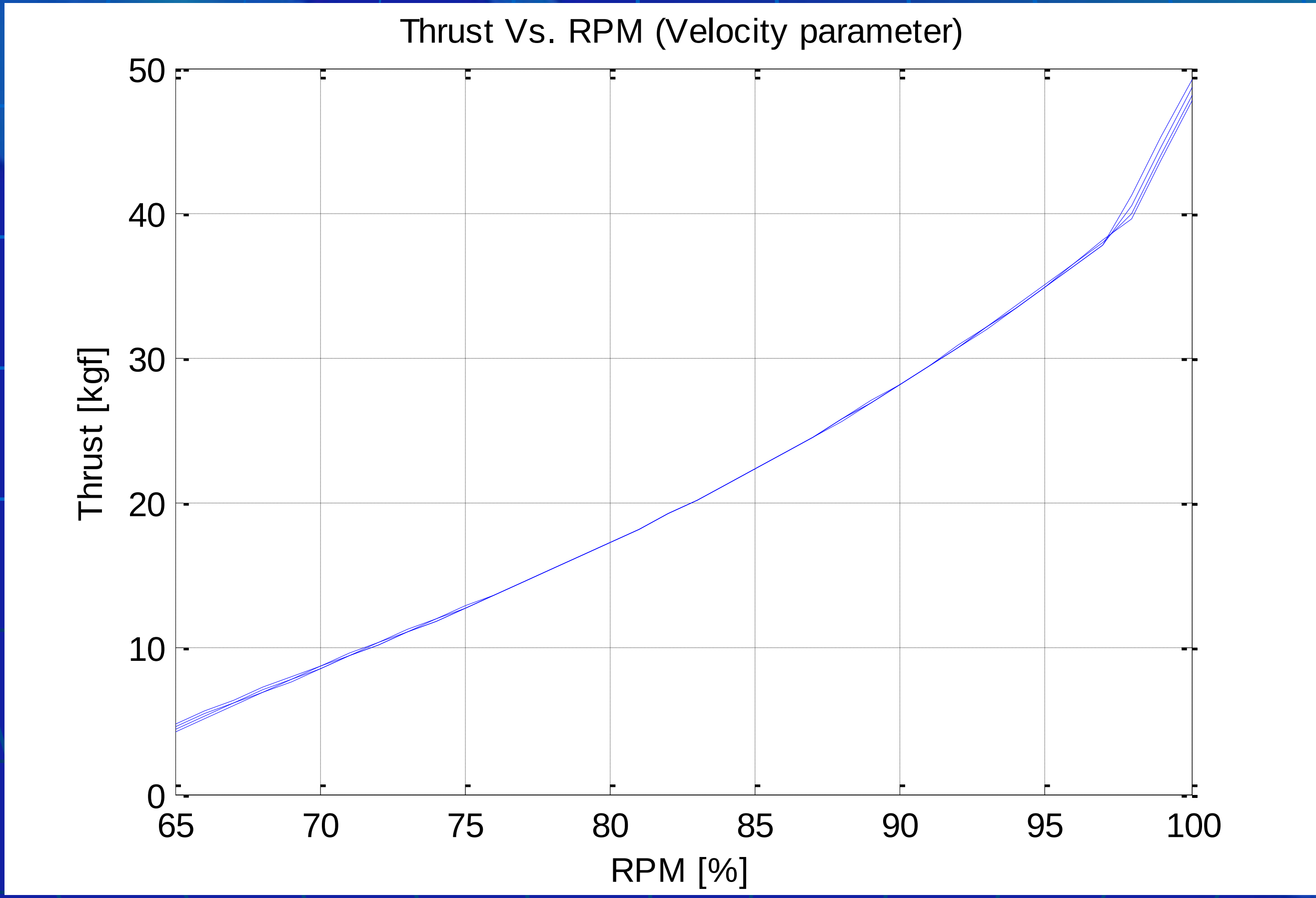
SWB-100	
Diameter	166 mm
Length	411 mm
Weight	5.2 kg
Design RPM	76,000
Thrust (@ max RPM, static exp., sea level)	50 kgf
T.S.F.C	1.31 1/hr

- Inlet design
- Pyrotechnic Ignition

SWB TURBINES
A Micro-Turbine Manufacturer

Performance and Propulsion continued

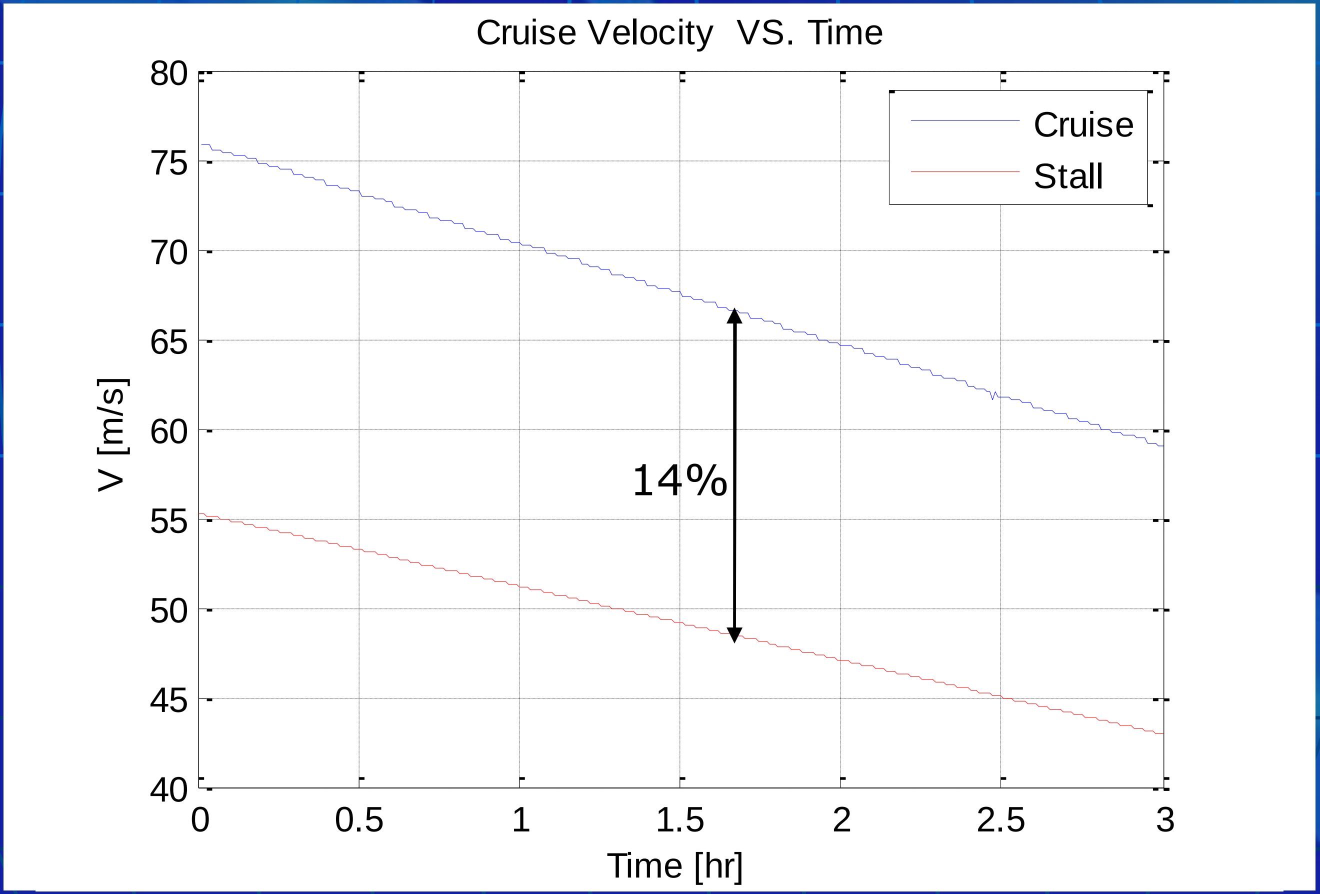
- According to the detailed specifications of the engine ,an engine-model for performance analysis was developed:



Performance and Propulsion continued

Cruise Stage

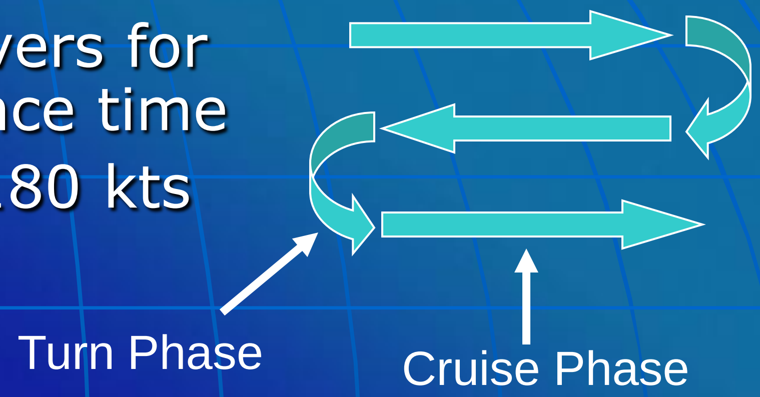
- The requirement for long endurance leads a growth of the fuel amount. Therefore, the velocity has to be suitable for minimum fuel flow (and not minimum drag).



Performance and Propulsion continued

Turn (Maneuver)

- It is assumed that the S-U maneuvers for approximately 10% of the endurance time
- Constant turn velocity was set to 180 kts



Results

Cruise:

$$\bar{W}_{cruise} = 203[kg] \quad \left(\frac{L}{D}\right)_{cruise} = 10.3 \quad C_L = 1.22$$

$$\bar{V}_{cruise} = 68\left[{}^{m}/_{s}\right] \; ; \; \bar{M}_{cruise} = 0.2 \quad \frac{T_{\max}}{\bar{W}} = 0.25$$

$$\Rightarrow (Fuel)_{cruise} = 90.5[kg]$$

Turn:

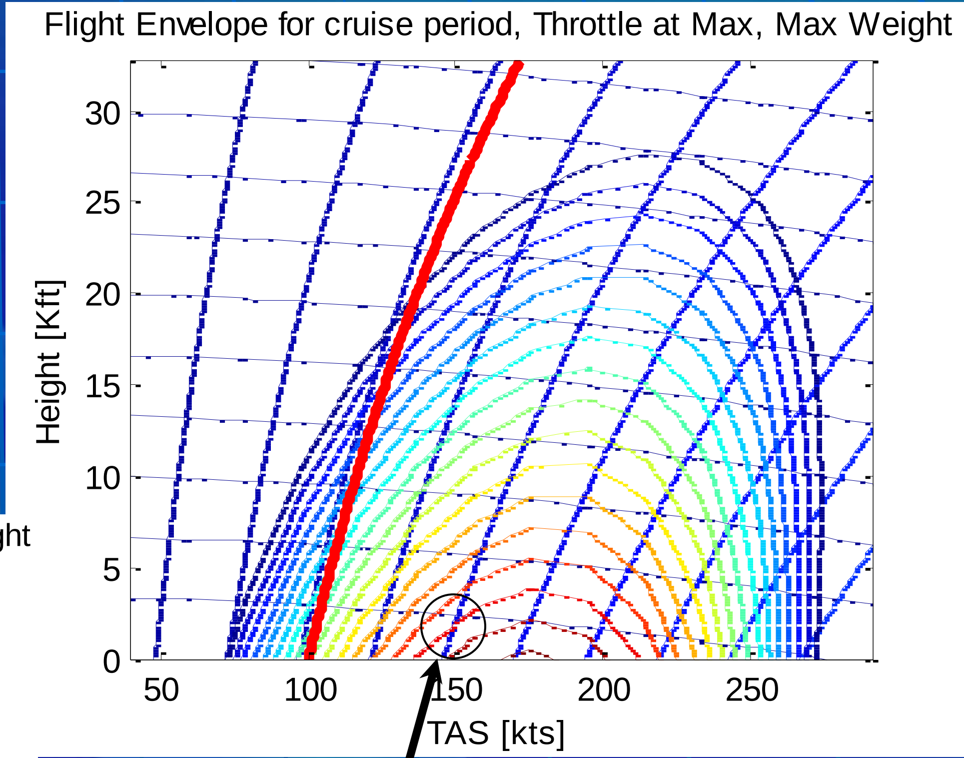
$$n_M = 1.93 \quad \phi = 58.8^\circ \quad \frac{N_{Rounds}}{2} \approx 62$$

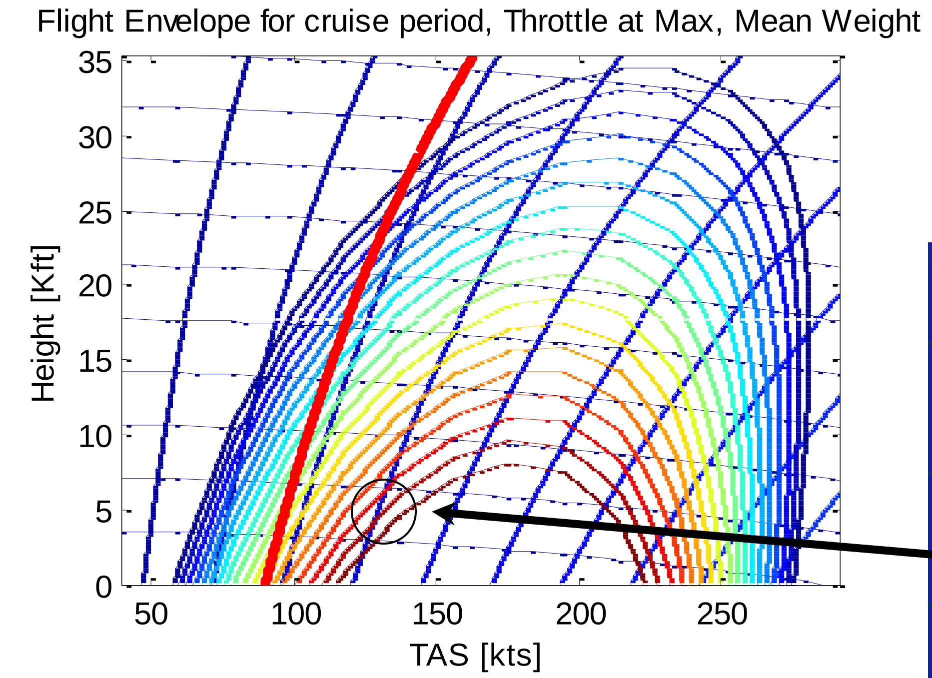
$$T_{\max,turn} = 49.7[kgf] \quad \bar{T}_{turn} = 41.5[kgf]$$

$$\Rightarrow (Fuel)_{turn} = 14.6[kg]$$

$$\text{Total Fuel} = 105\ [kg]$$

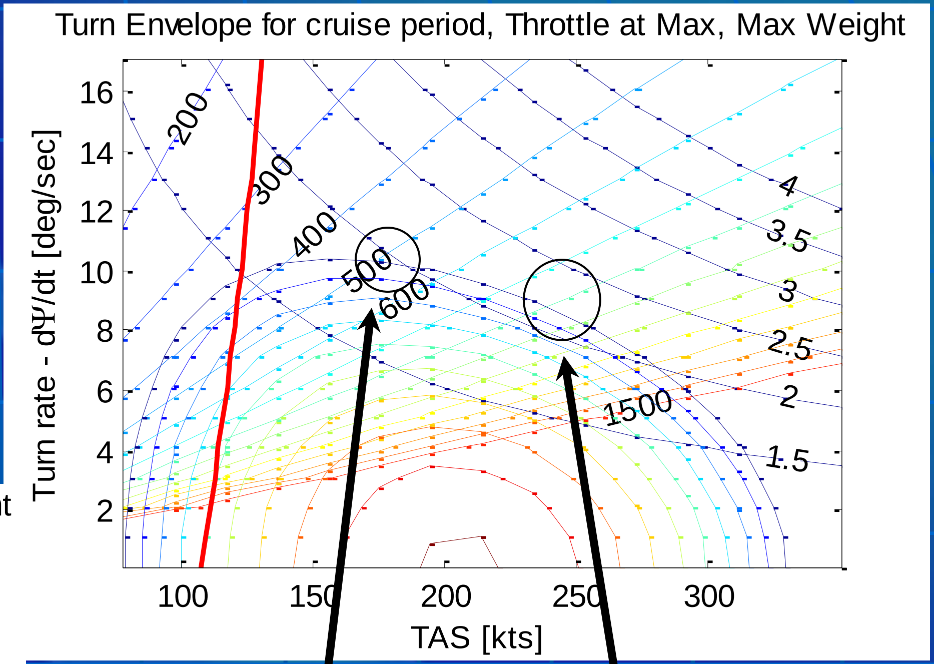
Flight & Turn Envelops





Cruise Work Points

Flight & Turn Envelops continued

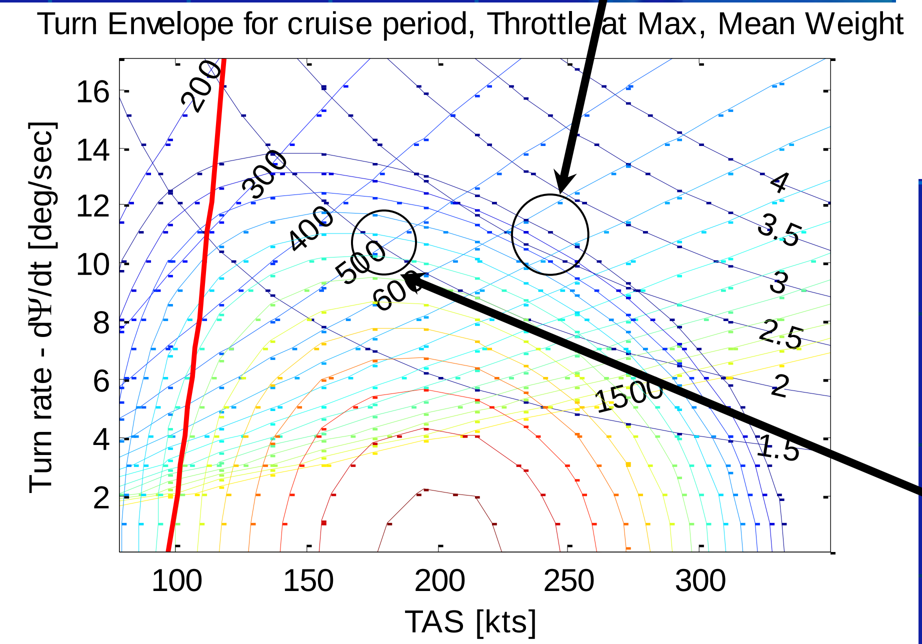


Max Manuver

$n = 2.67$

$TAS \approx 240[kts]$

$Thrust = 53[kgf]$



Max Manuver

$n = 2.15$

$TAS \approx 240[kts]$

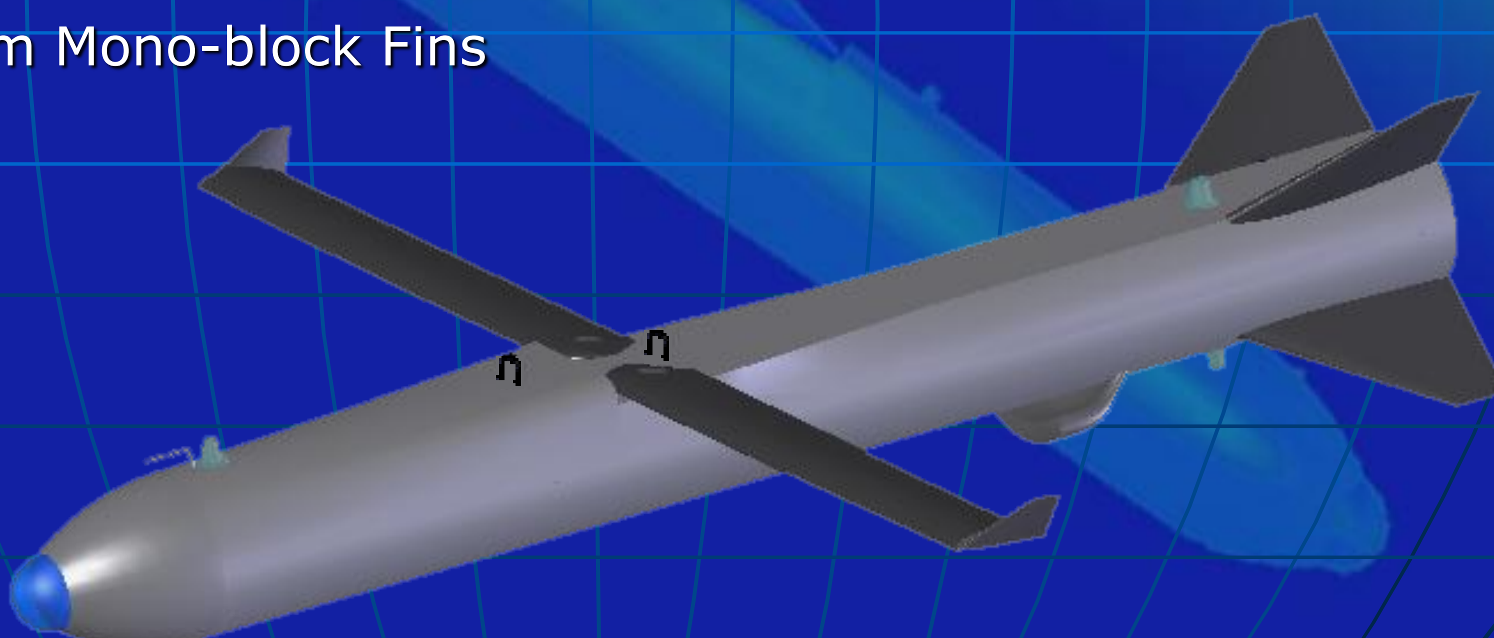
$Thrust = 54[kgf]$

Turn Work Points

Aerodynamic Design

Main Features:

- Ogive nose
- Variable cross section body
- Continuous wing sweep mechanism
- Aerodynamic & Geometric wash-in twisted wing
- Winglets
- Cruciform Mono-block Fins

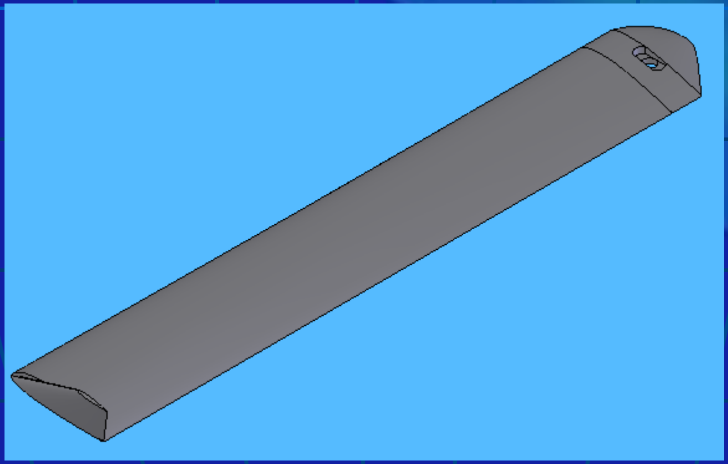


Wing Design

Requirements:

- High CL / Low speed working point at cruise
- Low drag design
- Low AoA cruise to avoid unnecessary body drag
- F-15/F-16 dimension envelope criterion
- Maneuverability at dive

High AR design: $c = 22[cm] \;\; b = 3.26[m] \rightarrow AR = 14.8$

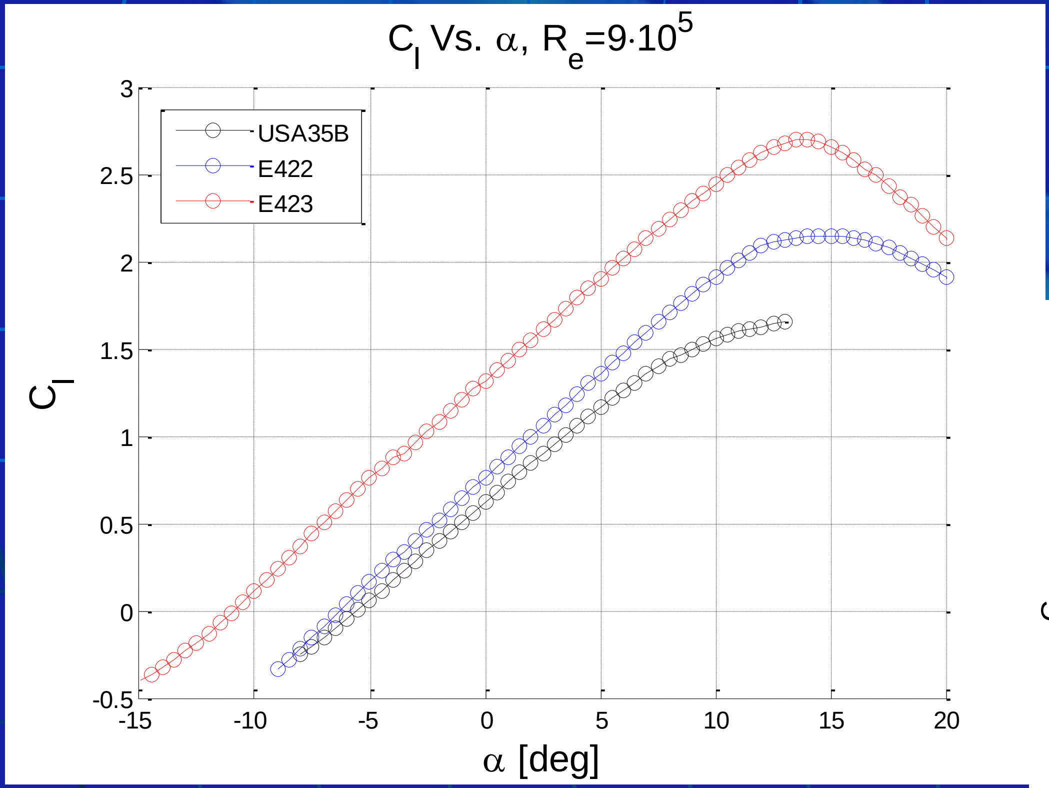


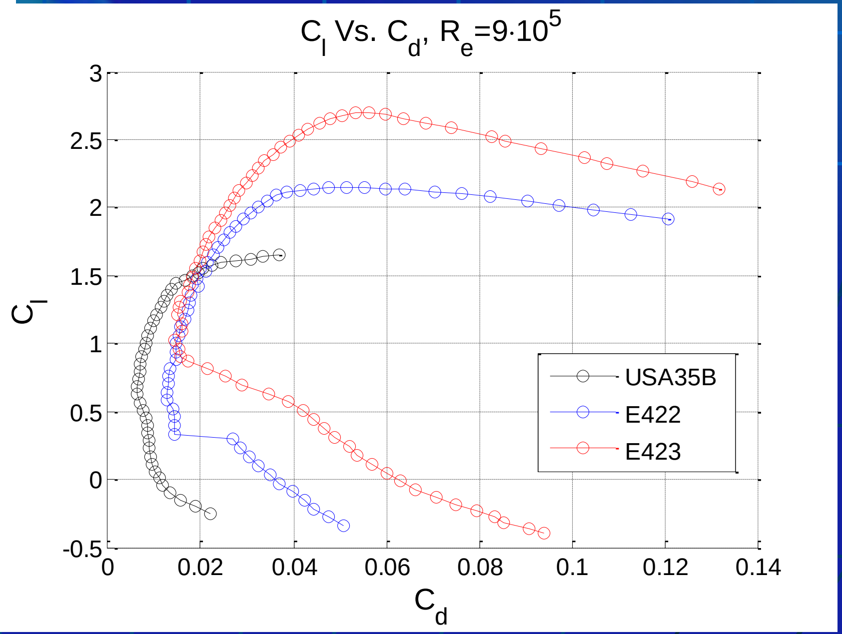
Wing Design continued

Airfoil Selection:

- High CL at low AoA → highly cambered airfoil
- High L/D → low thickness

f / c [%]	t / c [%]	
4.12	11.6	USA35b
7.15	14	E422
9.92	12.5	E423





Wing Design continued

Maneuverability Consideration:

- At cruise: Low speed, High CL, $\Delta X \approx 0.25c$
- At Dive: High speed → much smaller CL is needed → sweep angle

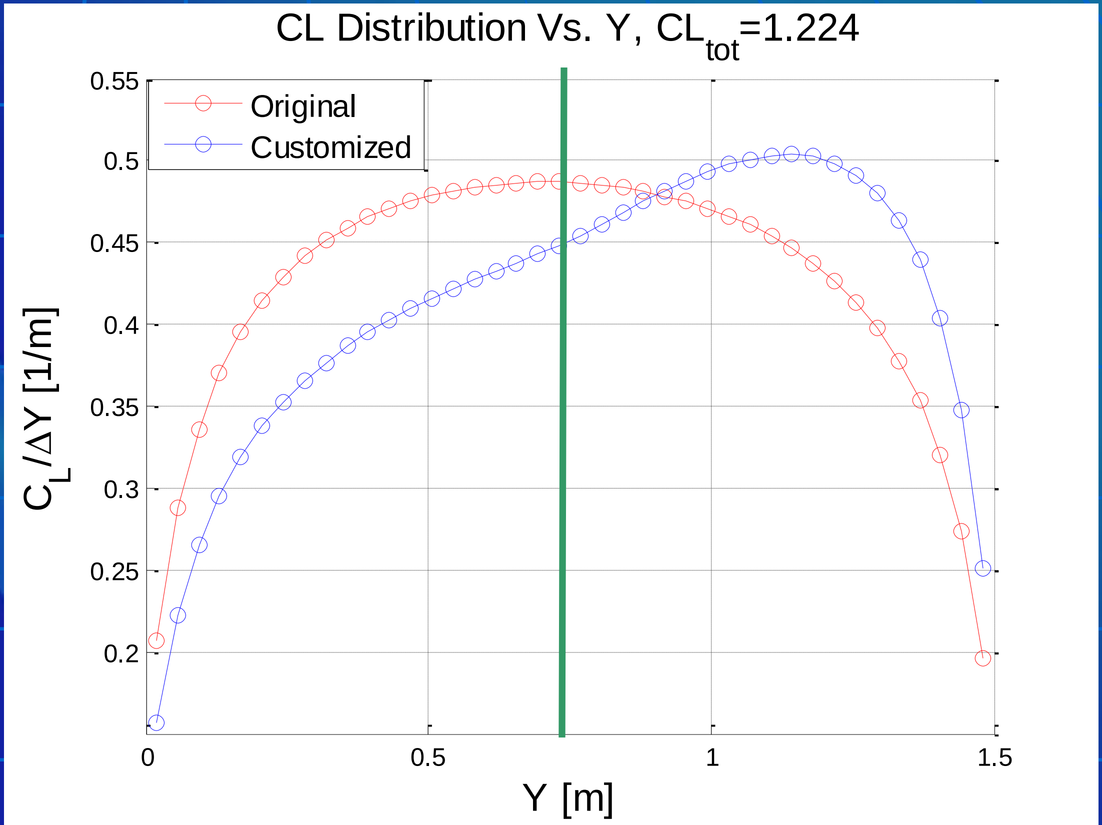
→ ΔX ↑↑ → low maneuverability

$$\Delta X_{Dive}\left(\Lambda = 70^{\circ}\right) \approx 2.9c$$

Solution: **Wing Slicing**

Wing Design continued

Custom CL Distribution:



i [deg]	Y [m]	Airfoil	
4	0	USA35b	**Root**
5	0.75	E422	**Middle**
7	1.5	E423	**Tip**

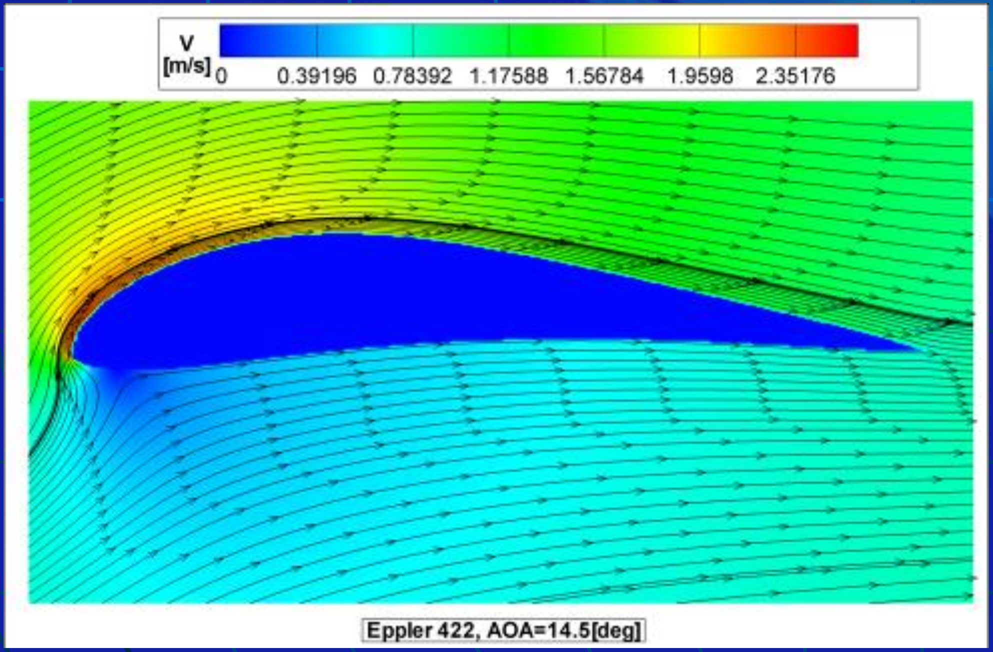
$$\Delta X_{Dive}\left(\Lambda = 25^{\circ}\right) \approx 0.69c$$

Wing Design continued

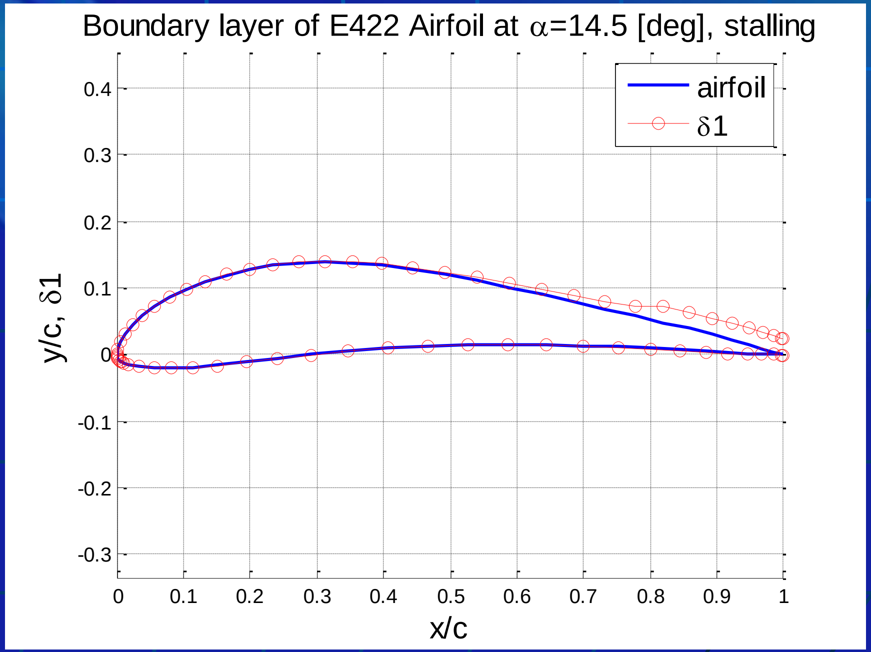
Stall Prediction:

	a_i (Cl_cruise)	i [deg]	Cl_max	a_stall [deg]	a0L [deg]
Root	-5	4	1.65	13	-5.56
Middle	-2.5	5	2.14	14.5	-6.27
Tip	-16	7	2.7	14	-10.87

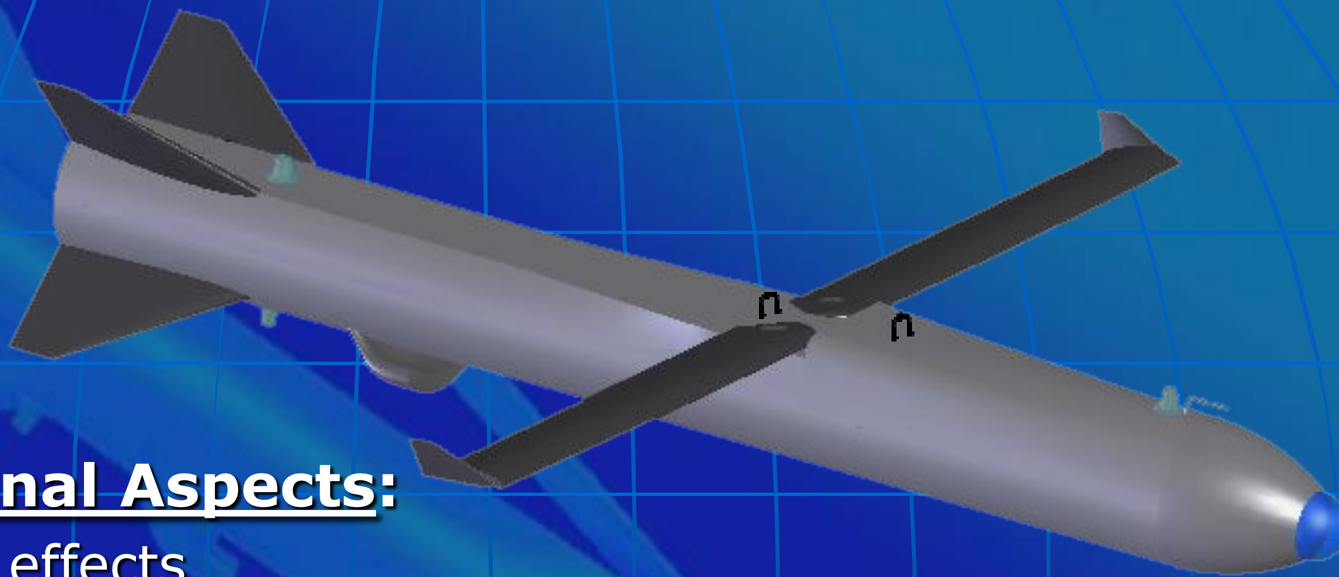
- At Cruise, middle section is first to stall, at $\alpha_{SATLA} \approx 16^\circ$ $C_{L-\max} = 2.3$



Eppler 422, AOA=14.5[deg]



Computational Model



Computational Aspects:

- Medium 3D effects
- Transition Mach numbers
- Highly swept, twisted, upper wing
- Non-symmetric wing wake
- Slender body
- Inlet effects
- Store separation calculations

Computational Model continued

Drag Model

- **Friction drag**, by Laminar Eckert & Turbulent Van Driest models
- **Pressure drag**, Roughness effect by Roskam method
- **Induced drag**, by VLM Program

	Cruise	Dive	Release
Height [ft]	5000	3000	40,000
Mach	0.2	0.5	0.9
CD0-Wing	0.014	0.015	0.18
CD0-Body	0.037	0.036	0.33
CD0-Tail	0.006	0.008	0.026
CD0-Inlet	9E-5	E-4	8E-4
Total CD0	**0.058**	**0.06**	**0.53**

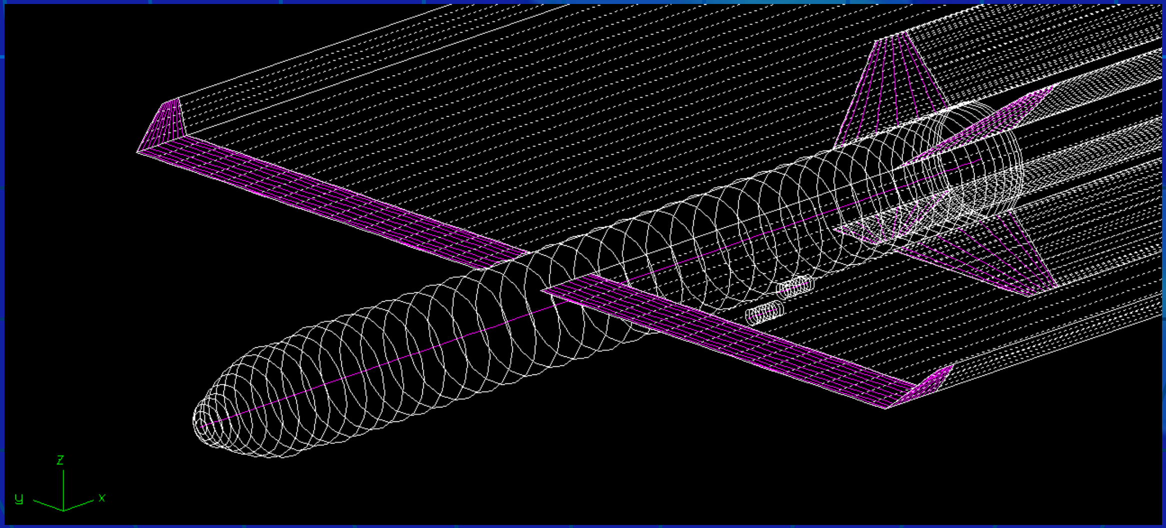
- At cruise: **K=0.041**
- Winglets effect: Reduction of 6% in K → 2 [Kg] of fuel, 2 [Kgf] of D_max

Computational Model continued

VLM Model:

Our **Extended Vortex-Lattice Model** is based on AVL GNU code, developed in MIT

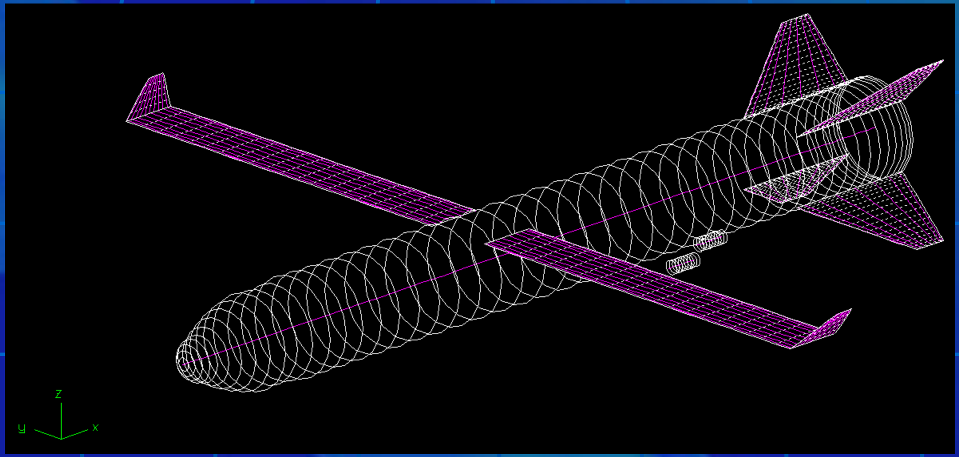
- 3D Potential, quasi-steady, Linear model
- Prandtl-Glauert compressibility application
- Bodies by Slender body theory, circular cross-section only
- Trim & constrain calculations
- Stability derivative calculations



Computational Model continued

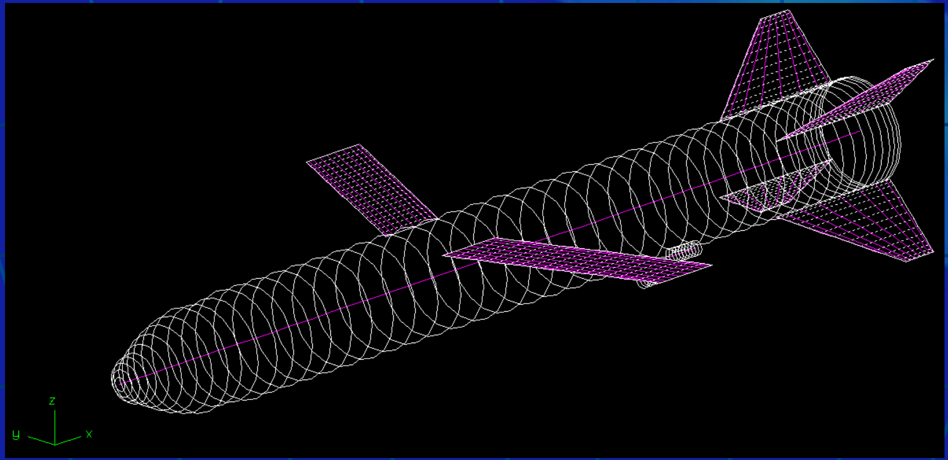
Cruise Calculations:

$$\alpha_{SATLA} = 0.8^\circ \quad C_L = 1.22 \quad C_D = 0.113 \quad \delta_{e-trim} = -0.387^\circ \quad X_{cg} = 1.39[m] \quad \Delta X = 0.23c$$

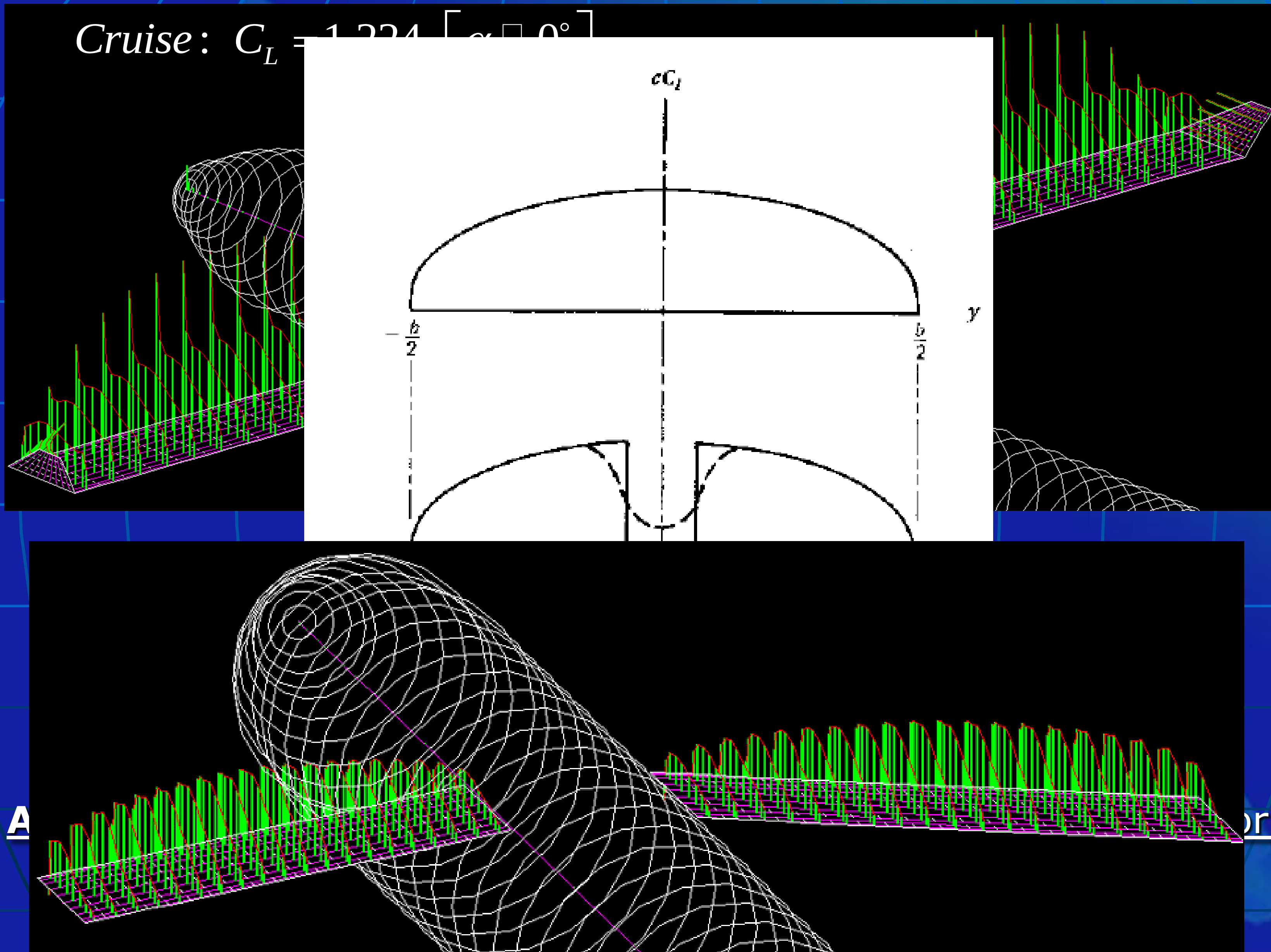


Dive Calculations:

$$\delta_{e-trim} = -0.25^\circ \quad X_{cg} = 1.395[m] \quad \Lambda_{LE} = 25^\circ \quad \Delta X = 0.68c$$



Computational Model continued

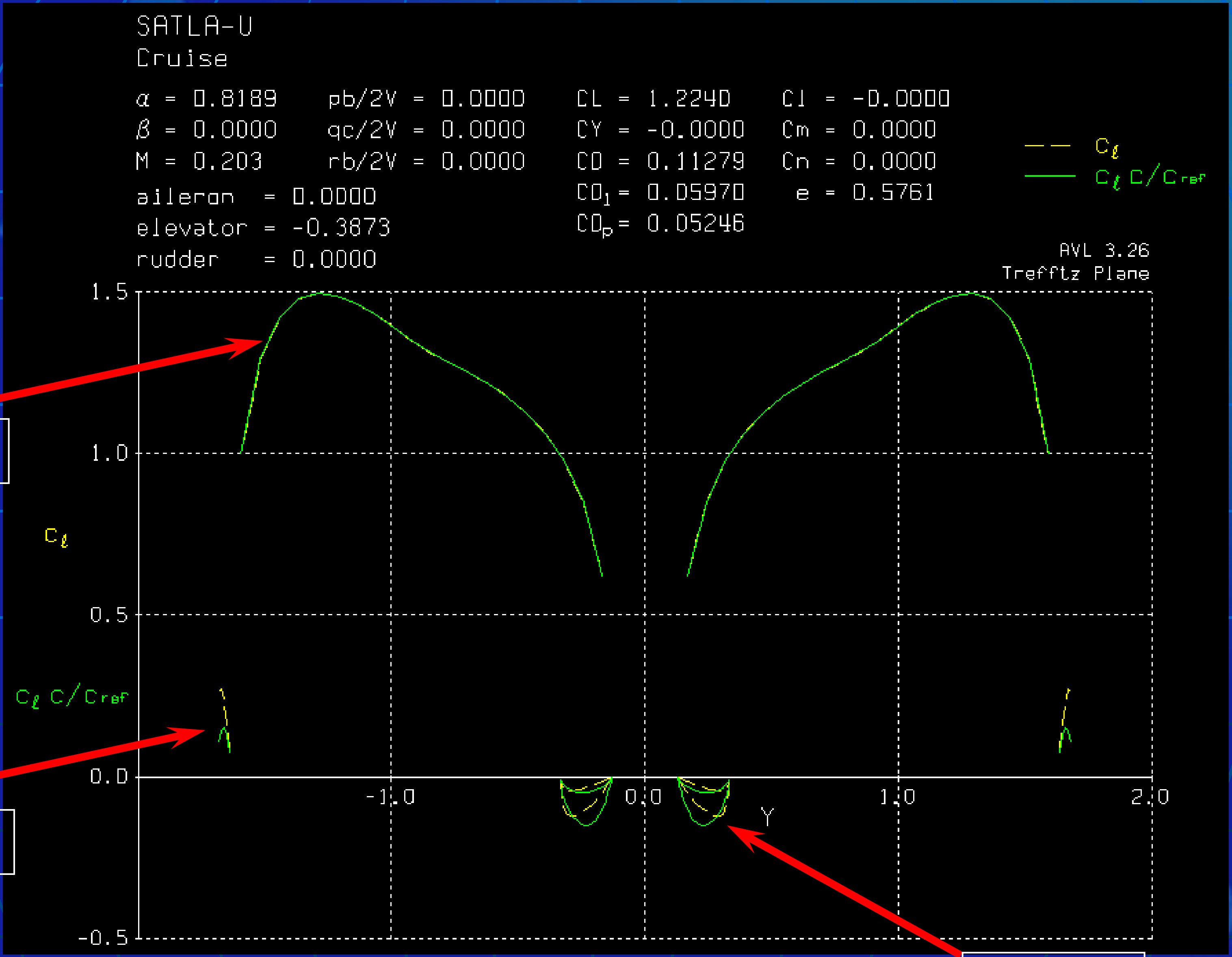


ΔC_p Distribution

A

ormick

Computational Model continued



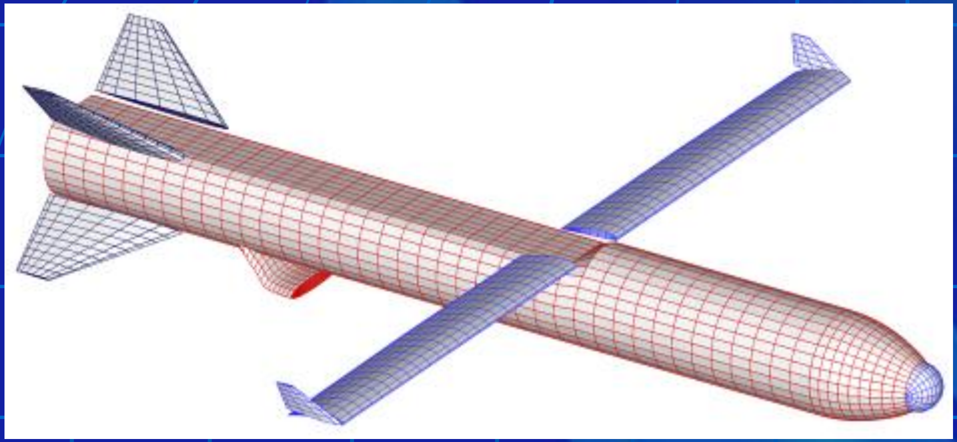
Wing

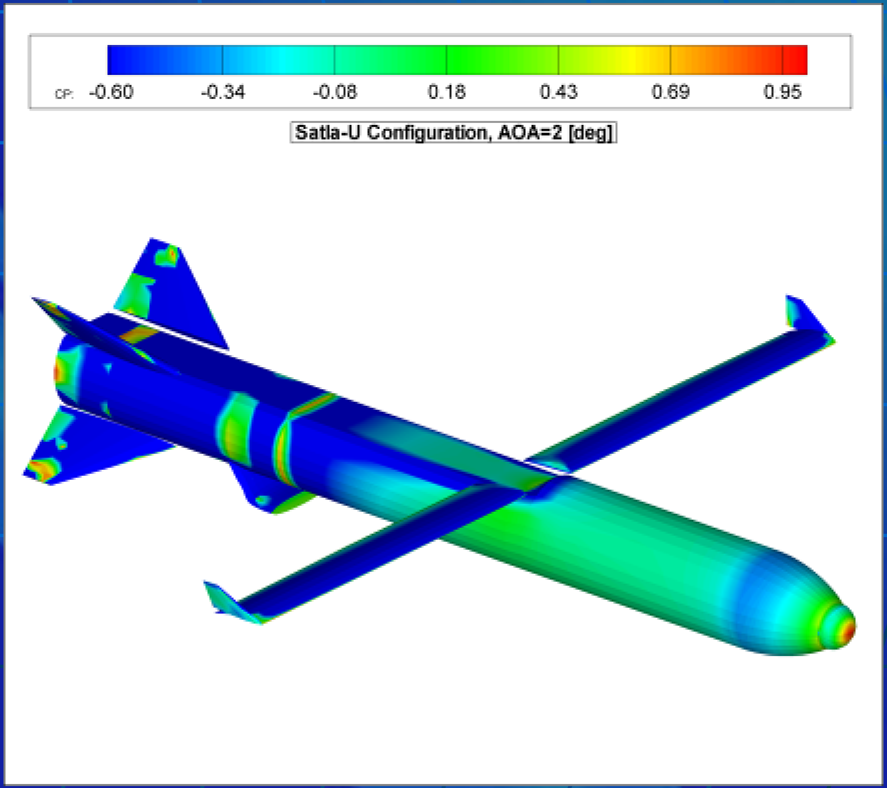
Winglet

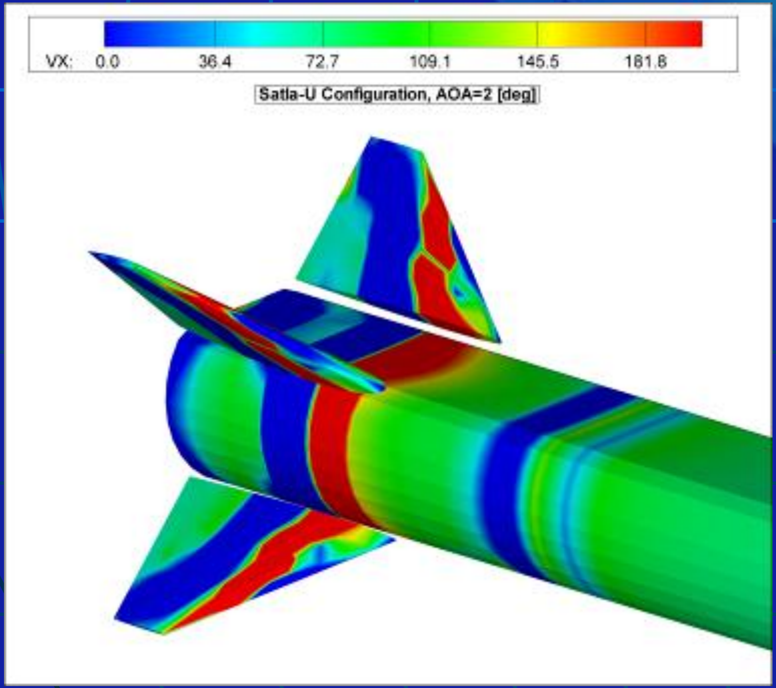
Fins

Computational Model continued

Comparison with Pmarc:

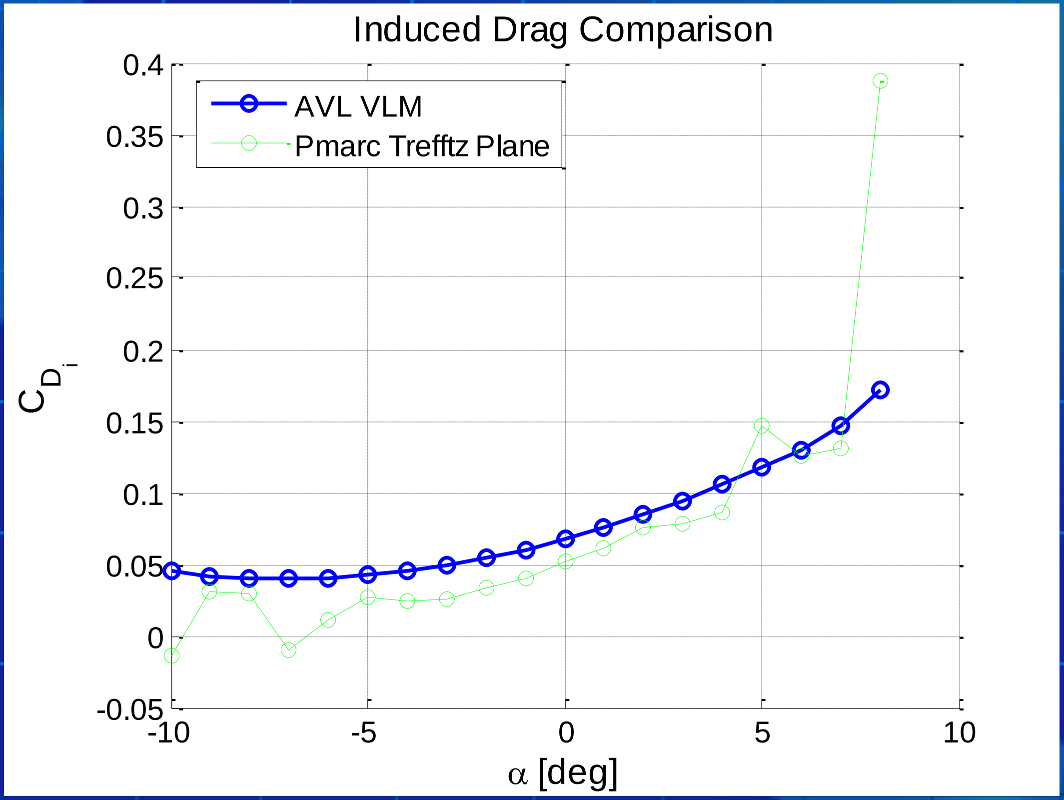






Computational Model continued

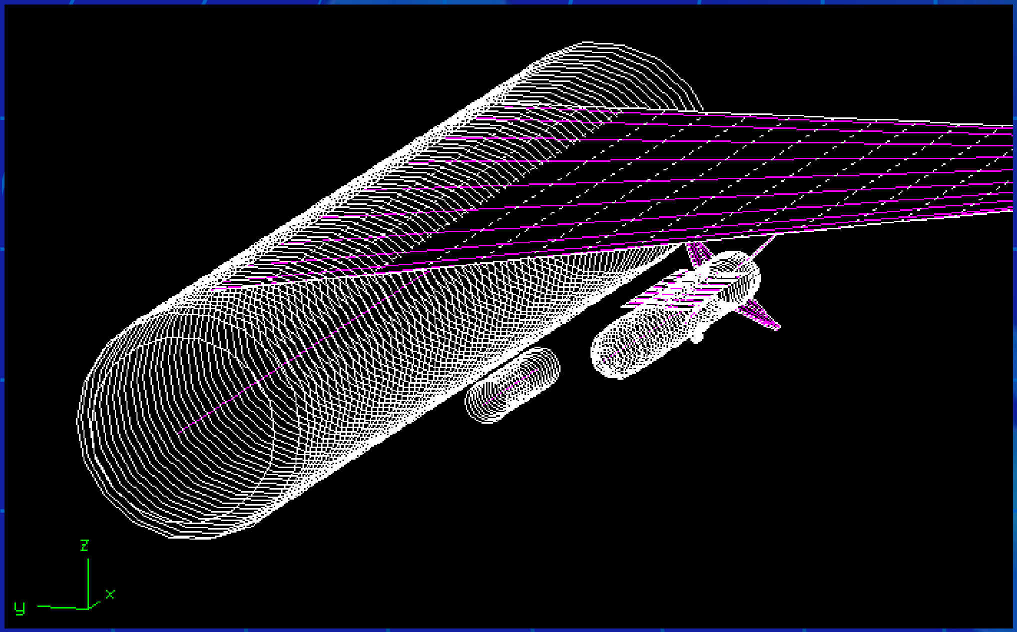
Comparison with Pmarc:



- Pmarc predicts a more negative Cm_a, which may increase S-U's static stability margin

Computational Model

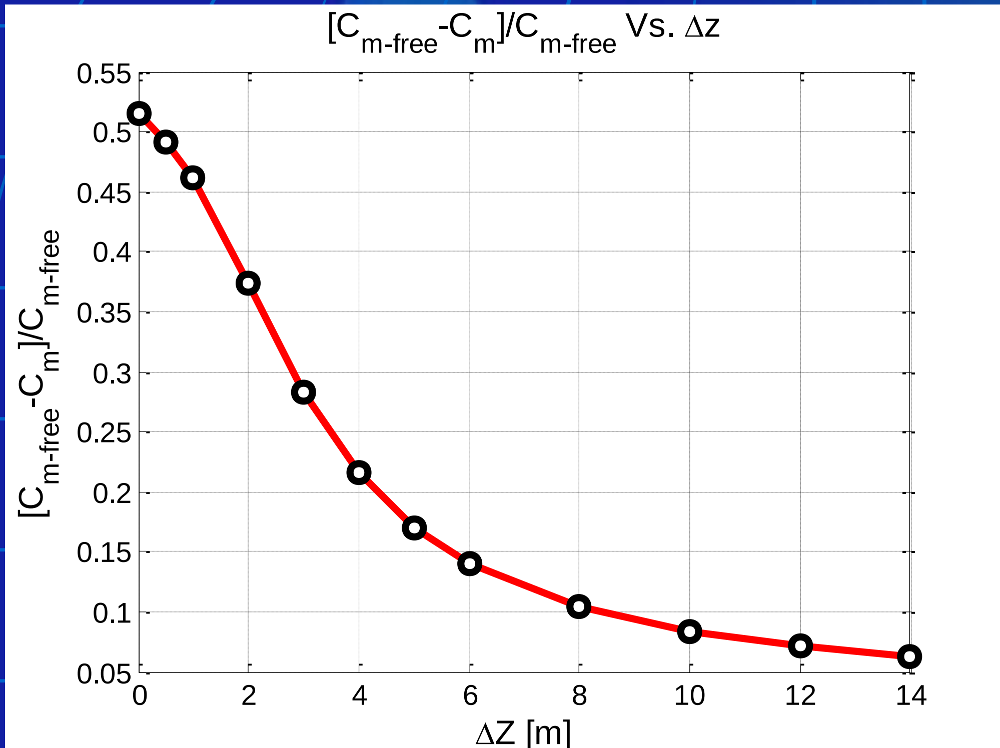
Store Separation Computational Model (SSCM):

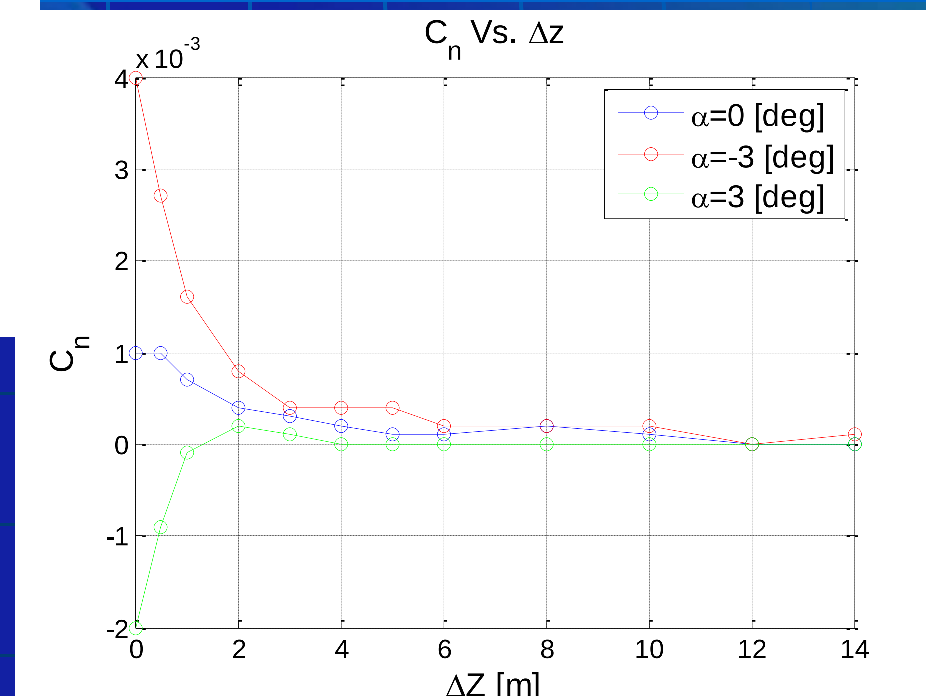


- S-U SSCM code was developed in order to calculate S-U's aerodynamic 6DOF coefficients with satisfied resolution
- $[C_X, C_Y, C_Z, C_L, C_M, C_N] = f(z, \alpha, \beta, p, q, r)$, $[\dot{u}, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}]$ are neglected
- S-U SSCM created a 14,580 calculations bank for the simulation

Computational Model

Store Separation Model:





- F-15's effect fades at Z>15 [m]

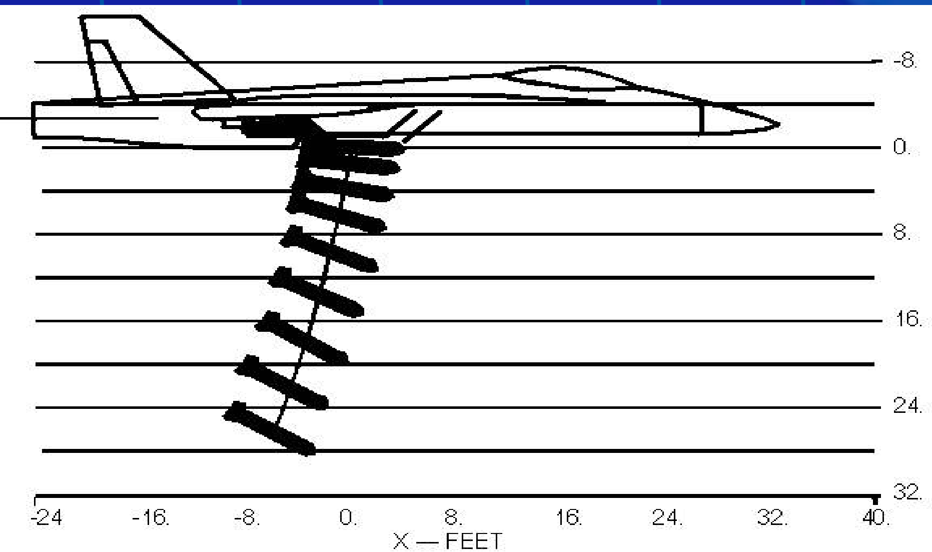
Store Separation

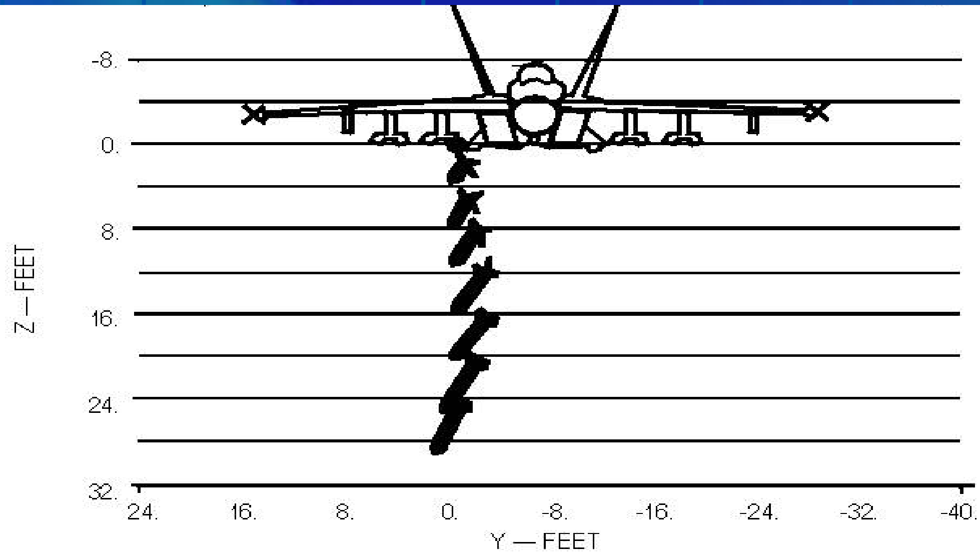
Goals:

1. Verify safe separation of S-U
2. Identify flight envelope for safe separation

Tunable parameters in design:

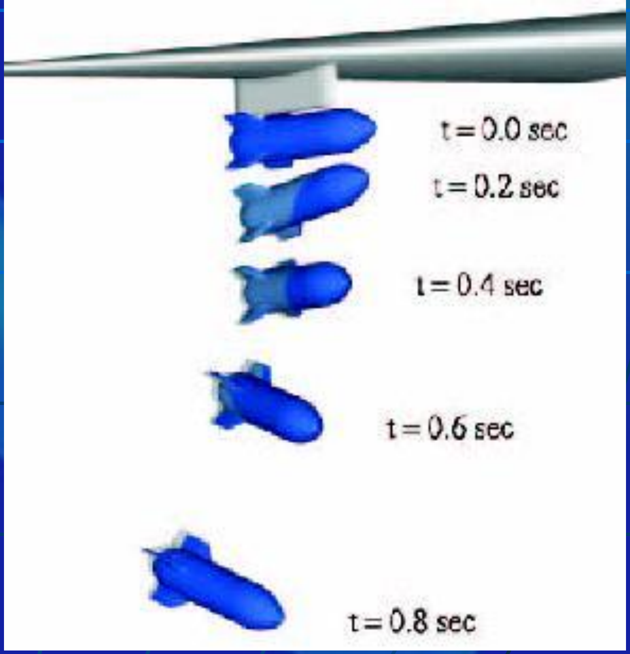
1. Speed and angular rate of deflection
2. Positioning angle under wing
3. Geometry
4. Moment of inertia



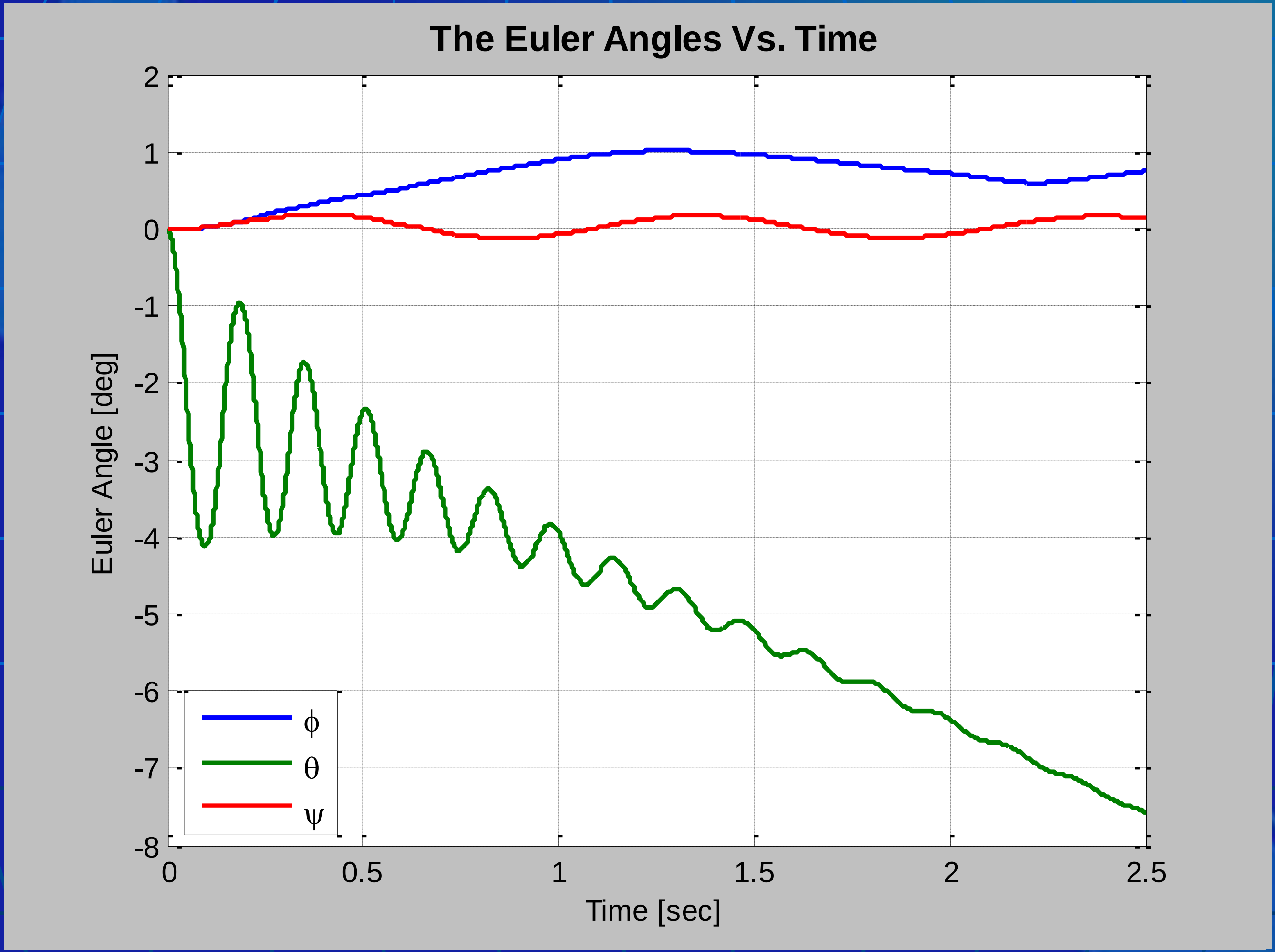


Solution Method:

- A Simulink 6DoF simulation in body axes.
- Aerodynamic force and moment coefficients are interpolated using S-U SSCH.
- Flight conditions and the effects of deflection are treated as starting conditions.
- We tried avoiding asymmetric deflections and positioned the S-U in the same plane as the carrier aircraft .
- The entire separation is with no steering.



Results continued



Store Separation Summary

- The S-U in its current configuration is safely separable.
- The flight envelope that was checked was a range of vertical maneuvers the carrier can be performing .
- This range was found to be $-0.6 < g$

<u>Future Work:</u>

1. Check of other carrying stations.
2. Check for F-16 as well.
3. Check for range of speeds.

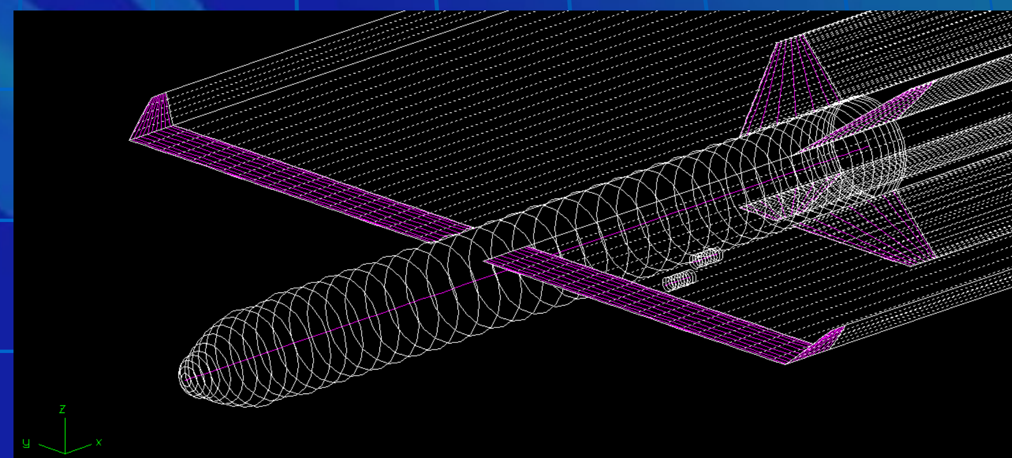
SATLA-U Control & Guidance

Control Analysis Method

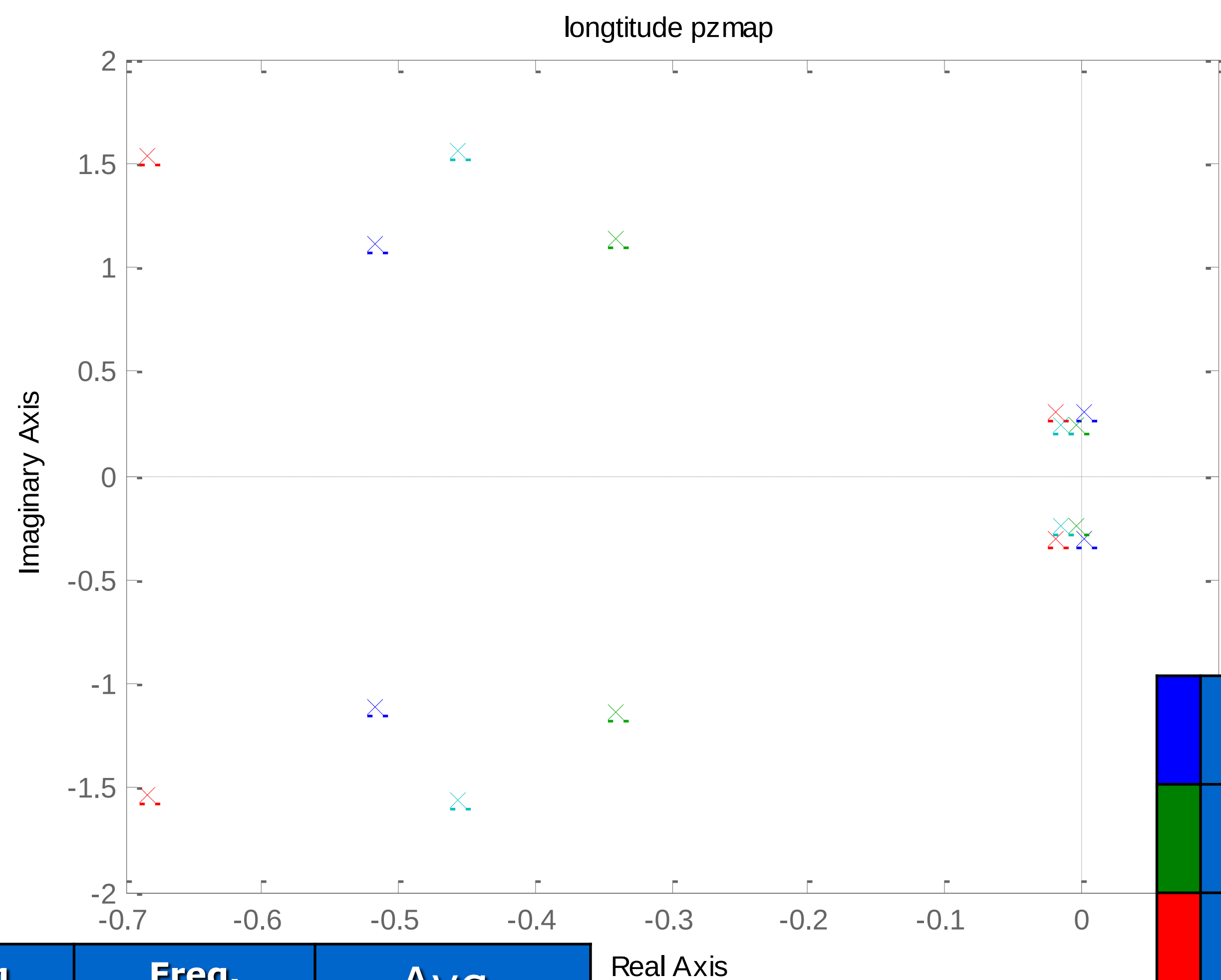
V.L.M & Roskam estimation → Stability & Control derivatives → Longitudinal & Lateral Eq. of motion

Motivation

- Aerodynamic model investigation
- Steering limitations
- Longitudinal & Lateral controllers design for cruise & dive



Cruise – Longitudinal Dynamics

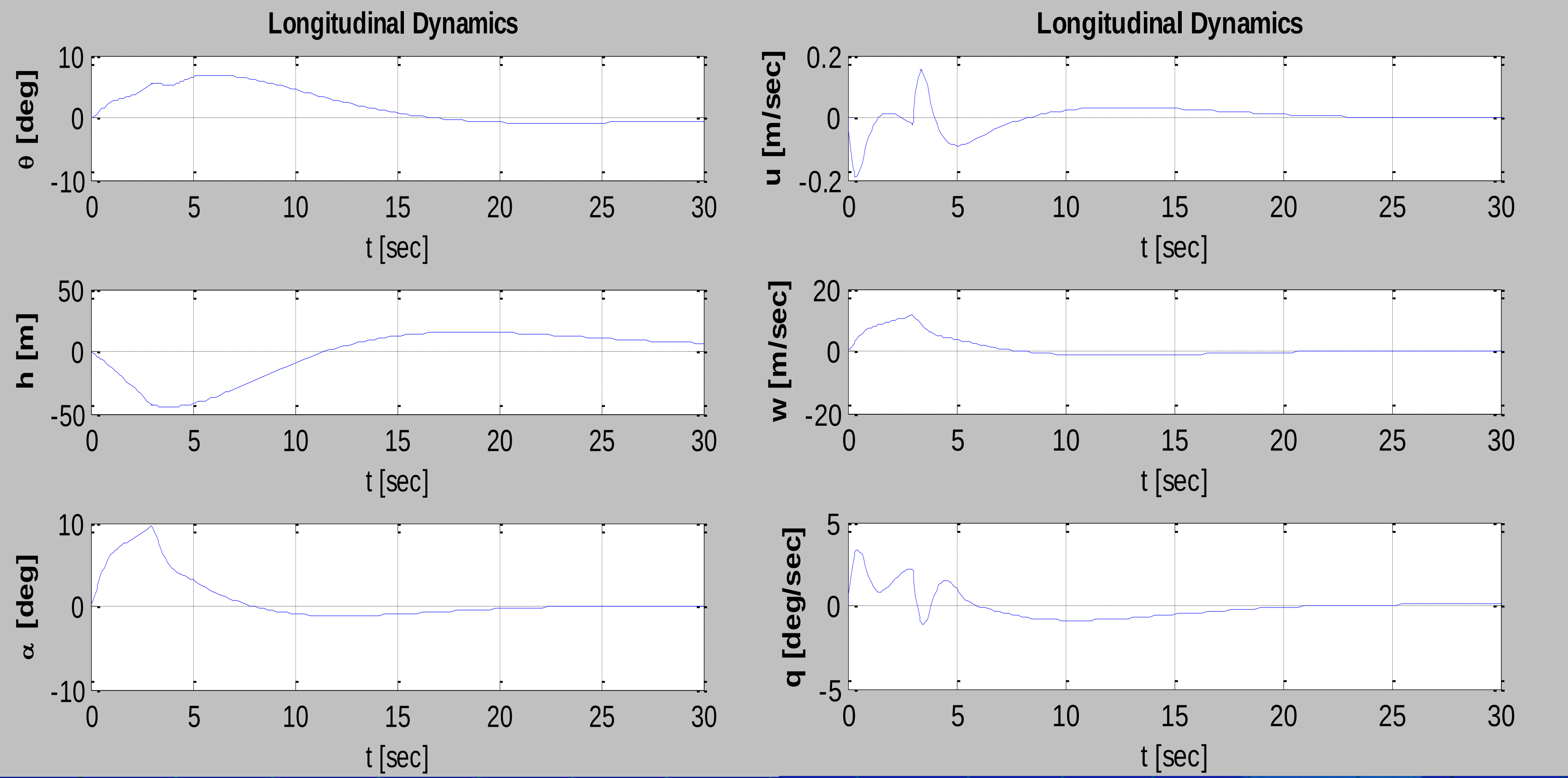


	v=55 m/s	m=150 Kg
	v=55 m/s	m=250 Kg
	v=75 m/s	m=150 Kg
	v=75 m/s	m=250 Kg

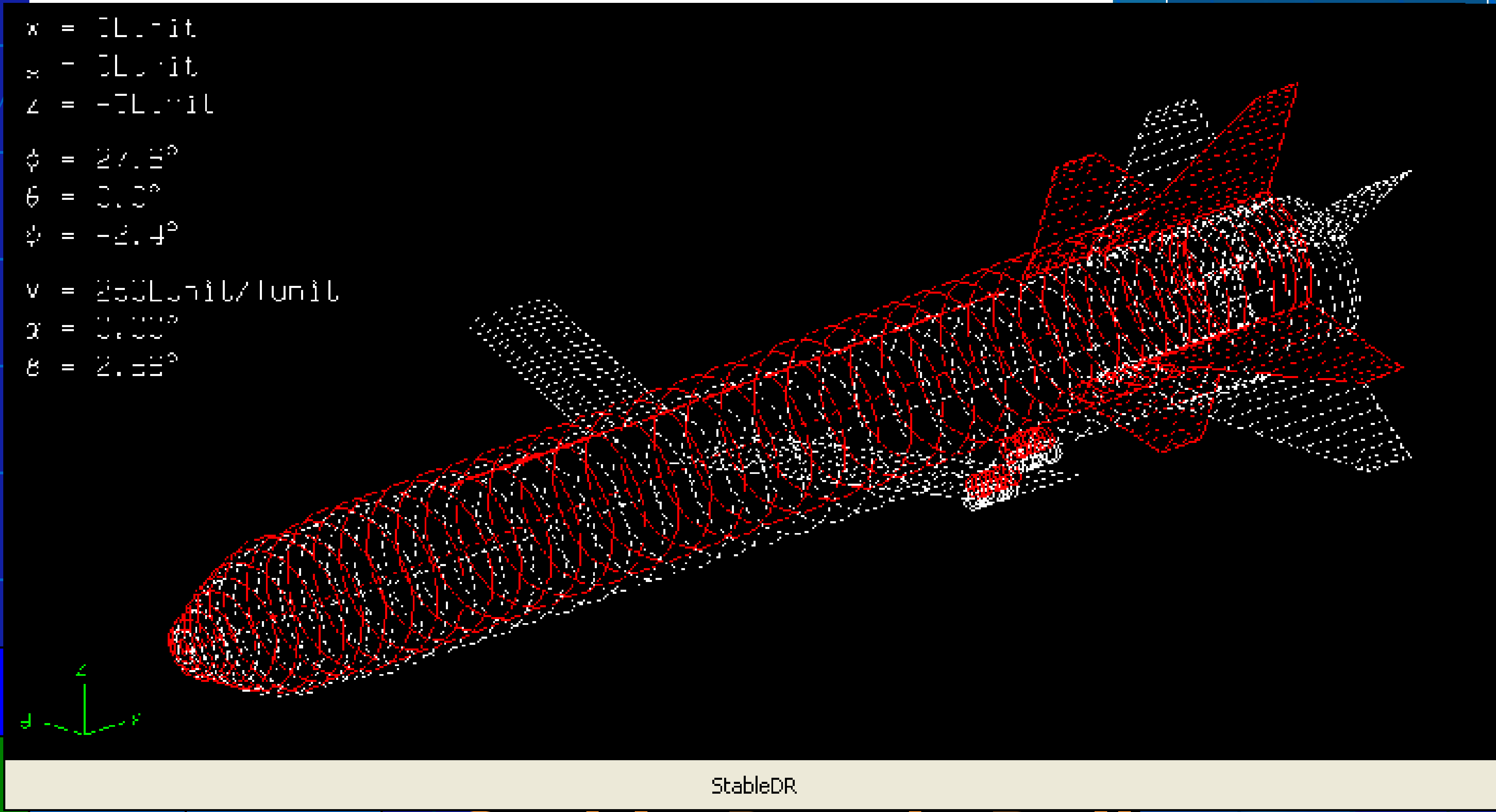
Damping	Freq. (rad/s)	Avg.
0.0388	0.273	Phugoid
0.355	1.37	Short Period

System Response

Using Velocity and Height controllers to 3 Second 20 Knots Vertical Wind Gust



Dutch-Roll Stability Analysis



Unstable Dutch Roll

Stable Dutch Roll

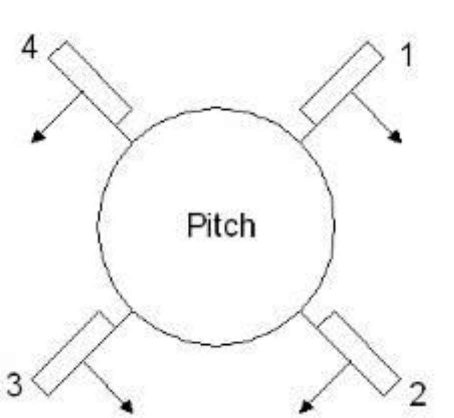
	v=75 m/s	m=150 K
	v=75 m/s	m=250 Kg

	(rad/s)	
0.0902	1.73	Dutch Roll

Control & Guidance

Steering

- **BTT** – Bank To Turn opposed to Skid To Turn
- Tail (elevator) – Pitch and Yaw
- Ailerons - Roll



Guidance

- Proportional Navigation
- Requires the homing head to output LOS rate and distance from target.
- Sensitivity to wind gusts and homing head bias was checked through simulation.

3 DOF Simulation

Main Assumptions

- The significant motion of the S-U is on the *x-z* plain
- The dive would start after locking on the target
- Only small roll corrections would be required

Guidance

- Navigation Constant: N=4
- Implementation of the PN guidance in the simulation:

$$a_{z,demand} = -NV_{\|}\dot{\lambda}_y - \underbrace{g\cos\theta}_{g_{bais}}$$

3 DOF Simulation continued

Goals

- Verify required hit accuracy: Square of 2X2 [m]
- Test the integration of the various models: Flight control, Aerodynamics, wind model….

Autopilot

- Acceleration controller in order to achieve the required normal acceleration
- Analog design

Propulsion: Off during the dive

Modes

- Complete wings
- Sliced wings at $\alpha \leq -6^0$
- Blind Range - At R = 200[m] the $a_{z,dem}$ is taken as the average of the last 9 $a_{z,dem}$.

3 DOF Simulation continued

Initial Conditions

$h_0 = 5000$ [ft] , $x_0 = 2000$ [m] , $v_0 = 68$ [m/sec]

$\alpha_0 = 0.8$ [deg] , $\theta_0 = 0$ [deg] , $q_0 = 0$ [deg/sec], $m = 203$[kg]

Simulation Stop

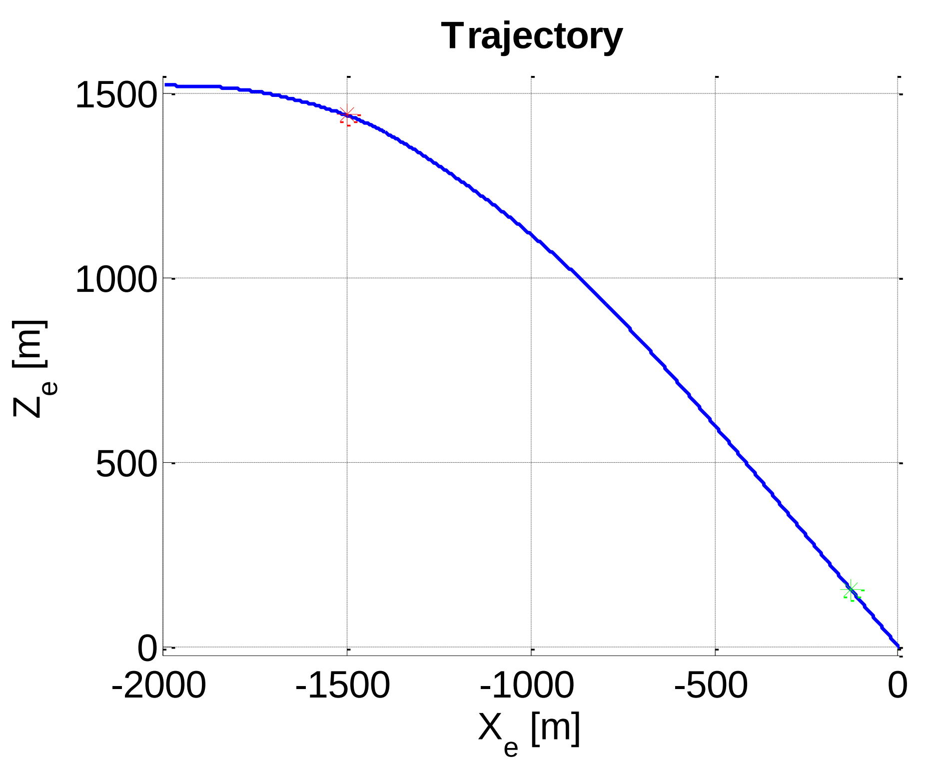
- When the S-U hits the ground or when $|\alpha| \geq \alpha_{stall}$

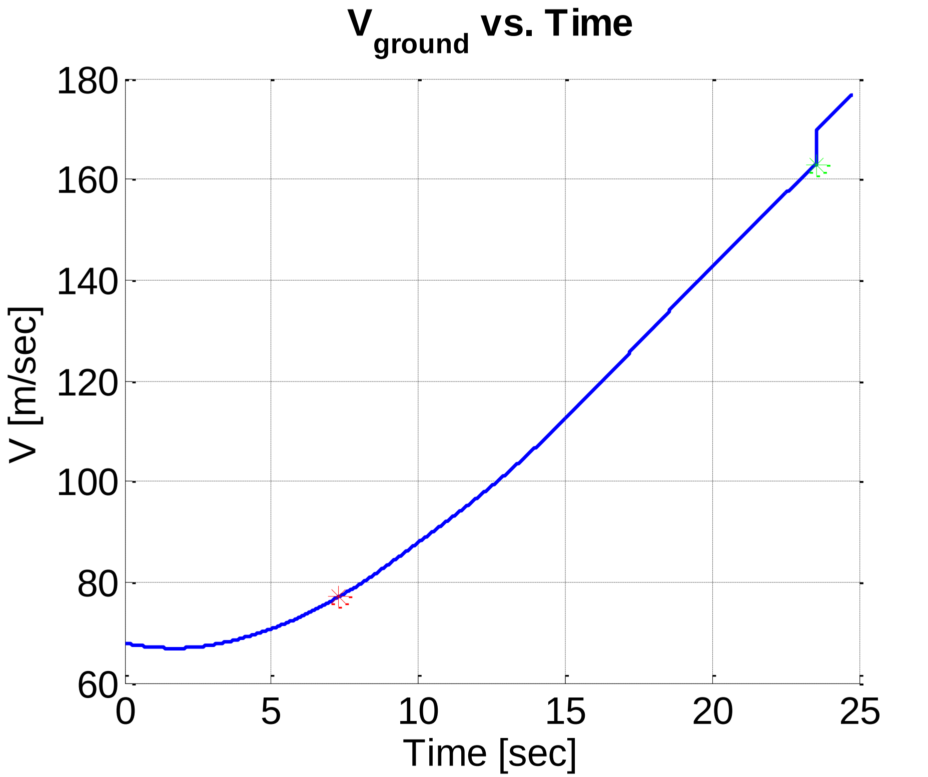
Wind

- A wind step was added at a predetermined range to test the miss distance sensitivity to wind input.

$V_{wind} = 20$ *knots, tail wind @ R=200 [m]*

Simulation Results

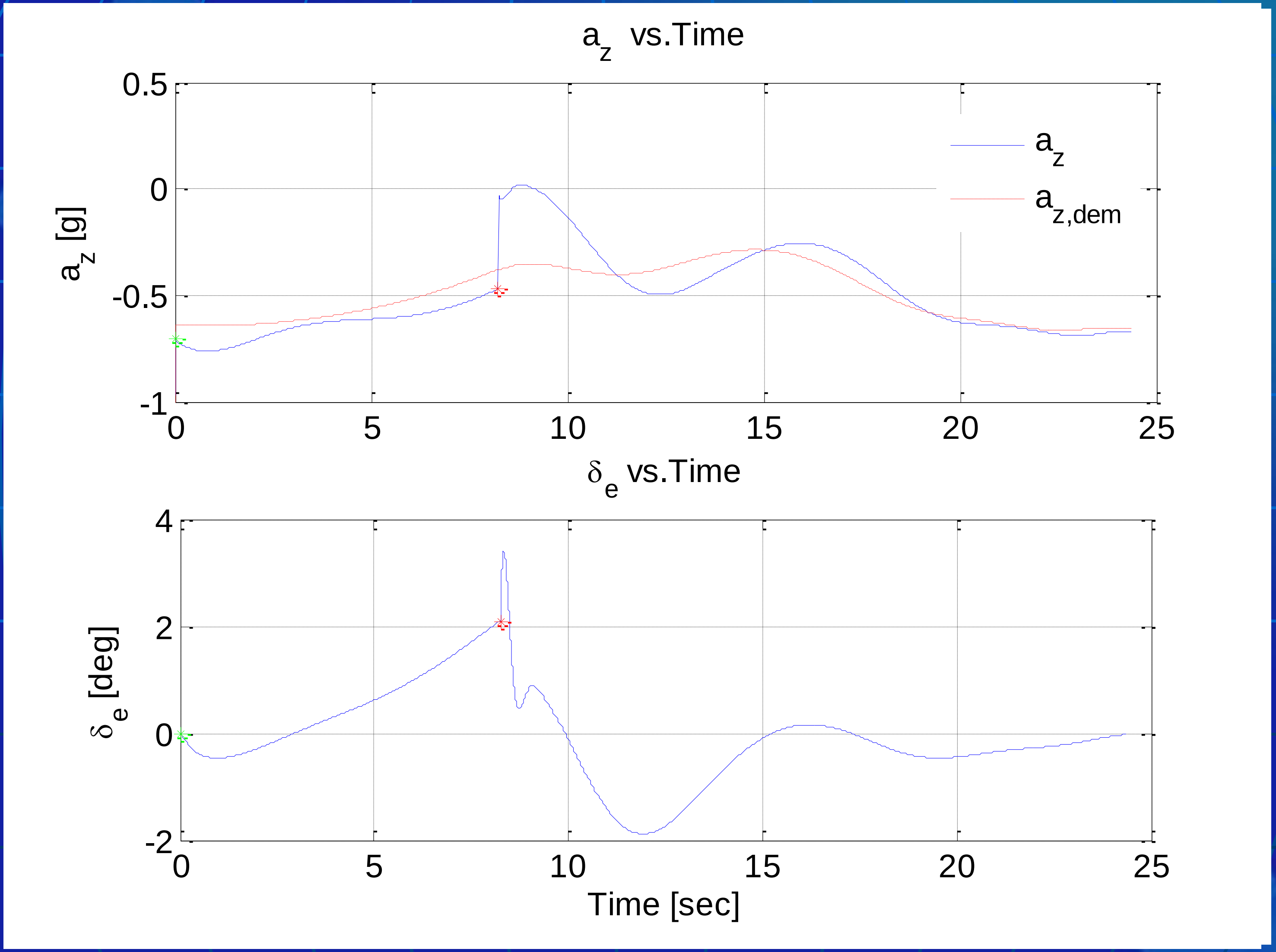




<u>Comments</u>: The green star (*) marks the wind entrance.

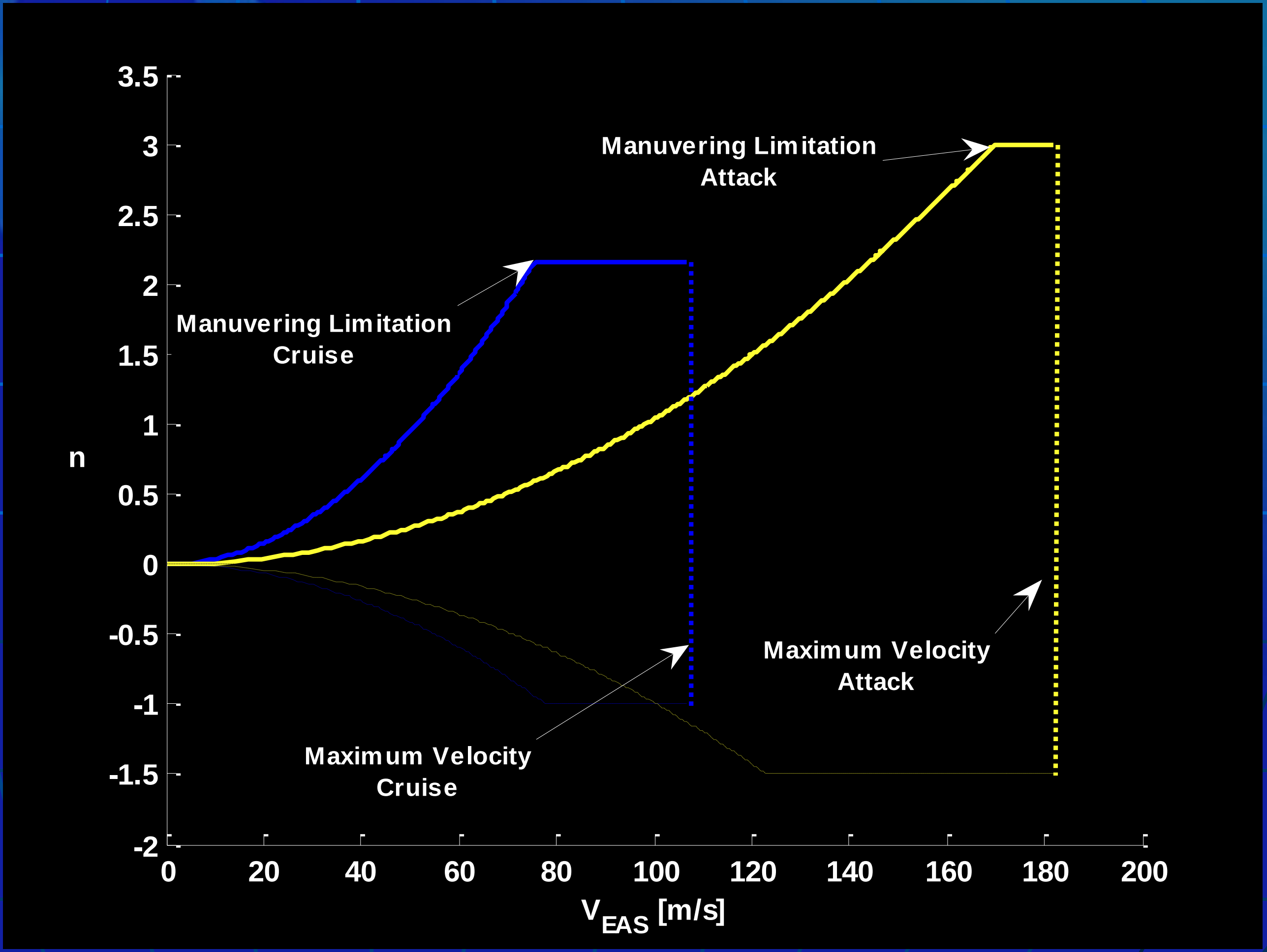
The red star (*) marks the slice wing point.

Simulation Results continued



Structural Analysis

- The S-U Structure is designed to withstand any critical load that may develop at most extreme maneuvers and at highest load factors with minimum weight and minimum cost.
- V-N diagram at cruise & attack stages:



Wing Development

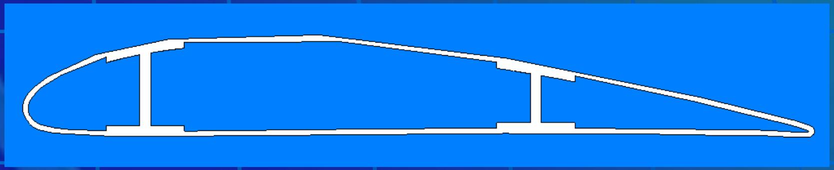
Material and Manufacture

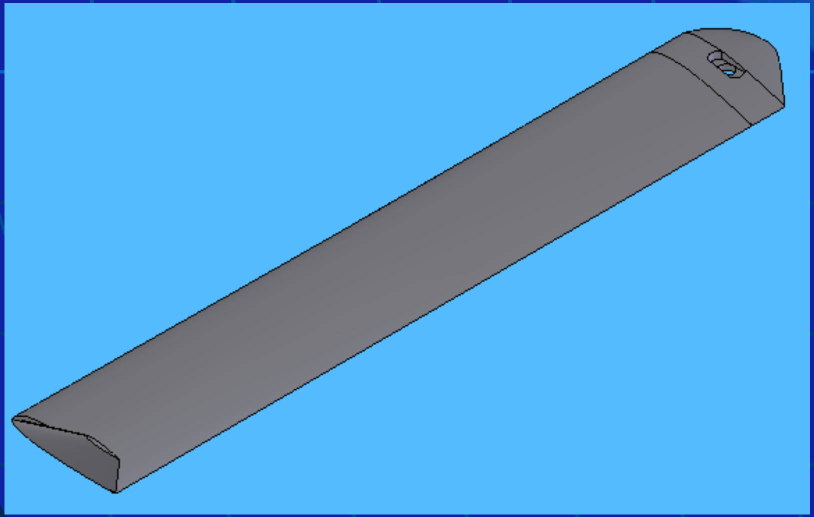
- Designed for AL 7075 T6
- Eventually will be Composite due to manufacture considerations.

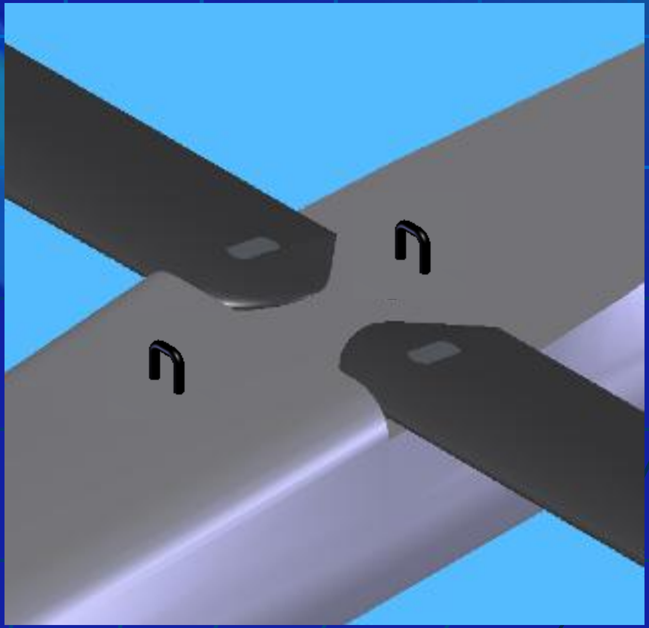
$$N = 1.2 \qquad \sigma_{max} = \sigma_y / N = 575[MPa]$$

Specifications

- Half wing span = 1.42 m
- Chord = 0.22 m
- Skin thickness 1.5 mm







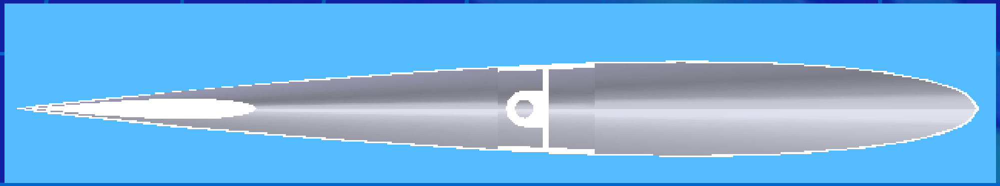
Tail Development

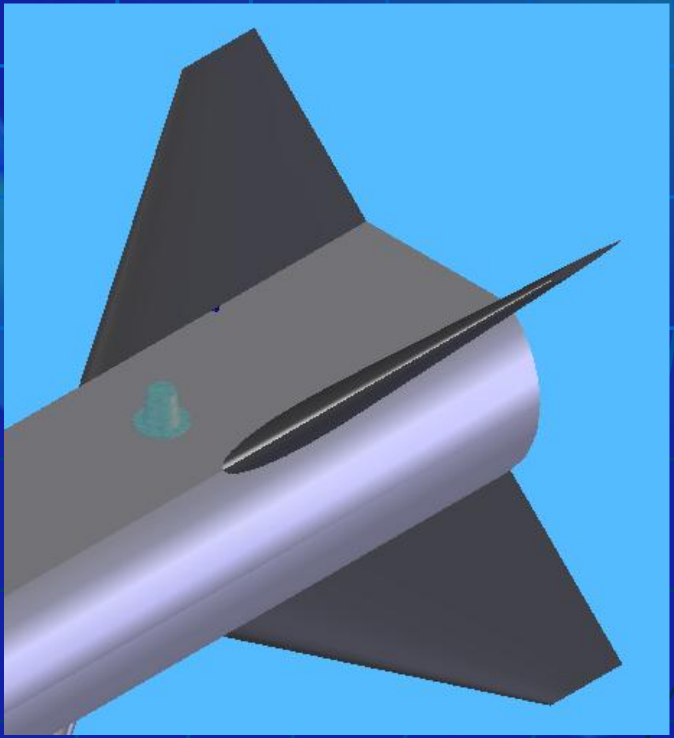
Material and Manufacture

- For low cost and weight: Al 7075 T6, Extrusion

Stress Calculations

- The tail is mono-block and therefore clamped to the body by a connecting rod.



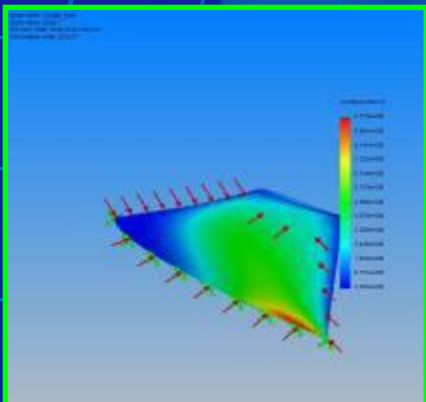


Specifications

- Skin thickness 1.5 mm
- Half tail span = 0.268 m
- Root chord = 0.52 m
- Tip chord = 0.13 m
- 1 rib
- Servo axis

Max. Static Stress and Displacements

Winglet Design:


Stress

Flight Condition	Max. Stress [MPa]		Max. Disp. [cm]	
	Wing	Tail	Wing	Tail
Straight & Level Flight (Nominal)	192.5	0.1	6.6	8e-5
	Cruise (n=2.15)			
Maneuvering Limitation	370.4	5.7	12.4	0.003
Maximum Velocity	413.5	2.8	14.2	0.002
	Attack (n=3)			
Maneuvering Limitation	106.1	15.2	0.6	0.01
Maximum Velocity	57.8	18.4	0.3	0.013

Maximum Wing Displacement:

SATLA-U

Max. Dynamic Stress

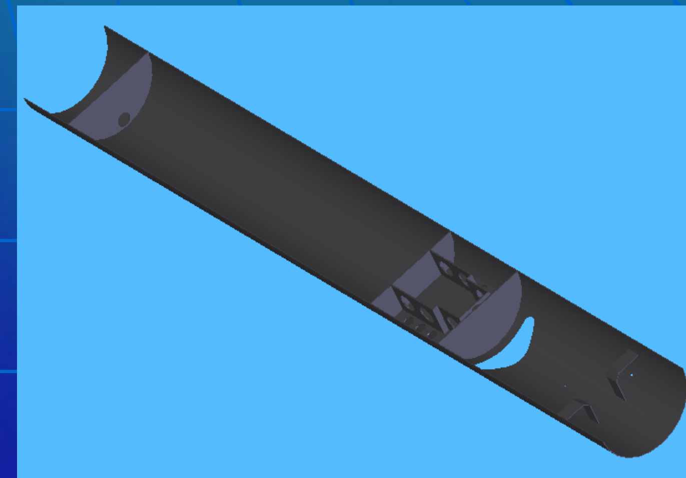
- The Dynamic loads as a product of step inputs of wind and Elevator were calculated.
- The structural limitation of Elevator step at high speed during attack is 10 [deg].

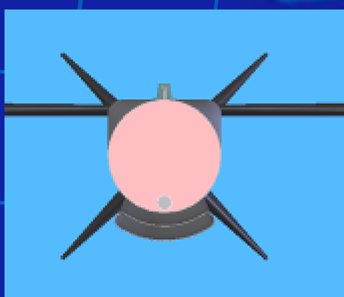
Step Magnitude	Max. Stress [MPa]			
	Cruise (V=68 m/s)		Attack (V=140 m/s)	
	Wing	Tail	Wing	Tail
	Elevator input			
5 [deg]	150	3.4	299.7	115.5
10 [deg]	165.7	9.2	515.8	171.3
11 [deg]	305.2	17.7	582.4	170.4
	Wind input			
20 [kts]	288.4	4.9	453.9	31.6

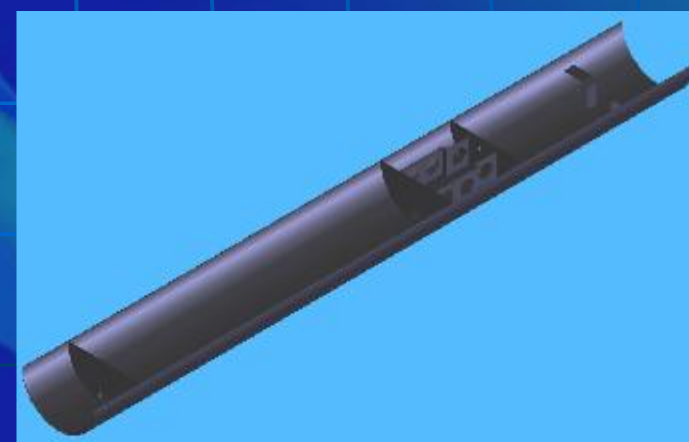
Fuselage Design

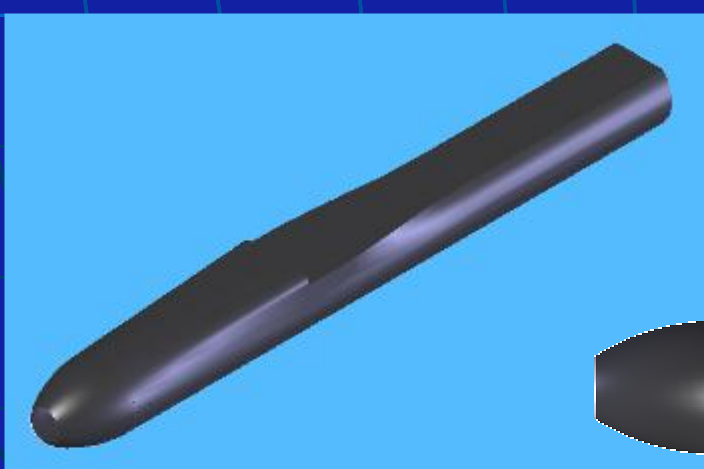
- AL 7075 T6
- 3 dividers
- Length: 3.4m
- Diameter: 368 [mm]

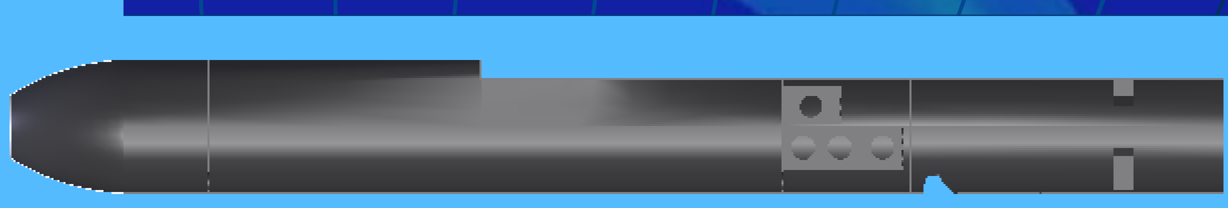
Ogive





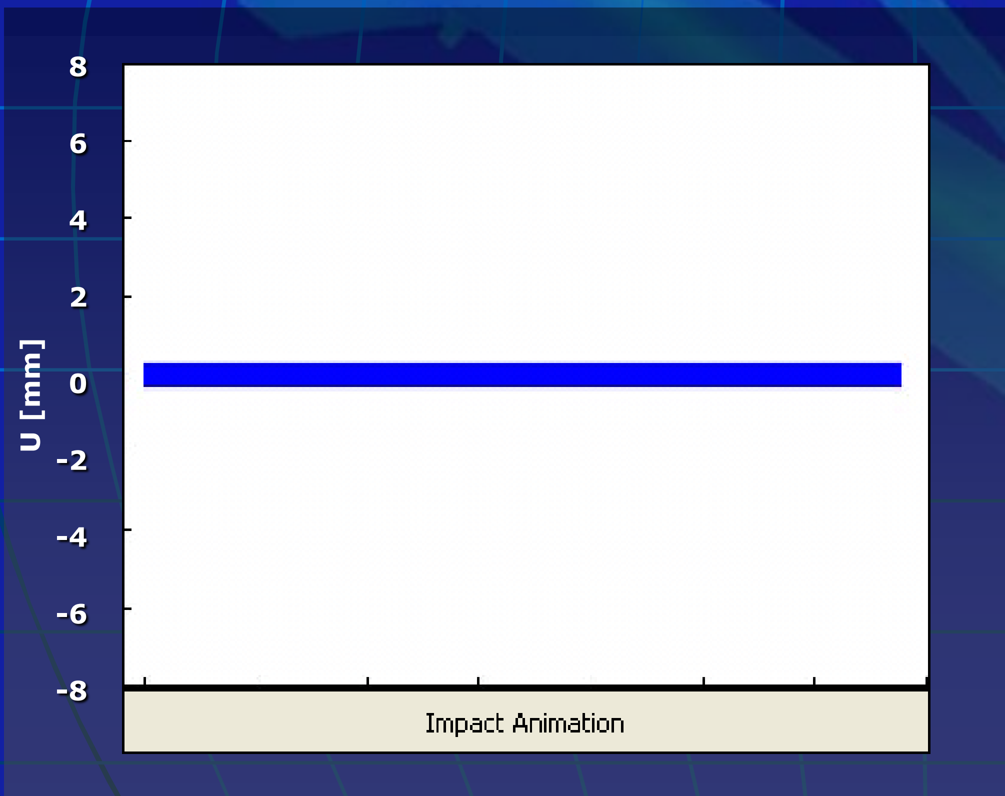


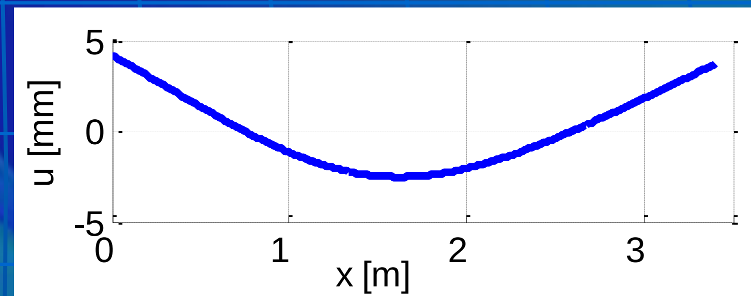


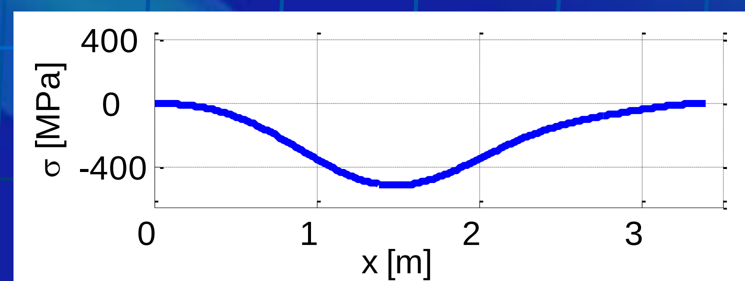


Impact Analysis

- The deployment of the S-U is performed by 2 pistons of 20g impact
- A frequency response is initialized
- The body response was simulated



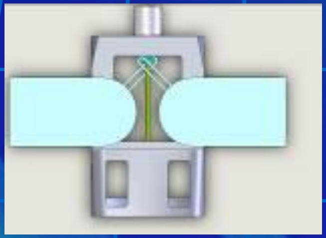




$$\sigma_{\max} = 514[MPa]$$

Wing Mechanism

- Wing mechanism is designed to change the wing sweep according to the specific stage of SATLA-U mission


- In order to find a perfect match for the S-U unique mission profile several concepts were analyzed

Tension Spring

Torsion Spring

Gear

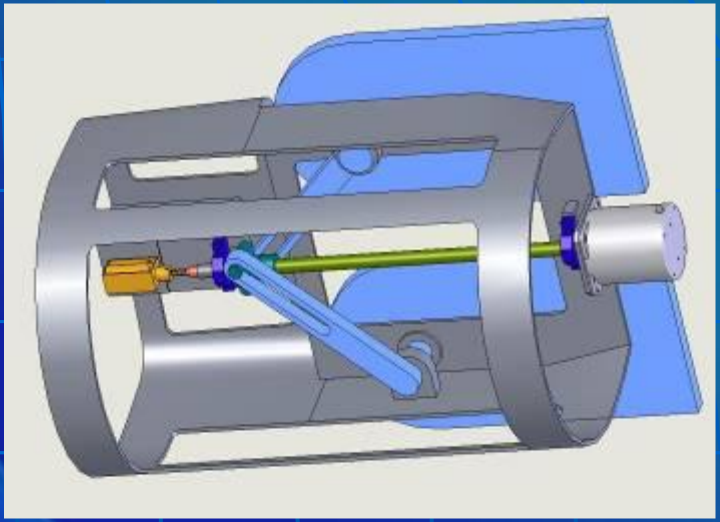
Ball Screw

- Due to relative simplicity and low weight the ball screw alternative was chosen

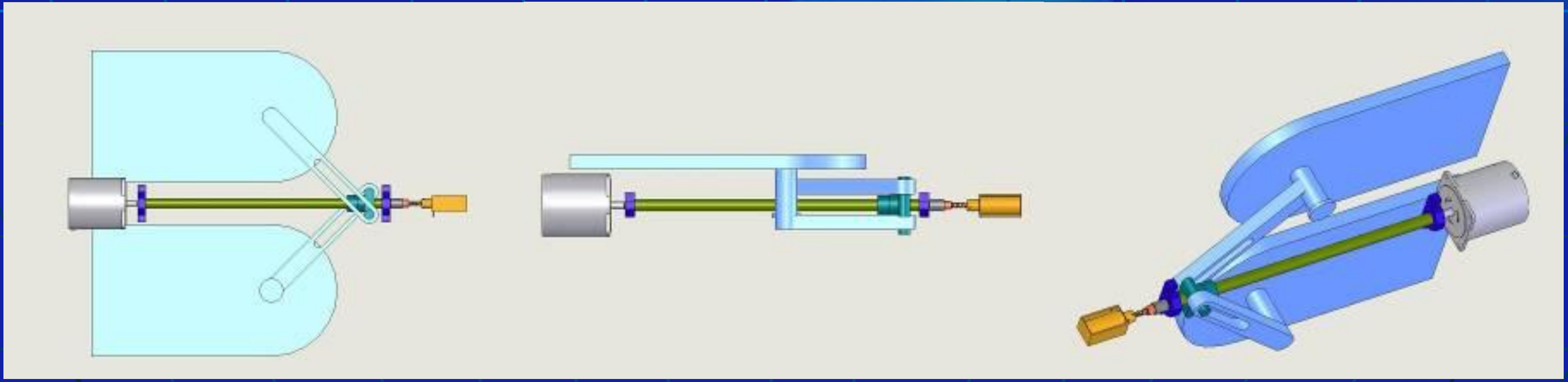
Wing Mechanism continued

System characteristics:

Max. Moment	400 [Nm]
Time for full wing opening	2-3 [sec]
Transmission ratio	1:400
Total Weight	3.5 [kg]



Operation Principle and Components



AV Systems

2 Batteries
UBI-2590
Ultralife

6 Servos
HSR-59952G
180 RC

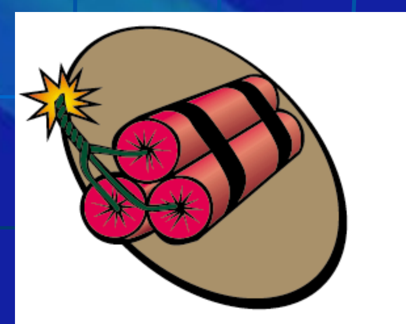
Tactical
Communication
Data Link

3 OMNI
Antennas

Fuel
Kerosene

Flight Computer
Athena's
GuideStar 311

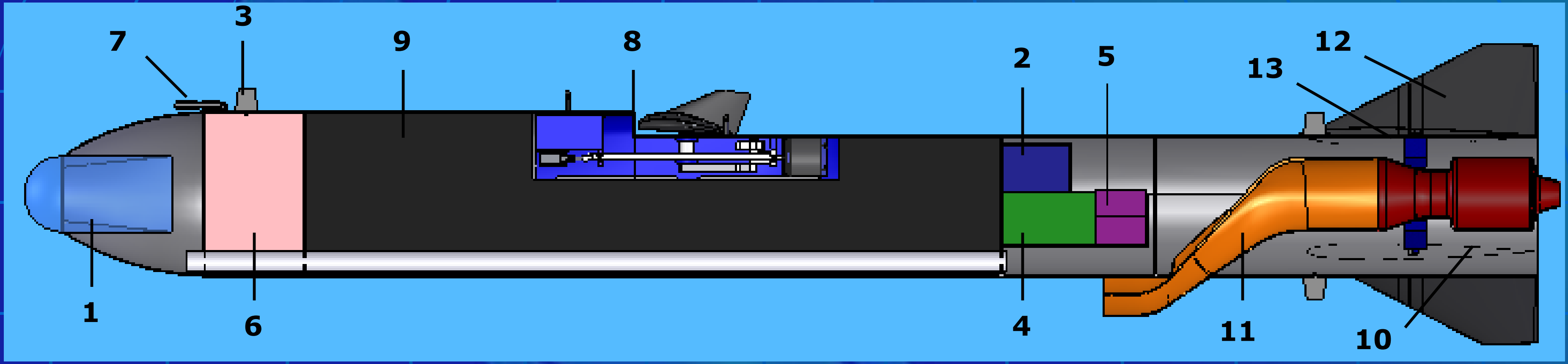
Imaging and Homing
EMIT's Microview



Warhead

Turbo-Jet
Engine
SWB 100

Fuselage Layout



1. Seeker
2. Avionics Unit
3. Antenna (x3)
4. Communication Unit
5. Batteries (x2)
6. Warhead
7. Pitot tube
8. Wings & Wing Mechanism
9. Fuel Tank & Fuel Control
10. Power Plant
11. Inlet
12. Fins (x4)
13. Fin Actuator (x4)
14. Hanging Hook

Layout Weight & Balance

Component	Weight [Kg]	x [m]	y [m]	z [m]
Fuselage	37.8	1.81	0	0
Warhead	45.1	0.52	0	0
Fuel	106.12	1.37	0	0.02
Wing mechanism	9.79	1.55	0	-0.08
Wings	8.74	1.48	0	-0.16
Inlet	3.52	2.72	0	0.09
Pitot tube	0.04	0.4	0	-0.2
Seeker	6.8	0.19	0	0
Engine	6	3.25	0	0
Tails	2.76	3.19	0	0
Tail servos	0.26	3.13	0	0
Data Link	8	2.3	0	0.06
Avionics & Navigatio	2.4	2.27	0	-0.06
Battery x2	2.88	2.46	0	0.05
F. Antenna	0.5	0.5	0	-0.2
Top R. Antenna	0.5	2.9	0	-0.15
Bottom R. Antenna	0.5	2.9	0	0.2
F. Hook	0.08	1.22	0	-0.21
R. Hook	0.08	1.58	0	-0.16
Tubing	1.5	1.29	0	0.15
Contingency	6.63			
Total	250	1.4	0	0

Cost Analysis

	Roskam	Rhaymer
Total Engineering Cost	$ 2,364,040	$ 8,234,590
Total Manufacturing Cost	$ 21,700,073	$ 9,462,327
Total Tooling Cost	$ 4,414,590	$ 3,381,493
Total Quality Control Cost	$ 2,821,010	$ 1,258,489
Total Engines & Avionics Cost	$ 55,460,000	$ 55,460,000
Total Materials Cost	$ 1,380,091	$ 1,151,760
Total Development Support Cost	$ 50,145	$ 1,635,264
Total Flight Tests Cost	$ 566,178	$ 4,719,609
Total Project Cost	**$ 88,756,127**	**$ 85,303,532**
Single Unit Cost	**$ 887,561**	**$ 853,035**

- The analysis was made for 100 production units, and 5 flight-test aircrafts

בס"ד

Closing Comments and Thanks

- We have shown the feasibility of the suggested platform though additional analysis is required

<u>Thanks and Gratitude!!</u>

Questions?

Impact Analysis	Guidance	Control	Wing Mechanism

Impact Analysis detailed

The formulation of the dynamic response:

$$(EIu'')''+\rho A\ddot{u} = f(x,t)$$

We assume a solution:

$$u(x,t) = \gamma(x)e^{i\omega t}$$

Structural Modes:

$$(\lambda L)_n = 0, \quad 4.73, \quad 7.853, \quad 10.996, \quad 14.137, \quad 17.279 \cong \frac{2n-1}{2}\pi$$

$$\gamma^e{}_n(x) = \cosh(\lambda_n x) + \cos(\lambda_n x) - \frac{\sin(\lambda L)_n - \sinh(\lambda L)_n}{\cos(\lambda L)_n - \cosh(\lambda L)_n}(\sinh(\lambda_n x) + \sin(\lambda_n x))$$

Free Modes: $(\lambda L)_1 = 0 \rightarrow \gamma^r{}_1 = 1, \quad \gamma^r{}_2 = x$

Galerkin Method: $u = \sum_{i=1}^{N} \gamma_i(x) q_i(t) \rightarrow \int_0^L \varepsilon \cdot \gamma_i dx = 0$

Impact Analysis detailed

Semi-Discrete System: $\underline{M}\,\underline{\ddot{q}} + \underline{K}\,\underline{q} = \underline{F}$

If free modes are disregarded then the system is explicit and every equation can be solved separately:

$$m_{ii}\ddot{q}_i^{\ e} + k_{ii}q_i^{\ e} = f_i \quad \rightarrow \quad q_i(t) = \frac{f_i}{k_{ii}}\left(1-\cos\left(\sqrt{\frac{k_{ii}}{m_{ii}}}t\right)\right)$$

At the end of the impact $f = 0$ and the frequency response is:

$$q(t) = A\sin\left(\sqrt{\frac{k}{m}}t\right) + B\cos\left(\sqrt{\frac{k}{m}}t\right)$$

PN and BTT

- As explained in the PDR the guidance law is based on PN and the steering law is 90-BTT.
- This requires the homing head to give the LOS rate $\dot{\lambda}$ and the range of the target.
- The simulation will give more restrictions on the homing head.
- The combination of PN and BTT isn't trivial.

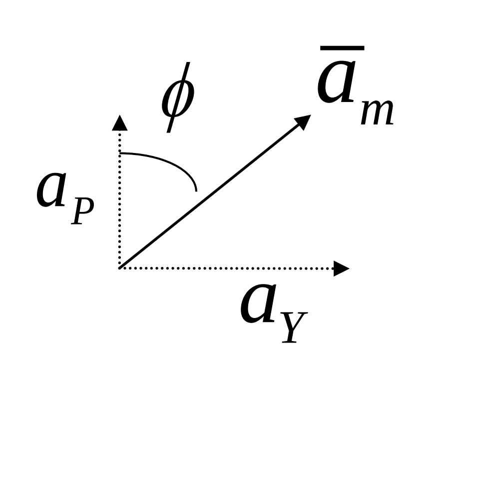
Side View–The longitude Plane

Top View – the lateral plane

PN and BTT continued

- The LOS rate is transformed to body axes. It now has a pitch rate and a lateral rate. The accel command is:

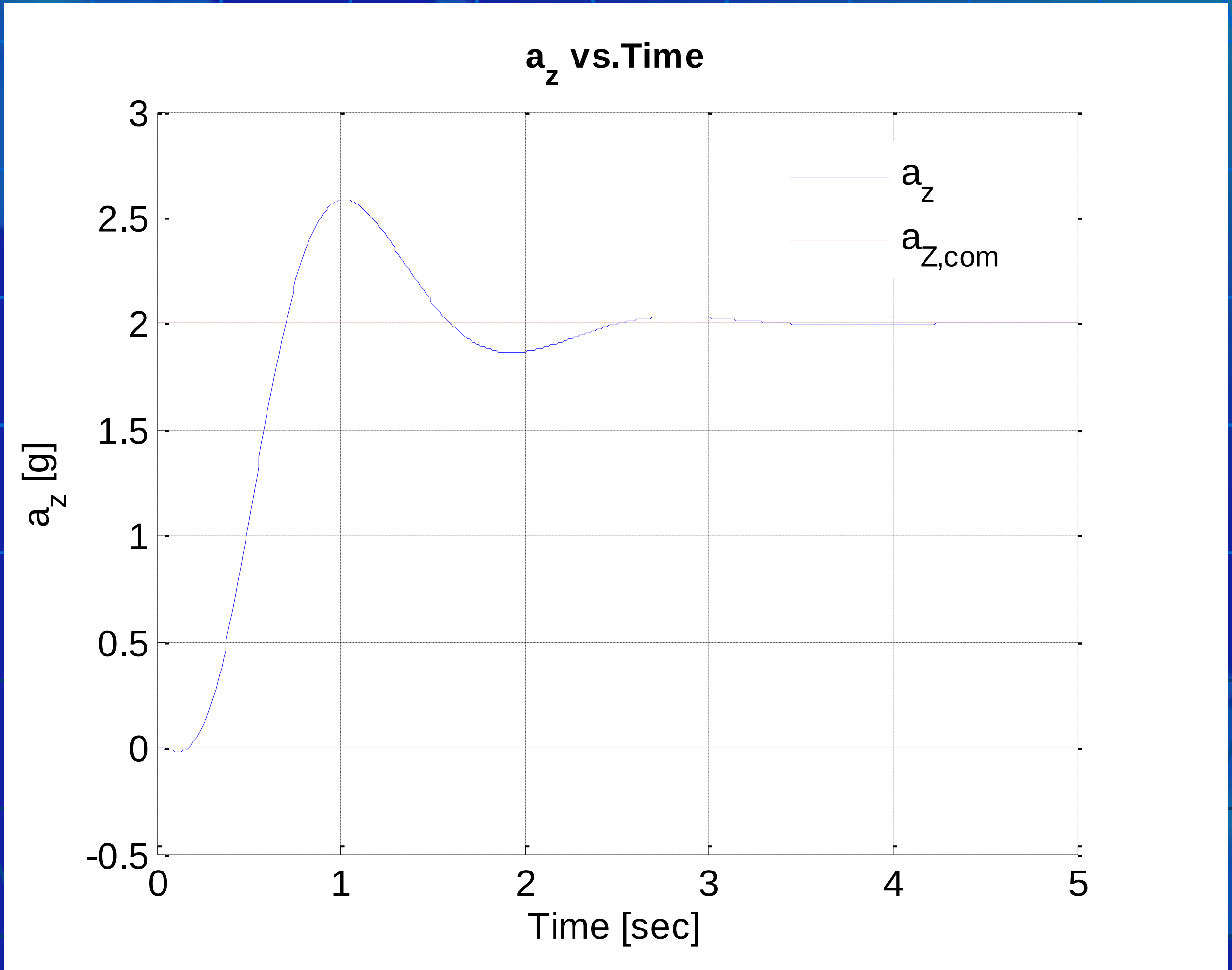
$$a_P = NV_M \dot{\lambda}_P$$
$$a_Y = NV_M \dot{\lambda}_Y$$



- The tangent trigo. function, causes over maneuvering and therefore should be avoided. We will use a licensed patent to avoid this.
- In simplified terms, the patent is to maneuver in the pitch plane according to a_{P_C} alone, and to roll according to a_{Y_C} alone.
- This eliminates the need of using trigonometric functions and produces highly accurate responses.

Dive – Longitudinal Dynamics

3 DoF Dive Simulation required a design of an az Controller.



בס"ד

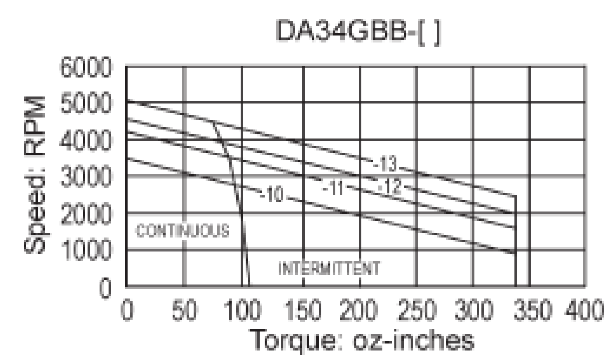
Wing Mechanism detailed

Electrical Ratings

Parameter	Symbol	Units	DA34DBB	DA34FBB	DA34HBB
Cont. Stall Torque[1]	T_C	oz-in N-m	77 0.55	134 0.95	147 1.04
Peak Torque[2]	T_P	oz-in N-m	190 1.34	335 2.37	580 4.10
Motor Constant	K_M	oz-in/√watt N-m/√watt	12.6 0.09	18.9 0.13	19.7 0.14
Elec. Time Constant	τ_E	msec	1.23	1.40	1.00
Mech. Time Constant	τ_M	msec	6.75	4.47	6.00
Rotor Inertia	J	oz-in-sec² gm-cm²	0.00913 644.8	0.0139 981.6	0.0193 1363
Thermal Resistance	R_{TH}	°C/watt	2.66	1.98	1.79
Weight	W	oz Kg	48 1.34	63 1.76	89 2.49
Motor Length	L	inch mm	3.2 80	3.7 94	4.7 119.4
# of Poles	—	—	4	4	4

Winding Data

Parameter	Symbol	Units	DA34DBB				DA34FBB				DA34HBB			
			-10	-11	-12	-13	-10	-11	-12	-13	-10	-11	-12	-13
Design Voltage	V	volts	24	48	90	160	36	48	90	160	36	48	90	160
Cont. Stall Current[1]	I_C	amperes	5.65	3.68	2.57	1.62	7.22	6.36	3.61	2.55	7.10	4.49	2.84	2.01
Peak Current[2]	I_P	amperes	17.2	10.7	7.5	4.6	21.8	20	11.6	7.4	23.7	21.8	14.1	9.3
Voltage Constant ±10%	K_E	V/kRPM V/rad/sec	8.4 0.080	13.5 0.129	19.5 0.186	31.4 0.300	11.7 0.112	12.9 0.123	22.2 0.212	35.1 0.335	18.4 0.176	20.2 0.193	31.3 0.299	47.8 0.456
Torque Constant ±10%	K_T	oz-in/amp N-m/amp	11.36 0.080	18.26 0.129	26.37 0.186	42.46 0.300	15.82 0.112	17.44 0.123	30.02 0.212	47.47 0.335	24.88 0.176	27.32 0.193	42.33 0.299	64.64 0.456
Resistance ±10%	R_M	Ohms	0.85	2	4.1	10.3	0.7	0.9	2.8	5.6	0.8	2	5	10
Inductance ±10%	L_M	mH	0.9	2.6	5	13	1.0	1.3	3.2	8.2	1.6	2.1	4.6	10.3

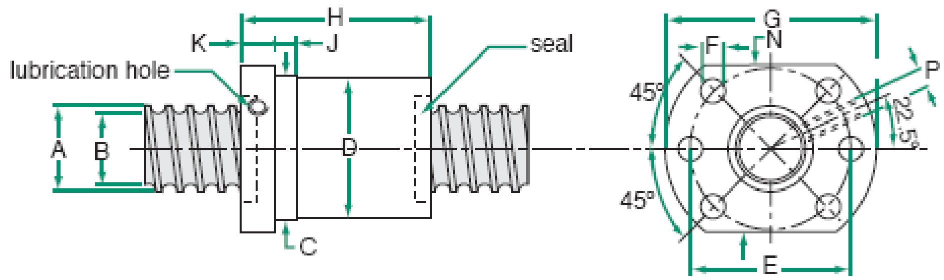


Wing Mechanism detailed

16mm Carry™ METRIC THREAD

LEAD ACCURACY: ±100μm/300mm

Carry Type FB Ball Nut



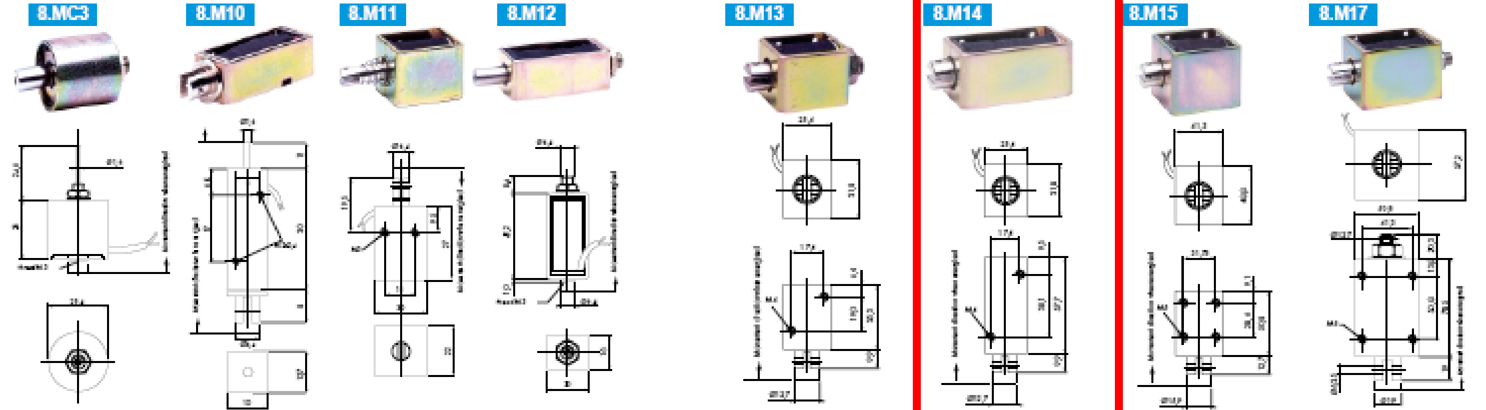
dimensions in mm

SCREW SPECIFICATIONS						NUT SPECIFICATIONS																	
dia x lead	helix	reference number*	A	B root dia	wgt. (g/m)	part number	C	D	E	F	G	H	J	K	N	P	lash	wiper **	ball return location	wgt. (g)	torque to raise 1 kN (N·m)	load rating (N) Dyn. (C_a)	load rating (N) Static (C_{oa})
16 x 2	RH	ECS-16020-RA	16.0	14.5	1416	ECN-16020-RBU	30	29.5	38	5.5	48	45	6	10	40	M6	0.06	Plastic	External	225	0.356	4500	11000
16 x 5	RH	ECS-16050-R□	15.7	13.0	1251	ECN-16050-□BU	28	27.8	38	5.5	48	45	6	10	40	M6	0.07	Plastic	Internal	160	0.889	9700	22000
16 x 10	RH	ECS-16100-RA	15.7	13.0	1251	ECN-16100-RBU	32	31.5	43	6.6	54	52	6	12	44	M6	0.07	Plastic	External	281	1.778	17000	25000

*Lengths available up to 3,000 mm. See page 154 and 174 to complete reference number **All nuts with wiper feature an M5 lubrication hole.

Wing Mechanism detailed

Small linear solenoids for standard use



Shown in energised position

For a more detailed drawing please request the specifications sheet of the product

Part number	8.MC3.11.62	8.M10.02.62	8.M11.02.52	8.M12.02.52	8.M13.02.52	8.M14.02.52	8.M15.02.52	8.M17.02.52
Nominal stroke	4 mm	3 mm	6 mm	9 mm	9 mm	12 mm	15 mm	18 mm
Absorbed power (W)	3,5 12,5 54	2 7 31	4 13,5 60	5 18 80	6,5 23 102	10,5 38 169	15 53,5 237	19 70 307
Force at beginning of stroke (N)	0,25 1,8 6,5	0,1 0,3 1,6	0,3 2,2 6,5	0,25 0,75 2,2	1 3 12	2 5 17	1 7,5 27	5 15 60
Force at end of stroke (N)	4,5 8,2 12	0,6 2 3	5 10 12,5	2,5 4 6	4 10 40	8 18 30	15 60 60	40 90 140
Duty cycle	100 % 25 % 5 %	100 % 25 % 5 %	100 % 25 % 5 %	100 % 25 % 5 %	100% 25% 5%	100% 25% 5%	100% 25% 5%	100% 25% 5%
Total length of cycle	2 mn 2 mn	2 mn 2 mn	2 mn 2 mn	2 mn 2 mn	2 mn 2 mn	2 mn 2 mn	2 mn 2 mn	2 mn 2 mn
Standard voltage	24 Vdc	24 Vdc	24 Vdc	24 Vdc	24 Vdc	24 Vdc	24 Vdc	24 Vdc
Type	Push-Pull	Push-Pull	Pull	Pull	Pull	Pull	Pull	Pull
Incorporated return spring	no	no	no	no	option on pull only	option on pull only	option on pull only	no
Plunger retainer	no	no	no	no	no	no	no	no
Total weight	70 g	20 g	55 g	60 g	160 g	250 g	570 g	1100 g
Plunger weight	7 g	4 g	5 g	10 g	35 g	65 g	85 g	145 g
Protection rating	IP00	IP00	IP00	IP00	IP00	IP00	IP00	IP00

Possible variants (please call us to define the part numbers)
Detailed technical specification sheets available on request

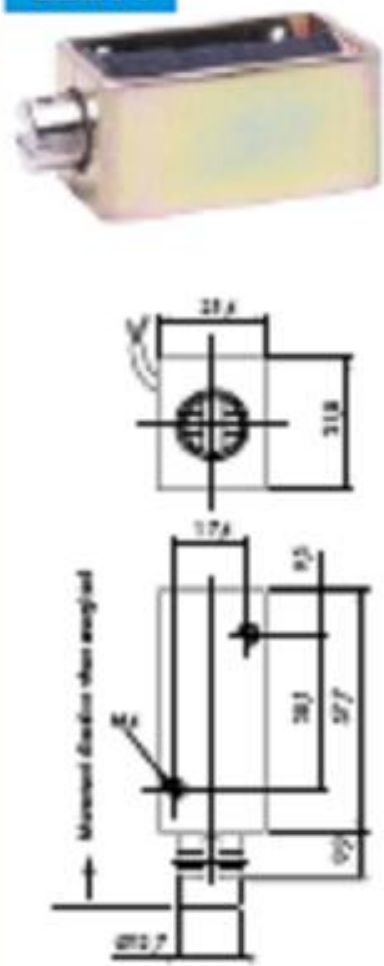
	8.MC3	8.M10	8.M11	8.M12	8.M13	8.M14	8.M15	8.M17
	Pull	Pull	Push with spring	Push	Push Push-Pull	Push Push-Pull	Push Push-Pull	Push Push-Pull
Stroke (mm)					12 mm	15 mm	18 mm	21 mm
Duty cycle 100% Force at beginning of stroke (N)					1	2	4	5
Force at end of stroke (N)					3	6	11	25
Duty cycle 5% Force at beginning of stroke (N)					13	24	31	65
Force at end of stroke (N)					25	30	51	90
Supply voltage	6 to 24 Vdc	6 to 24 Vdc	6 to 48 Vdc	6 to 110 Vdc	6 to 240 Vdc 6 to 250 Vac	6 to 240 Vdc 6 to 250 Vac	6 to 250 Vdc 6 to 250 Vac	6 to 250 Vdc
...tion								

...tant: for all orders, please specify: part number-voltage-duty cycle.

Important: for all orders, please specify: part number-voltage-duty cycle.

Wing Mechanism detailed

8.M14



8.M14.02.52		
12 mm		
10,5	38	169
2 8	5 18	17 30
100%	25% 2 mn	5% 2 mn
24 Vdc		
Pull		
option on pull only no		
250 g 65 g		
IP00		

Push Push-Pull
15 mm
2 6
24 30
6 to 240 Vdc 6 to 250 Vac