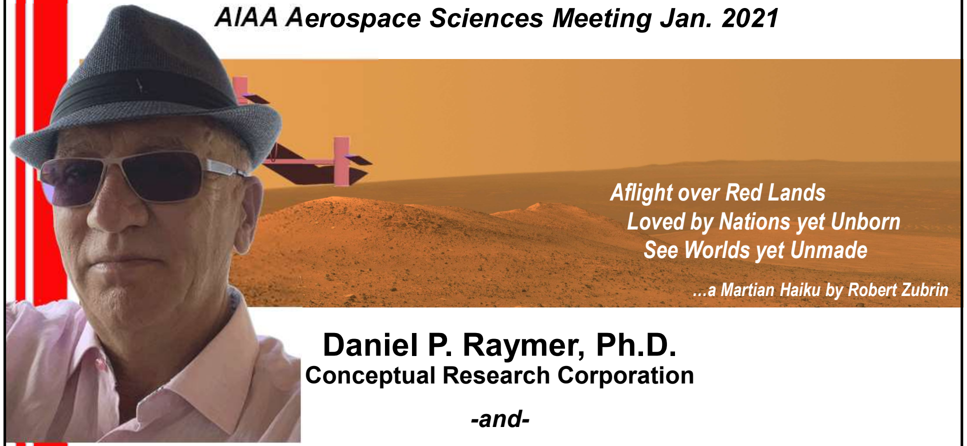
Full version, 2nd edit

The Raymer Manned Mars Airplane: A Conceptual Design and Feasibility Study

AIAA Aerospace Sciences Meeting Jan. 2021



Aflight over Red Lands
Loved by Nations yet Unborn
See Worlds yet Unmade

...a Martian Haiku by Robert Zubrin

Daniel P. Raymer, Ph.D.
Conceptual Research Corporation

-and-

James French, Felix Finger, Arturo Gómez, Jaspreet Singh, Ramlingam Gyanasampath Pillai, Matheus Monjon, Joabe Marcos de Souza, & Aviv Levy

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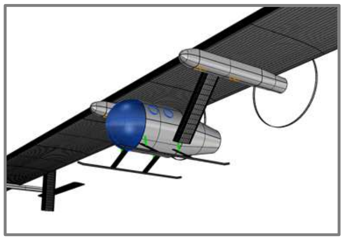


MARS PLANE – An Old Idea

- 1978 NASA concept: aeroshell entry, parachute extracts airplane, which unfolds, starts its engine, and flies away
- Single use only, cannot land and take off again
- 1999 began development with goal of Dec. 2003 arrival, cancelled
- Designed for briefly exploring Mars, not living there

Getting Around – the Manned Mars Plane

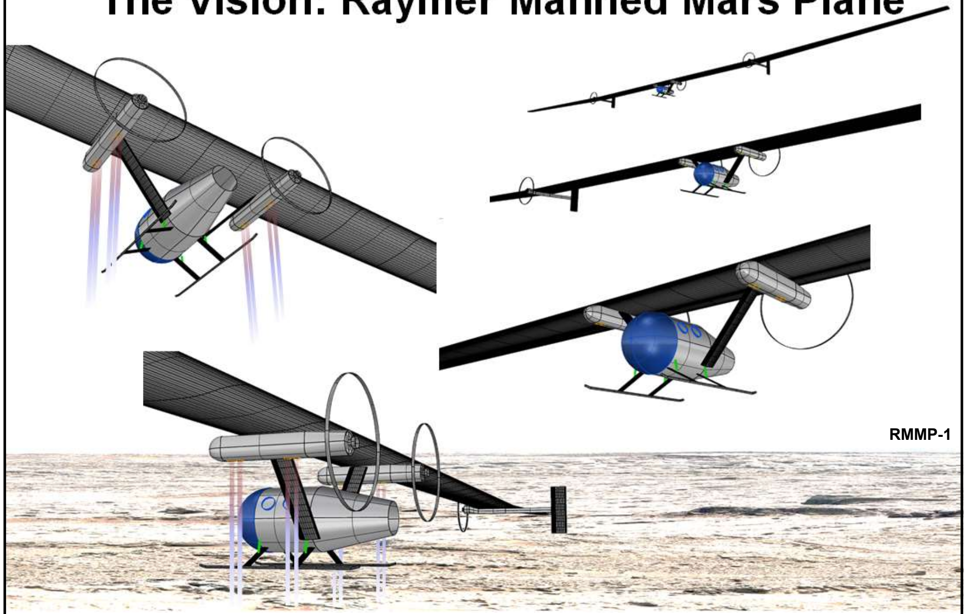
- When people are living on Mars, they'll need a way to get around

- Imagine a flying Jeep:
  - Two people or 500 lbs (unmanned)
  - Goes almost anywhere on Mars
  - Significant range (>260 nmi)
  - Adaptable, maintainable

- Assume Mars permanent base(s)
  - Available electrical energy (solar or nuclear)
  - Large pressurized buildings (inflatables?)
  - Smart people who are there to stay

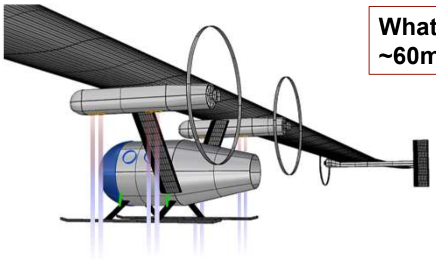
- Maybe produce the big stuff locally
  - 3-D printing with locally-sourced materials
  - Cannibalize arrival vehicle airframes for metals and electronics
  - Propellants cracked from atmosphere

The Vision: Raymer Manned Mars Plane



RMMP Operational Concept

- Optionally manned, no “pilot” – crew can command takeoff, spot landing, destination, cruise, climb, descend, turn, terrain following
- Can fly unmanned to programmed destination or under control
- Before a mission, batteries are charged from ground source
- Wing-mounted solar cells cannot fly the aircraft but can extend range (not credited), and trickle-charge batteries on the ground
- Sizing allows for two takeoff/landing cycles, so out-and-back
- Vehicle would be built mostly of bonded-together 3-D printings



What about the famous winds on Mars?
~60mph max, q=0.1 psf (~4mph here)

2030 technologies, or later!

Design Drivers, Desires, & Assumptions

Drivers:

- Insanely thin atmosphere (1.6% of Earth's sea level standard day)
- Reduced gravity (.379 of Earth) so net effect: need ~23x the lift
- Watch propeller tips – speed of sound is only 788 fps (vs. 1117)

Desires:

- Pressurized cabin with excellent field of view
- VTOL (probably required anyway due to that 1.6%)
- Good ground clearance needed for off-airbase operations

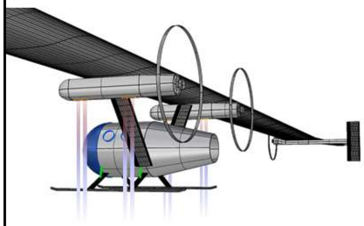
Assumptions/Decisions:

- Wing & battery-electric props for forward flight
- Wing-integral solar cells for recharging & augmentation in flight
- CO-O_2 rockets for VTOL *(defined by Jim French; thanks Jim!)*
- Consider but don't depend upon onboard propellant extraction*
- 2030 timeframe, study will determine how much the technologies must improve to make this possible

**carbon monoxide and oxygen can be produced by electrolysis from the Martian atmosphere*

RMMP International Volunteer Team

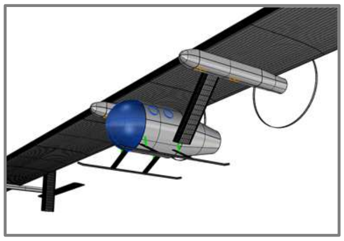
- The conceptual design and initial analysis work was done by Dr. Raymer to provide new material for a keynote presentation to the "New Space" online conference sponsored by the AIAA LA-LV Section in April 2020
- At the end of that presentation, a call was made for volunteers to carry the design and analysis effort to the next level
- Seven people volunteered, luckily covering key disciplines of aerodynamics, structures, stability & control, propulsion, and even CAD rendering – their work is included below



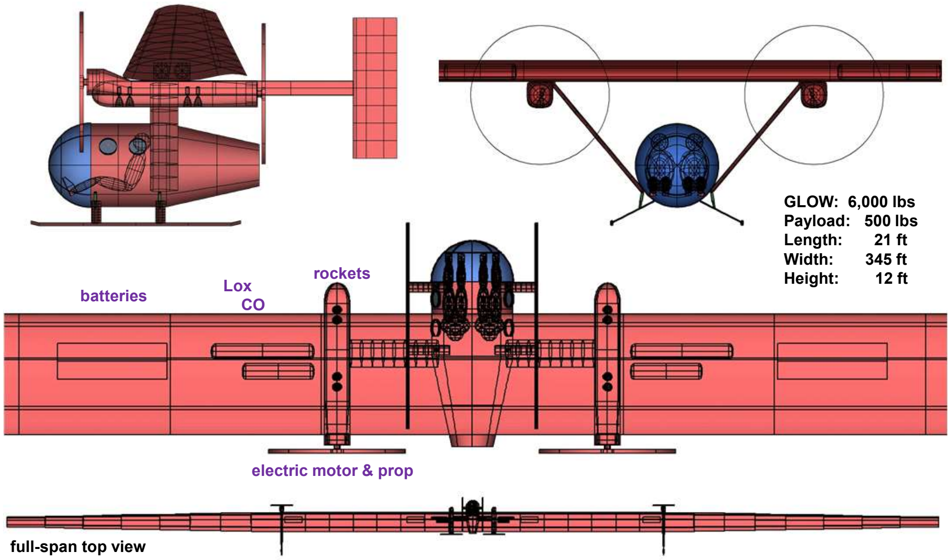
Felix Finger	*-Germany*
Arturo Gómez	*-Spain*
Jaspreet Singh	*-India*
Ramlingam G. Pillai	*-India/USA*
Matheus Monjon	*-Brazil*
Joabe Marcos de Souza	*-Brazil*
Aviv Levy	*-Israel*

Raymer Manned Mars Plane

1. Introduction & Operational Concept
2. **Initial Design Concept (RMMP-1)**
3. Aerodynamics & Airfoil Design
4. Structural Design & Analysis
5. Stability & Control Analysis
6. Takeoff and Transition Analysis
7. Propulsion and Performance
8. Cabin & Human Factors
9. Refined Design Concept (RMMP-2)
10. Summary and Next Step

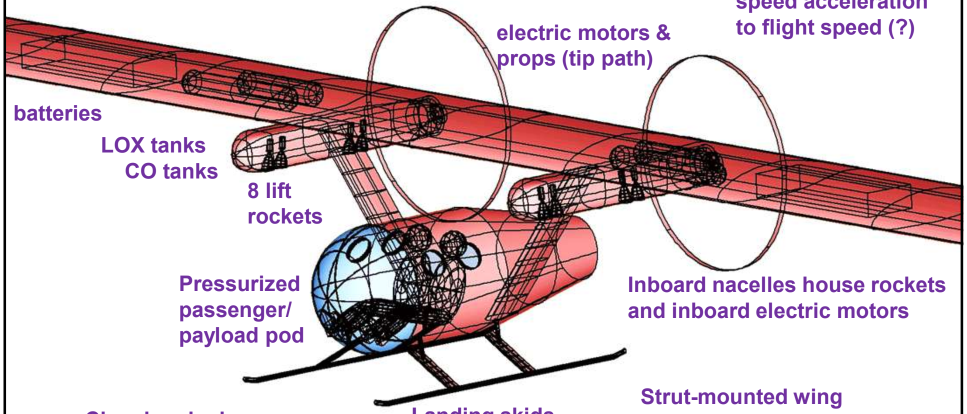


RMMP-1 General Arrangement



GLOW: 6,000 lbs
Payload: 500 lbs
Length: 21 ft
Width: 345 ft
Height: 12 ft

Design Features



Skin-integral solar cells for on-ground recharging

Add two rockets in back of fuselage to speed acceleration to flight speed (?)

electric motors & props (tip path)

batteries

LOX tanks

CO tanks

8 lift rockets

Pressurized passenger/ payload pod

Inboard nacelles house rockets and inboard electric motors

Clear hemisphere front opens as door

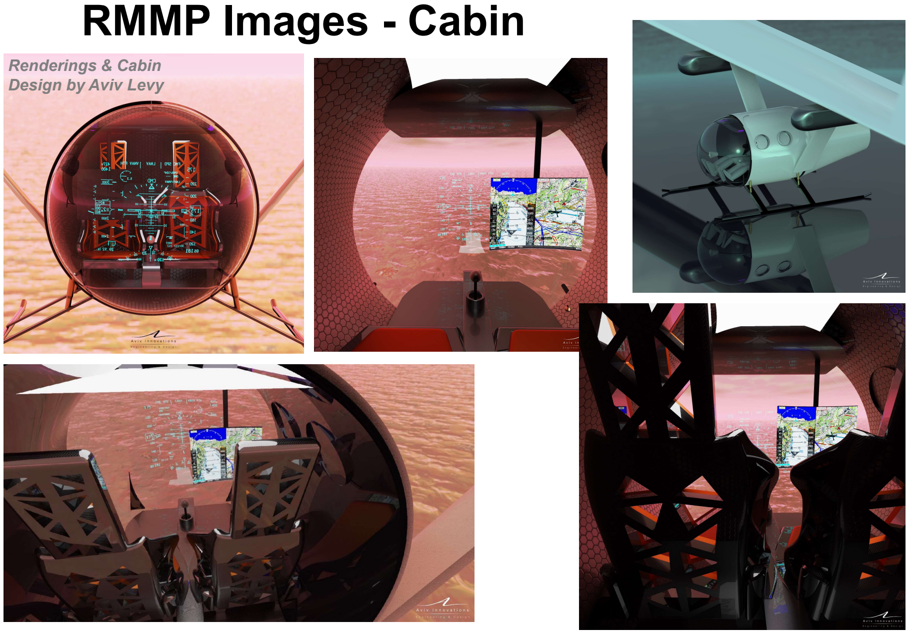
Landing skids

Strut-mounted wing arrangement provides ground clearance & avoids putting lift loads into pressure shell

RMMP Images

Renderings by Aviv Levy

RMMP Images - Cabin

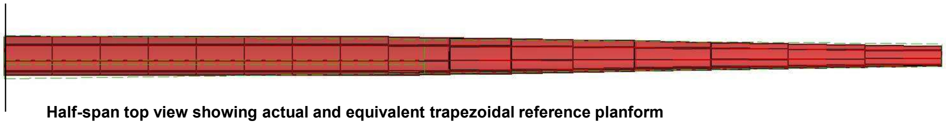


Renderings & Cabin Design by Aviv Levy

RMMP-1 Aero Surfaces

	[FPS]				[MKS]			
	Wing- Inboard	Wing- Outboard	Wing - Aero Reference	Vertical Tail	Wing- Inboard	Wing- Outboard	Wing - Aero Reference	Vertical Tail
Area Sref	1000	1080	2079.3	20	92.9	100.34	193.17	1.86
Aspect Ratio	20	38.401	57.221	3.2	20	38.401	57.221	3.2
Taper Ratio	1	0.5	0.526	1	1	0.5	0.526	1
Sweep (LE)	0	0.995	0.714	0	0	0.995	0.714	0
Sweep (c/4)	0	0.497	0.402	0	0	0.497	0.402	0
Thickness t/c	17.50%	17.50%	17.50%	15%	17.50%	17.50%	17.50%	15%
Span	141.421	203.649	344.934	8	43.105	62.072	105.136	2.438
Root Chord	7.071	7.071	7.903	2.5	2.155	2.155	2.409	0.762
Tip Chord	7.071	3.535	4.154	2.5	2.155	1.078	1.266	0.762
Mean Chord	7.071	5.5	6.222	2.5	2.155	1.676	1.897	0.762
Y-bar	35.355	45.255	77.295	4	10.776	13.794	23.56	1.219

- Advanced flow control devices used for pitch & roll control, or else large elevons
- Differential thrust for yaw control and roll augmentation



Half-span top view showing actual and equivalent trapezoidal reference planform

Wing Sizing vs Speed

- Pre-layout study varied stall speed to determine impact on required wing size
- Result: faster is better!
- V_{stall} = 115 kts, V_{cruise} = 150 kts

	Inputs		
Wing Loading	Stall speed	(kts)	115
	Takeoff air density	(slugs/ft^3)	0.000039
	Wing CLmax		1.6

Calculated Values		
Stall speed	(ft/sec)	194.2
Dynamic pressure	(psf)	0.7
W/S EarthGrav	(psf)	1.18
Eqiv W/S Mars	(psf)	3.11
Wo - lbsm Earth	(lb)	6000.0
Wing Area MarsGrav	(sq ft)	1931.9

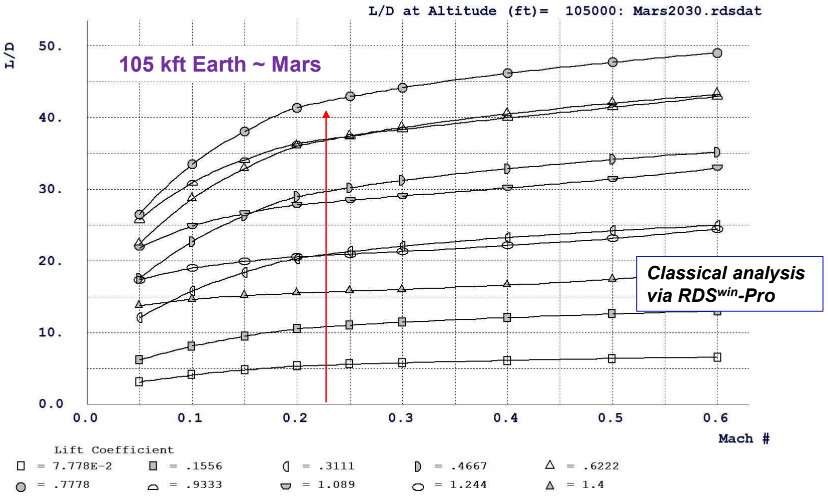
Deep Stall Landing Study

- Initial thought was to use deep stall vertical descent to landing, arrest sink rate at last second with rockets

Rocket Motor Run Time Calcs			
Deep Stall	Area projected	1931.9	
	CD	1	
	Sink rate	245.69	fps
		145.46477	kts
	engine thrust each	600	was 300
	engine Isp	260	
	# engines running	8	8 total
	decel time	18.14	
	decel distance	2228.22	BAD !
VTOL TO & Land	Assumed Time	30.0	at max
	(actually more, will be throttling up/down)		
	engine thrust each	300	
	engine Isp	260	
	# engines running	8	
	total propellant	296.99	per cycle
	# TO-Lnd cycles	2	

- Better to make level approach at just over stall speed, slow down and transition to rocket lift
- Isp of 260 sec. is conservative for 2030+, later analysis used 295

MMP-1 Lift to Drag Ratio



105 kft Earth ~ Mars

Classical analysis via RDS^{win}-Pro

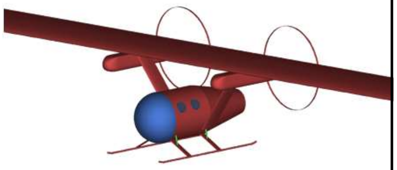
RMMP-1 Weights Buildup

We/GLOW excl batts	**0.69**
Wstructure/GLOW	**0.43**

	Weight	Loc	Moment		Weight	Loc	Moment
	lbs	ft	ft-lbs		lbs	ft	ft-lbs
STRUCTURES	**2732.0**		**18641**	**EQUIPMENT**	**640.0**		4220
Wing	1871.4	7.2	13556	Flight Controls	40.0	5.5	220
Vertical Tails	30.3	18.4	559				0
Wing Struts	125.0	6.4	806				0
Passenger Pod	253.3	4.1	1048	Electrical (incl actuators)	100.0	6.0	600
Fuselage (rest of)	75.2	9.2	695	Avionics	20.0	5.0	100
Canopy	73.8	1.5	109	Pressurization and AC	80.0	5.0	400
Nacelle Inbd	78.2	7.3	569	Solar Cells & equip	300.0	7.0	2100
Nacelle Outbd	73.5	7.5	551	Furnishings & Equipment	100.0	8.0	800
	0.0		0				
	0.0		0	(% We Allowance)	5.0		
Landing Gear	151.3	4.9	748	Empty Weight Allowance	195.8	6.8	1329
PROPULSION	**544.3**		**3719**	**TOTAL WEIGHT EMPTY**	**4112.1**	**6.8**	27909
Electric Motors (4)	52.2	7.0	368				
Motor Installation	40.0	7.0	282	**USEFUL LOAD**	**1887.9**		
Engine Controllers	41.8	7.0	294	Crew	400.0	4.1	1640
Propeller	40.0	7.0	280	Battery Wt available	834.1	7.0	5839
Battery Installation	200.0	7.0	1400				0
	0.0		0	Rocket propellant	553.8	7.0	3877
Rockets (8)	82.3	6.3	514	Payload	100.0	6.4	640
Rocket Installation	48.0	6.3	300				
Propellant tanks	40.0	7.0	280	**TAKEOFF GROSS WEIGHT**	**6000.0**	**6.7**	39905

Range, Level Flight, & Climb Calcs

Range (Level Flight):			
mb/m = battery mass fraction	0.1300	for cruise	
Esb = battery energy density {wh/kg}	500	260	
ηb2s = efficiency -battery to motor shaft	0.9		
ηp = propeller efficiency	0.8		
L/D	42		
Range {km}	1901.4	1026.7	nmi
Velocity {km/h} -not needed for Range calc	277.8	150.0	kts
Motor Power Used P/W {Watt/g}	0.0085	0.0052	hp/lb
time	6.84		



Climb Vertical Velocity			
Velocity {km/h}	277.8		
Motor Power Used P/W {W/g}	0.0318	3.72	multiplier on level flight power setting
ηb2s = efficiency -battery to motor shaft	0.9		
ηp = propeller efficiency	0.8		
L/D	42		
Vertical Velocity {m/s}	4.997	5	300 meters/60 sec
Vertical Velocity {fpm}	983.5		

- *Seems to work, and it exceeds the stated requirements*
- *Classical aero analysis methods are not reliable at these conditions - need CFD analysis*

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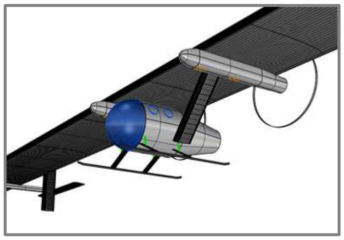
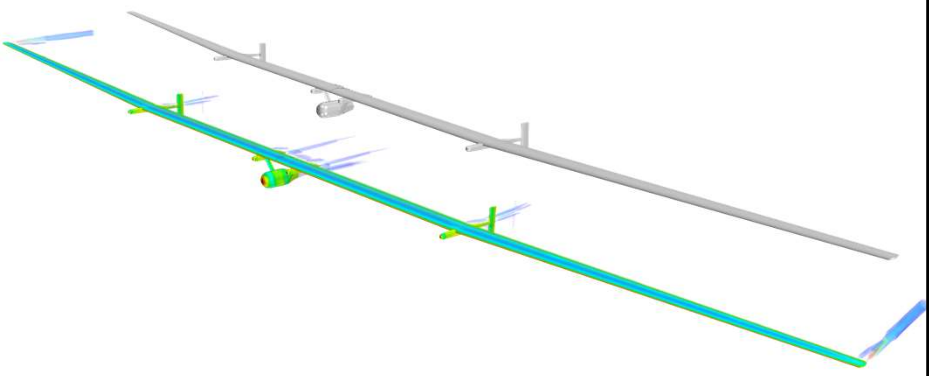


Aerodynamics & Airfoil Design

D. Felix Finger



CFD Set Up

Flow conditions and mesh

Added certain fairings to get watertight geometry and eliminate gaps, landing gear removed

Half-model (x-z axis symmetric), 21 mio cells

Bullet flow field (480 m diameter)

k-w SST turbulence model (no transition modelling)

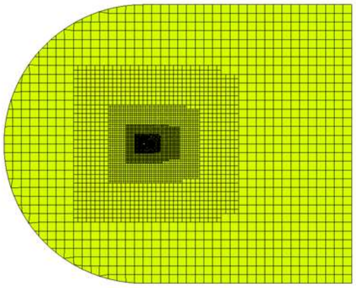
Fully resolved boundary layer (y+ <)

Constant density assumptions. since flow is only mildly compressible and memory requirements are doubled for compressible flow solver

3 runs:
2° AoA at MSL
2° AoA at 105k ft
4° AoA at 105k ft

Boundary layer thickness adjusted for Re on each part, for both ambient conditions

Parameter	105k ft	MSL
Free stream velocity V_∞ [m/s]	77.17	66
Reference pressure p_∞ [Pa]	867.5	101.325
Density ρ_∞ [kg/m^3]	0.01322	1.225
Dynamic viscosity μ [Pa·s]	$1.4869 \cdot 10^{-5}$	$1.812 \cdot 10^{-5}$
Reynold's number Re [-]	$0.142 \cdot 10^{6}$	$9.593 \cdot 10^{6}$
Turbulence intensity (inlet) [-]	1%	1%
Turbulent viscosity ratio (inlet) [-]	10	10



CFD Set Up

Mesh

Mesh resolution is sufficient on fuselage and nacelles

Wing's mesh resolution could be higher in chordwise direction

Typical high AR and low W/S problem

Initial analysis was memory limited to 32 GB (ran on workstation)

CFD Results

Data

Wing drag is dominant for all cases (>90% of total drag, incl. induced drag)

L/D at MSL is as high as expected

L/D at 105k ft is much lower than expected

Increasing AoA at 105k ft does not give higher L/D

→ Low Re problem

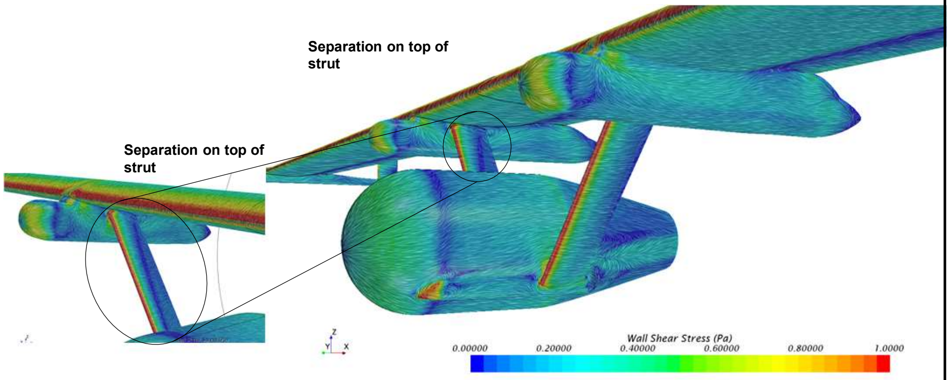
Landing gear drag is not yet included – L/D will be further reduced

Parameter	MSL 2deg	105k ft 2deg	105k ft 4deg
CL	0.891	0.749	0.937
CD	0.01823	0.03456	0.04559
L/D	48.88	21.67	20.55
CD Wing	0.01679	0.03200	0.04269
CD Nacelle inner	0.00032	0.00052	0.00059
CD Nacelle outer	0.00011	0.00028	0.00053
CD Fuselage	0.00055	0.00095	0.00093
CD Struts	0.00021	0.00045	0.00049
CD Vertical Tails	0.00025	0.00036	0.00036

(but this is with "placeholder" airfoil, not R#-optimized airfoil as discussed below)

CFD Results

Problem areas 1 – 105k ft conditions



Separation on top of strut

Separation on top of strut

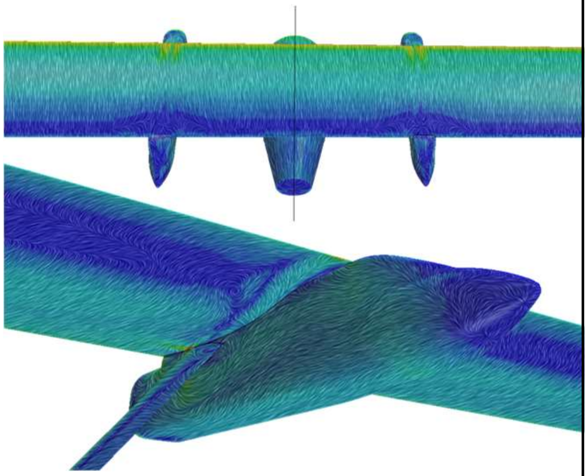
CFD Results

Problem areas 2 – 105k ft conditions

Trailing edge separation on the wing’s top surface

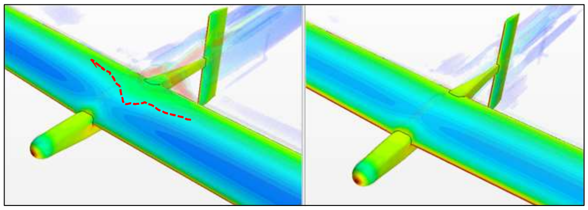
Separation at the wing’s cusp

Strut-wing-nacelle junction needs refinement to eliminated vortices and separation



CFD Results

Problem areas 3 – 105k ft conditions



Separation at 4deg (left) vs. normal interference at 2deg (right)
Pressure coefficient distribution, vortices visualized with the Q-criterion

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CFD Results

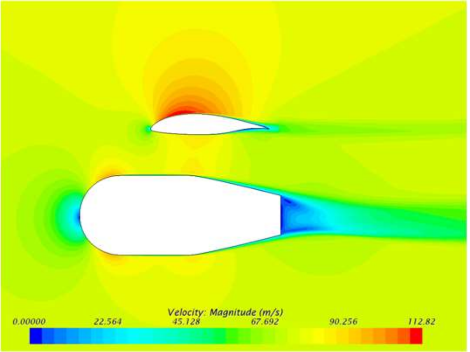
Fuselage base drag – 150k ft conditions

Data for the cut-off fuselage at 2° AoA:

Total drag: 9.5 drag cts
Pressure drag: 5.9 drag cts
Shear drag: 3.6 drag cts

Pressure drag dominates

Next step: compare to properly streamlined geometry



Symmetry Plane – Velocity Contours

Conclusions

Low Re design problem

Design of the RMP is driven by wing design. Fraction of fuselage, strut, VT, and nacelle drag is very low, compared to the impact of the wing.

Very low Re in thin Mars atmosphere causes separation and higher than anticipated drag

Recommendations for next steps:

1. **Define pitching moment requirements**

2. **2D airfoil design to get rid of laminar separation bubbles**
   - → **Typical low Re airfoils are thin (t/c < 12%)**
   - → **Conflict with high t/c that is required by high AR**
   - → **Maybe look into multi-section airfoils (IAI Heron, Selex Falco)?**

3. **Analyze wing only**

4. **Once wing is OK, add fuselage and the rest of the attachments and refine the analysis**

RMMP Custom Airfoils

Approach to airfoil design V1

Analyzed airfoils for human powered flight. Unsuitable. All optimized for Re > 200,000

RMMP Re < 150,000

Used optimization in Xfoil to find airfoil geometries for the Re-range of the RMMP (Re# 100k…200k).

4 custom airfoils: 10%, 12%, 14%, 16% thickness ratio

Because of the low-Re conditions, less t/c significantly increases performance

Optimizer converged on “bumpy” airfoils, results didn’t look right at the first glance

Turns out, the bumps are used to limit the extend of the laminar separation bubbles

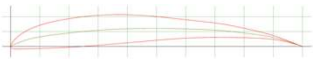
Because L/D from Xfoil is unreliable, airfoils were analyzed at 5 different angles of attack using a 2D RANS method (incl. transition modeling) at a fixed Re# = 147k

2D Results are presented on the next slides

D. Felix Finger

RMMP Custom Airfoils

Overview V1

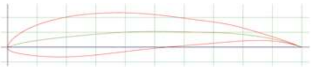


RMMP 10

Max thickness 10.1% at 28.8% chord **Max camber 6% at 48.3% chord**

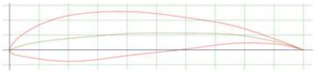
RMMP 12

Max thickness 12% at 28.5% chord **Max camber 5% at 48.2% chord**



RMMP 14

Max thickness 14% at 27.6% chord **Max camber 5.2% at 49.6% chord**



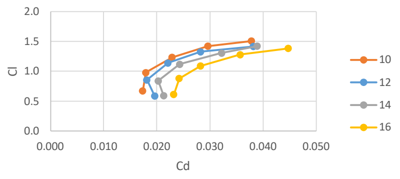
RMMP 16

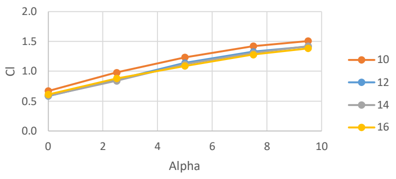
Max thickness 16% at 27.1% chord **Max camber 5.6% at 49.1% chord**

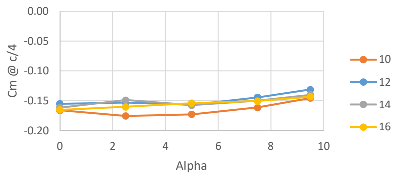
	10% t/c				12% t/c				14% t/c				16% t/c			
	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D
0,0	0,6700	0,01737	-0,1660	38,57	0,5883	0,01962	-0,1550	29,99	0,5917	0,02130	-0,1615	27,78	0,6149	0,02317	-0,1650	26,54
2,5	0,9795	0,01795	-0,1751	54,56	0,8556	0,01814	-0,1532	47,17	0,8384	0,02027	-0,1490	41,36	0,8795	0,02423	-0,1601	36,30
5,0	1,2326	0,02290	-0,1729	53,83	1,1391	0,02212	-0,1567	51,50	1,1174	0,02433	-0,1575	45,92	1,0876	0,02822	-0,1539	38,54
7,5	1,4221	0,02960	-0,1613	48,04	1,3285	0,02827	-0,1444	46,99	1,3046	0,03220	-0,1500	40,51	1,2803	0,03569	-0,1506	35,88
9,5	1,5103	0,03783	-0,1452	39,92	1,4182	0,03816	-0,1311	37,17	1,4224	0,03889	-0,1400	36,57	1,3859	0,04476	-0,1434	30,96

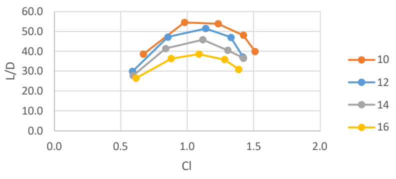
RMMP Custom Airfoils

Overview V1









RMMP Custom Airfoils

Comments on airfoil performance V1

Cl data looks promising. High Cl_{max} (>1.5) seems achievable for all airfoils (stall was not studied). Compares positively to the initial RMMP assumptions

High pitching moment is required to get that high lift performance.
$Cm_{c/4}$ varies between -0.15 and -0.17 Could be problematic for stability and control.

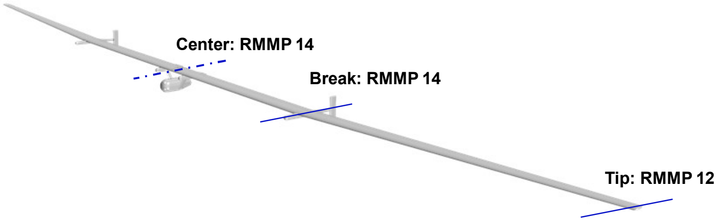
L/D data is not as good as expected. The low Re conditions take their toll.
L/D_{max} of the thinnest airfoil is 54. Very hard to get an aircraft L/D of 44 with such airfoil performance.

RMMP Custom Airfoils

Complete aircraft analysis V1

To assess the 3D performance of a wing with the new airfoils an updated simulation was carried out.

New wing:



Very optimistic with respect to structural strength and stiffness

CFD Results

3D Data at 105k ft V1

AOA	2deg	4deg
CL	0,866	1,02
CD	0,02775	0,03265
L/D	31,21	31,24
CD Wing	0,02566	0,03034
CD Nacelle inner	0,00052	0,00062
CD Nacelle outer	0,00031	0,00048
CD Fuselage	0,00054	0,00047
CD Struts	0,00036	0,00038
CD Vertical Tails	0,00036	0,00036

Reference: NASA airfoil L/D: ~21
Invisicd + friction L/D: ~44

Got a 50% L/D improvement over NASA NLF1 airfoil from using the new airfoils. Higher benefit is obtainable by reducing t/c. Challenge: Structures.

RMMP Custom Airfoils

Outlook V1

Doubling Re would bring the RMMP into the human-powered aircraft Re-range
→ Much improved performance

Iterate design to get larger Re?
- **Higher Re could be obtained by smaller AR and/or lower W/S**
- **Deeper wings could help to facilitate lower t/c**
- **Trade study for AR is not straightforward because low-Re drag estimation is challenging**

RMMP Custom Airfoils

Approach to airfoil design V2

→ Worked the optimization pipeline in Xfoil again to find airfoils for 150% of the Re-range of the RMMP (Re 150k … 300k).

4 custom airfoils: 11%, 12%, 14%, 16% thickness ratio (The 10% t/c constraint converged to an 11% thickness ratio)

Again, the new 150% airfoils were analyzed at 5 different angles of attack using a 2D RANS method (incl. transition modeling) at a fixed Re# = 221k

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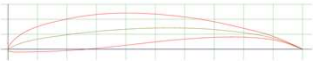
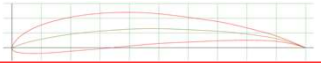
RMMP Custom Airfoils

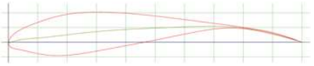
Overview V2



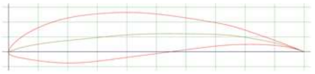
RMMP 150 11
Max thickness 11.3% at 30.6% chord Max camber 7.1% at 55.2% chord



RMMP 150 12
Max thickness 12% at 30.1% chord Max camber 6.5% at 48.4% chord



RMMP 14
Max thickness 14% at 22.6% chord Max camber 5.4% at 68.7% chord

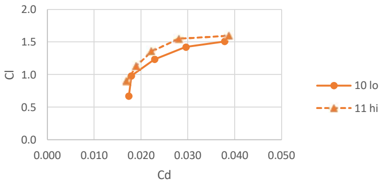


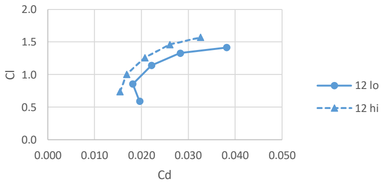
RMMP 16
Max thickness 16% at 28.2% chord Max camber 6.1% at 43.7% chord

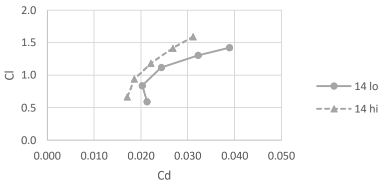
	11% t/c - Re 150%				12% t/c - Re 150%				14% t/c - Re 150%				16% t/c - Re 150%			
	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D
0,0	0,8980	0,01695	-0,2241	52,99	0,7366	0,01542	-0,1859	47,7830	0,66746	0,0171	-0,18	39,08	0,7020	0,01902	-0,1851	36,90
2,5	1,1301	0,01901	-0,2160	59,46	1,0046	0,01682	-0,1835	59,7234	0,94100	0,0186	-0,17	50,62	0,9604	0,02071	-0,1830	46,38
5,0	1,3563	0,02220	-0,2111	61,08	1,2603	0,02070	-0,1820	60,8905	1,18371	0,0221	-0,17	53,54	1,1892	0,02417	-0,1784	49,20
7,5	1,5493	0,02808	-0,2006	55,18	1,4625	0,02601	-0,1729	56,2217	1,41376	0,0268	-0,16	52,77	1,3694	0,03047	-0,1708	44,94
9,5	1,5976	0,03882	-0,1798	41,16	1,5713	0,03257	-0,1597	48,2368	1,59149	0,0311	-0,16	51,22	1,4702	0,03744	-0,1602	39,27

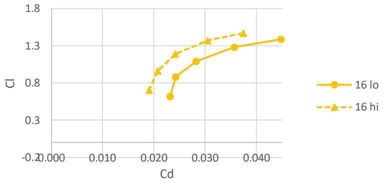
RMMP Custom Airfoils

Overview low Re vs. high Re



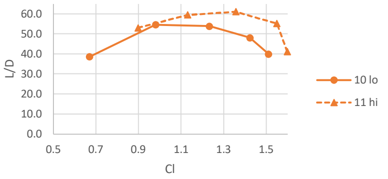


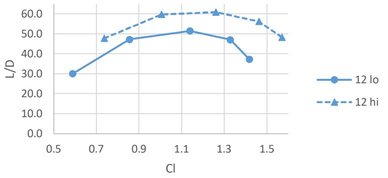


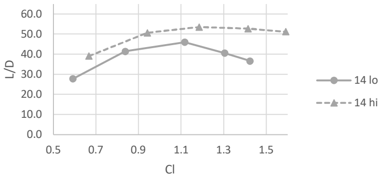


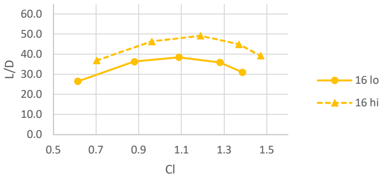
RMMP Custom Airfoils

Overview low Re vs. high Re









RMMP Custom Airfoils

Comments on airfoil performance V2

Higher Re allows higher Cl_{max}, so the target of Cl_{max} >1.5 seems reasonable for the 150% airfoils (stall was not studied).

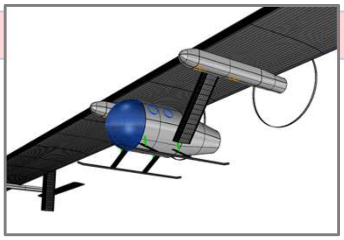
$Cm_{c/4}$ for the high-Re airfoils is even higher than for the low-Re airfoils

Optimizer found a loophole for the 14% high-Re airfoil. Extremely thin trailing edge seems impractical for structures.

L/D is much improved. Still, the whole-aircraft L/D of 44 is challenging to reach for t/c > 12%.
AR - W/S – t/c trade studies necessary

D. Felix Finger

Raymer Manned Mars Plane



WING STRUCTURAL ARCHITECTURE

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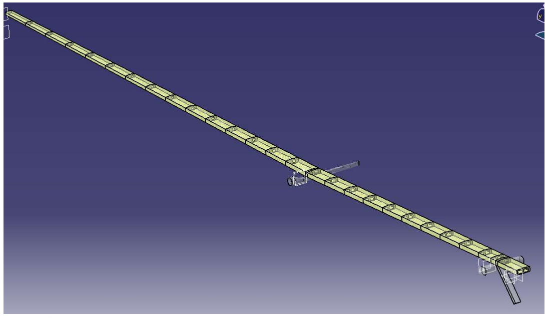
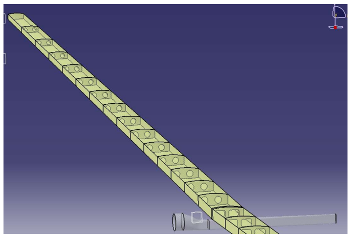
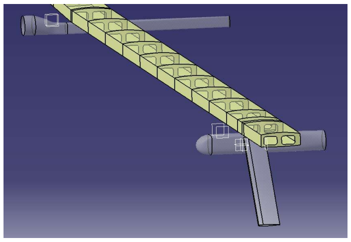
V1 Basic architecture

Single Wing-Box divided in two sections (Inboard, Outboard)

- 2 Spars, CFRP, Woven, [0,45,90,45,0]4 (inb) t=4mm , [0,45,90,45,0]2 (out) t=1.56mm
- Skin, CFRP, UD, [0_3, 45,-45,0_3]_2 (inv) t=2mm, [0_2, 45,-45,0_2]_2 (out) t= 1.56
- 30 ribs, CFRP, Woven, [0,45,-45,90]s t=1.56. (x3 extra ribs for strut, and nacelles)







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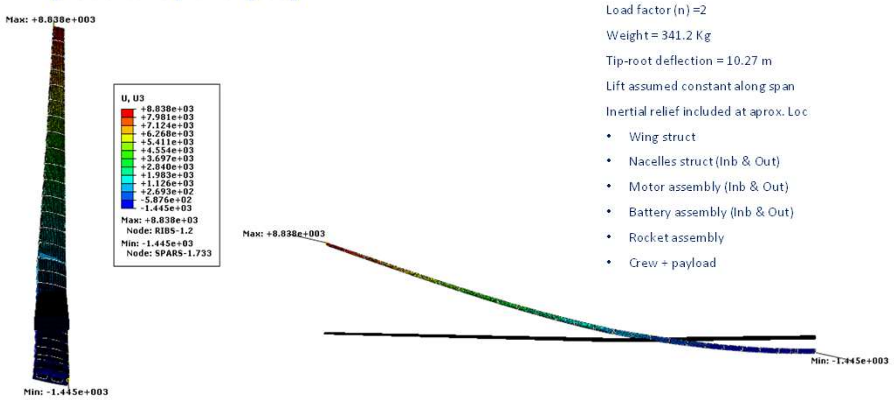
V1 (Feasibility analysis)



FEA linear-static

Load factor (n) =2

Weight = 341.2 Kg

Tip-root deflection = 10.27 m

Lift assumed constant along span

Inertial relief included at aprox. Loc

- Wing struct
- Nacelles struct (Inb & Out)
- Motor assembly (Inb & Out)
- Battery assembly (Inb & Out)
- Rocket assembly
- Crew + payload

Ideas / Requests

- Who is going to design the fuselage structure and the struts?
- Define tail-boom/wing structural interaction (Mohammed – Arturo)
- Determine H. stabilizer load during symmetrical manoeuvre loads (Mohammed)
- Define battery size and Y_loc
- Define propellant tank size and Y_loc

- Wing structural response highly dominated by inertial relief and spanwise weigth distribution.

V-n diagram (Sailplane)

Assumptions:

$$n = 1 \pm \left[\frac{\left(\frac{k}{2}\right) \rho_o \, U V a}{\left(\frac{mg}{S}\right)} \right]$$

Gust speed at VB
10 m/s
Gust speed at VD
30 m/s

where:

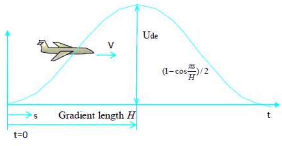
ρ_o = density of air at sea-level (kg/m^3)
U = gust velocity (m/s)
V = equivalent air speed (m/s)
a = slope of wing lift curve per radian
m = mass of the sailplane (kg)
G = acceleration due to gravity (m/s^2)
S = design wing area (m^2)
k = gust alleviation factor calculated from the following formula:

$$k = \frac{0{\cdot}88\mu}{5{\cdot}3 + \mu}$$ where:

$$\mu = \frac{2\frac{m}{S}}{\rho \, lm \, a}$$ (non-dimensional sailplane mass ratio

where:

ρ = density of air (kg/m^3) at the altitude considered
lm = mean geometric chord of wing (m)



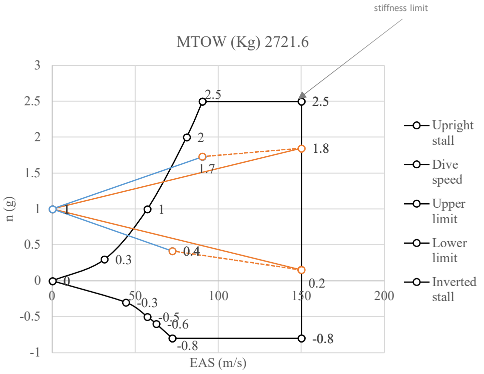
$$U = \frac{U_{de}}{2}\left(1 - \cos\frac{\pi \cdot s}{H}\right)$$

V-n diagram (Sailplane)

Assumptions:

ρ (Kg/m3)	0.02	Atmosphere density
g (m/s2)	3.71	gravity acceleration
MTOW (Kg)	2721.6	Maximum take off weight
FWD C.G		Forward centre of gravity
S (m2)	193.2	Wing area
MAC (m)	1.9	Mean aerodynamic chord
l_t		Tail arm
S_t		Tail area
n_1 (g)	2.5	Max. Positive normal acceleration
n_3 (g)	-0.8	Max negative normal acceleration
Vc (m/s)	77.2	Design cruise speed
VD (m/s)	150	Design dive speed

dCL/dα (per radian)	4.967	Airplane´s lift curve slope
CL_max	1.6	Maximim lift coefficient
CL_min	-0.8	Minimum lift coefficient
CD_min	0.01453	Minimum drag coefficient



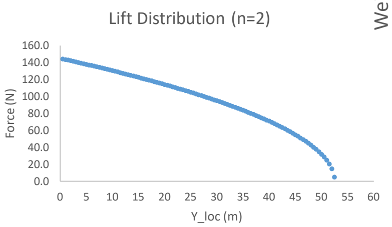
Weight and Lift distribution

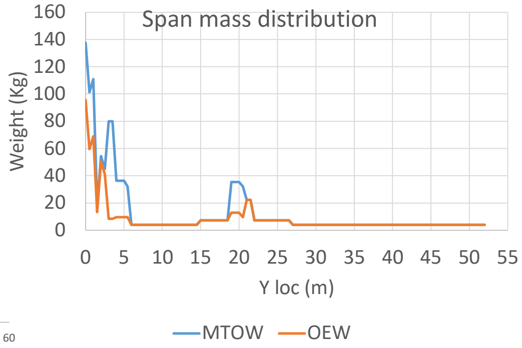
Assumptions:

Solar panels at 15m <Y> 27m (inertial relief)

Wing structure mass uniformly distributed

	MTOW	OEW
Y_CG (m)	12.50	15.99
I_yy (Kg.m2)	268311.3	215947





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SF and BM diagrams

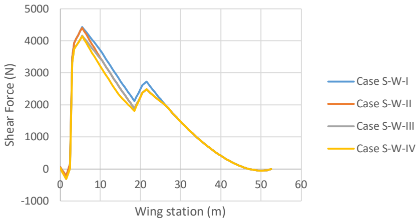
Assumptions:

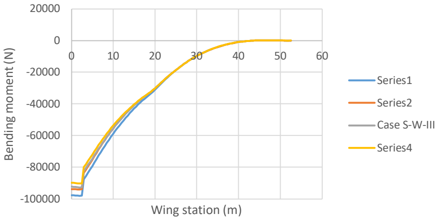
All cases at n=2

4 different solar panel locations

0-10m
0-5m & 22-27m
5-10m & 22-27m
15-20m & 22-27m

Locating the solar panels outboard decreases max SF and BM in symmetric pull-up manoeuvre





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V2 Basic architecture (modifications)

Single Wing-Box divided in two sections (Inboard, Outboard)

2 Spars: CFRP 8552/IM7, UD,

- Inb: [45,-45,0_3,90]_4, t=3.14 mm
- Out: [45,-45,0_3,90]_2, t=1.57mm

Skin: CFRP 8552/IM7, UD

- Inb: [0_2, 45, 60, -60, -45,0_3]_s, t=2.36 mm,
- Out: [0_2, 45, 60, -60, -45,0_3]_s, t= 2.36 mm

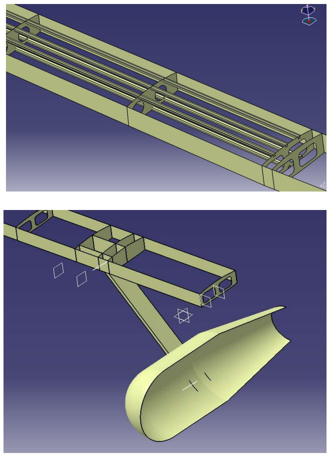
Ribs: CFRP 8552/AS4, Woven. 30 ribs (+3 extra ribs for strut, and nacelles)

- [0,45,-45,90] t=0.8 mm.

Stringers

- Out (x6), Hat H=30mm, CFRP 8552/AS4 [0]_2

Strut WB and Fuselage (modelled as rigid body)



V2 (Feasibility analysis)

FEA linear-static

Load factor (n) =2

Weight = 404 Kg

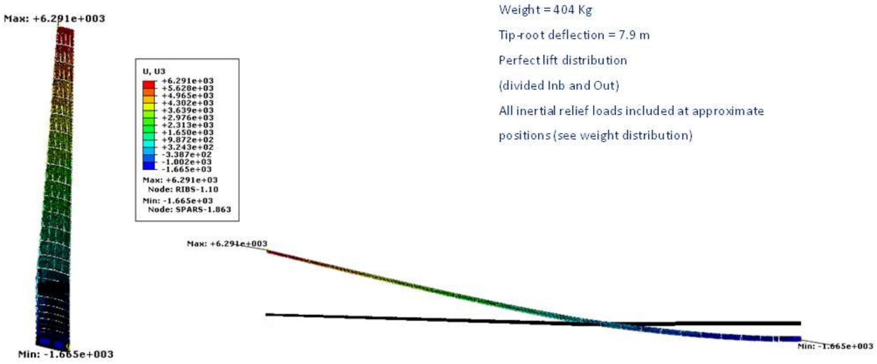
Tip-root deflection = 7.9 m

Perfect lift distribution

(divided Inb and Out)

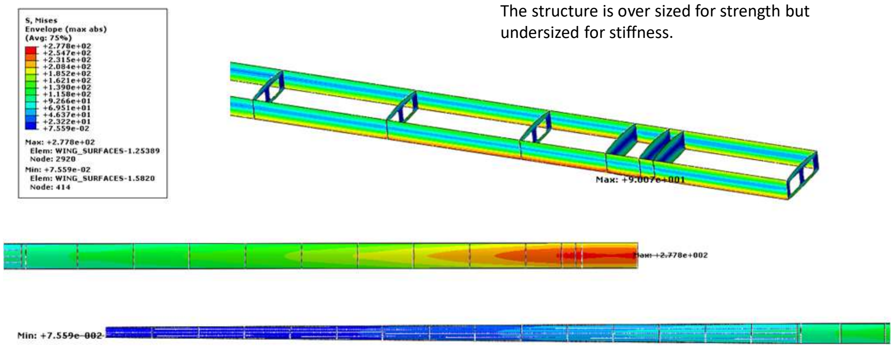
All inertial relief loads included at approximate

positions (see weight distribution)



V2 (Feasibility analysis)

Max. Hashin's failure = 0.025
The structure is over sized for strength but undersized for stiffness.



Ideas / Requests

- Tip deflection is a **L^4** function of wing span and a **h^2** function of airfoil max_thickness.
- Compromise between aerodynamic wing aspect ratio and structural efficiency. Spar height is too small (very low moment of inertia). Decrease in span-wise and increase in the chord should provide lower bending moments and higher moment of inertia. Therefore structural dead weight will be improved. (AR=**20** Si2, RMMA=**57**).
- A positive dihedral angle in the platform wing seems unnecessary if the wing deflection is considered
- What is the max allowable tip deflection and twist angle?
- The structure could be strengthen by adding weight however weight objectives could be badly harmed.
- We can start doing now a preliminary aeroelastic analysis with the current V2 configuration
- More detailed aerodynamic data is required for a more detailed analysis (Lift distribution, AC loc, Cm, tail load, etc…)
- For analysing take-off condition I may require:
  - Exact location of the rocket nozzles. Vector inclination
  - Thrust history (for dynamic analysis) or max_load factor for static analysis

Materials analysed

Hexcel 8552S AS4 3K plain weave		Hexcel 8552S AS4 3K unidirectional		Hexcel 8552 IM7 3K unidirectional		Hexcel 8552 HM63 12K unidirectional		Hexcel 8552 IM7 3K unidirectional	
T (C)	21	T (C)	21	T (C)	21	T (C)	21	T (C)	-54
Property	**g/cc**	**Property**	**g/cc**	**Property**	**g/cc**	**Property**	**g/cc**	**Property**	**g/cc**
ρ	1.57	ρ	1.57	ρ	1.58	ρ	1.58	ρ	1.58
ELASTIC PROPERTIES (in plane)		**ELASTIC PROPERTIES (in plane)**		**ELASTIC PROPERTIES (in plane)**		**ELASTIC PROPERTIES (in plane)**		**ELASTIC PROPERTIES (in plane)**	
Property	**MPa**	**Property**	**MPa**	**Property**	**MPa**	**Property**	**MPa**	**Property**	**MPa**
E_1	64742	**E_1**	123589	**E_1**	151512	**E_1**	231319	**E_1**	147755
E_2	64363	**E_2**	138550	**E_2**	9308	**E_2**	9067	**E_2**	10308
G_12	4964	**G_12**	4826	**G_12**	4688	**G_12**	5929	**G_12**	5929
v12	0.046	**v12**	0.3185	**v12**	0.336	**v12**	0.316	**v12**	0.316
v21 c	0.054	**v21 c**	0.029	**v21 c**	0.024	**v21 c**	0.028	**v21 c**	0.028
STRENGTH PROPERTIES		**STRENGTH PROPERTIES**		**STRENGTH PROPERTIES**		**STRENGTH PROPERTIES**		**STRENGTH PROPERTIES**	
Property	**MPa**	**Property**	**MPa**	**Property**	**MPa**	**Property**	**MPa**	**Property**	**MPa**
F_1 tu	769	**F_1 tu**	1928	**F_1 tu**	2206	**F_1 tu**	2489	**F_1 tu**	2434
F_1 cu	844	**F_1 cu**	1484	**F_1 cu**	1731	**F_1 cu**	1351	**F_1 cu**	2013
F_2 tu	753	**F_2 tu**	64	**F_2 tu**	64	**F_2 tu**	45	**F_2 tu**	66
F_2 cu	781	**F_2 cu**	268	**F_2 cu**	286	**F_2 cu**	381	**F_2 cu**	381
F_12	56	**F_12**	92	**F_12**	91	**F_12**	100	**F_12**	78

V3 (Feasibility analysis)

FEA linear-static

Load factor (n) =1 (normal flight condition)

Weight = 371 Kg (out of 424 Kg available)

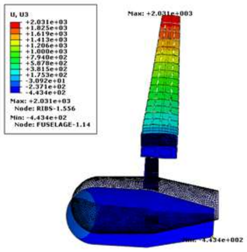
Tip-root deflection = 2.03 m

Elliptical lift distribution

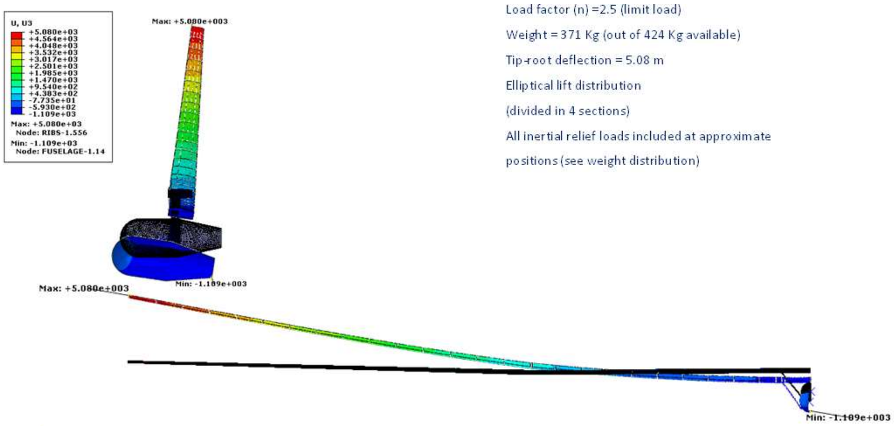
(divided in 4 sections)

All inertial relief loads included at approximate

positions (see weight distribution)



V3 (Feasibility analysis)



FEA linear-static

Load factor (n) =2.5 (limit load)

Weight = 371 Kg (out of 424 Kg available)

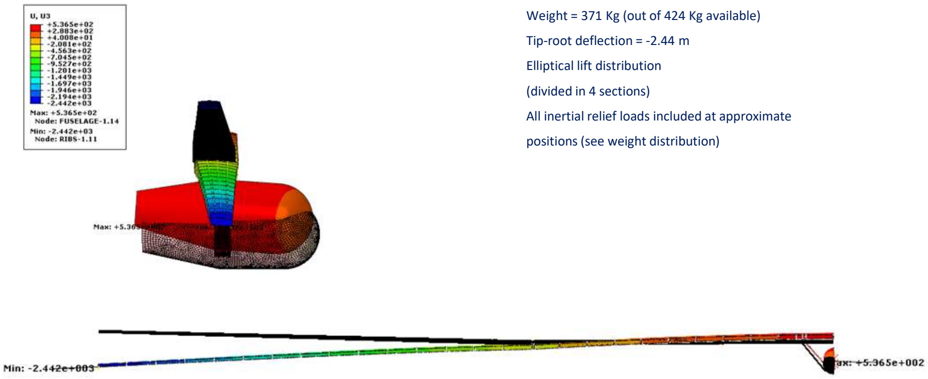
Tip-root deflection = 5.08 m

Elliptical lift distribution

(divided in 4 sections)

All inertial relief loads included at approximate positions (see weight distribution)

V3 (Feasibility analysis)



FEA linear-static

Load factor (n) =-0.8 (ultimate load)

Weight = 371 Kg (out of 424 Kg available)

Tip-root deflection = -2.44 m

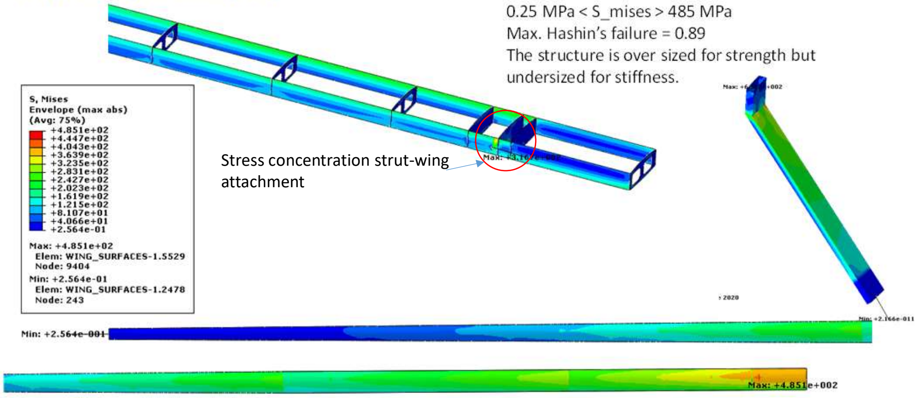
Elliptical lift distribution

(divided in 4 sections)

All inertial relief loads included at approximate positions (see weight distribution)

V3 (Strength analysis)

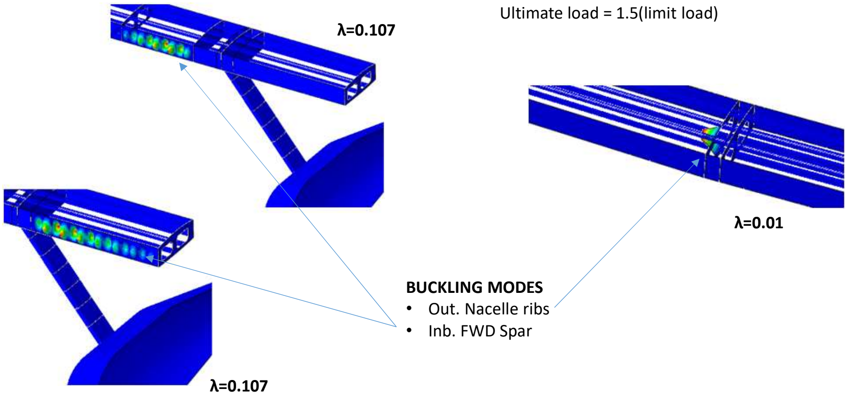
n=2.5 (ultimate load)
0.25 MPa < S_mises > 485 MPa
Max. Hashin's failure = 0.89
The structure is over sized for strength but undersized for stiffness.



Stress concentration strut-wing attachment

V3 (Buckling analysis)

n=-0.8 (symmetric)
V=72.3 m/s
Ultimate load = 1.5(limit load)

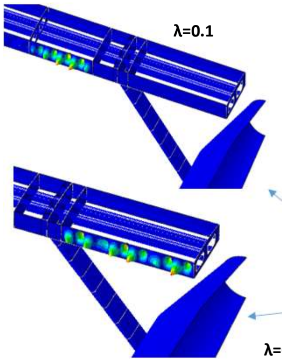


BUCKLING MODES

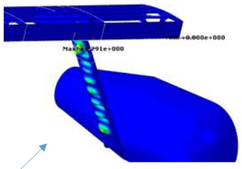
- Out. Nacelle ribs
- Inb. FWD Spar

V3 (Buckling analysis)

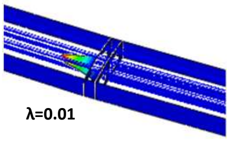
n=2.5 (symmetric)
V=72.3 m/s


λ=0.1

λ=0.1


λ=0.2

BUCKLING MODES
- Strut wing-box
- Out. Nacelle ribs
- Inb. FWD Spar


λ=0.01

Arturo Gómez

Fuselage Structural Analysis

Jaspreet Singh

- The pressurized crew cabin is sized for two occupants wearing suitable pressure suits for the Mars environment. In order to estimate the weight and thickness of the shell structure, key benchmarks like pressurized high altitude earth-bound gliders and early manned spacecraft cabins were closely studied to gather an understanding of both the operating pressures and pressure vessel weights as prior art.
- The crew cabin is designed using the ASME codes [1] as a composite overwrapped pressure vessel [2].
- The cabin is divided into hemispherical, cylindrical and isotensoid (approximated here as torispherical) segments. The shell weight and thickness for each segment is calculated individually. The highest thickness value obtained is then applied to all segments and the combined weight computed.
- For hemispherical segment: thickness, $th = \frac{P * R}{2 * S * E - (0.2 * P)}$
- weight, wh = (1.57) * material density * th * di2
- For cylindrical segment: thickness, $tc = \frac{P * R}{S * E - (0.6 * P)}$
- weight, wc = developed length * shell length * material density * tc
  where, developed length = π (do – tc)
- For torispherical segment: thickness, $tt = \frac{(0.885) * P * Li}{S * E - (0.1 * P)}$
- weight, wt = area * material density * tt
  where, area = 1.084 * di2
- where: P is Design Pressure,
  R is Inside Radius,
  S is Allowable Stress,
  E is Joint Efficiency; (E=1 here)
  di is Inside Diameter,
  do is Outside Diameter,
  Li is Inside Length,
- Average surface pressure on Mars is estimated at 6 millibars or 0.088 psi and is less than 1% of Earth's value. Therefore, for cabin internal operating pressures, a range of values corresponding to 10k, 21k and 35k feet in Earth atmosphere are evaluated as a trade study. Cabin shell thickness was sized to withstand a high bursting pressure (50 psi) based upon a maximum design value of 14.7 psi (Earth sea level). The overall weight estimated for the complete shell was in the range of 100 lbs. When insulation and secondary structure is accounted for with 25 mm wall thickness, the pressurized cabin structural weight is estimated around 390 lbs.

Cabin: DPR Notes

- On the internal pressurization of the cabin, you've picked a pressure load (6.5 psi) that is equivalent to Earth at about 21,000 feet. That's not a bad compromise starting point.
- FAR 135.89 says pilots don't need any oxygen up to 10,000 feet which gives 10.1 psi. If we could allow that it would be great for the aircrew but would probably make the cabin too heavy.
- The upper limit of long-duration unpressurized cabins was probably defined by the B-17 which flew at 35,000 feet (3.5 psi). At that altitude an oxygen mask is required all the time, but otherwise it is OK provided the cabin isn't too cold. But if you lose your mask you'll soon be in trouble and on Mars, you can't descend to find thicker air!
- I've gone to 35kft myself during my USAF ROTC training, where they made us take off our oxygen masks to see the effect. I just got a numb upper lip and found it harder to do the little math tests they gave us. Some guys started laughing and being silly, like they'd been drinking Another guy started yelling and fighting the guy next to him.

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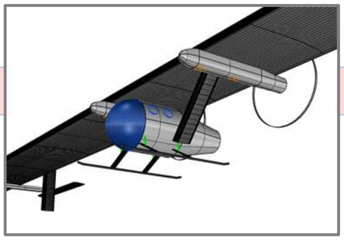
7. **Propulsion and Performance**
8. **Cabin & Human Factors**
9. **Refined Design Concept (RMMP-2)**
10. **Summary and Next Step**

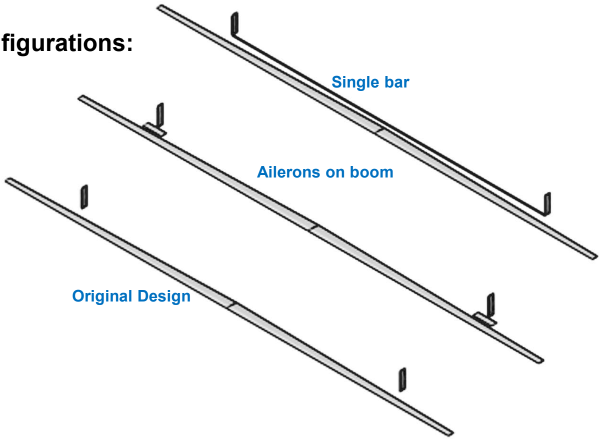


Longitudinal Stability

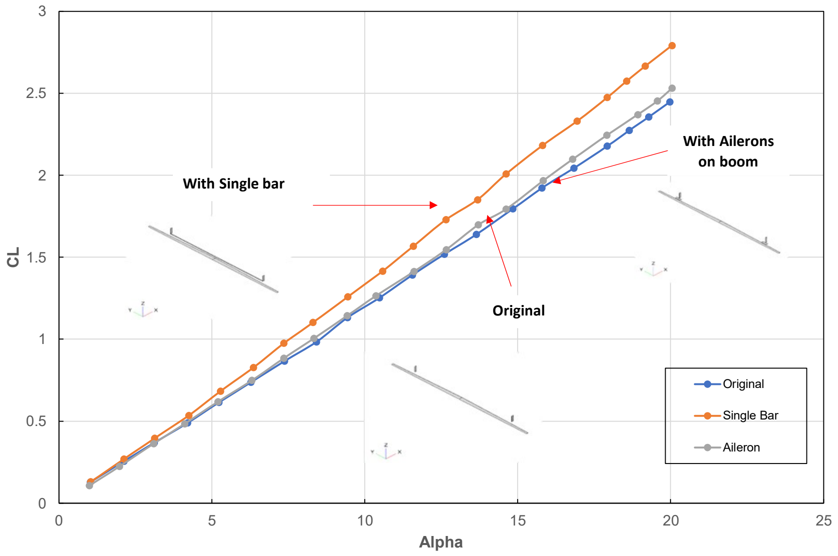
Ramlingam Gyanasampath Pillai

- Stability analysis done using Vortice Lattice Method in OpenVSP

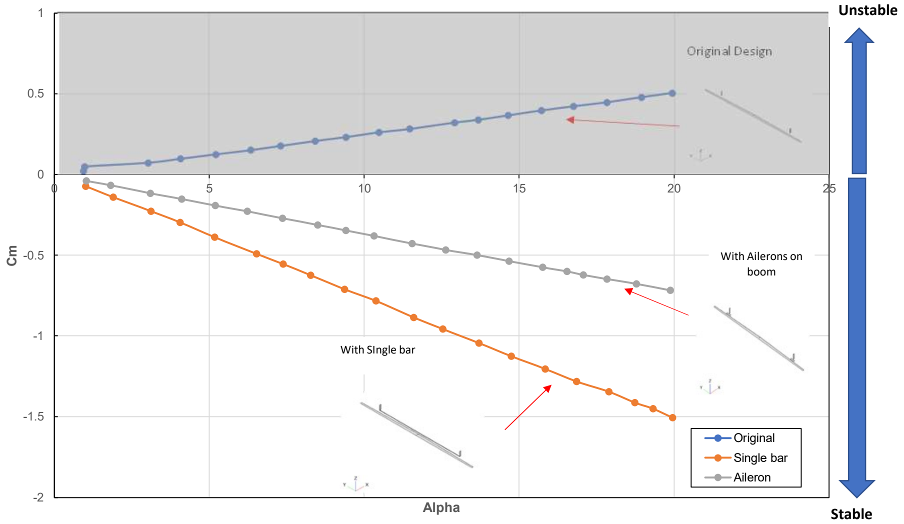
- Three trade Study configurations:
  - Original Design
  - Single Bar
  - Ailerons on boom



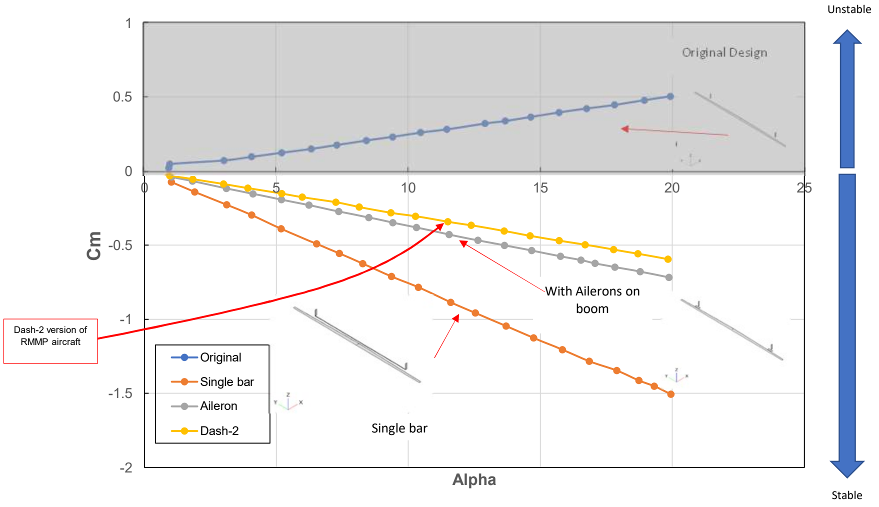
Longitudinal Stability: CL vs Alpha



Longitudinal Stability: Cm vs alpha

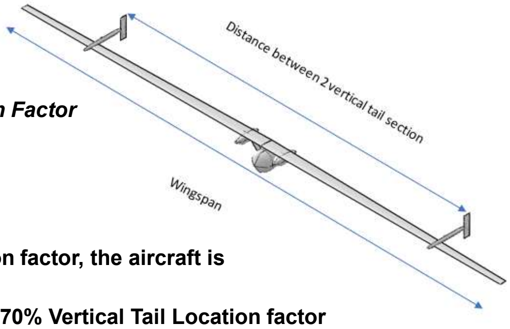


Longitudinal Stability : Cm vs alpha



Directional Stability

Effect of Vertical Tail Location on Stability

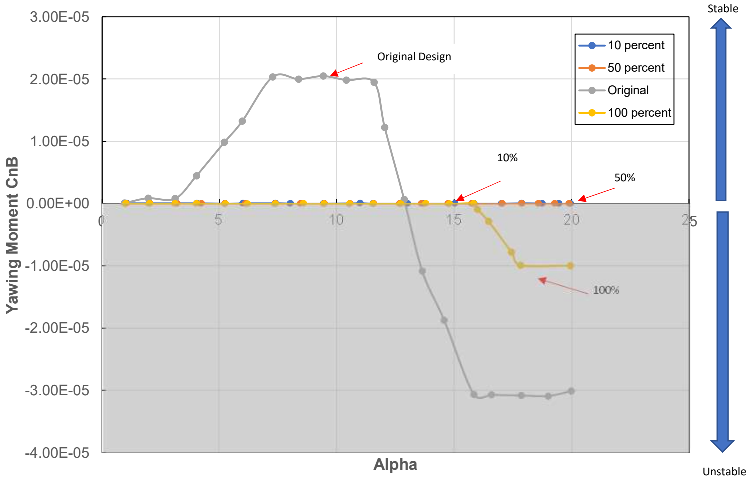


Vertical Tail Spanwise Location Factor

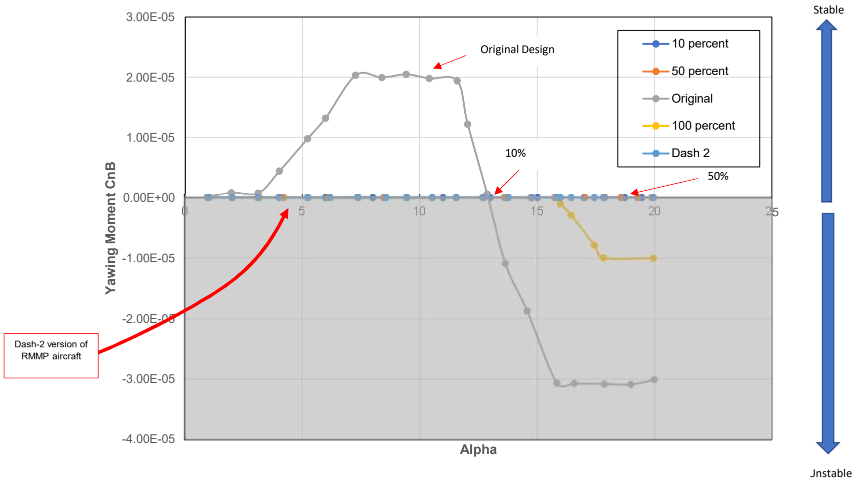
$$= \frac{Distance\ between\ Tails}{Total\ Wing\ span}\ \%$$

- **Up to ~ 50 % Vertical Tail Location factor, the aircraft is directionally neutral**
- **Aircraft becomes more stable at 70% Vertical Tail Location factor especially at low angle of attack**
- **As the factor increases the aircraft becomes unstable at high angle of attack – tip fins are quite unstable**

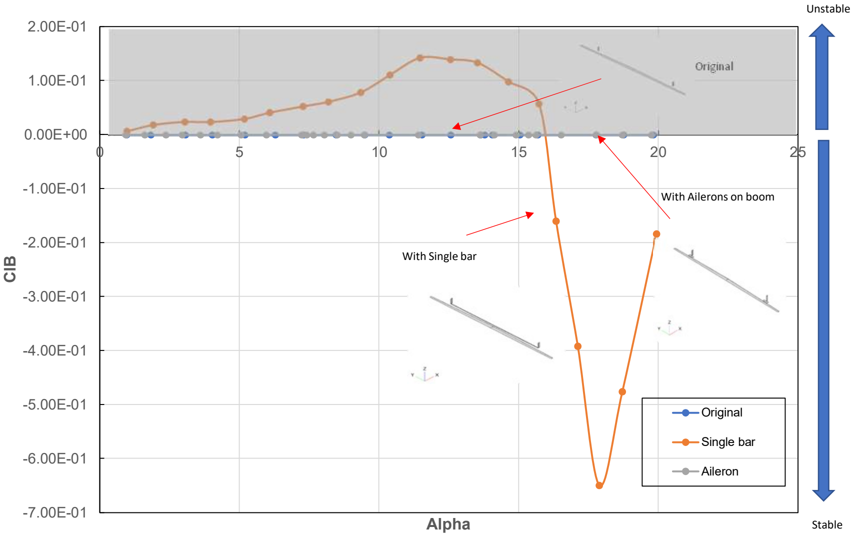
Directional Stability: Cn_β vs Alpha



Directional Stability: Cn_β vs Alpha



Lateral Stability: Cl_β vs Alpha



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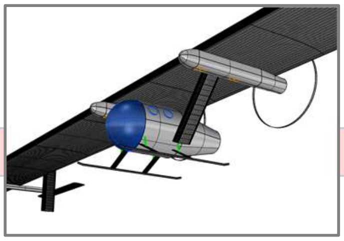
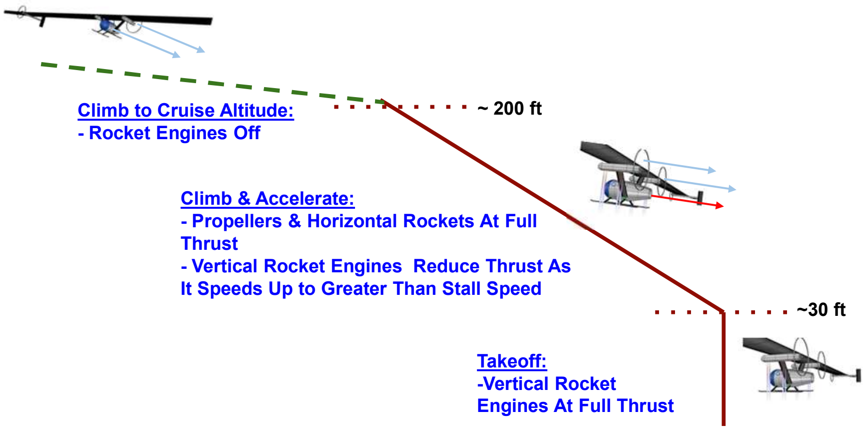


Takeoff & Climb Schematic

Matheus Monjon



Climb to Cruise Altitude:
- Rocket Engines Off

Climb & Accelerate:
- Propellers & Horizontal Rockets At Full Thrust
- Vertical Rocket Engines Reduce Thrust As It Speeds Up to Greater Than Stall Speed

Takeoff:
-Vertical Rocket Engines At Full Thrust

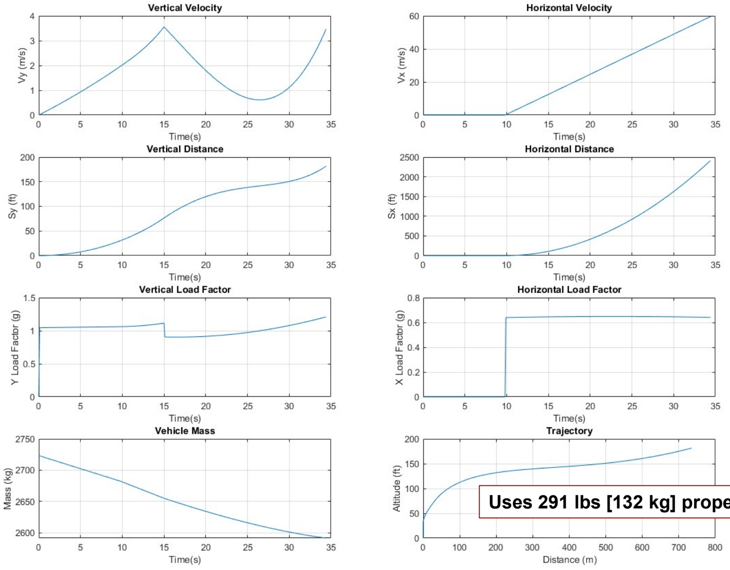
Analysis Inputs & Considerations

- **Thrust = 300lbf ~ 1334N**
- **8 vertical rockets ~ 10675N**
- **2 horizontal rockets ~ 2668N**
- **Total Propeller Thrust ~ Actuator Disk Theory**
- **Drag coefficient estimated from VLM and simple estimation for fuselage.**
- **Vertical thrust control function after ground clearance**
- **No thrust vectoring**
- **Vertical rockets only to z direction**
- **Horizontal rockets only to x direction**

- **The takeoff modeling was implement with MATLAB, with standard mechanics equations**
- **Analysis ran from t=0 (ground) to time when the vehicle achieves sustainable flight (Horizontal Velocity > Stall velocity)**
- **A thrust control function was implemented to reduce thrust after ground clearance**

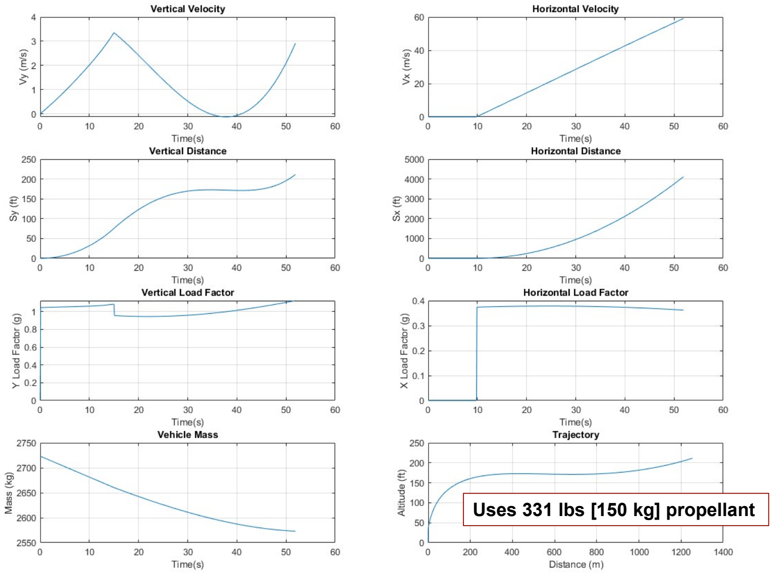
MAJOR INPUTS		Source
Cd (wing + fus)	0.04	Estimated (VLM)
Motor Power	125 (hp)	RMMP
Rocket Thrust (x8)	10675 (N)	RMMP
Propeller Diameter	2.26 (m)	RMMP
Propeller Thrust (x4)	3760 (N)	Estimated
Specific Impulse	260 (s)	RMMP
Wing Area	193 (m2)	RMMP
Climb Lift Coeff.	90% of 1.6 ~1.44	Approximation
Date of inputs	November 07	

Takeoff: With Horizontal Thrust



Uses 291 lbs [132 kg] propellant

Takeoff: Without Horizontal Thrust



Uses 331 lbs [150 kg] propellant

Takeoff Discussion

- With horizontal rocket thrust, takeoff uses 291 lbs [132 kg] of propellant
- Without horizontal rocket thrust it uses 331 lbs [150 kg] of propellant
- The initial estimate was 554 lbs [251 kg] for 2 takeoff and landing cycles
- But this used 260 Isp, we can safely assume 295 sec for 2030+
- This is a one-pass analysis, we can probably find a better answer with trajectory optimization, thrust vectoring, propeller optimization, etc…
- The RMMP-2 was analyzed including configuration changes and use of 295 Isp, and found to use 258 lbs [117 kg] less propellant
- Later trade studies indicate that the benefit of horizontal thrust rocket engines is less than expected and perhaps they should be eliminated

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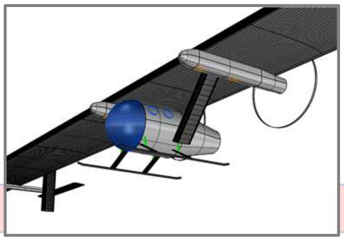
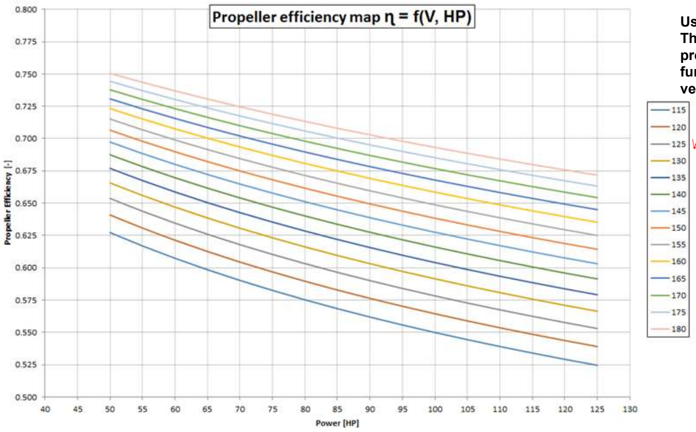


RMMP- Detailed analysis

Joabe Marcos de Souza



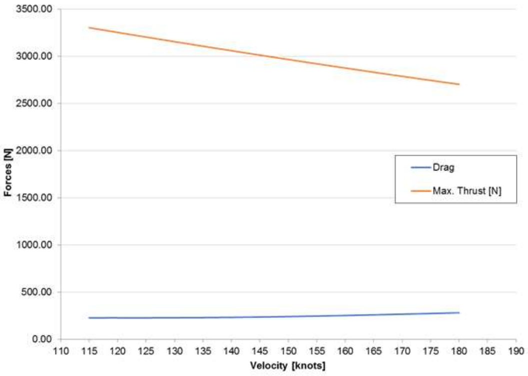
Using the Momentum Theory it was build a propeller efficiency map in function of power and velocity in knots.

RMMP- Detailed analysis – Cruise flight

Joabe Marcos de Souza

- **Propeller efficiency in function of speed**
- **Specific energy = 500 Wh/kg**
- **Efficiency from battery to motor shaft = 0.9**
- **Efficiency due installation losses = 0.97**

Again, it seems that we are over estimating the power designed (500 HP)

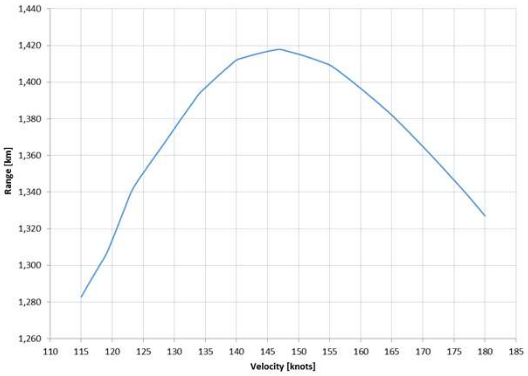


RMMP- Detailed analysis – Cruise flight

Joabe Marcos de Souza

Considering:

- **mbat/TOW = 0.13**
- **Propeller efficiency in function of speed**
- **Specific energy = 500 Wh/kg**
- **Efficiency from battery to motor shaft = 0.9**
- **Efficiency due installation losses = 0.97**

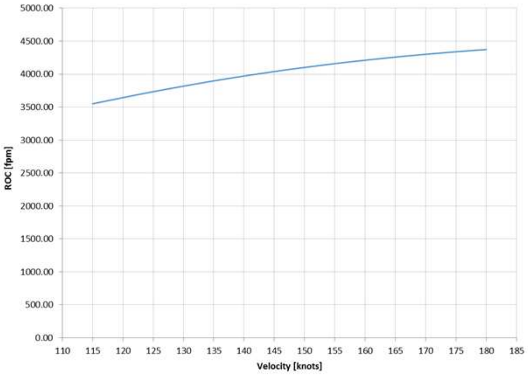


RMMP- Detailed analysis - Climb

Joabe Marcos de Souza

Considering:

- **Propeller efficiency in function of speed**
- **Efficiency from battery to motor shaft = 0.9**
- **Efficiency due installation losses = 0.97**



RMMP- Suggested Modifications

Joabe Marcos de Souza

The following modifications are suggested:

- **Resize the engine from 500 hp to 200 hp (4 engines of 50 hp each)**
- **Use Lithium-Sulfur batteries with Specific energy = 700 Wh/kg**
- **Reduce wing-span until the L/D reaches the value of 30.**

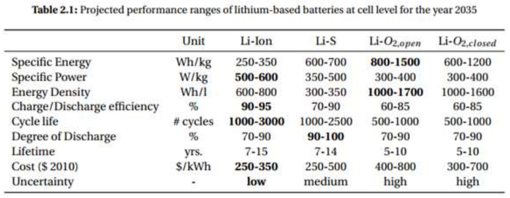
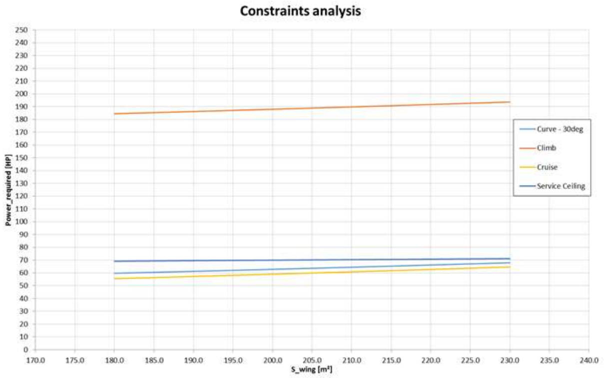


Table 2.1: Projected performance ranges of lithium-based batteries at cell level for the year 2035

	Unit	Li-Ion	Li-S	Li-$O_{2,open}$	Li-$O_{2,closed}$
Specific Energy	Wh/kg	250-350	600-700	**800-1500**	600-1200
Specific Power	W/kg	**500-600**	350-500	300-400	300-400
Energy Density	Wh/l	600-800	300-350	**1000-1700**	1000-1600
Charge/Discharge efficiency	%	**90-95**	70-90	60-85	60-85
Cycle life	# cycles	**1000-3000**	1000-2500	500-1000	500-1000
Degree of Discharge	%	70-90	**90-100**	70-90	70-90
Lifetime	yrs.	7-15	7-14	5-10	5-10
Cost ($ 2010)	$/kWh	**250-350**	250-500	400-800	300-700
Uncertainty	-	**low**	medium	high	high

Results with Suggested Modifications

Joabe Marcos de Souza



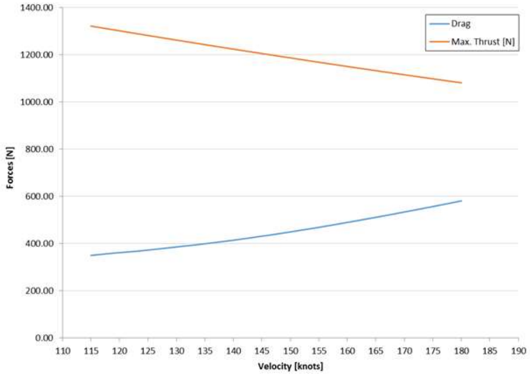
- Propeller efficiency = 0.8
- Climb at a maximum value of ROC = 1500 fpm
- Cruise at 150 KCAS
- Service Ceiling with ROC = 100 fpm

- New drag polar considering the maximum L/D = 30

Results with Suggested Modifications - Cruise

Joabe Marcos de Souza

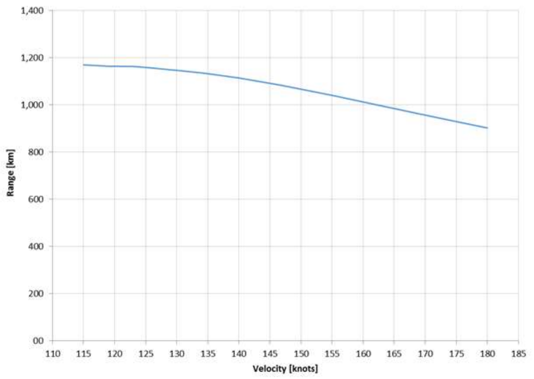
Considering:
- Propeller efficiency in function of speed
- Efficiency from battery to motor shaft = 0.9
- Efficiency due installation losses = 0.97



Results with Suggested Modifications - Range

Joabe Marcos de Souza

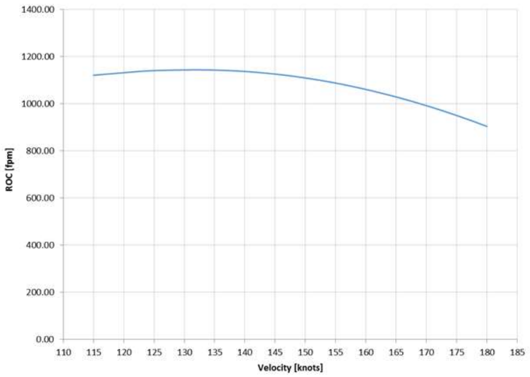
Considering:
- **mbat/TOW = 0.13**
- **Propeller efficiency in function of speed**
- **Specific energy = 700 Wh/kg**
- **Efficiency from battery to motor shaft = 0.9**
- **Efficiency due installation losses = 0.97**



Results with Suggested Modifications - Climb

Joabe Marcos de Souza

Considering:
- **Propeller efficiency in function of speed**
- **Efficiency from battery to motor shaft = 0.9**
- **Efficiency due installation losses = 0.97**



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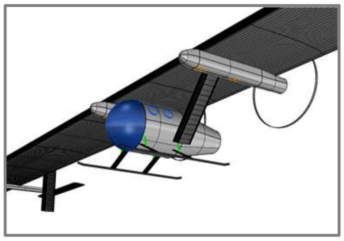
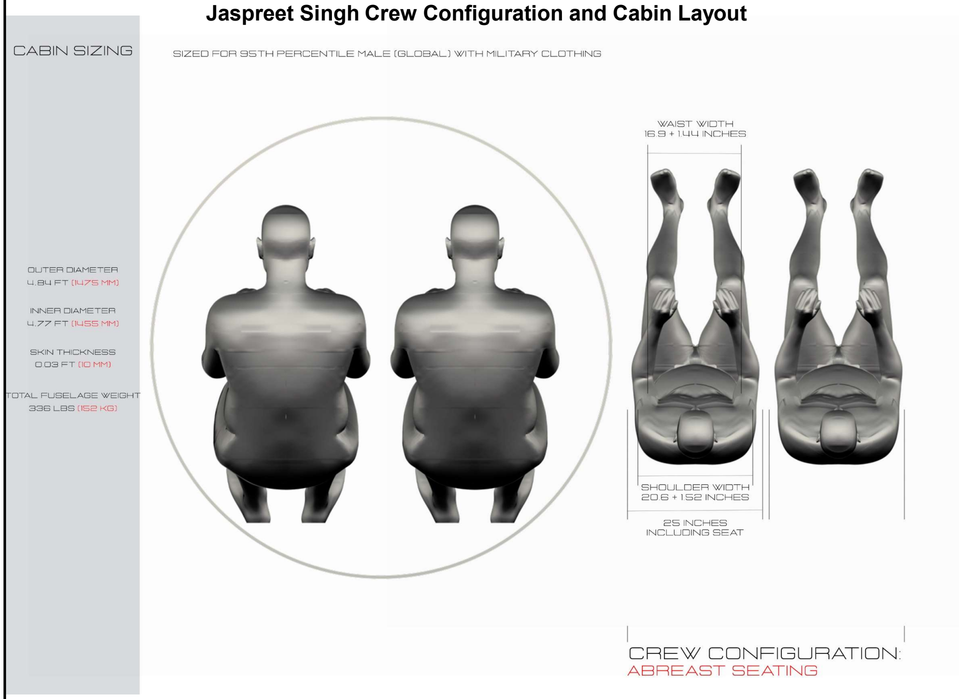


Jaspreet Singh Crew Configuration and Cabin Layout



CABIN SIZING

SIZED FOR 95TH PERCENTILE MALE (GLOBAL) WITH MILITARY CLOTHING

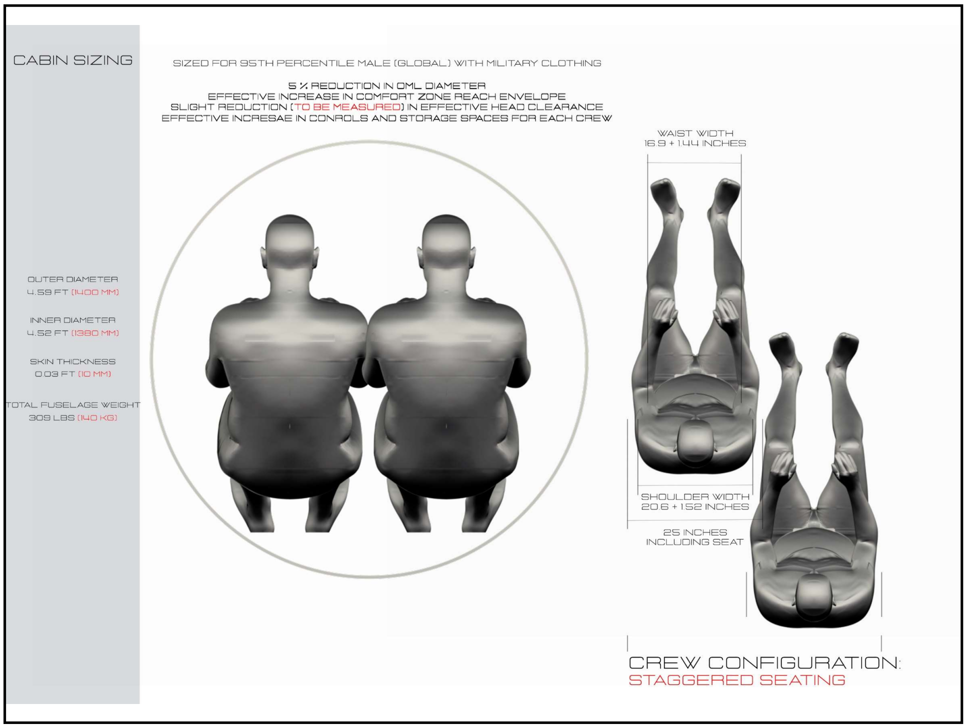
OUTER DIAMETER
4.84 FT (1475 MM)

INNER DIAMETER
4.77 FT (1455 MM)

SKIN THICKNESS
0.03 FT (10 MM)

TOTAL FUSELAGE WEIGHT
336 LBS (152 KG)

CREW CONFIGURATION:
ABREAST SEATING



CABIN SIZING

SIZED FOR 95TH PERCENTILE MALE (GLOBAL) WITH MILITARY CLOTHING

5 % REDUCTION IN OML DIAMETER
EFFECTIVE INCREASE IN COMFORT ZONE REACH ENVELOPE
SLIGHT REDUCTION (TO BE MEASURED) IN EFFECTIVE HEAD CLEARANCE
EFFECTIVE INCRESAE IN CONROLS AND STORAGE SPACES FOR EACH CREW

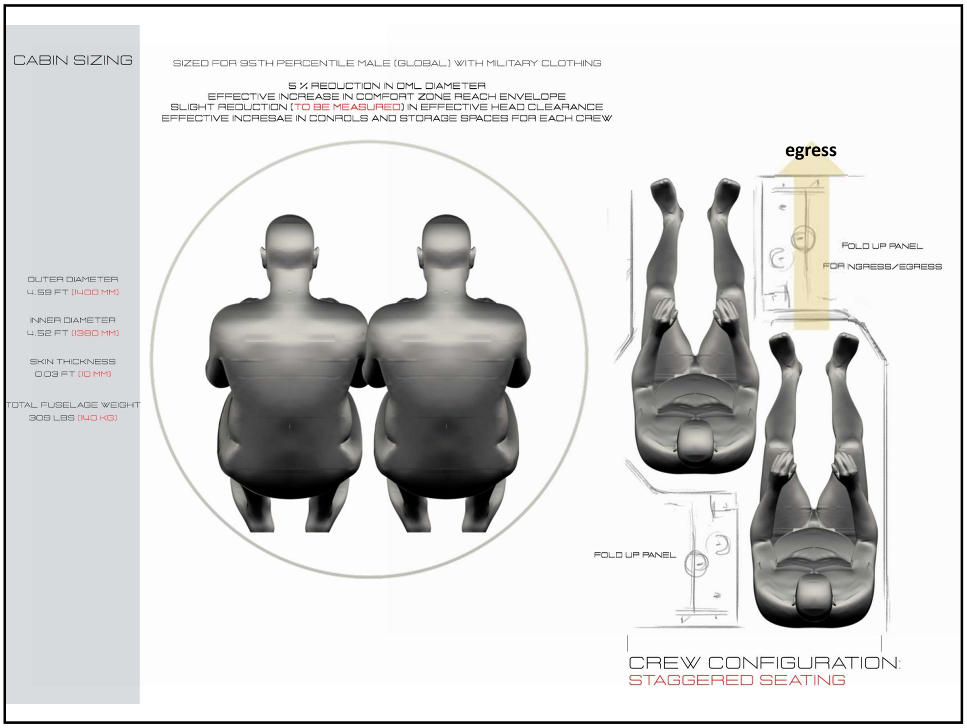
OUTER DIAMETER
4.59 FT (1400 MM)

INNER DIAMETER
4.52 FT (1380 MM)

SKIN THICKNESS
0.03 FT (10 MM)

TOTAL FUSELAGE WEIGHT
309 LBS (140 KG)

CREW CONFIGURATION:
STAGGERED SEATING



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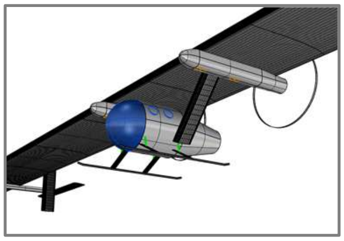
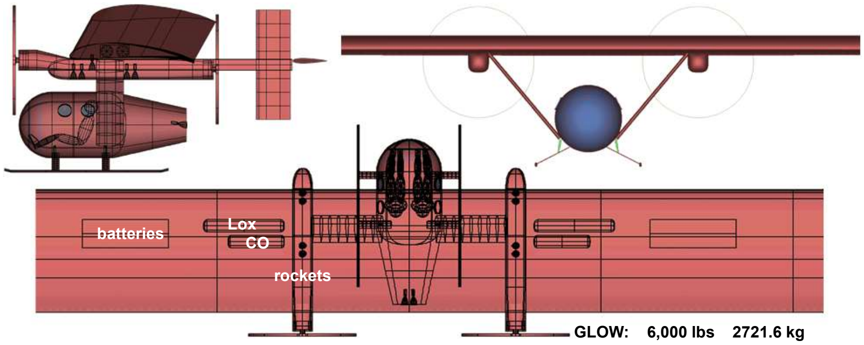


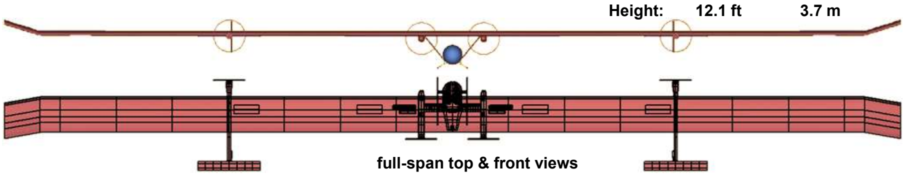
RMMP-2 Design Changes

- Wing AR reduced to 25 to increase chord R# and improve structure
- Wing untapered so that tip R# is not reduced
- Wing twisted to improve lift distribution, avoid tip stall
- Wing incidence added
- Wingtip with sweep and dihedral added for roll control and possible winglet effect
- Wing strut chord increased for structural reasons
- Horizontal tails added for pitch trim since good airfoils at that low R# are aft-cambered
- Horizontal tails will also be used for roll control (twisting wing)
- Inboard nacelle lengthened to get prop away from trailing edge
- Outboard nacelle moved closer in since wingspan reduced
- Rocket motor added to outboard nacelle for roll control

RMMP-2 General Arrangement

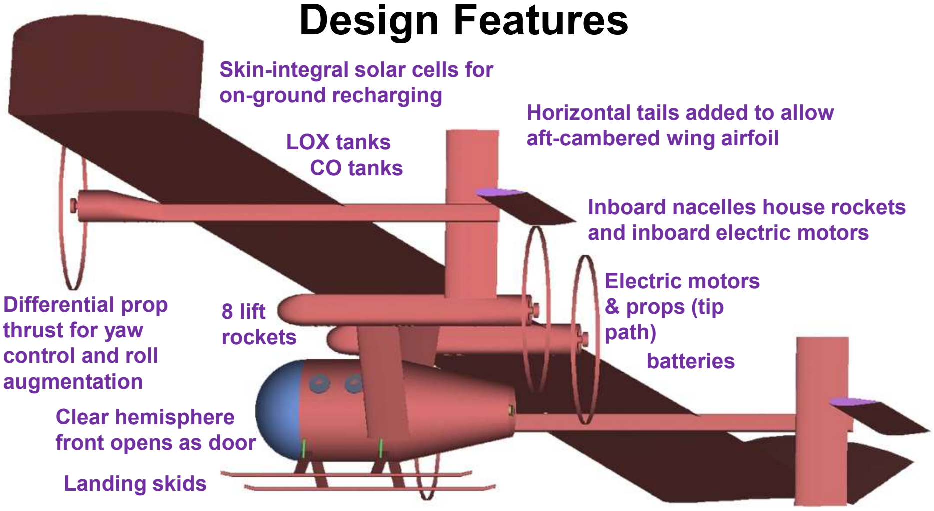


GLOW:	6,000 lbs	2721.6 kg
Payload:	500 lbs	226.8 kg
Length:	23.6 ft	7.2 m
Width:	228.0 ft	69.5 m
Height:	12.1 ft	3.7 m



full-span top & front views

Design Features



Skin-integral solar cells for on-ground recharging

Horizontal tails added to allow aft-cambered wing airfoil

LOX tanks
CO tanks

Inboard nacelles house rockets and inboard electric motors

Electric motors & props (tip path)

batteries

Differential prop thrust for yaw control and roll augmentation

8 lift rockets

Clear hemisphere front opens as door

Landing skids

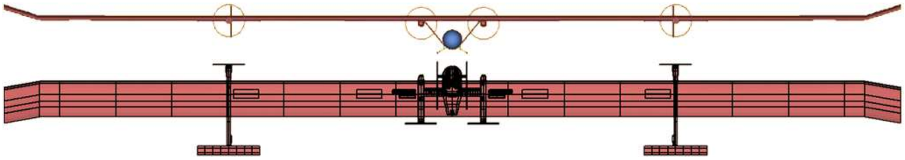
Pressurized passenger/ payload pod

Strut-mounted wing arrangement provides ground clearance & avoids putting lift loads into pressure shell

Two rockets in back of fuselage to speed acceleration to flight speed

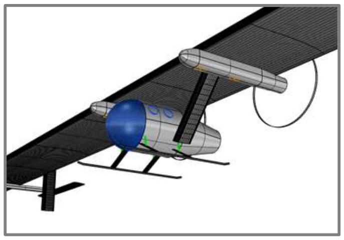
RMMP-2 Aero Surfaces

	[FPS]				[MKS]	
	Wing	Vertical Tail	Horizontal Tail	Wing	Vertical Tail	Horizontal Tail
Area Sref	2080	20	40	193.24	1.86	3.72
Aspect Ratio	25	3.2	6.4	25	3.2	6.4
Taper Ratio	1	1	1	1	1	1
Sweep (LE)	0	0	0	0	0	0
Sweep (c/4)	0	0	0	0	0	0
Thickness t/c	0.12	0.15	0.15	0.12	0.15	0.15
Dihedral	0.00	0.00	0.00	0.00	0.00	0.00
Incidence	2.50	0.00	0.00	2.50	0.00	0.00
Twist	-2.00	0.00	0.00	-2.00	0.00	0.00
Span	228.035	8	16	69.505	2.438	4.877
Root Chord	9.121	2.5	2.5	2.78	0.762	0.762
Tip Chord	9.121	2.5	2.5	2.78	0.762	0.762
Mean Chord	9.121	2.5	2.5	2.78	0.762	0.762
Y-bar	57.009	4	4	17.376	1.219	1.219



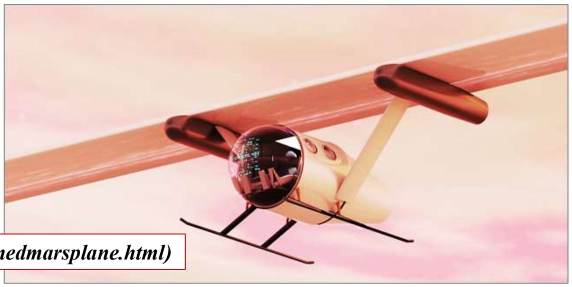
Raymer Manned Mars Plane

1. **Introduction & Operational Concept**
2. **Initial Design Concept (RMMP-1)**
3. **Aerodynamics & Airfoil Design**
4. **Structural Design & Analysis**
5. **Stability & Control Analysis**
6. **Takeoff and Transition Analysis**
7. **Propulsion and Performance**
8. **Cabin & Human Factors**
9. **Refined Design Concept (RMMP-2)**
10. **Summary and Next Steps**



Raymer Manned Mars Plane: Summary

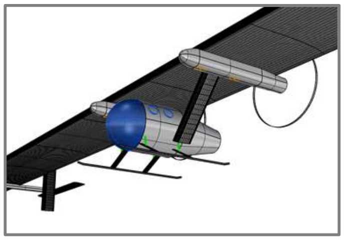
- Conceptual Research Corporation and an international team of volunteers have done conceptual design for a manned utility aircraft to be operated by future residents of Mars
- RMMP is designed for exploration, research, cargo transport, photography, and the linking of multiple settlements
- Total payload of 500 lbs, optionally manned (2), 260+ nmi. range
- VTOL, fully autonomous flight for cargo transport and extraction
- Nobody needs it today, not even Elon
- Funding is welcome anyway



(see www.aircraftdesign.com/mannedmarsplane.html)

Raymer Manned Mars Plane

Backup Slides



What Raymer Insanity Made This Work?

Light-weight structures, especially wing

- 0.95 lbs/ft^2 vs ~2.5 typical GA with much lower aspect ratio
- But “weight” is ~1/3 that on earth (nb: 0.95 is Earth lbs-mass)

Better battery technology

- 500 wh/kg vs ~260 today (range is directly proportional)

Light-weight equipment (life support, actuation & power supply,…)

Conceptual-level analysis, assumed prop & drivetrain efficiencies

Wing C_{lmax} of 1.6 – difficult at low R#

Note:
LOX-CO rocket is a no-brainer, already fired (Isp used here)
LOX-CO production is no-brainer except for providing electrical power