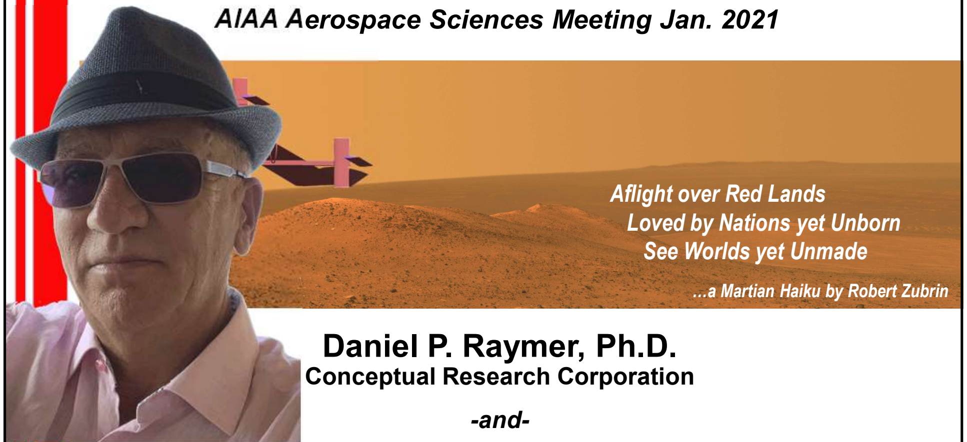
10 minute version

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

AIAA Aerospace Sciences Meeting Jan. 2021



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-and-

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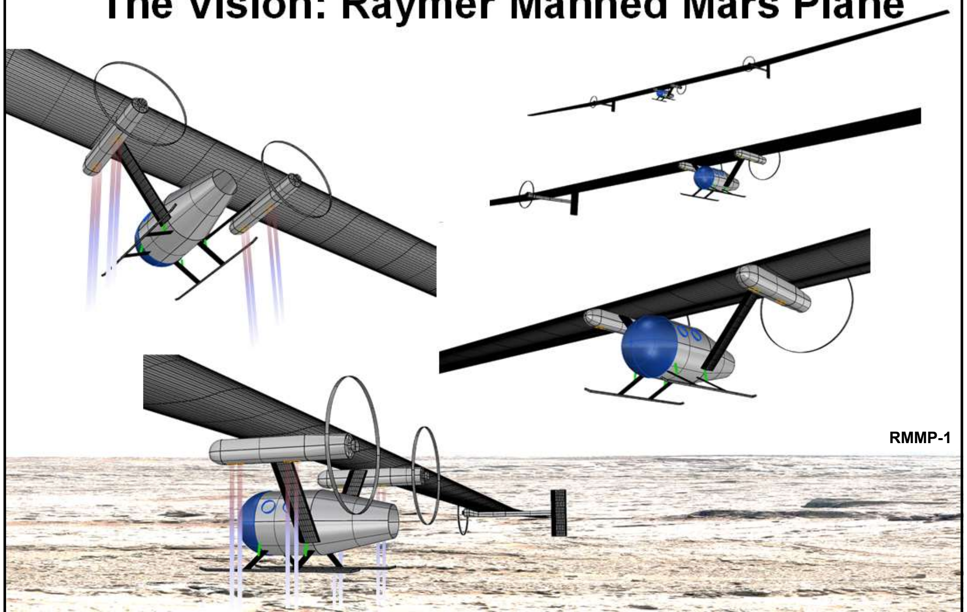
Getting Around – the Manned Mars Plane

- 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)

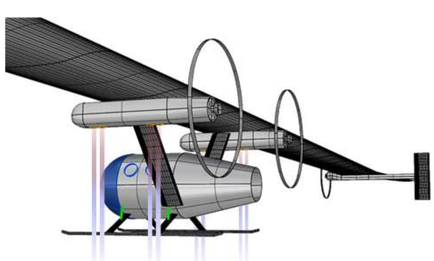
- Assume Mars permanent base(s)
  - Available electrical energy (solar or nuclear)
  - Large pressurized buildings

The Vision: Raymer Manned Mars Plane



RMMP Operational Concept

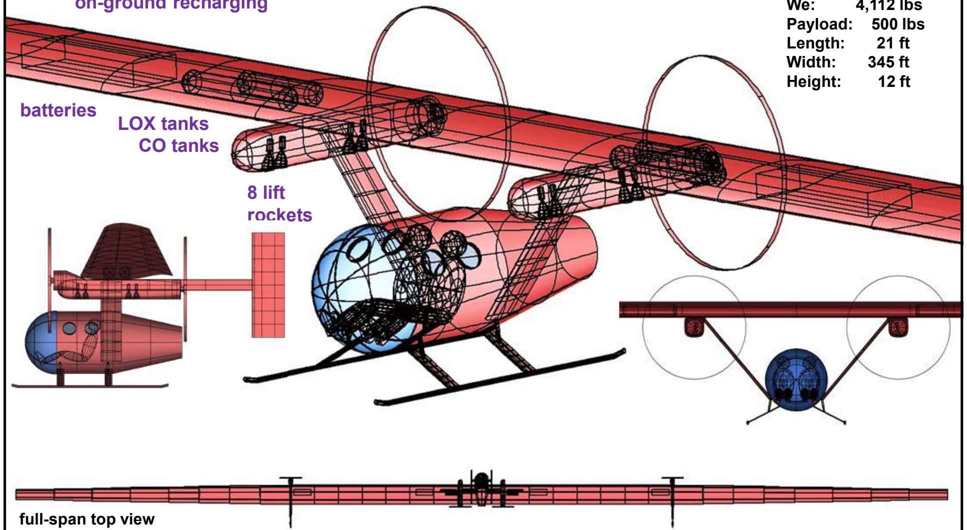
- Optionally manned, no “pilot” – crew can command takeoff, landing, destination, turn, etc
- Can fly unmanned to programmed destination
- Before a mission, batteries are charged from ground source
- Sizing allows for two takeoff/landing cycles, so out-and-back



2030 technologies, or later!

Design Features

Wo:	6,000 lbs
We:	4,112 lbs
Payload:	500 lbs
Length:	21 ft
Width:	345 ft
Height:	12 ft



Range, Level Flight, & Climb Calcs

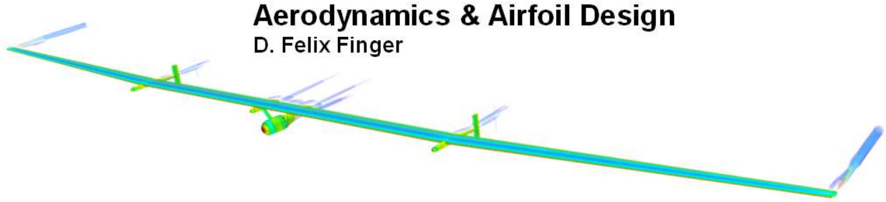
Range (Level Flight):			
mb/m = battery mass fraction	0.1300	for cruise	
Esb = battery energy density {wh/kg}	500	260	
ηb2s = efficiency -battery to motor shaft	0.9		
ηp = propeller efficiency	0.8		
L/D	42		
Range {km}	1901.4	1026.7	nmi
Velocity {km/h} -not needed for Range calc	277.8	150.0	kts
Motor 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*

Aerodynamics & Airfoil Design

D. Felix Finger



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

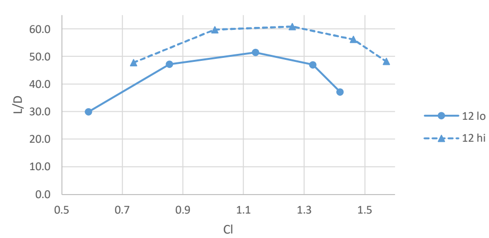
Very low Re in thin Mars atmosphere causes separation and higher than anticipated drag

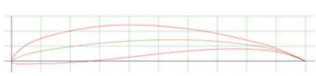
Need 2D airfoil design to get rid of laminar separation bubbles

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

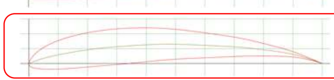
(but this is with “placeholder” airfoil, not R#-optimized airfoil as discussed below)

RMMP Custom Airfoils

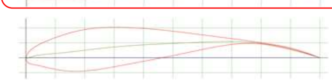




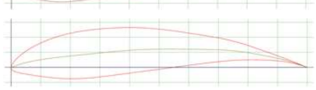
RMMP 150 11
Max thickness 11.3% at 30.6% chord **Max camber 7.1% at 55.2% chord**



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**



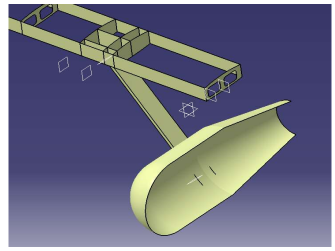
RMMP 16
Max thickness 16% at 28.2% chord **Max camber 6.1% at 43.7% chord**

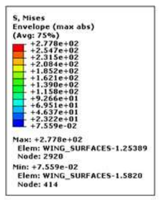
	11% t/c - Re 150%				12% t/c - Re 150%				14% t/c - Re 150%				16% t/c - Re 150%			
	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D	Cl	Cd	Cm	L/D
0,0	0,8980	0,01695	-0,2241	52,99	0,7366	0,01542	-0,1859	47,7830	0,66746	0,0171	-0,18	39,08	0,7020	0,01902	-0,1851	36,90
2,5	1,1301	0,01901	-0,2160	59,46	1,0046	0,01682	-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

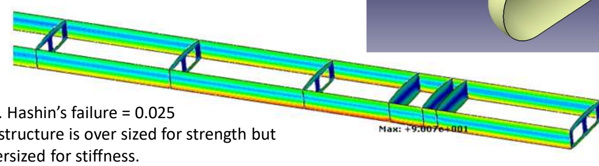
D. Felix Finger

WING STRUCTURE

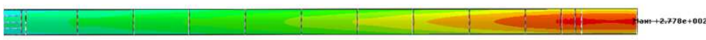
A. Gómez

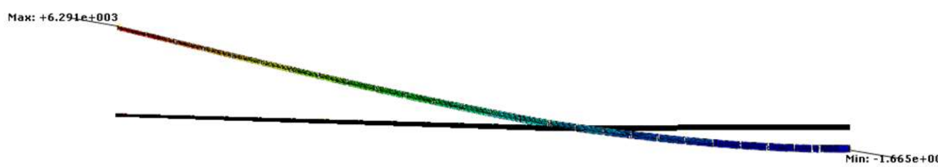






Max. Hashin's failure = 0.025
The structure is over sized for strength but undersized for stiffness.

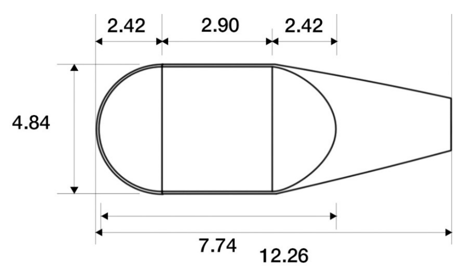




Cabin & Fuselage Pod Structure

Jaspreet Singh

- Given configuration layout, greatest loads are likely to be pressurization
- Skin thickness requirements calculated using ASME codes for pressurized vessels
- Weight estimated from calculated volume and material density
- 25mm-thick insulation added to cabin region
- Results: weight – 390 lbs [177 kg]

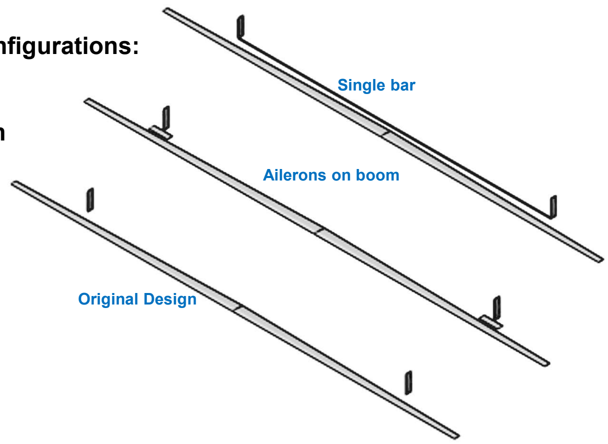


Operational and Design Pressure Conditions				
Atmospheric Pressure on Mars	0.088	psi	6.1870E+01	kg/sq. m
Internal Cabin Pressure (Assumed)	6.500	psi	4.5695E+03	kg/sq. m
Maximum Design Pressure	14.700	psi	1.0334E+04	kg/sq. m
Hydrostatic Pressure	19.11	psi	1.3434E+04	kg/sq. m
Bursting Pressure	51.032	psi	3.5876E+04	kg/sq. m
Bursting Pressure Factor [K]	1.043	-	1.043	-
Design Criteria				
Mechanical Joint Efficiency [E]	1			
Safety Factor	3			
Corrosion Allowance [CA]	3	mm		
Maximum Allowable Stress [S]	403.3	MPa		
Ultimate Tensile Stress	1210	MPa		

Longitudinal Stability

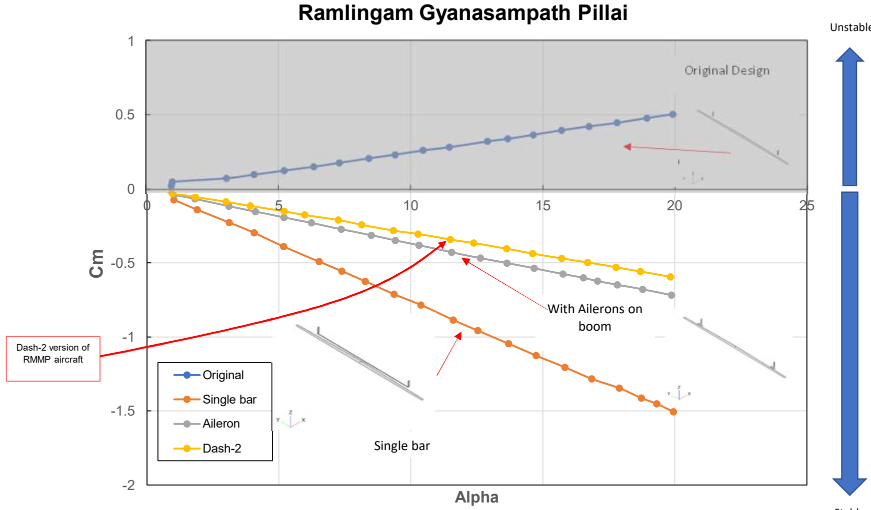
Ramlingam Gyanasampath Pillai

- Stability analysis done using Vortice Lattice Method in OpenVSP
- Three trade Study configurations:
  - Original Design
  - Single Bar
  - Ailerons on boom



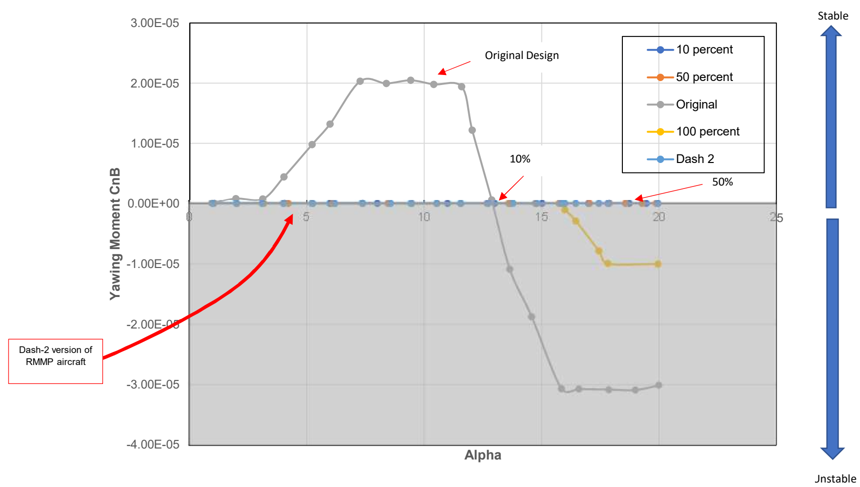
Longitudinal Stability : Cm vs alpha

Ramlingam Gyanasampath Pillai



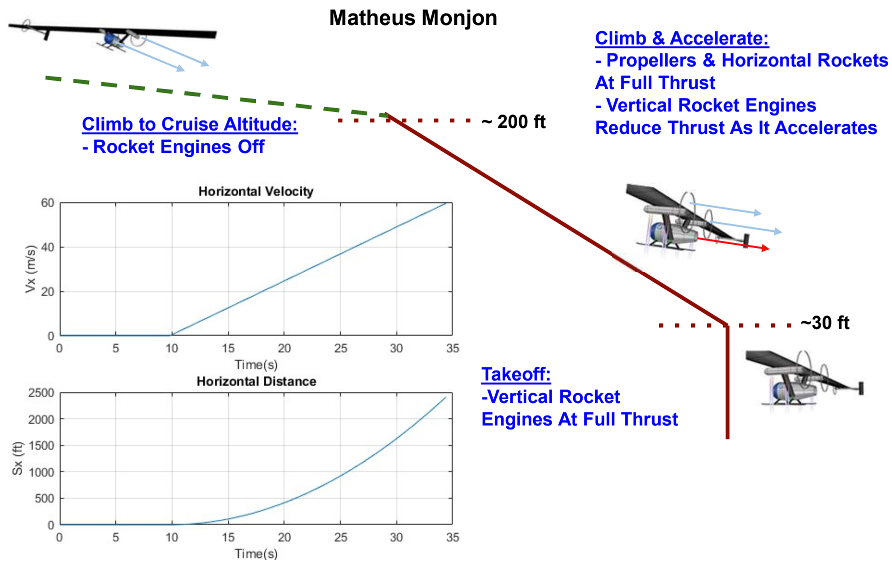
Directional Stability: Cn_β vs Alpha

Ramlingam Gyanasampath Pillai



Takeoff & Climb Schematic

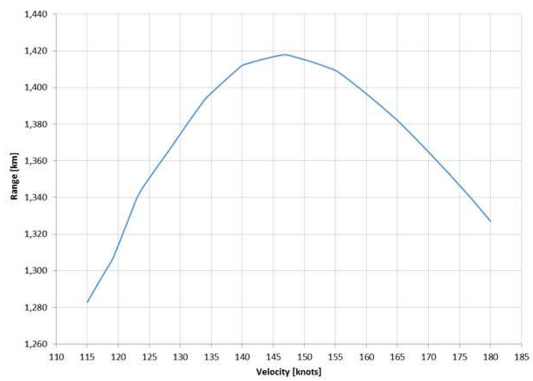
Matheus Monjon



RMMP- Range vs. Velocity

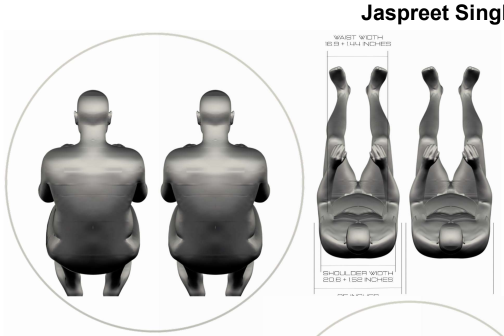
Joabe Marcos de Souza

- m_{bat}/TOGW = 0.13
- Propeller efficiency as function of speed
- Specific energy = 500 Wh/kg
- Efficiency from battery to motor shaft = 0.9
- Efficiency due installation losses = 0.97



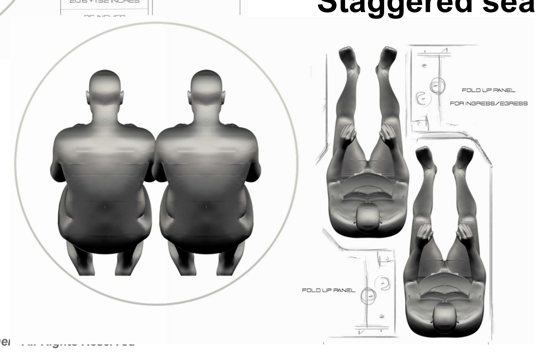
Crew Configuration and Cabin Layout

Jaspreet Singh

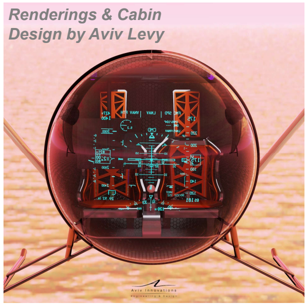


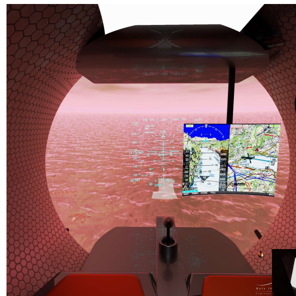
Abreast seating

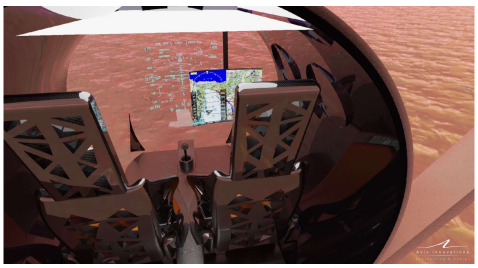
Staggered seating



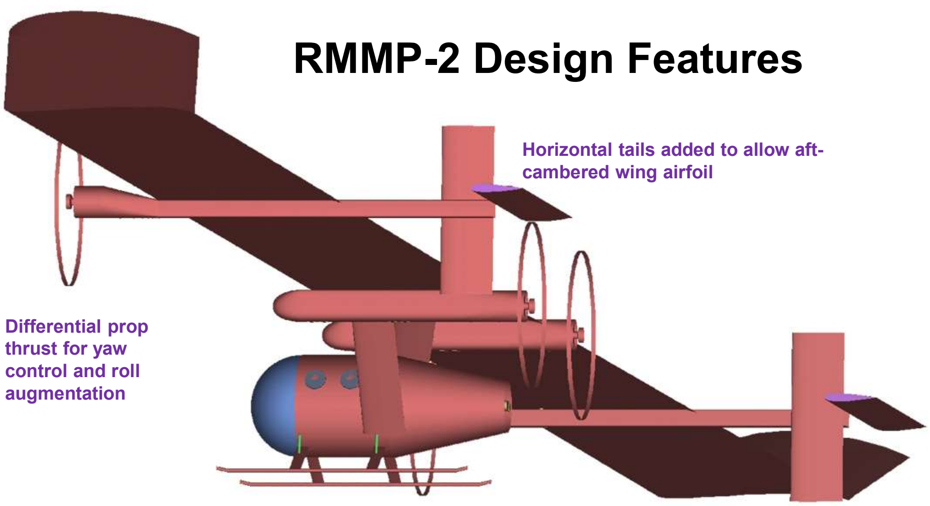
RMMP Images - Cabin





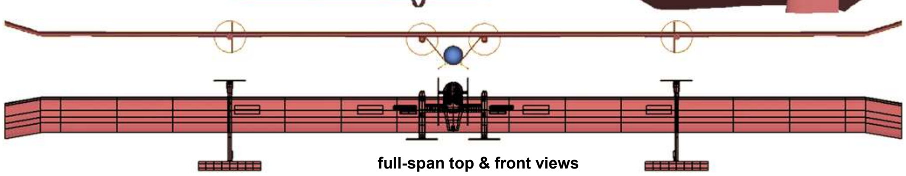


RMMP-2 Design Features



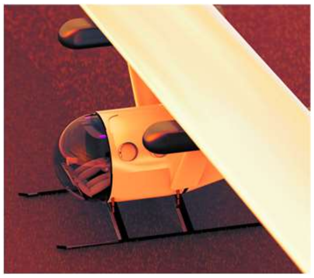
Horizontal tails added to allow aft-cambered wing airfoil

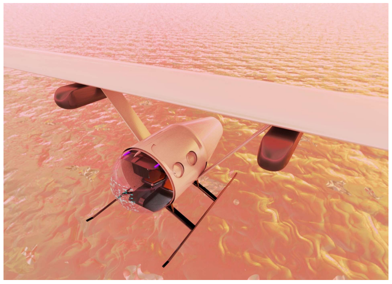
Differential prop thrust for yaw control and roll augmentation



full-span top & front views

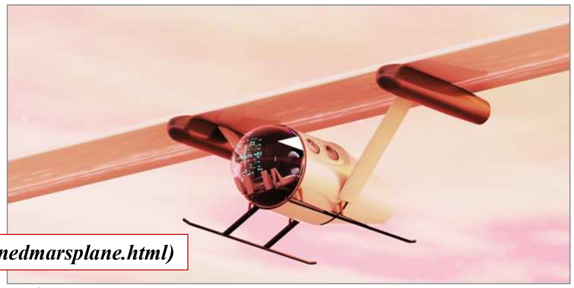
RMMP Images





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)