Martian Aircraft and Exploration Concepts

Presented by David J. File, Boeing
[2001]

Abstract

The history of early Martian aircraft developments is reviewed and recent studies are evaluated resulting in several proposed Delta II launched concepts. Mars' atmospheric and global surface investigations can benefit greatly from the aerial mobility of flying platforms. Advances in autonomous guidance and navigation create new missions by enabling these concepts to accurately target specific terrain features. Three concepts were developed and are evaluated in this report: a mid-weight concept relative to the large-spanned flyer, circa 1978, a "minimum mission" winged concept and a parasail-equipped lander delivery system. In addition to concept design and feature descriptions a systems engineering, risk reduction approach is developed which delineates the necessary technology program to achieve performance goals and mission success.

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First Flyers for Mars Exploration

Introduction

Goals – Mars flyer overview, top level design considerations, evaluate new flying wing-like concepts

Status – Many past efforts and papers – good resources, overall concept is good – more to do, basis for next paper in-work

Concept Basis – A lot has happened in the past 20 years, original JPL Flyer was ahead of its time (AIAA 79-0067)!

Mission Definition – A good mission that promotes success

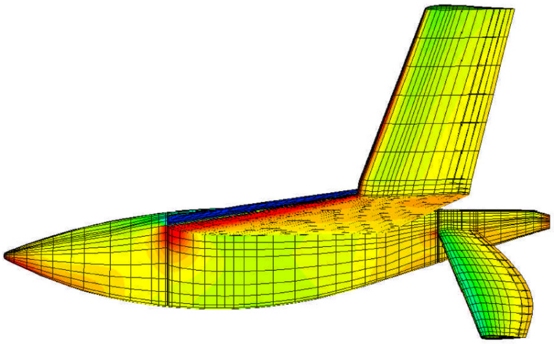
Assumptions – Comm architecture developed separately

Technology Gains
- Composites
- Avionics
- Aero design tools

Development Challenges
- Mono-propellant engine
- Wing and Parasail deployment

New Operational Vistas
- Remote control
- Autonomous control

Concept Definition and Aerodynamics
- System form and function
- Design allowables and margins



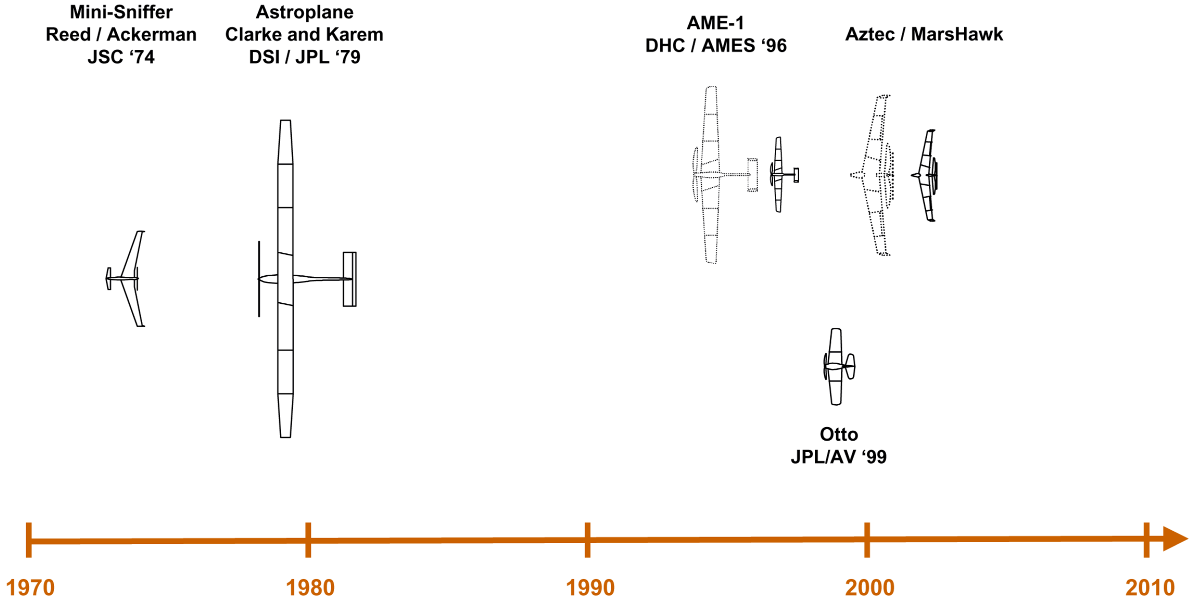
Mass	80.0 kg
W, Earth	784.0 N
W, Mars	295.6 N
S, wing area	7.5 m2
w/s, Earth	104.5 N/m2
w/s, Mars	39.4 N/m2
CL, Lift coef.	0.6
rho, Earth	0.007 kg/m3
rho, Mars	0.007 kg/m3
velocity, Earth	223.1 m/sec
velocity, Mars	137.0 m/sec

And in all degrees to anywhere I please . . .
I want to get away, I want to fly away . . .
Let's go and see the stars, the Milky Way or even
Mars . . .
(Fly Away – Lenny Kravitz)

How to fly on Mars . . .

$$V = \sqrt{\frac{W}{S}\,\frac{2}{rho}\,\frac{}{CL * S}}$$

Mars Flyer Concept Timeline



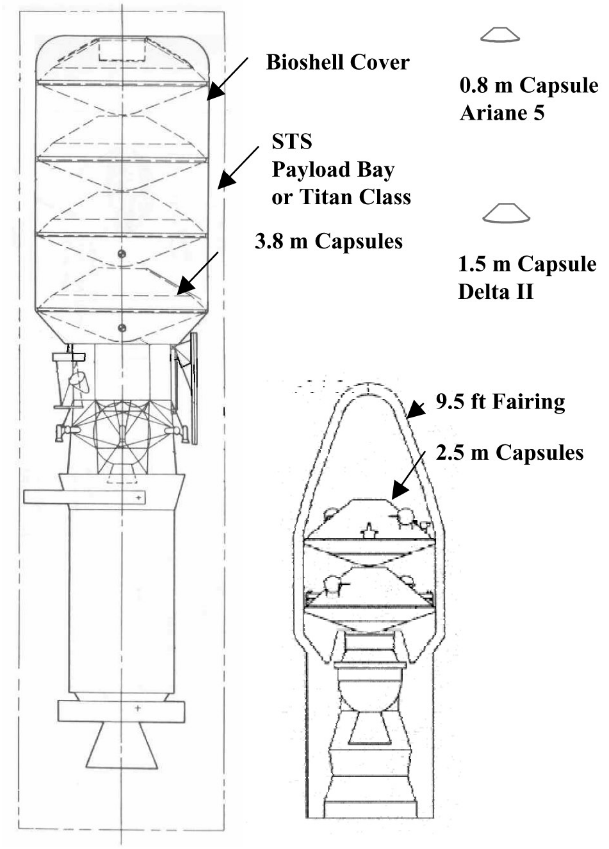
Concept Basis – Launcher Options

Booster Considerations

Early flyers developed for Mars utilized a Titan class booster (the same used for the Viking missions) and would have filled a gap in remote sensing by providing broad coverage and resolution of Martian planetary details. However, at this time orbiting probes like MGS clearly address many of the original, flyer mission requirements and, therefore, the increased cost of large flyers that necessitate using large and costly boosters is no longer justified. Also, technology has advanced such that probes deliver greater capability at a reduced mass.

In the past two years several concepts exploiting the Ariane 5 auxiliary payload carrier have been proposed by several NASA centers. The original intent of these flyers was to commemorate in 2003 the 100th anniversary of the Wright Brothers' first powered flight. This proposed mission resulted in small aircraft with endurance between 15 and 30 minutes and achieved a range of less than 200 km.

The author feels that these small missions lack the valuable scientific return on the scale necessitated by recent MGS surveys and are inadequate to substantially aid the exploration of the Martian surface. Lastly a small flyer (< 30 kg) cannot guarantee reaching a target site for exploration, because the entry dispersion could exceed its range. The author designed a flying wing concept for this mission that led to continued interest in a larger aircraft.



Flyers designed as Delta II class payloads result in robust and exploration capable systems.

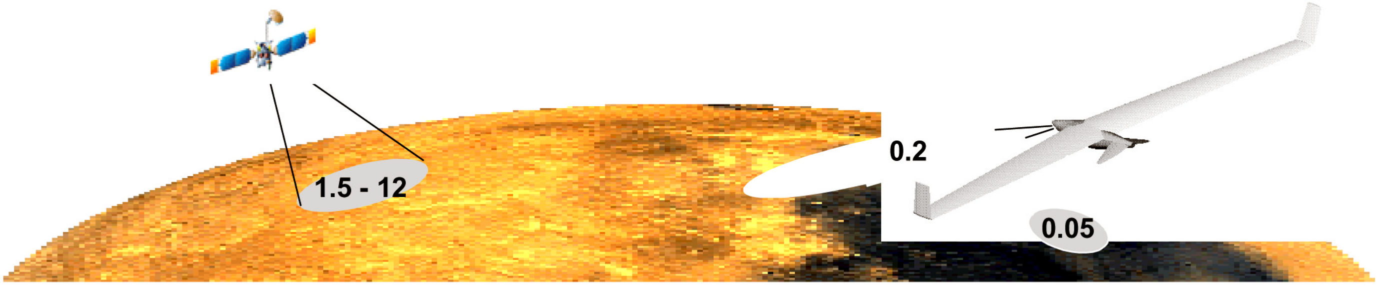
Concept Basis – Orbiting vs. Flyer

Orbiting space platforms with long duration missions provide:

- Targeted terrain imagery at 1.5-12 m/pixel
- Atmospheric phenomena – MGS
  - – Cyclones
  - – Dust devils
- Repeated coverage

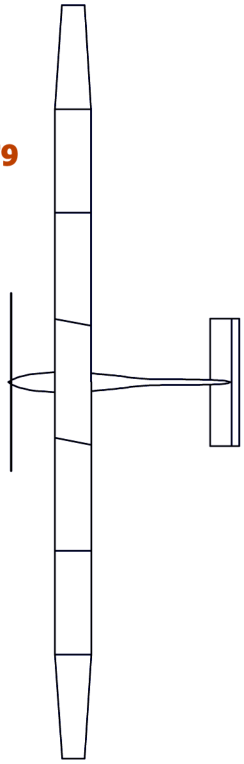
Flying airborne platforms can provide additional key understandings:

- High risk, targeted terrain imagery at 0.1-0.2 m/pixel – Valles Marineris (Scout proposal)
- Additional gravity and magnetic soundings
- Turbulence measurements
- Deployment of multiple sondes dropped to Martian surface
- Targeted landing



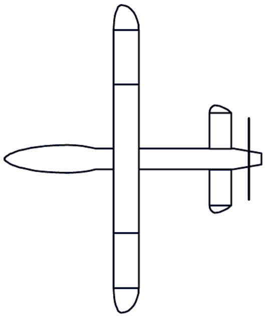
Concept Basis – UAV Comparisons

1979



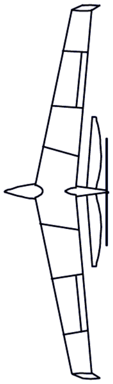
“Astroplane”
JPL / DSI
Span 21 m
Mass 300 kg
W/S 55 N/m2

1988



AMBER
Leading Systems
Span 8.5 m
Mass 340 kg
W/S 840 N/m2

2000



AZTEC
Delta II Flyer
Span 10.4 m
Mass 80 kg
W/S 40 N/m2

2000+

MARSHAWK
“Minimum” Flyer
Span 4.5 m
Mass 25 kg
W/S 62 N/m2

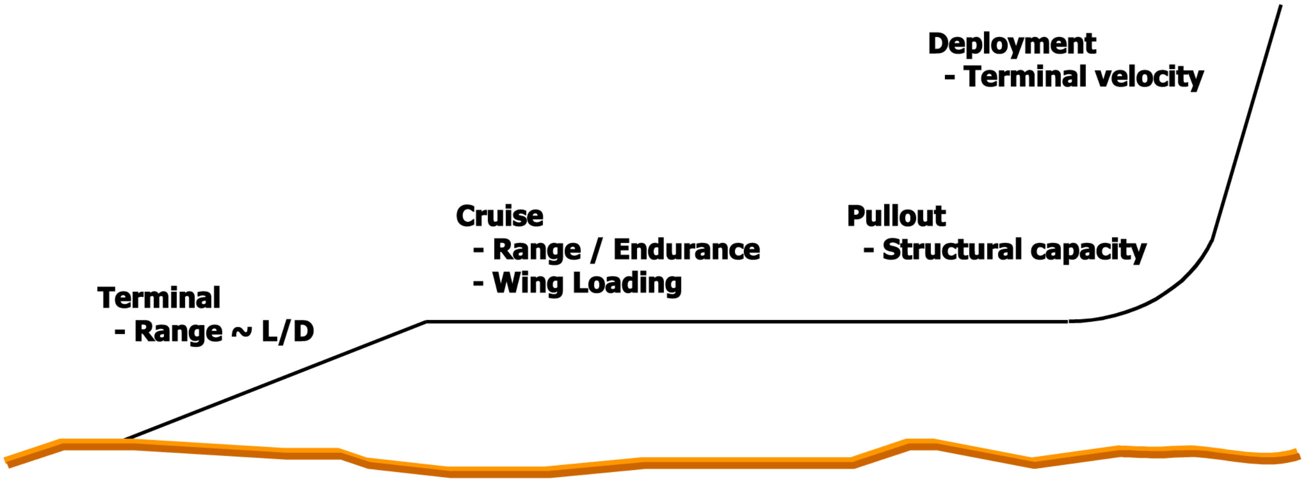
Concept Basis – Performance Comparisons

Table 1. Flyer Concept Comparisons

Size Class / Parameters	Titan IV *JPL'79*	Delta II *Flyer*	Delta II *Parasail*	Ariane *Auxiliary*
Range ~km	4000	1100	580	130
Endurance ~hr	15	6	4	0.25
W / S ~kg/m^2	15	11	7	25
Payload	40	15	40	11.5
Airframe	50	14	30	1.75
Propulsion	13	9	13	1.80
Avionics	30	7	7	—
Fuel	147	30	30	0.95
Misc./Margin	20	5	10	4
Total ~kg	300	80	130	20

Performance Assumptions and Status

- Current – basic, empirical methods for estimates and comparisons
- In Work – lift and drag models for performance
- Future – flight planning and 3 DOF simulation



Flyer Innovations

Key Options

Swept wing

- Capsule packaging of swept wing design
- Range verses loiter design considerations
- Winglets synergistically provide yaw stability and increased L/D
- Inverted v-tail adds additional degrees of control by building capability into the hardware

Parasail with high L/D proposed

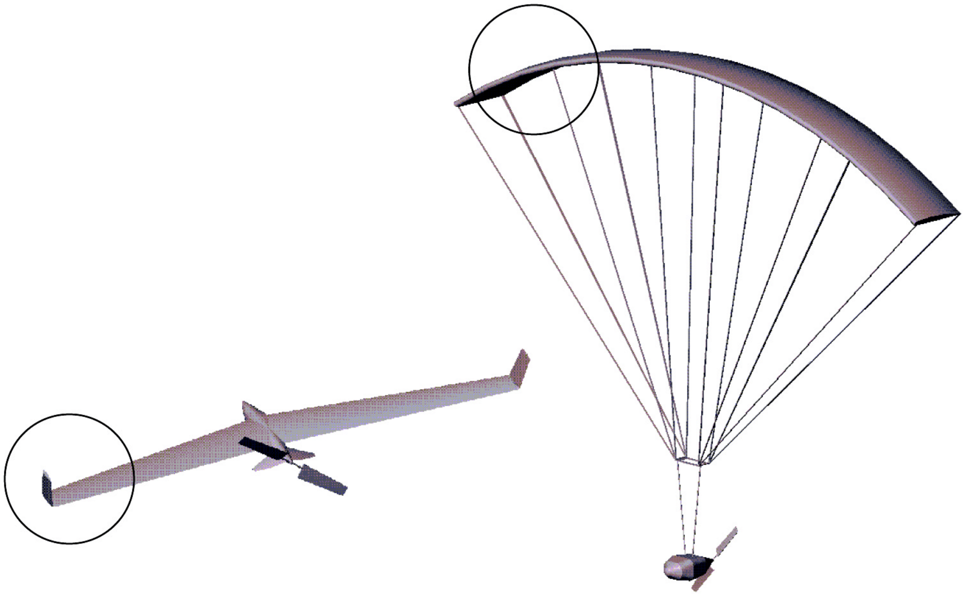
- Deployment mechanisms – Vertigo air-beams

Recommend motor development

- Hydrazine or H_2O_2

“Minimum flyer” concept proposed

- 500 km and/or 1 hour flyer



Top Level Trades

- Wing thickness and weight verses performance – No more that ~10% t/c
- Blended wing body shaping to reduce drag
- Wing loading and fuel quantity
- Alternate Power Provisions
  - Battery – short mission – small flyer
  - Solar – advanced mission – higher costs, higher risks

Mission Definition

Goal – Minimize Complexity

- Reduce development risk and cost
- Achieve adequate flight range and time
- Determine mission performance criteria

Winged Flyer – Terrain Coverage

- Initial 360° view / terrain coverage w/ 180° for 360° view / final course for target coverage

Parasail – Delivery of Payload

- Initial 360° view / target correction / loiter / land
- The parasail flyer achieves accurate, terminal targeting for its payload reducing the risks associated with landing site selection for roving explorers.

Design Allowables and Margins

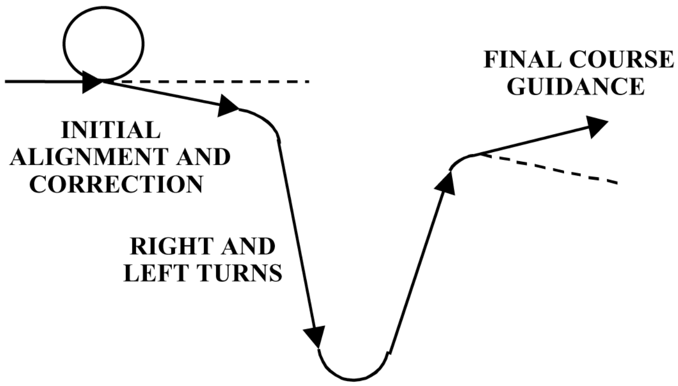
Mission Performance

- "Everything that can go wrong…"
- Atmospheric variations from Mars "standard day"
- Communications issues

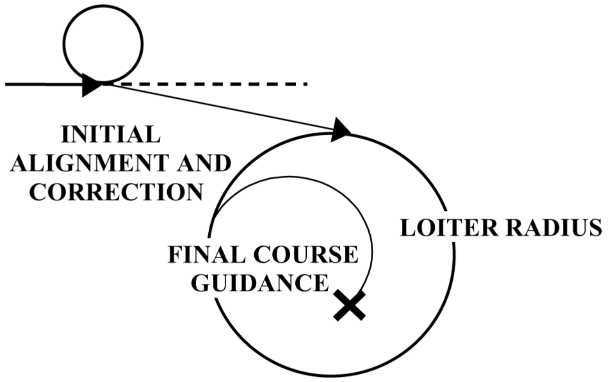
Concept Design and Development Tolerances

L/D estimates	± 5% of design
Propulsion goals	+ 15% HP/Weight
Mass reserve	15%

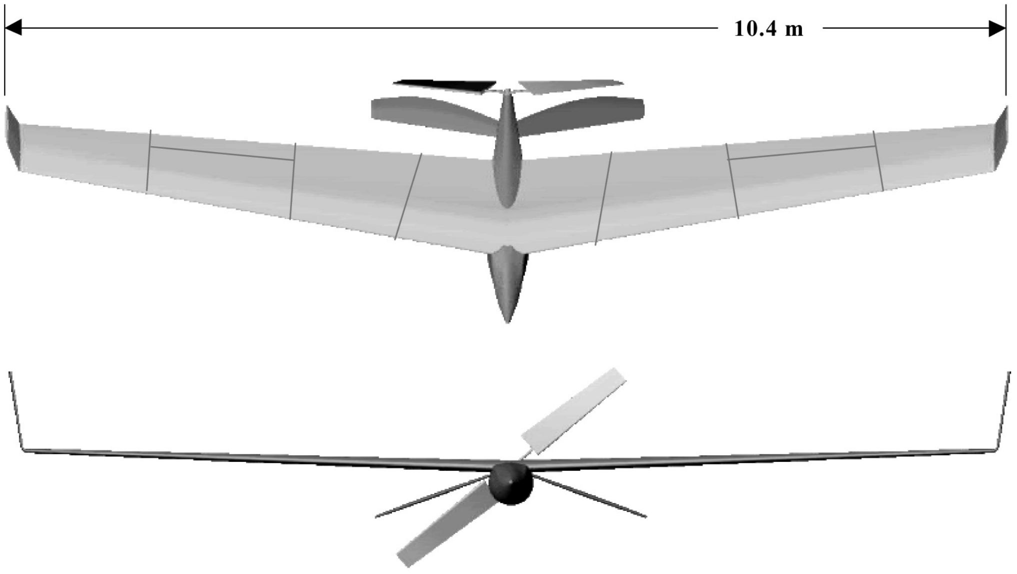
Winged Flyer - Terrain Coverage



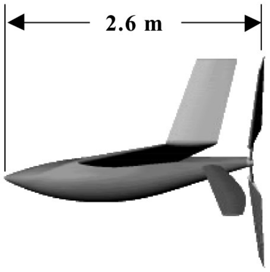
Parasail - Delivery of Payload



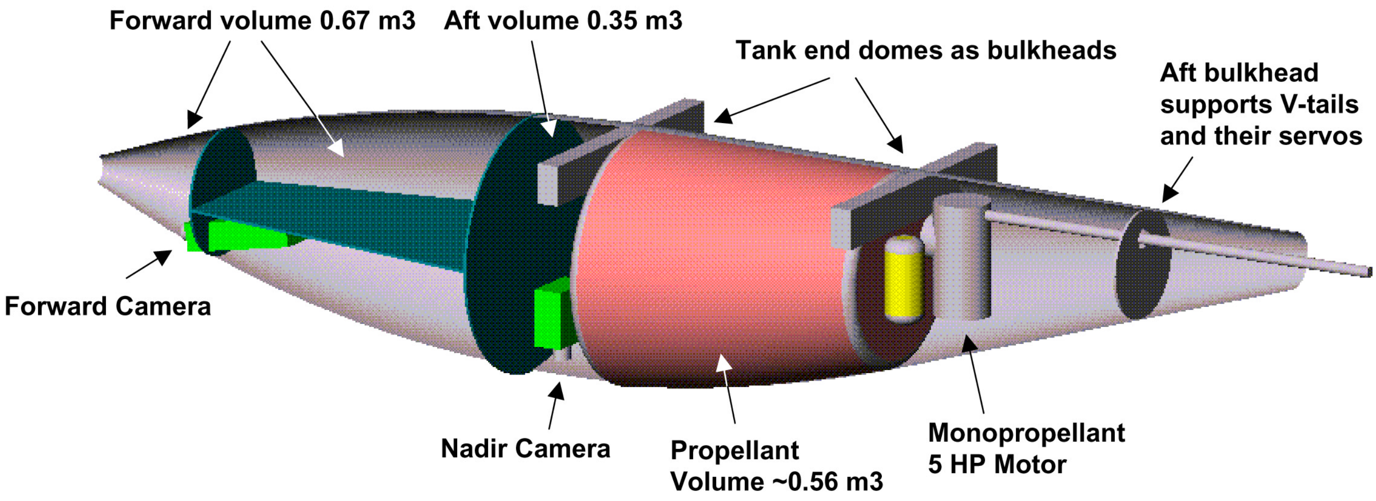
Aztec – Winged Flyer for Delta II



AZTEC - Mars Flyer	
Wmax	80 kg
Wowe	50 kg
Span	10.4 m
Sref	7.5 m2
AR	13.3
c,root	1 m
λ	.5
Λ_{LE}	10º
Dihedral	2º
Propeller	3 m



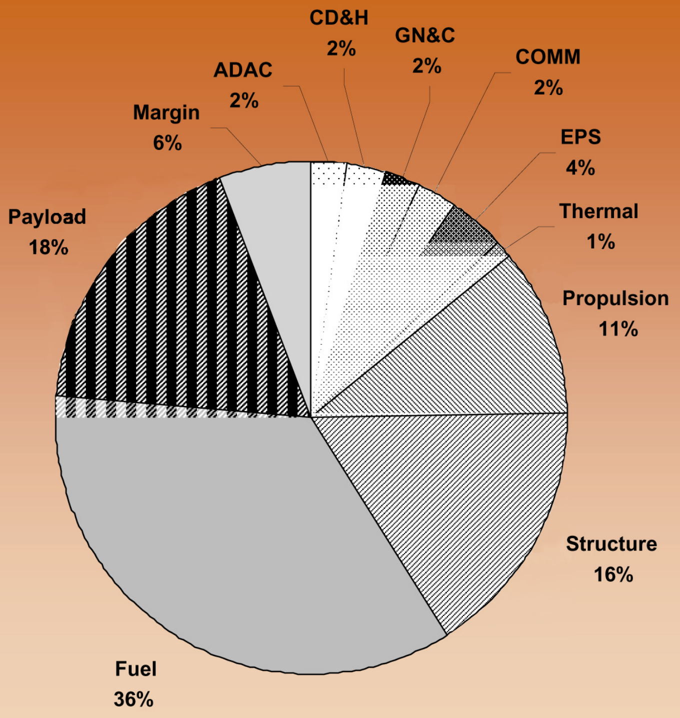
Inboard Profile – Winged Flyer



Mass Allocations – Subsystems

A satellite with wings...

<u>Subsystem</u>	<u>kg</u>	<u>%</u>
ADAC	2	2.5%
CD&H	2	2.5%
GN&C	2	2.5%
COMM	2	2.5%
EPS	3	3.8%
Thermal	1	1.3%
Propulsion	9	11.3%
Structure	14	17.5%
Fuel	30	37.5%
Payload	15	18.8%
Margin	5	6.3%
Total	80	100%



Aerodynamic Evaluation

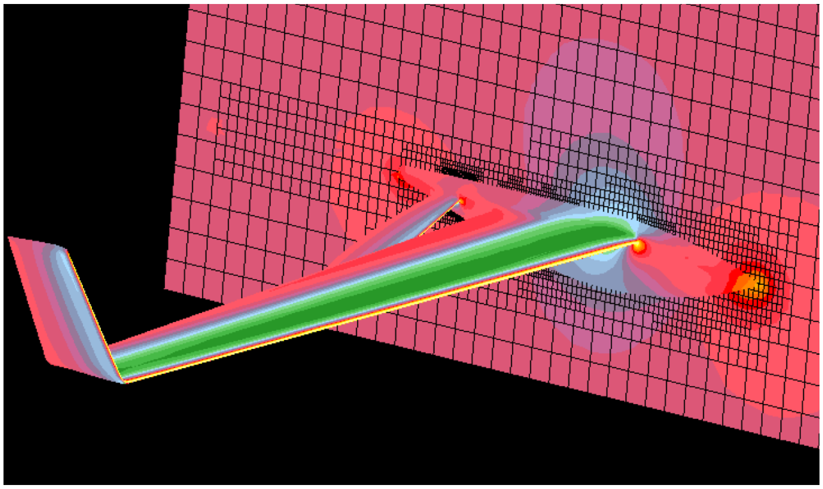
Flying wing design considerations
- Range design goal mitigates need for high C L
- Short tail moment / control volume
- Airfoil reflex investigations and trim

Performance issues
- Performance characteristics still “in work”
- Drag polar determined empirically
- Airfoil selection
  - Thickness ratio, t/c
  - Drag characteristics
- Future work
  - t/c and packaging
  - Propeller design

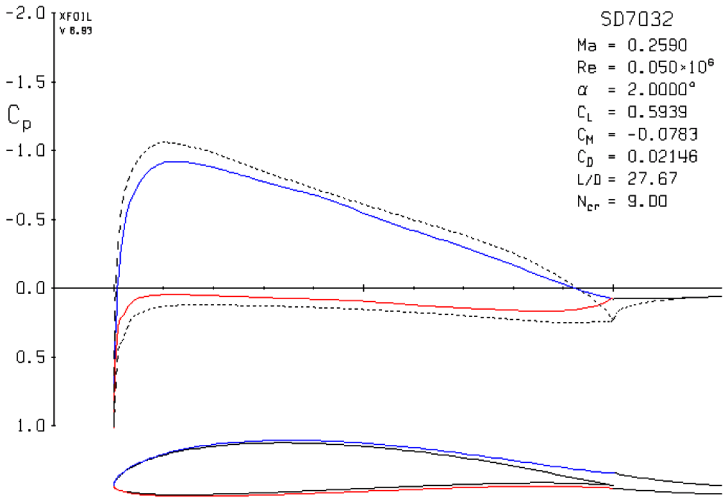
Analysis – Three Step Process
1) Airfoil Analysis using XFoil
   - <u>2D</u> Linearized-potential panel code
   - Coupled ISES boundary layer
   - Reynolds numbers are on low end for XFoil
2) Stability & Control Analysis using A502 (PANAIR)
   - <u>3D</u> Linearized potential panel code
   - Assumes attached flow, no viscous drag
   - Gives full set of longitudinal and lateral-directional stability derivatives including damping derivatives
3) Performance Aero (Drag) Analysis using TRANAIR CFD and Empirical Data at low angles of attack
   - <u>3D</u> Full Potential CFD Solver
   - ISES Coupled boundary layer yields viscous drag
   - More Accurate CL and CM values than A502
   - Run times of 8 to 12 hours for 1 AOA / Mach combination

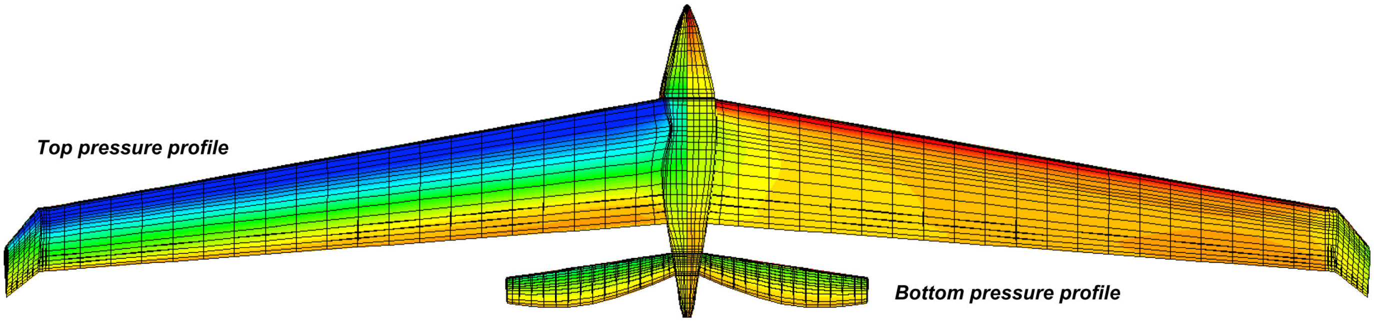
AOA for Max Lift Determined Semi-Empirically
- Root Hepperle-MH46 t/c 11%, Tip Selig-SD7032 t/c 10%
- Combined with A502 span loads and DATCOM correlation

Propeller Design – TBD



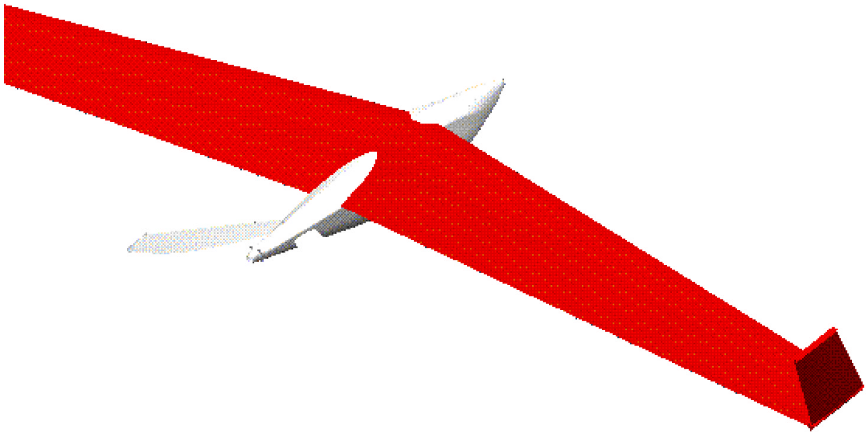
Design Status
- Insufficient drag polar for adequate endurance modeling / range comparison
- Possible alternate power source – battery for short mission
- Low fuel fraction allows for increased payload





MarsHawk – Preliminary

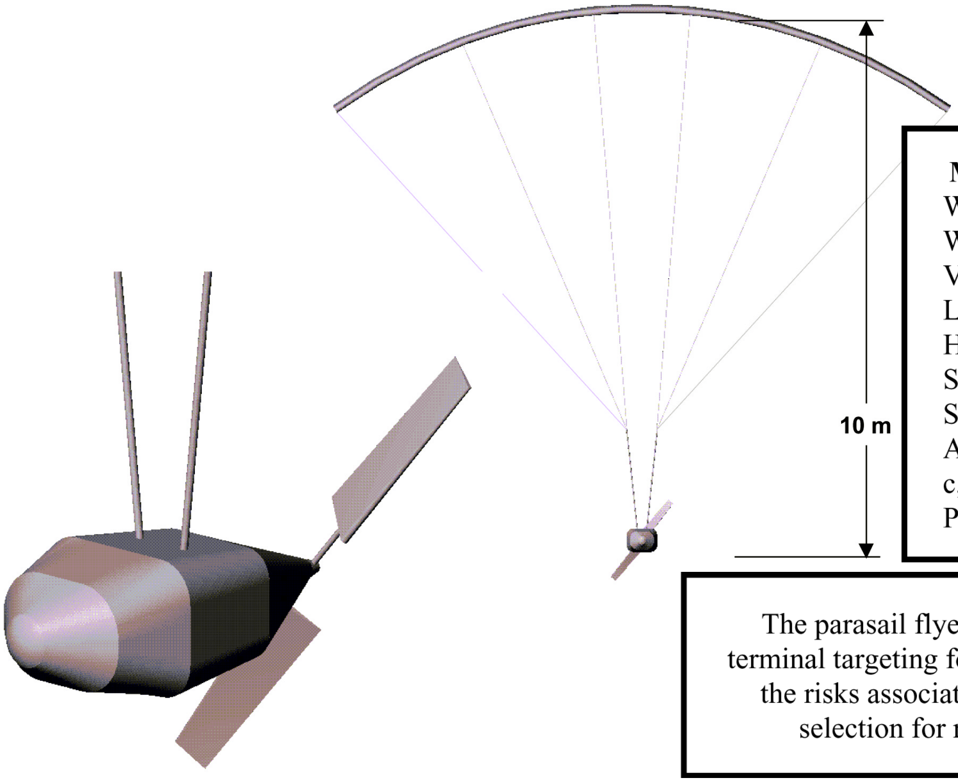
Range	500 km
Wmax	25 kg
Wowe	22.7 kg
Length	1.2 m
L/D	15
AR	13.3
s, wing area	1.5 m^2
b, span	4.47 m2
w/s	61.58 N/m^2
CL	0.50
CD	0.033
Altitude, start 8	km
Mars gravity	3.69 N/m/sec2
eta	0.85 km
flight v	187.58 m/sec
glide range	120 km
powered range	380 km
time of flight	0.740 hr
mass fuel	2.26 kg
prop. power	1.36 kW
sfc	.821E-3 kg/sec/kW
fuel/total	0.090 ratio



"Minimum Flyer" Definition

Design Status
- Insufficient drag polar for adequate endurance modeling / range comparison
- Possible alternate power source – battery for short mission
- Low fuel fraction allows for increased payload

Parasail for Delta II



Mars Parapoint Flyer

Wmax	130 kg
Wowe	100 kg
Volume	4.1 m^3
Length	2.1 m
Height	10 m
Span	12.7 m
Sref	20 m^2
AR	8
c, root	2 m
Propulsion	13 hp

The parasail flyer achieves accurate, terminal targeting for its payload reducing the risks associated with landing site selection for roving explorers.

Risk Reduction Program

Key efforts define program strategy
- Propulsion development
- System flight testing

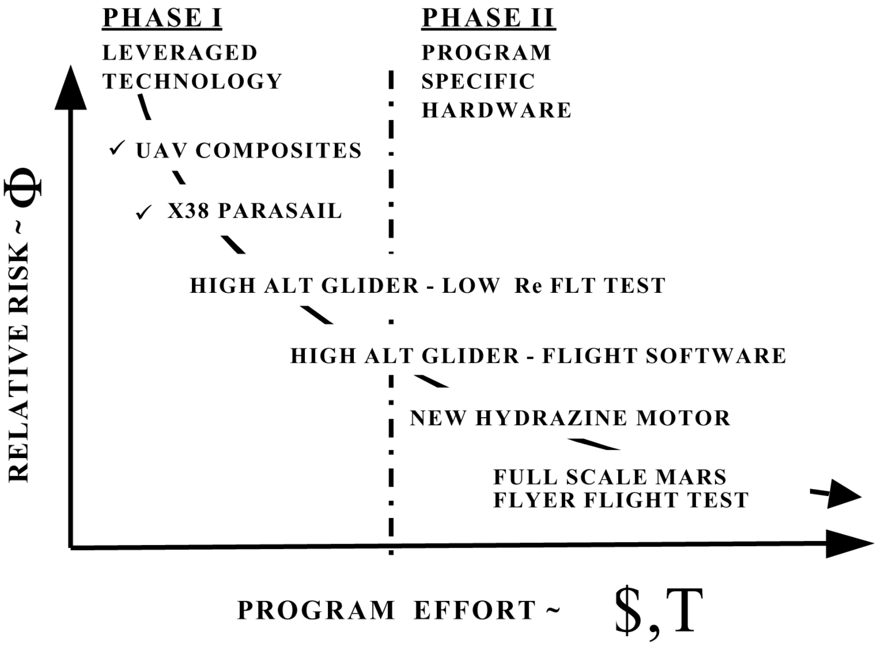
Key elements define system requirements
- Mars orbital communication assets
- GN&C capabilities

Program opportunities
- 2005 and 2007

Propulsion approach – mono propellant, reciprocating motor
- Utilize materials advances
- Optional Hydrazine and/or Peroxide (H_2O_2) fuel
- Additional expenditures to develop fullest performance

System flight testing – “parallel efforts”
- Airframe and software integrated using simulated motor
- Most flyer concepts can benefit from development efforts

Development Planning Weighs Key Risks Against Reliability / Schedule / Cost

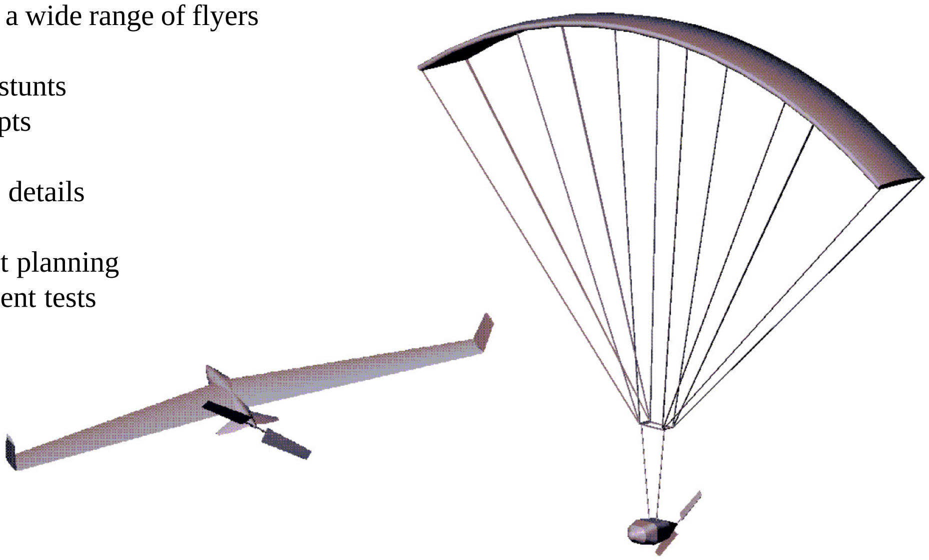


Summary – Fly Mars

Minimum and maximum flyer sizes defined
- Recommend lower wing loadings at large weights
- Challenged by low propellant fraction at small end of scale

Development programs should support a wide range of flyers
- Call it a “Mars flight initiative”
- Technology exists to do more than stunts
- Develop multiple propulsion concepts

Aztec future work
- Develop avionics suite and mission details
- Detail and finalize the design
- Monopropellant motor development planning
- MarsHawk R/C flight and deployment tests



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  2 Years Phantom Works, SSP, SLI, OE
Four Years Aeronautical Systems, General Atomics:
  3 Years Amber UAV (Leading Systems)
  1 Year Predator UAV
Currently working as systems integrator, Orbital Express On-orbit servicing platform
Fresh out of school in 1985 began prototyping work on Amber UAV at Leading Systems. Skilled in aircraft and launch vehicle design with broad experience including project and proposal development.
Mars Society Member, 2001
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“If science is a way of not fooling ourselves” (Fynman), then engineering is a way of not killing ourselves. . .

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Ad Astra Per Aspra!