

Planetary Aircraft concepts and design evolution

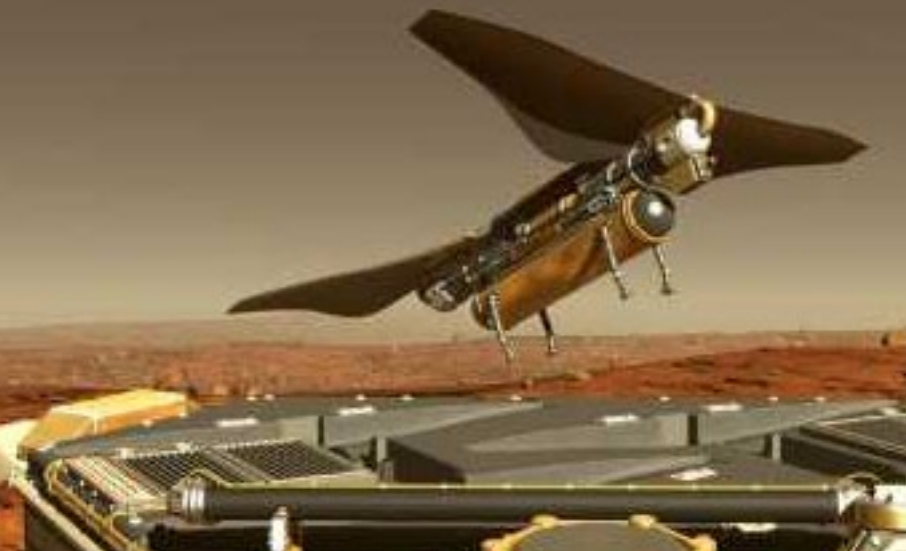
Geoffrey A. Landis
NASA John Glenn Research Center
Cleveland, OH



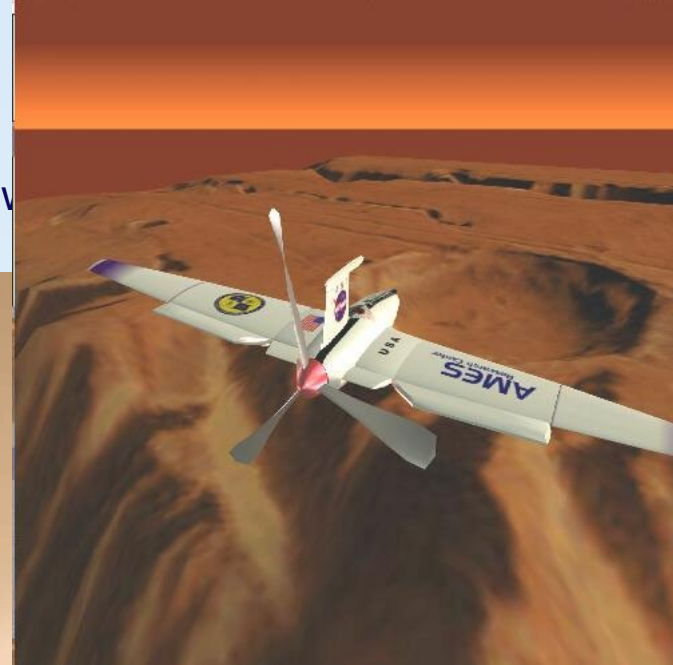
Mars aircraft

1990s conceptual design for small solar-powered airplane

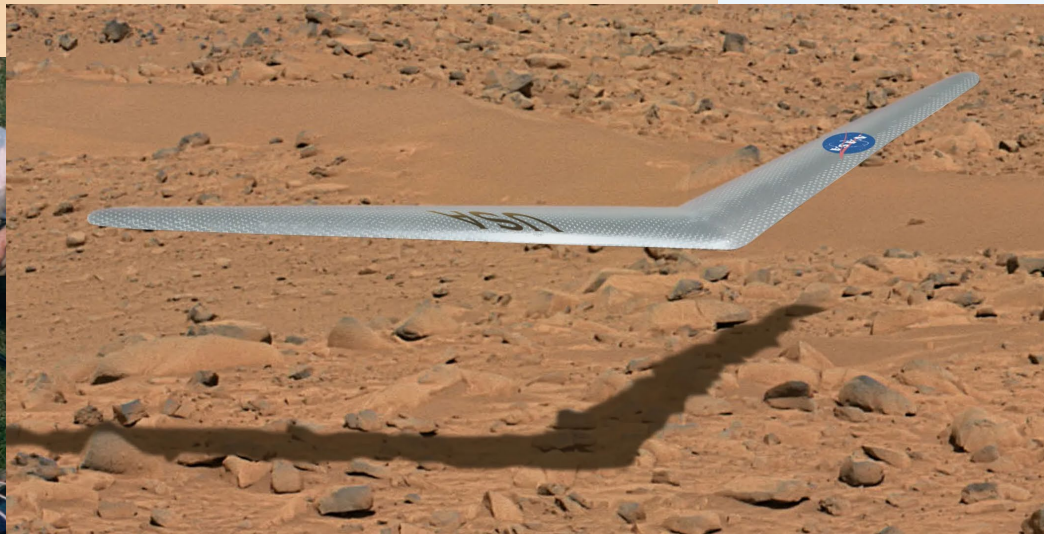
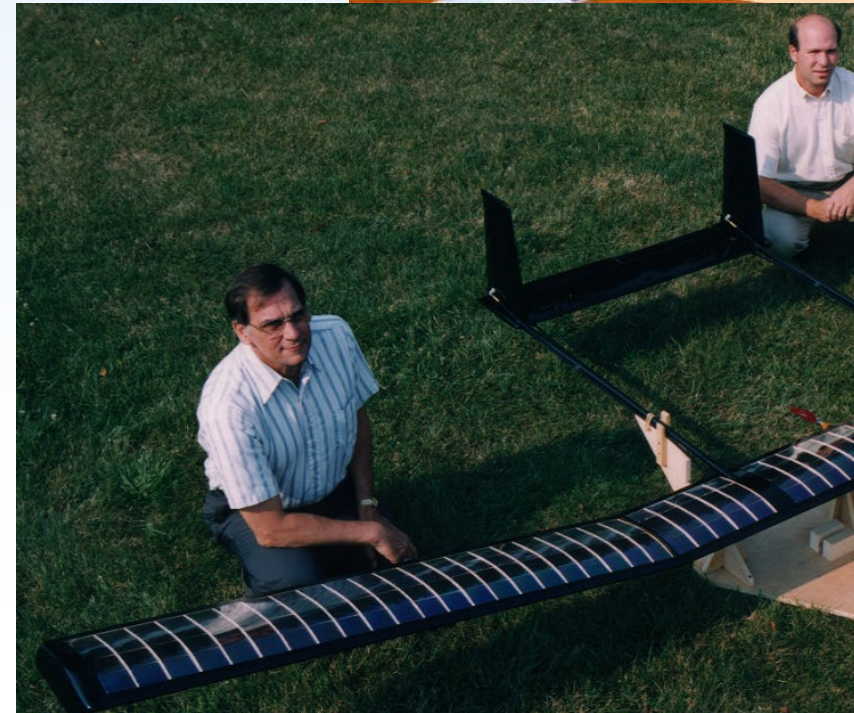
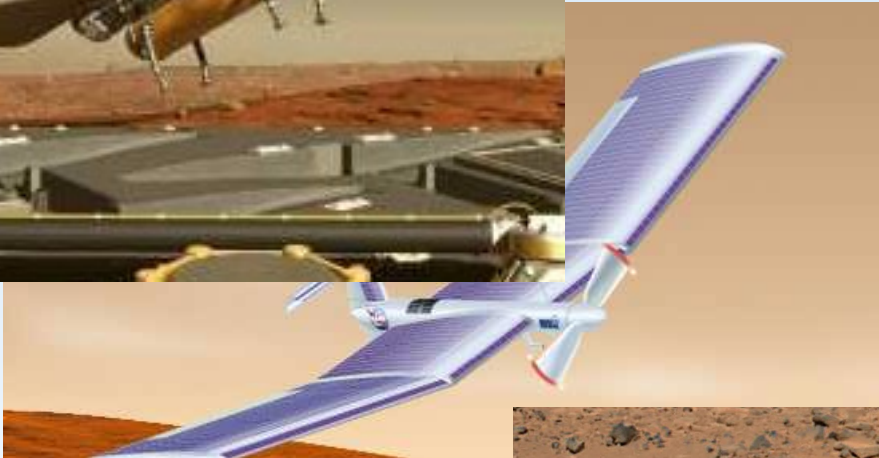




aircraft
or small solar-pov



Tony Colozza
Mars entomopter



Prandtl concept

NASA Lewis Mars
Solar airplane

Planetary Aircraft



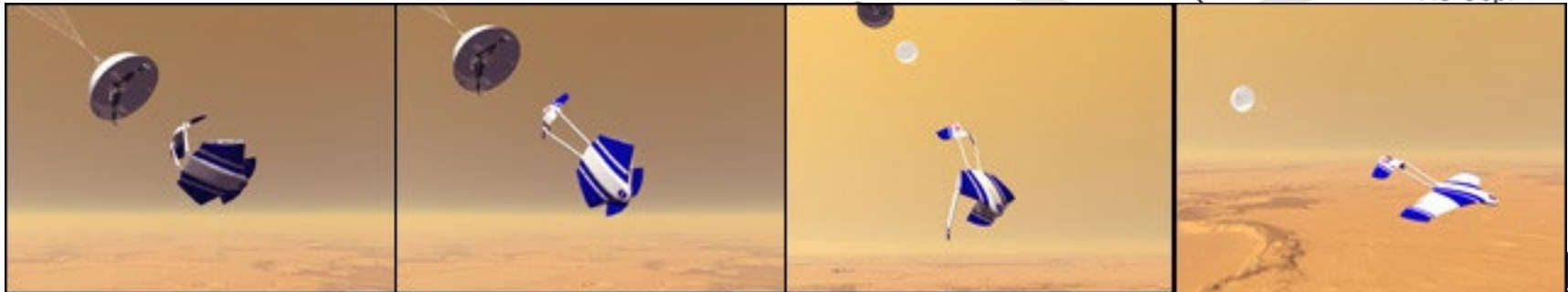
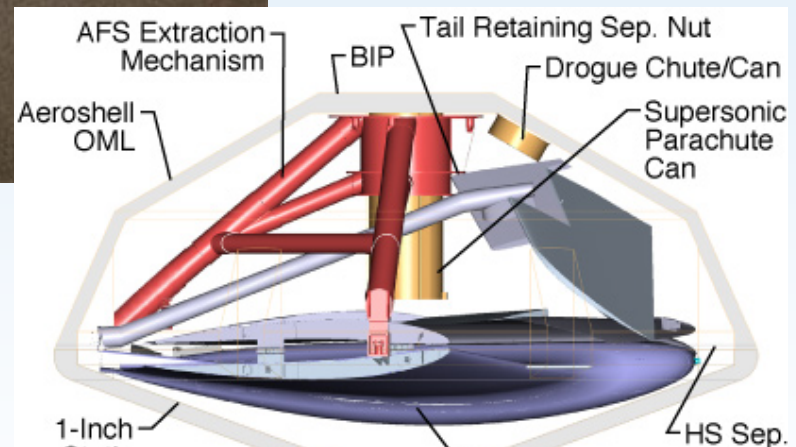


Ares Mars airplane

- Proposed as 2007 Mars Scout mission
- Prototype build and tested by Aurora Flight Sciences
- 1 hour flight on rocket power
- Not selected

ARES Mars airplane demonstration models

- 6.25 m span
- Aspect ratio 5.6
- 101 kg including margin



Required power for flight on other planets (simplified)

- Horizontal flight requirement: lift on wing = gravity

$$\bullet F = \frac{1}{2} \rho C_L A V^2 = mg$$

Variables

- ρ (atmospheric density): function of altitude
- C_L (lift coefficient): typically around 1 for optimum flight
- A (wing area)
- V (velocity)

Flight velocity and power:

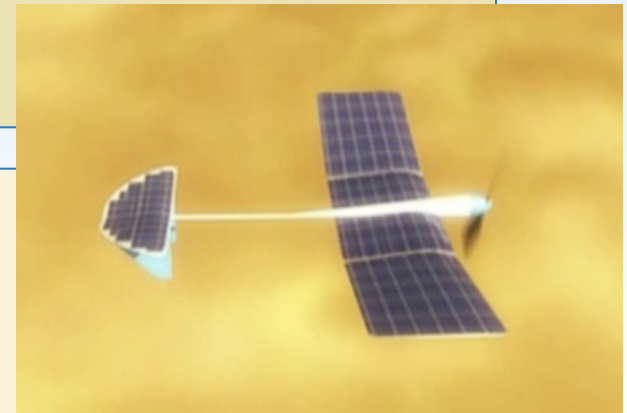
$$\bullet V = \text{SQRT} (mg/A)/(2\rho C_L)$$

- Note that (m/A) = wing loading

• Power = drag force times velocity

- If we make the simplifying assumption that drag is proportional to lift via the L/D (lift to drag) ratio, and C_L is approximately 1:

$$\bullet P = mg/(L/D) * V = (mg)^{3/2} (L/D)^{-1} (2\rho A)^{-1/2}$$



Required power for flight on other planets (simplified)

- Horizontal flight requirement: lift on wing = gravity

$$\bullet F = \frac{1}{2} \rho C_L A V^2 = mg$$

Variables

- ρ (atmospheric density): function of altitude
- C_L (lift coefficient): typically around 1 for optimum flight
- A (wing area)
- V (velocity)

Flight velocity and power:

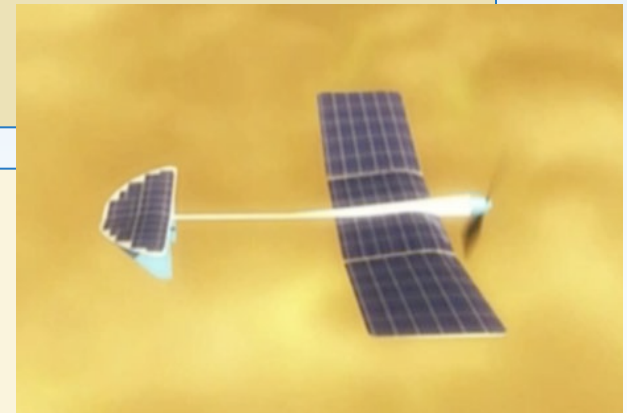
$$\bullet V = \text{SQRT} (mg/A)/(2\rho C_L)$$

- Note that (m/A) = wing loading

• Power = drag force times velocity

- If we make the simplifying assumption that drag is proportional to velocity squared via the L/D (lift to drag) ratio, and C_L is approximately constant

$$\bullet P = mg/(L/D) * V = (mg)^{3/2} (L/D)^{-1} (2\rho A)^{-1/2}$$



Mars is hard: low density,
low solar power

What about Venus?

Venus

Atmospheric exploration trade-study



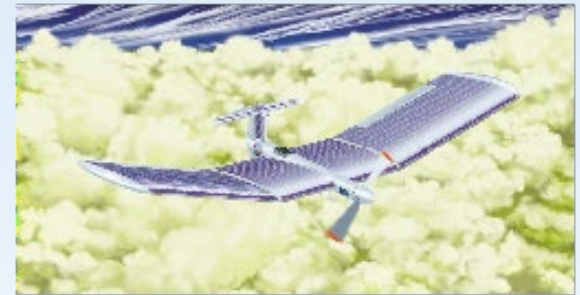
•Balloon

- Simple technology
- Demonstrated on Venus
 - Soviet VeGa mission
- Altitude change possible, but difficult
- Location change not possible
- Circles planet with wind; drifts toward pole



•Airship

- Difficult to stow and deploy
- Altitude change possible, but difficult
- Speed is slow:
 - cannot stationkeep
 - cannot stay in sun
 - Can keep latitude



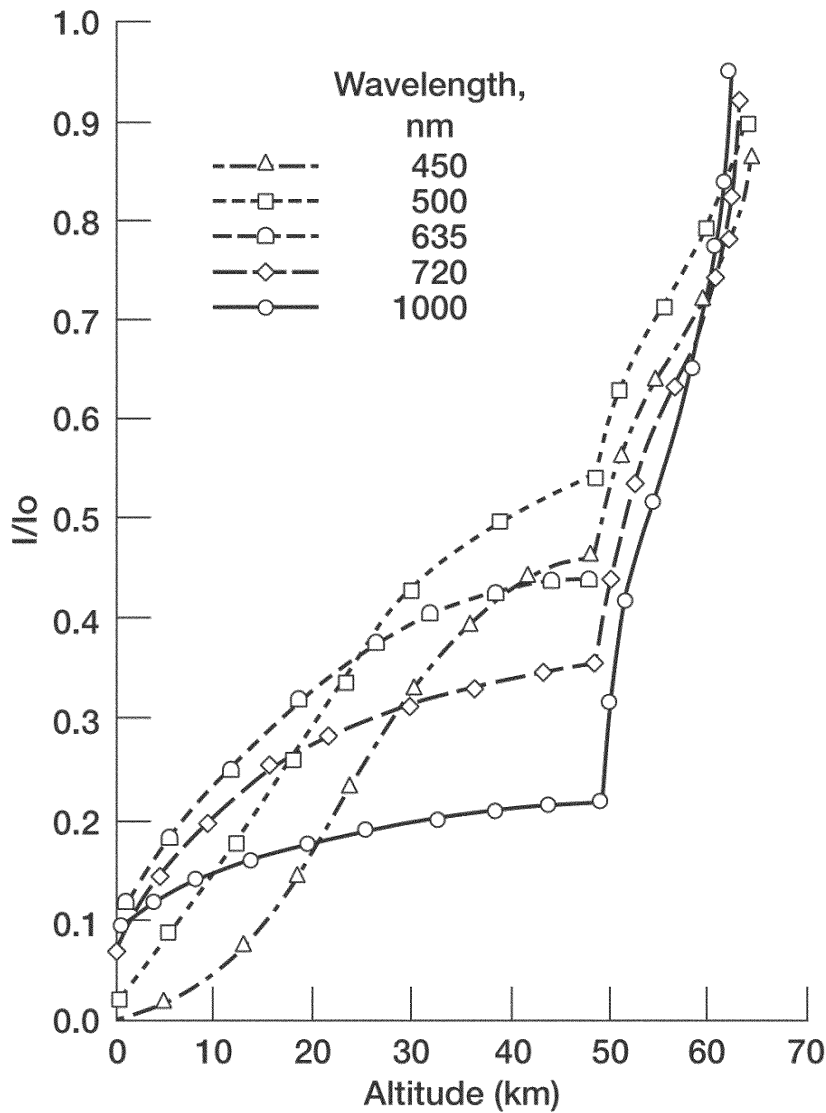
•Airplane

- Airplane design uses terrestrial experience
- Stow and deploy concepts demonstrated by ARES
- Altitude change easy (within design limits)
- Speed allows stationkeeping and continuous sun
- Easy to keep latitude

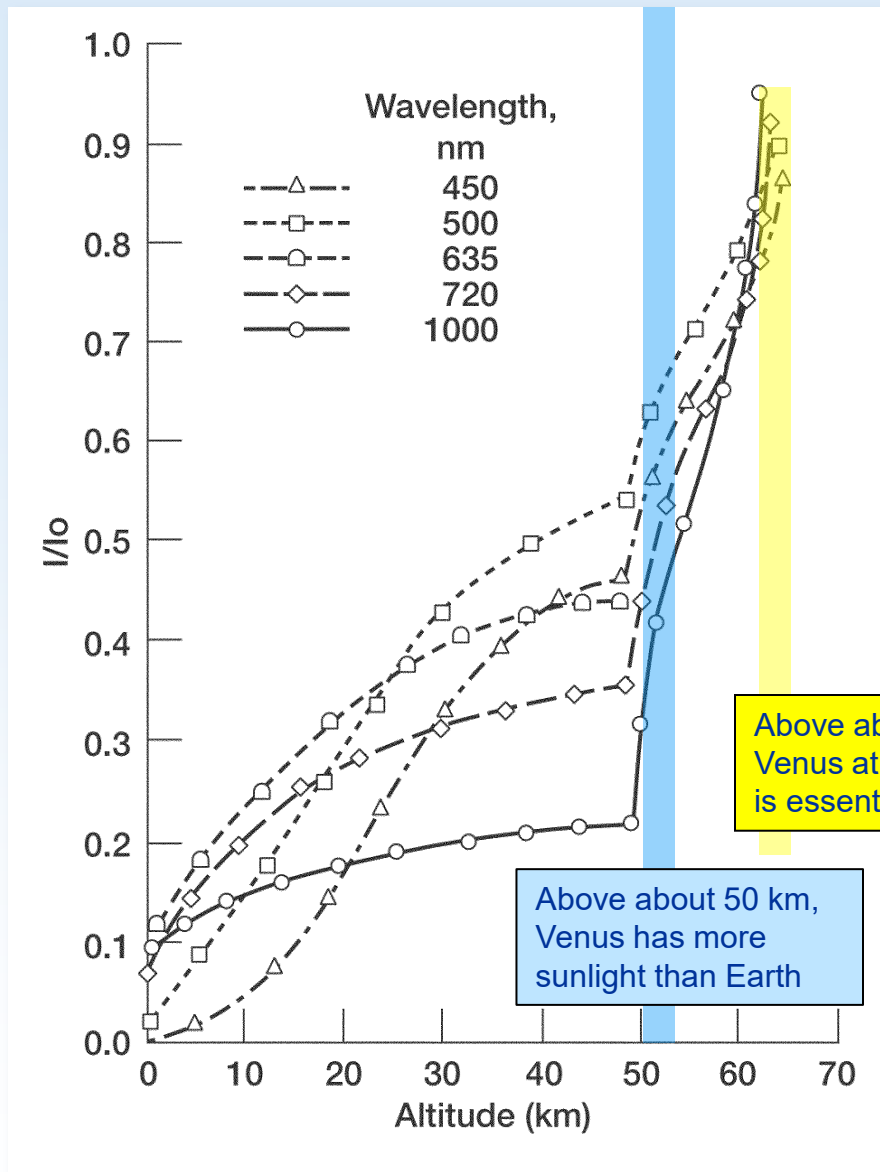


Solar energy vs altitude in the Venus atmosphere: data from Venus atmospheric probes

- At surface, power available is 10% of exoatmospheric power at 1000 nm, but <1% at 450 nm



Solar energy vs altitude in the Venus atmosphere: data from Venus atmospheric probes



Solar Airplane Figure of Merit

- 50-60 km above surface, Venus atmosphere density profile similar to Earth's

- Airplane design can use Earth experience

- Gravity 90% of Earth's

- Powered flight easier

- Above the clouds, Venus has more sunlight than Earth

- Solar flight is easier on Venus than on Earth

- Acid droplets in atmosphere require all exposed surfaces be corrosion resistant

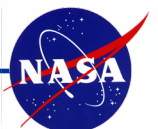
- Avoid exposed metal surfaces.

- All metal surfaces need passivation coating

- Acid-resistant materials are well developed technology

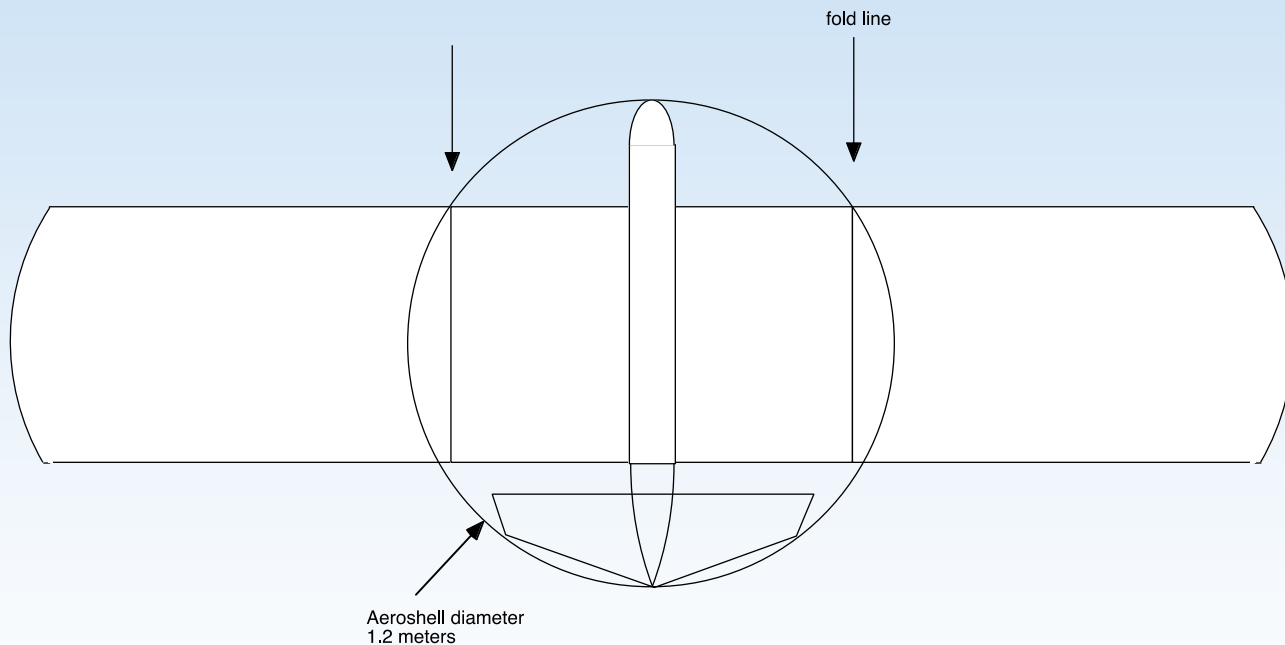
- e.g., Teflon used on Soviet VEGA balloons

If you can fly a solar airplane
on Earth, you can fly one on
Venus



Initial sketch of wing-folding for small aircraft for Venus

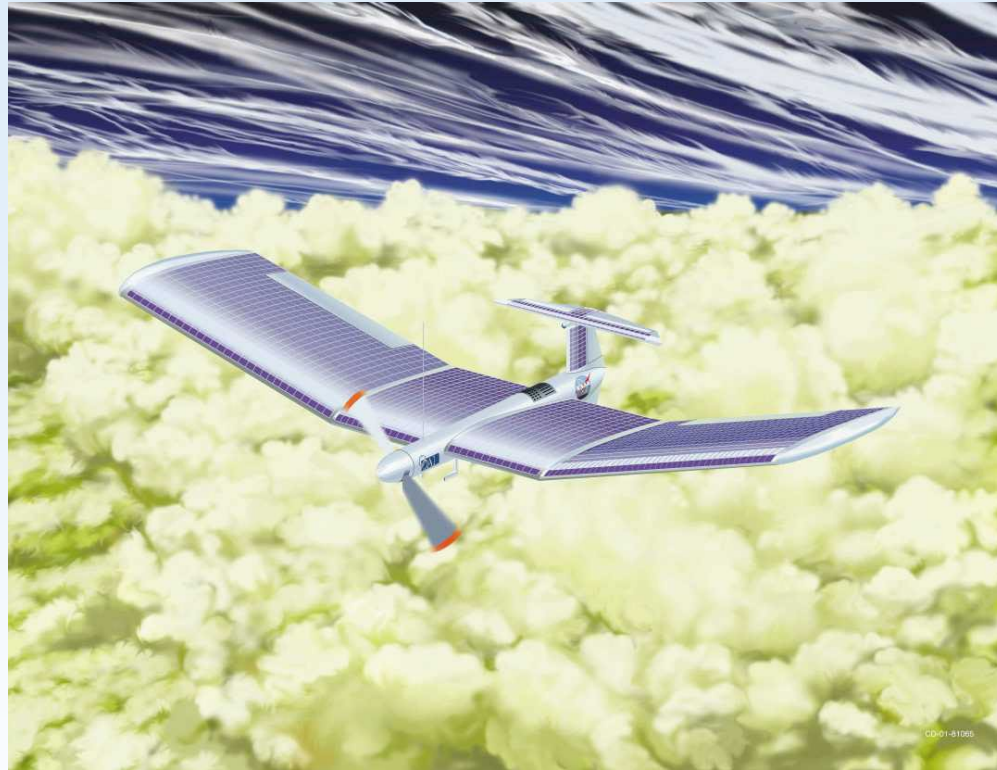
2000 version



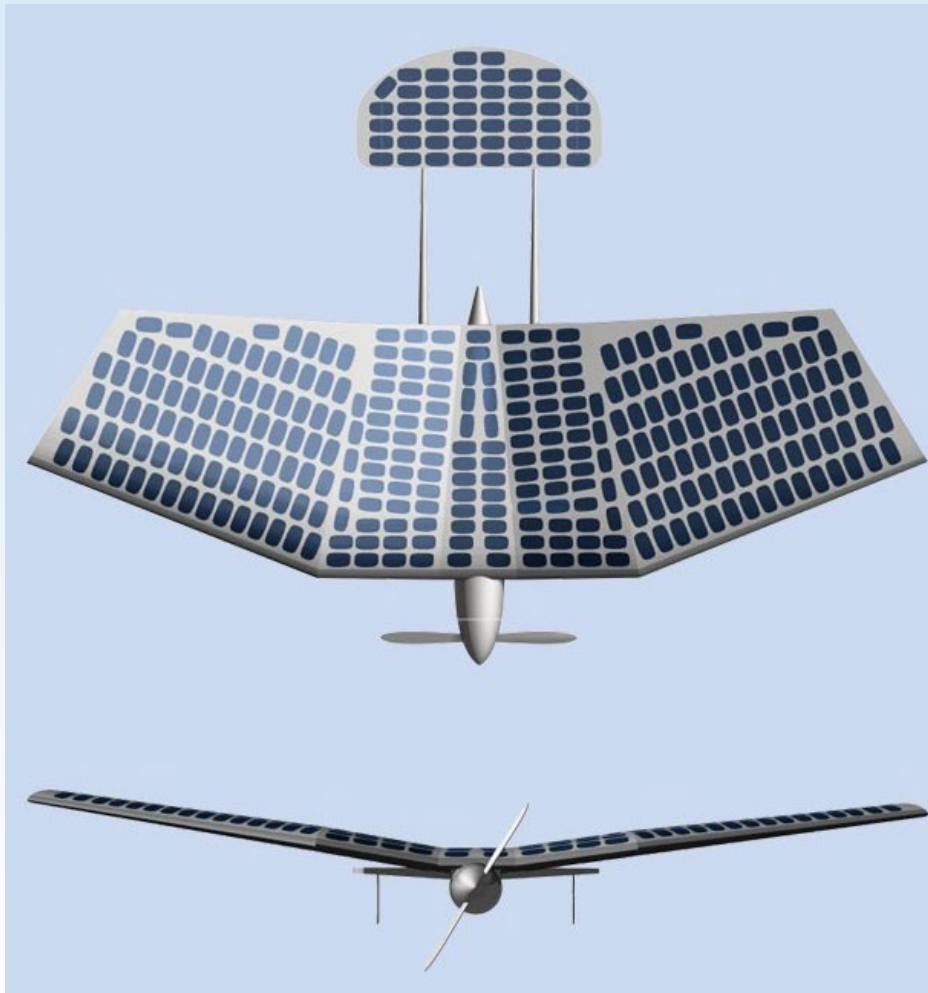
Concept aircraft is scaled to fit into Pioneer Venus aeroshell
Aircraft design is a flying-wing design with the addition of a small tail for additional control authority with no additional fold.

Venus airplane initial concept

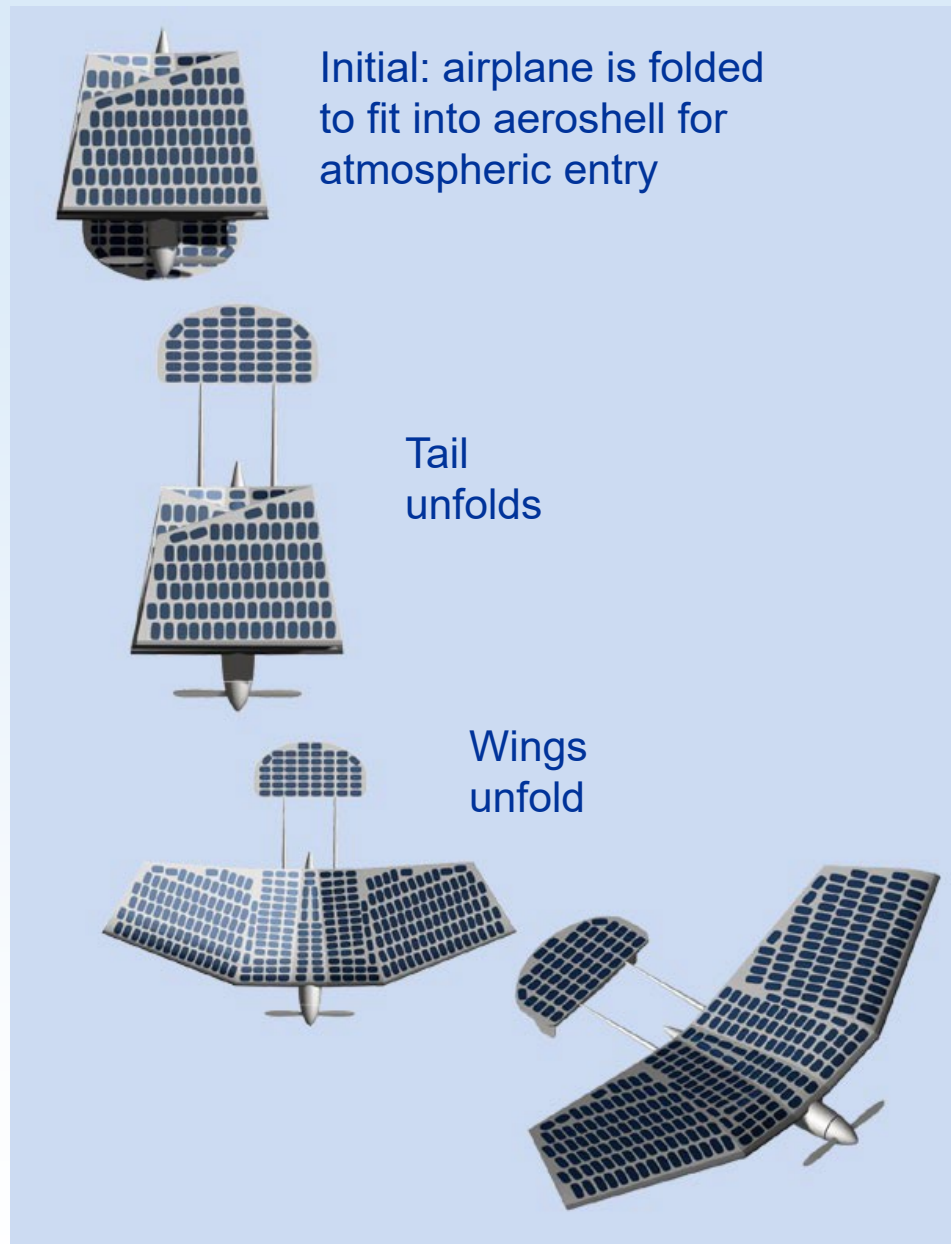
artist's conception



Evolution of design concept 2002



Venus airplane deployment



Note solar cells on top and bottom of wing!

Design challenge:

Venus wind will blow airplane out of the sunlight

at cloud-top altitudes, superrotation wind circling the planet takes the airplane from sunlit to night in ~2 days

Solutions

1. Mission lasts <2 days

But ... we really want a longer mission!

2. Battery power for night flight

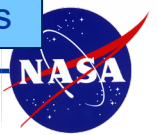
But ... night flight is for ~two days, and batteries are heavy!

3. Glide during night flight

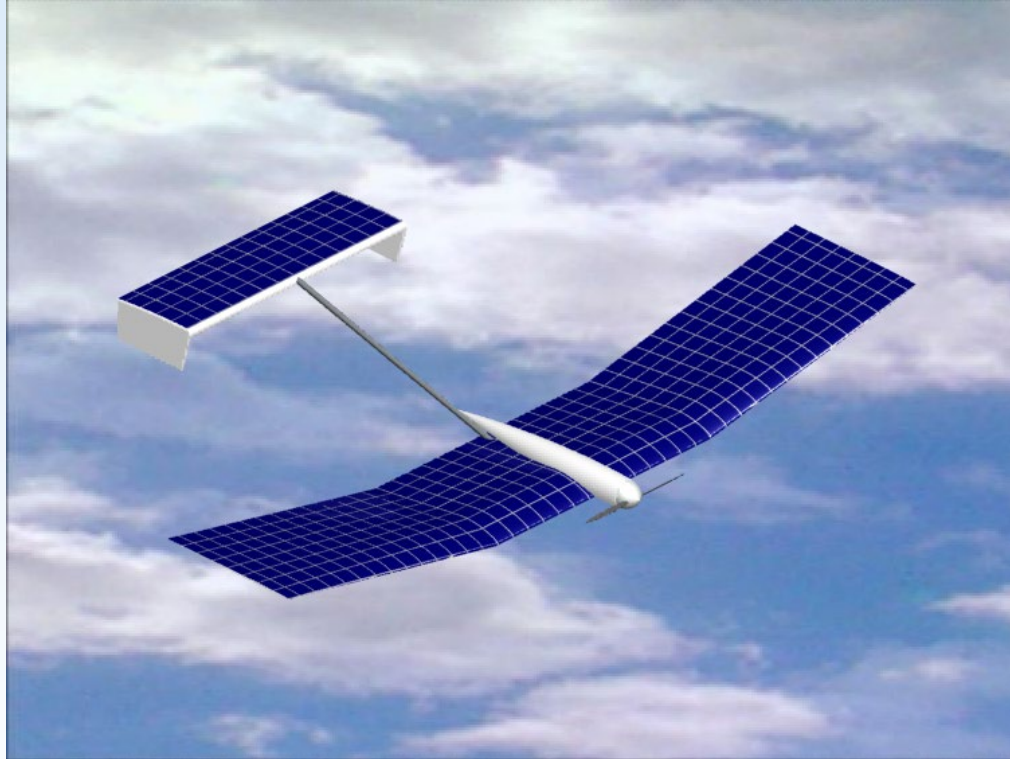
But ... can't stay aloft for two days!

4. Fly faster than the wind to stay at subsolar point

Design approach chosen for detailed analysis



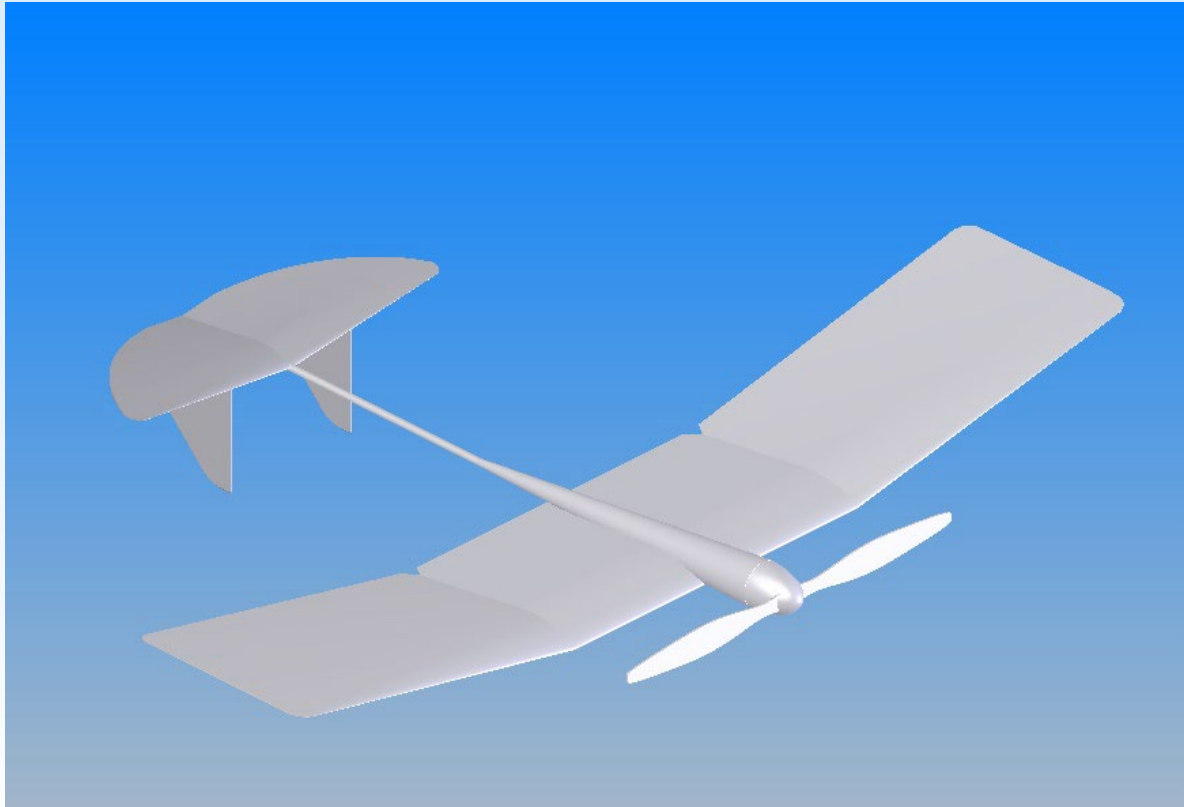
RASC study- concept evolution

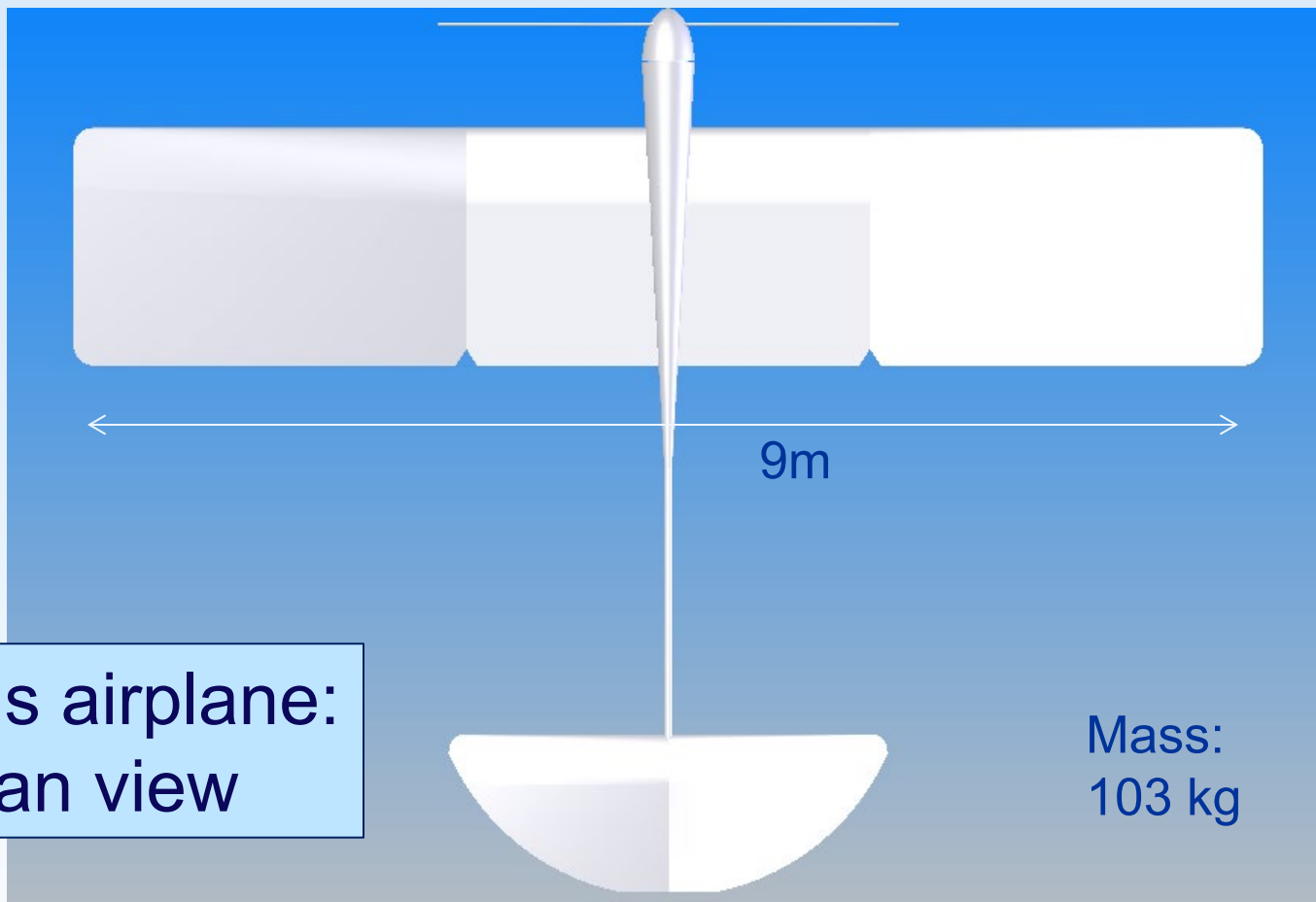


RASC: Revolutionary Aerospace Systems Concepts



RASC Venus airplane: final design



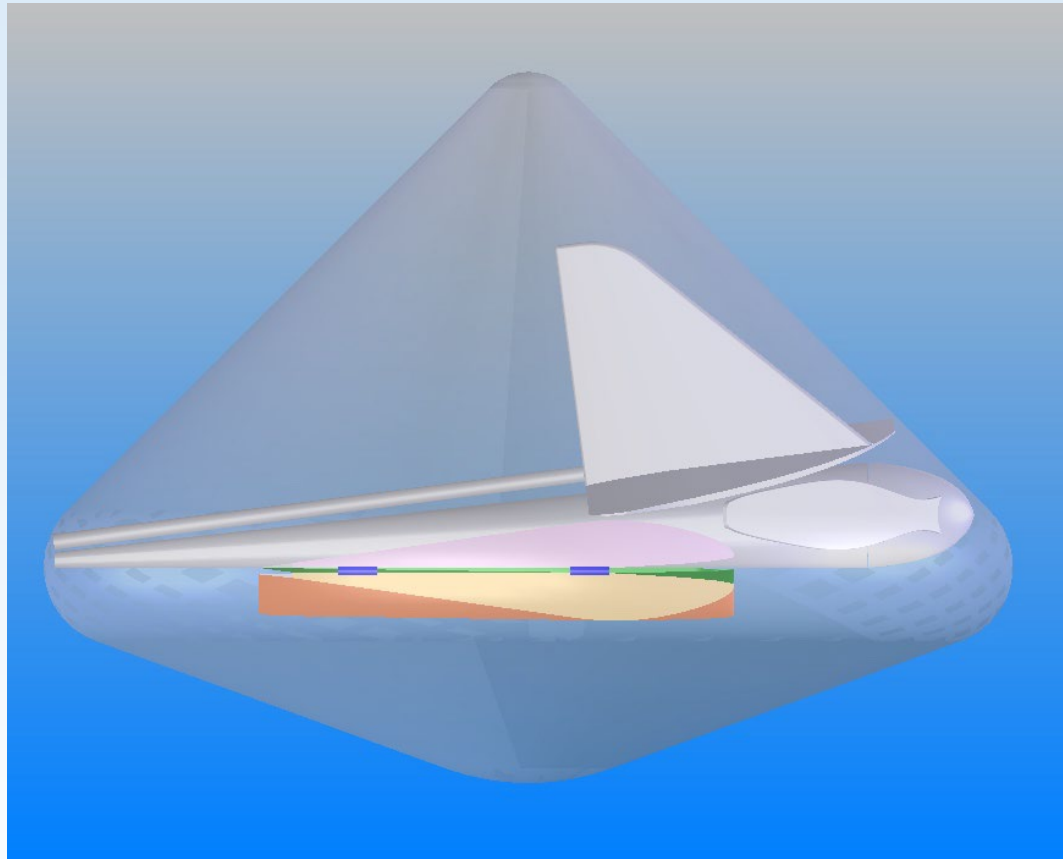


Venus airplane:
plan view



Aircraft folded into aeroshell

3.7 meter
diameter
aeroshell

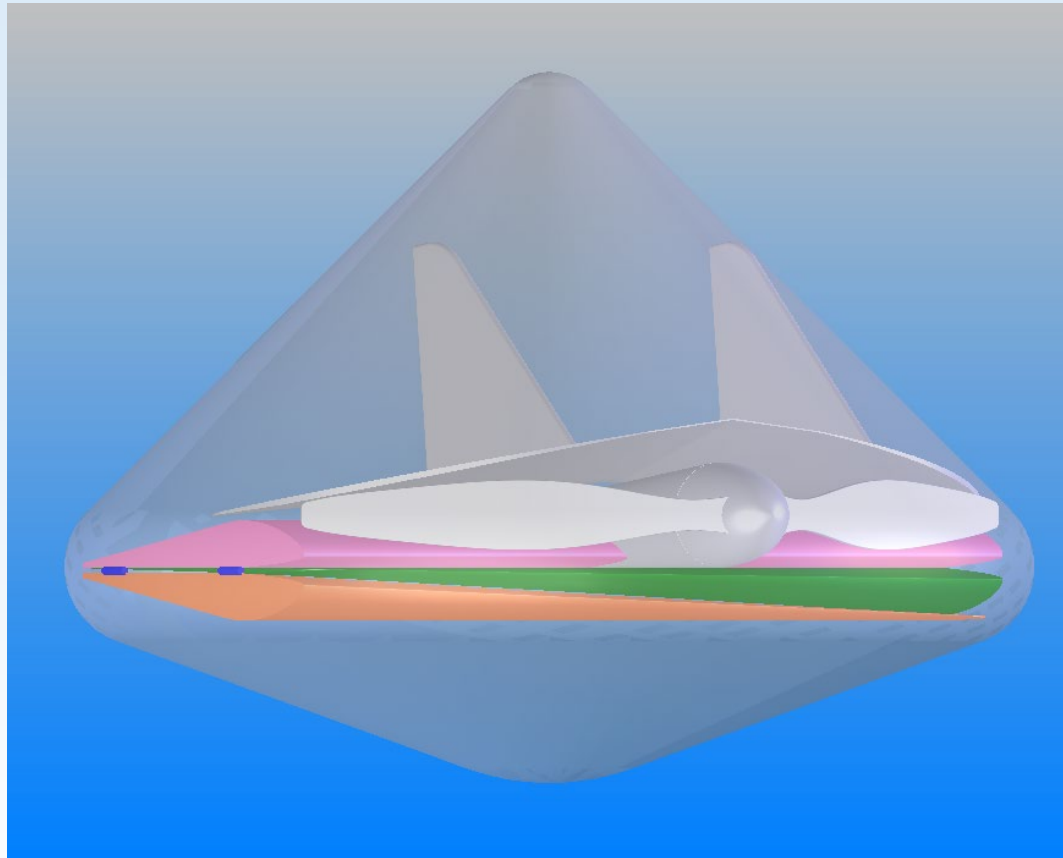


Side view

- Aeroshell is the size of the Viking lander entry system
- Aeroshell shape based on Mars Pathfinder

Aircraft folded into aeroshell

3.7 meter
diameter
aeroshell



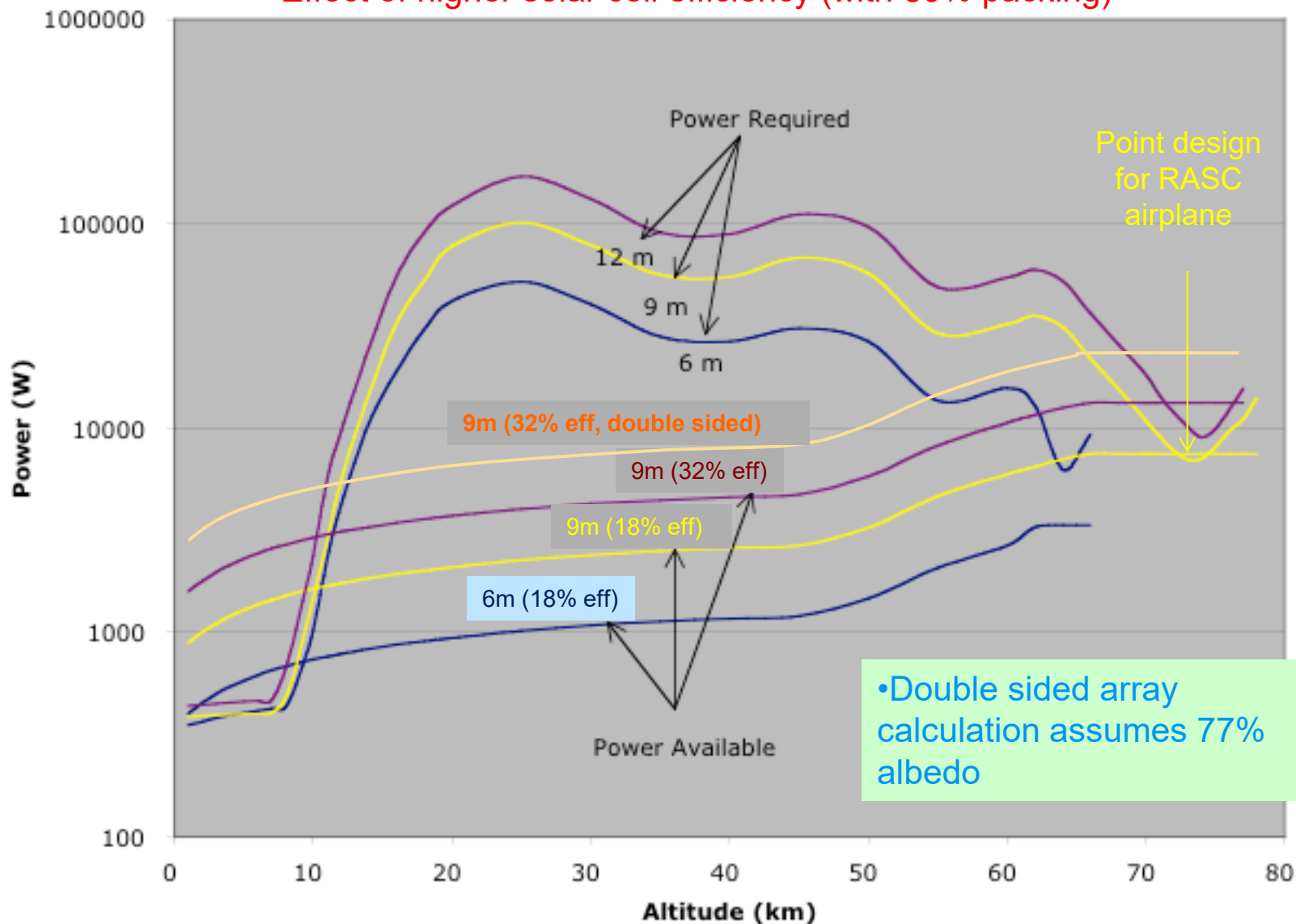
isometric view from front

- Aeroshell is the size of the Viking lander entry system
- Aeroshell shape based on Mars Pathfinder



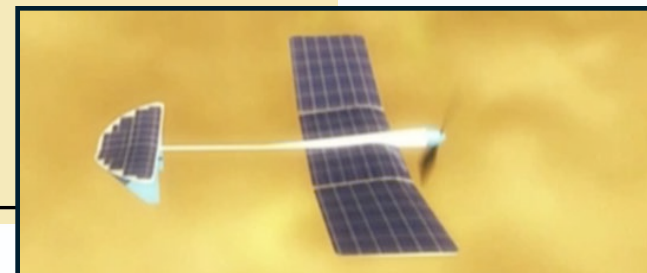
Power Required to fly at wind speed

- Effect of higher solar cell efficiency (with 80% packing)



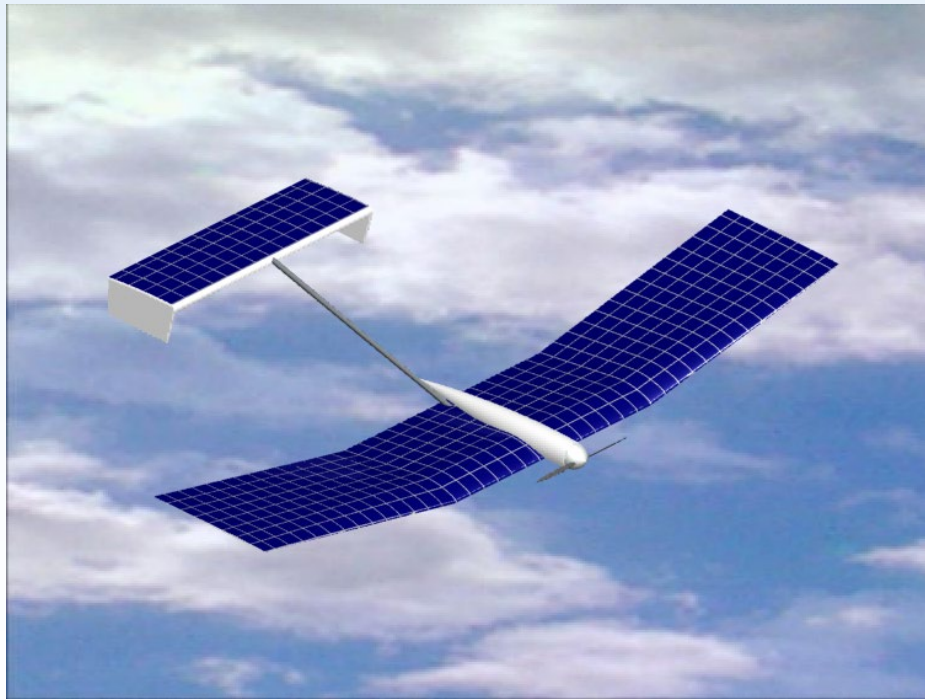
Venus Airplane entry mass

VENUS AIRPLANE MASS SUMMARY			
System Description	Mass Fraction	Mass (kg)	Source
Airplane	20%	103	(includes 10 kg payload)
Heatsheild Structure	7%	36.05	Pioneer
Heatsheild TPS	13%	66.95	Pioneer
Backshell Structure (Gussets, Separation ftgs, Paint, Vent, etc)	12%	61.80	Pioneer
Backshell TPS	8%	41.20	Pioneer
Parachute System	10%	51.50	Pioneer
Airplane Deployment Mechanism (Separation from Backshell)	15%	77.25	Mars Airplane
Misc (COMM, Power, Ballast, etc)	15%	77.25	Mars Airplane
Total Entry Mass	100%	515	
Contingency Mass	30%	155	
Total With Contingency		670	

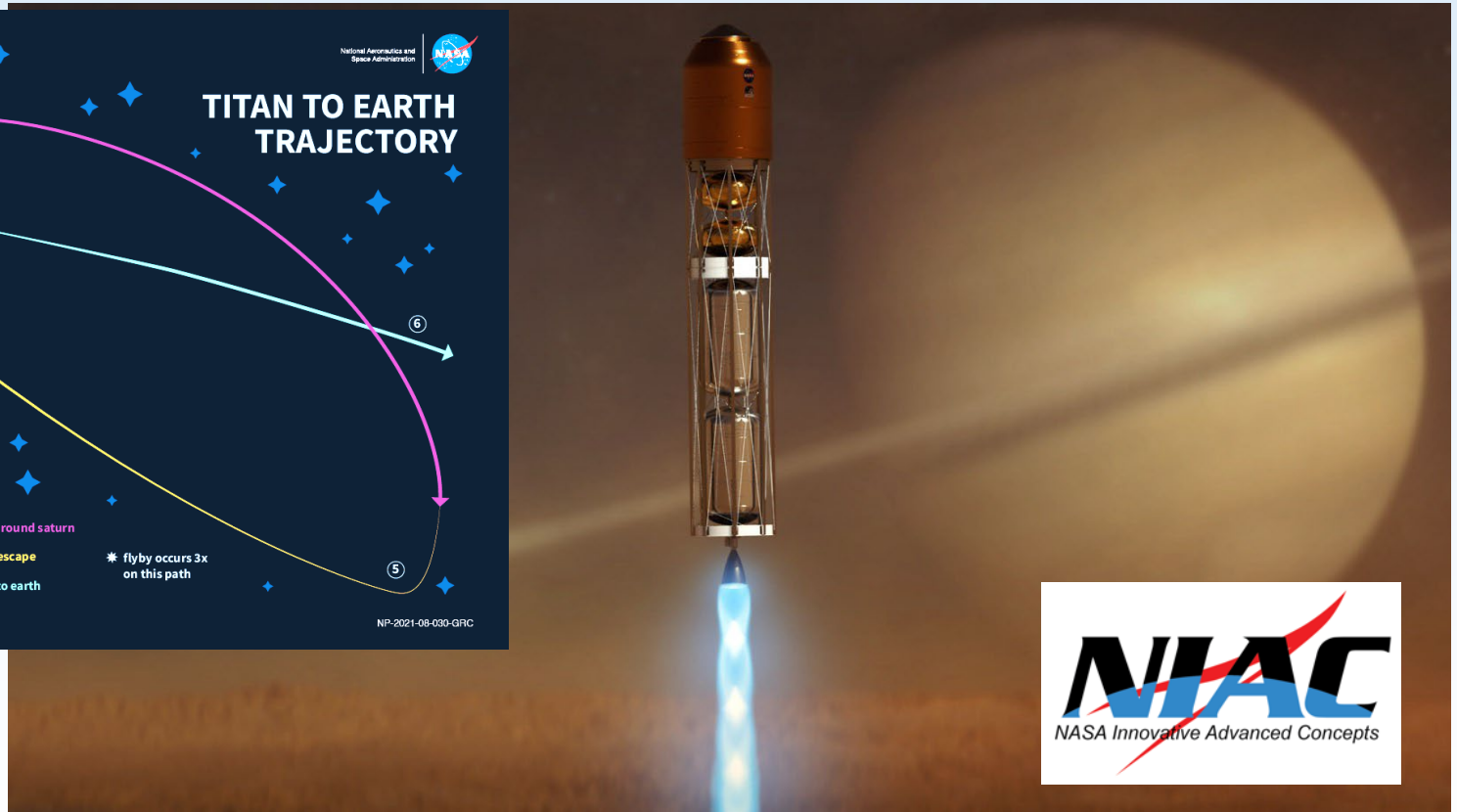
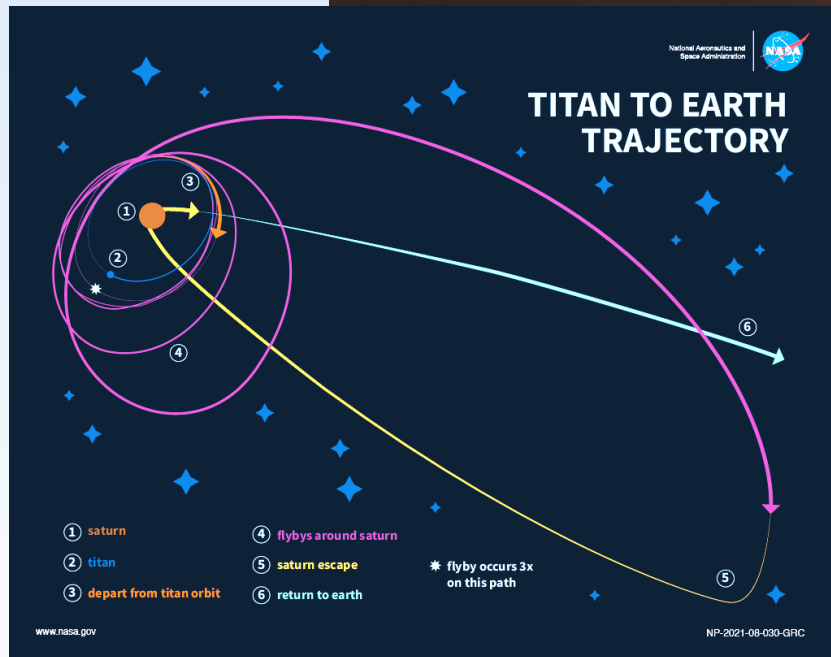


Venus

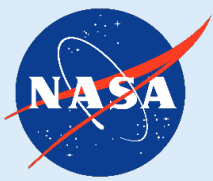
- Solar-powered flight is not hard on Venus
- Possible tool to explore the cloud level (50-75 km altitudes)
- Venus is exciting: let's go!



Titan Sample Return Mission Using In-Situ Propellants



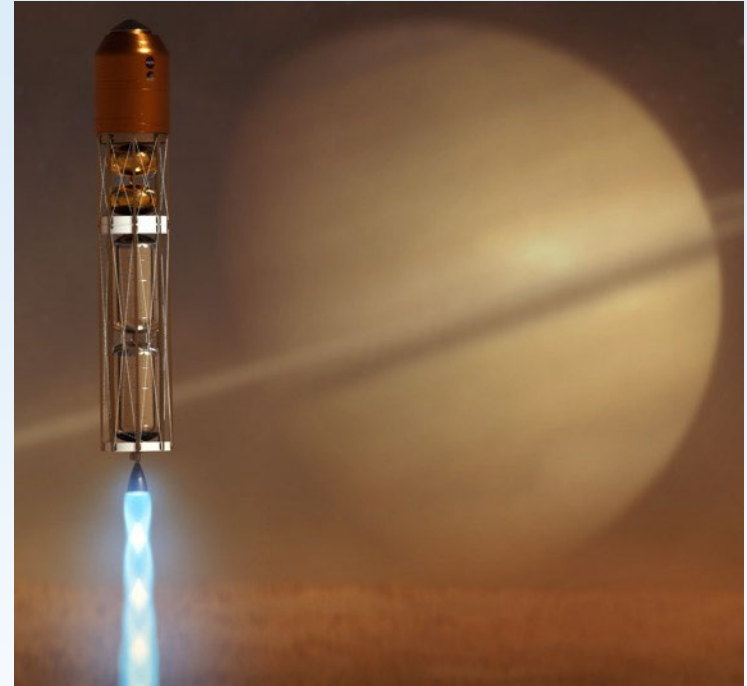
**GRC COMPASS design team
NASA Glenn Research Center**



Titan sample return: NIAC phase-I study



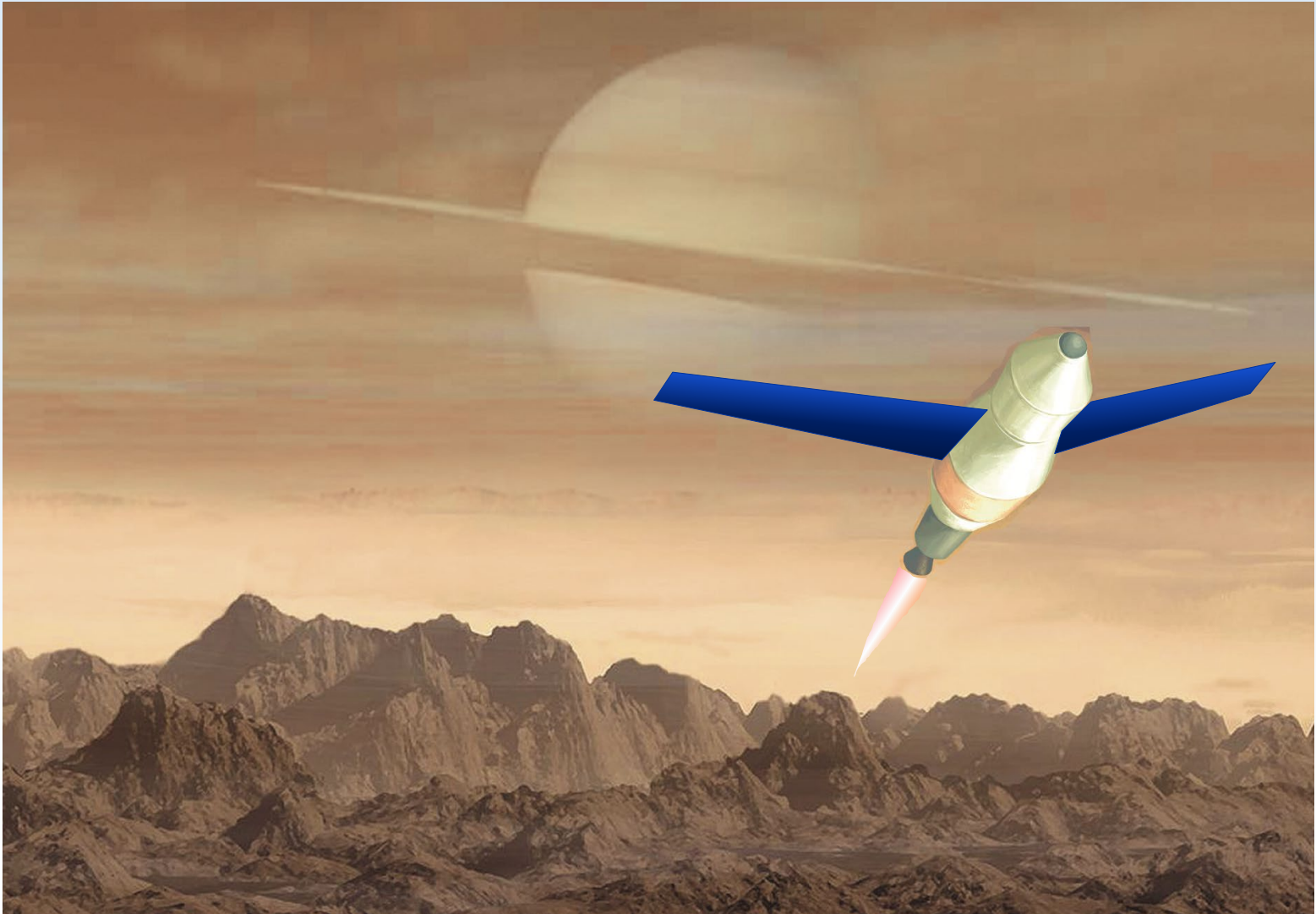
- A sample-return mission from Titan would be invaluable for science and for its contribution to understanding organic compounds in the solar system.
- Analysis of the production and use of in-situ propellants for a sample return launch shows we can make propellant on Titan.
- But... HALF of the delta-V needed to launch from Titan is simply to punch through the thick atmosphere!
- Can we instead use the atmosphere?



Reference: G. Landis, S. Oleson, E. Turnbull, et al., "Mission Incredible: A Titan Sample Return Using In-Situ Propellants," paper AIAA 2022-1570, AIAA Science and Technology Forum, Jan 3-9 2022.



Titan Sample Return: winged rocket?



Titan Sample Return

aircraft launch concept



Titan Sample Return

quadcopter launch concept (proposed)



A Conceptual Architecture for Venus Surface Sample Return

NASA Innovative Advanced Concepts



Geoffrey A. Landis and Steven R. Oleson
NASA John Glenn Research Center, Cleveland, OH 44135
Anthony Colozza
HX5, LLC, Fort Walton Beach, FL 32548

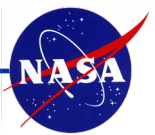


Approach



Two hard problems:

- Collecting a sample from the surface of Venus
 - Get to the surface
 - operate on the surface of Venus to collect a sample
 - rise off the surface
- Launching a sample from Venus into orbit
 - Since Venus is almost as large as Earth, it takes as much ΔV to launch from Venus into orbit as launching from Earth
 - But even harder, because of the thick atmosphere



Approach

Launching a sample from Venus into orbit

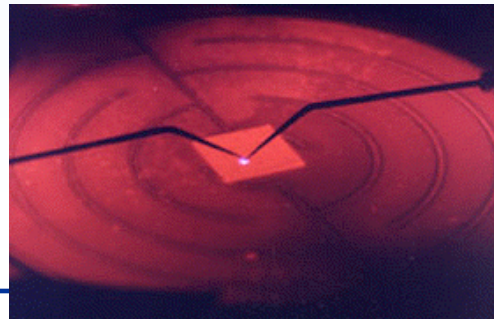
- At a temperature of 450°C , we don't want to land the fully-fueled sample return rocket on the surface!
- Solution: Float the rocket high above the surface in a balloon
- Solution: manufacture the return fuel using the atmosphere of Venus

Reference: G. Landis, S. Oleson, *et al.*, "Conceptual Design for a Venus Surface Sample Return Mission," paper AIAA-2024-4831, *AIAA ASCEND Conference 2024*, Las Vegas NV, 30 July-1 August 2024.



High Temperature technology for Venus

- NASA Glenn's Silicon Carbide high-temperature electronics (LSC) have been tested to work at Venus conditions
- Batteries for Venus being developed led by LEX
- GEER chamber simulates conditions at the surface of Venus
 - Developed a long list of what materials can be used on the surface... and which can't
- Compass Concurrent-engineering team has done many studies of Venus missions
- Proposed and developed concepts for atmospheric flight on Venus
- Developed LLISSE small mission as a technology-demonstration of long-lived operation on the surface



NASA Glenn SiC devices have repeatedly demonstrated proper operation at temperatures as high as 650 C.

Venus sample return:

How to collect a sample from the surface of Venus?

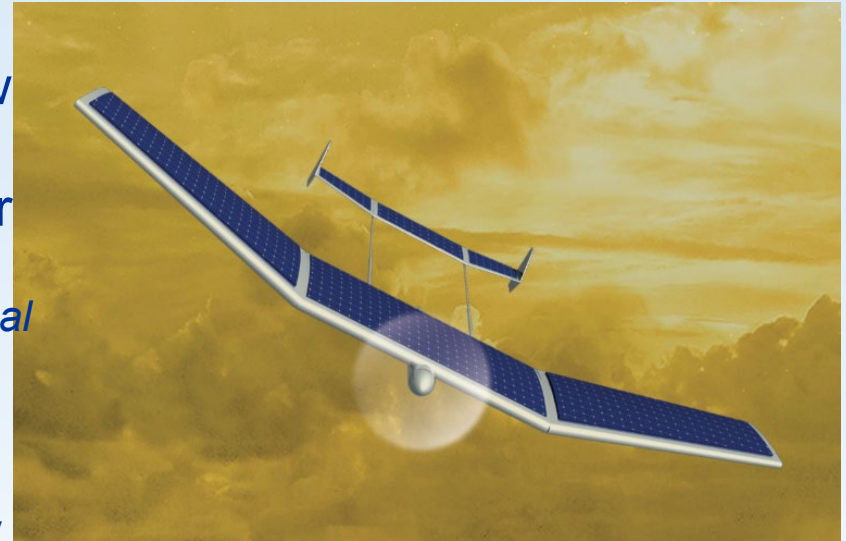
- Get to the surface
- operate on the surface of Venus to collect a sample
- Take off from the surface
- rendezvous with the balloon carrying the fueled return rocket

- NASA Glenn has developed high-temperature technologies to operate on the surface of Venus
 - High temperature SiC electronics
 - High temperature molten-salt electrolyte batteries
 - High temperature solar cells
- We will put these technologies together to make a **high-temperature airplane** to land on the surface, collect a sample, and fly up to the balloon with the return vehicle



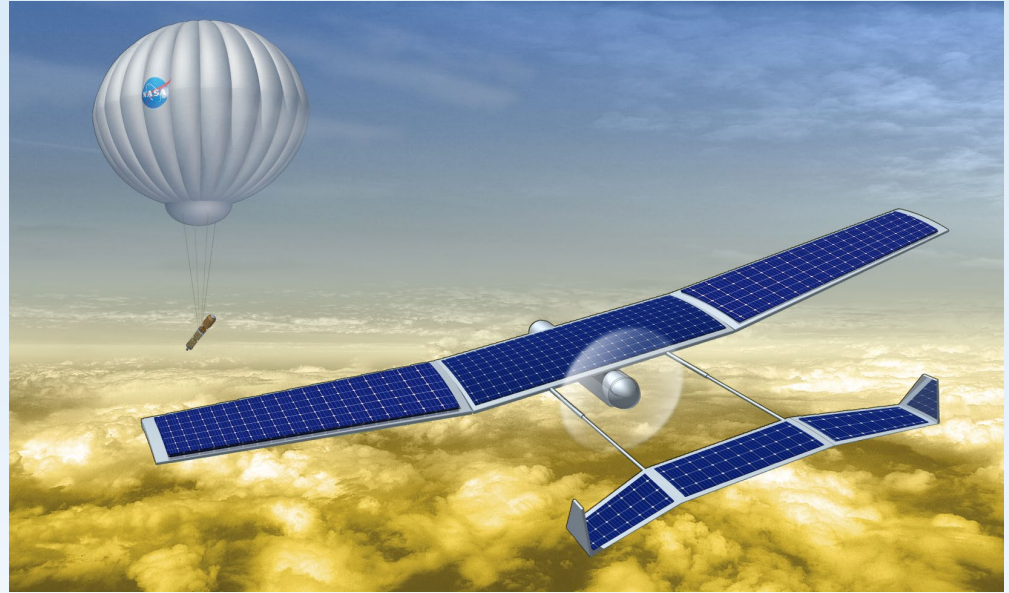
Airplane design requirements

- Capable of both low-altitude/high temperature flight and high-altitude/low temperature flight
- Solar powered when above cloud layer
 - Requires high temperature solar cells
 - Build on prototype cells from Grandier *et. al*
- Battery powered below clouds
 - Leverage NASA GRC work on high-temperature batteries
 - High-temperature batteries dropped as they are depleted
- Low speed at Venus Surface
 - Due to high atmospheric density, minimum airspeed is low near surface
 - Take-off speed is only a few m/s (walking speed!)
- High-temperature motor
 - Designs from Honeybee robotics operate at Venus temperature
- High temperature electronics
 - NASA GRC SiC integrated circuits



Why Venus? Why Sample Return?

- Because it is hard
 - If it wasn't hard, we wouldn't do it



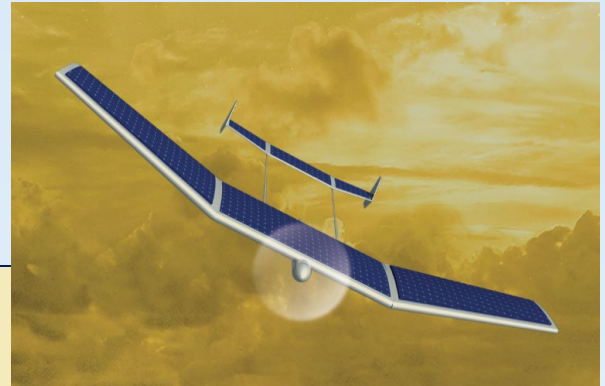
Artist's conception by Terrance Condric, NASA Glenn

- Because it applies and showcases NASA's strengths and technologies

- Because the technologies we develop will have applications to other missions

- Because it's cool

Summary



- We can fly on other planets!
- **Mars** is hard... but possible
 - **Venus** is easy above the clouds
 - But pretty hard below the clouds
 - **Titan** is very easy
 - (Except there's no solar power on Titan)

Winged flight may make “impossible” sample return missions possible

- On Venus and Titan, half the difficulty is in getting through the thick atmosphere
- Winged flight allows you to use the atmosphere, instead of fighting it

