Venus Landsailer:
A new approach to exploring our neighbor planet

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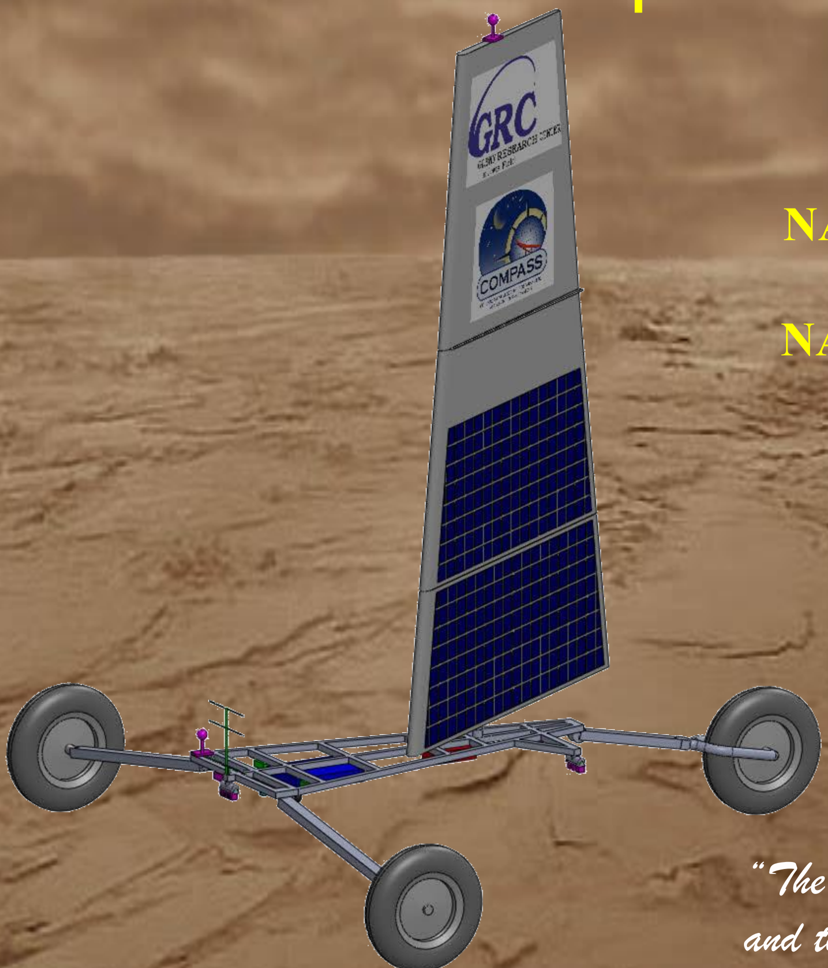
Cleveland OH



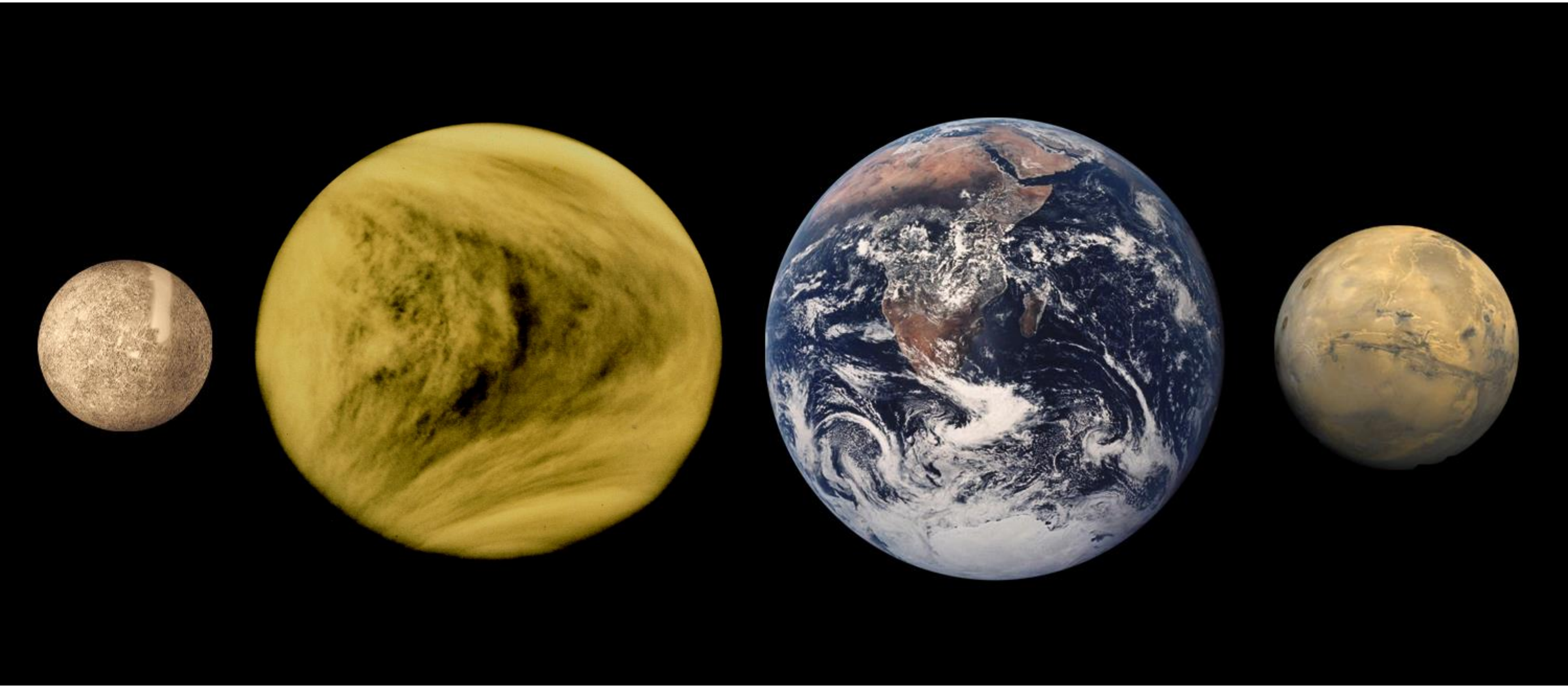
"The gentle winds carried Aphrodite across the sea, to Cythera and then to Cyprus, by the god of the west wind, Zephyrus."

Venus Landsailer: COMPASS study Team

Principal Investigator	Geoffrey Landis
COMPASS Lead	Steve Oleson
Science lead	Geoffrey Landis
High Temperature electronics elements	Gary Hunter, Mike Krasowski
Venus environment	Geoffrey Landis
System integration/PEL	David Grantier
Mission	Michael Martini, Jeff Woytach
CONOPS	Jeff Woytach
Guidance, navigation, and control	Michael Martini
Propulsion	James Fittje, Tom Benson
Mechanical systems	John Gyekenyesi
Thermal	Tony Colozza
Power	Paul Schmitz
Configuration and data handling	Glenn Williams
Communications	Joe Warner, George Ponchak
Configuration	Tom Packard
COST / Risk	Jon Drexler / Leon Dozier

National Aeronautics and Space Administration

The inner planets
to scale



Mercury Venus Earth Mars

www.nasa.gov

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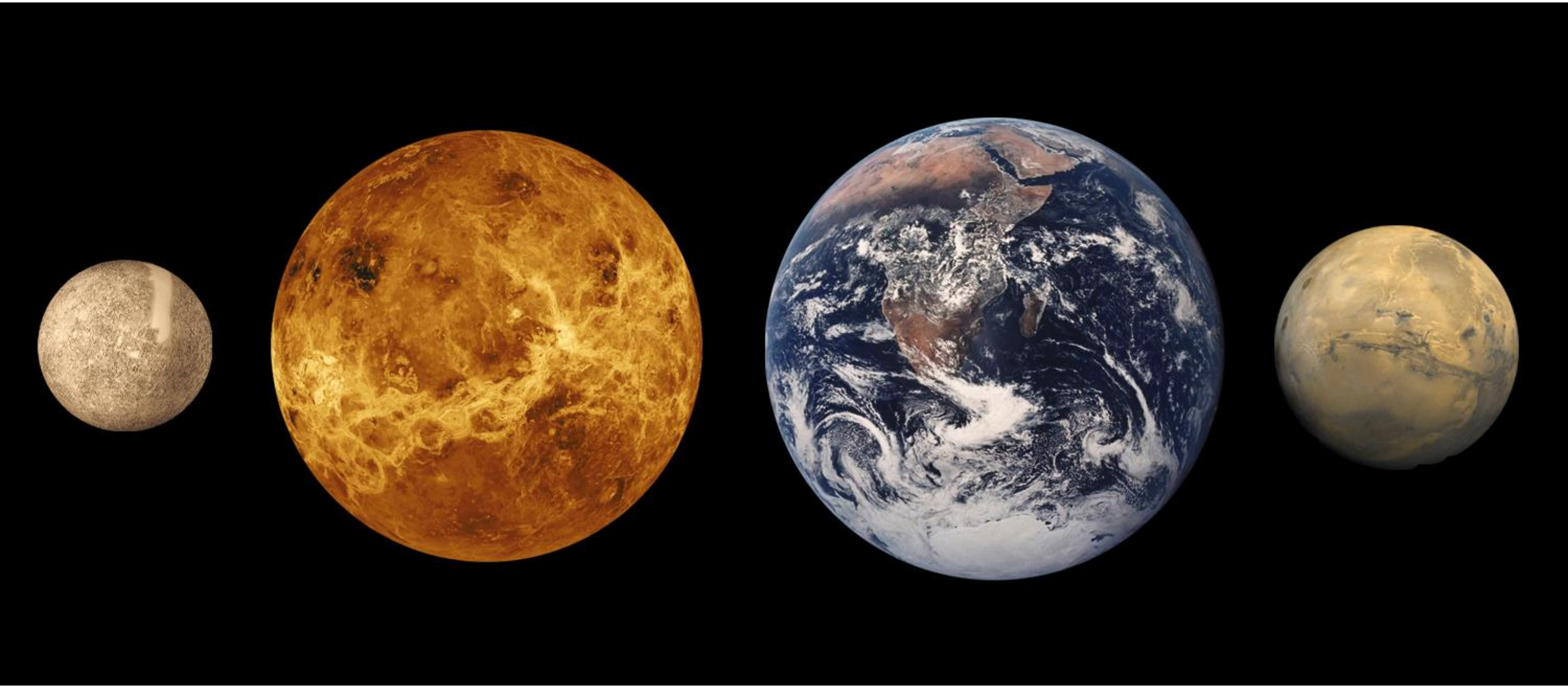
The inner planets: surface comparison



Mercury Venus Earth Mars

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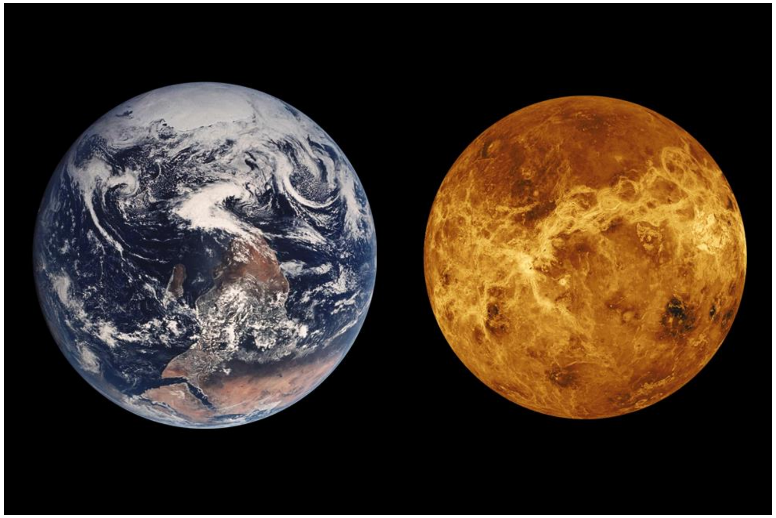
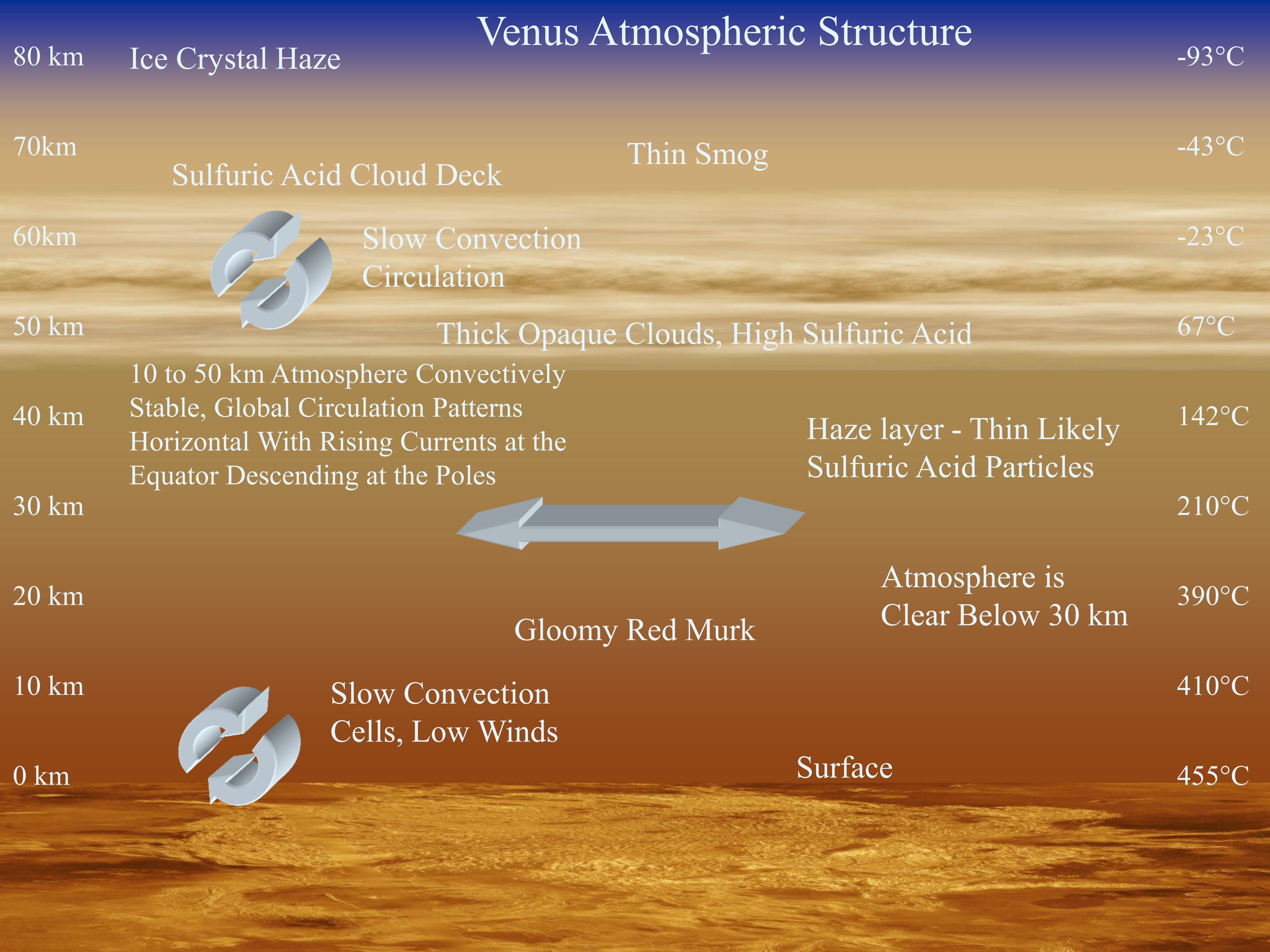
Earth/Venus Comparison



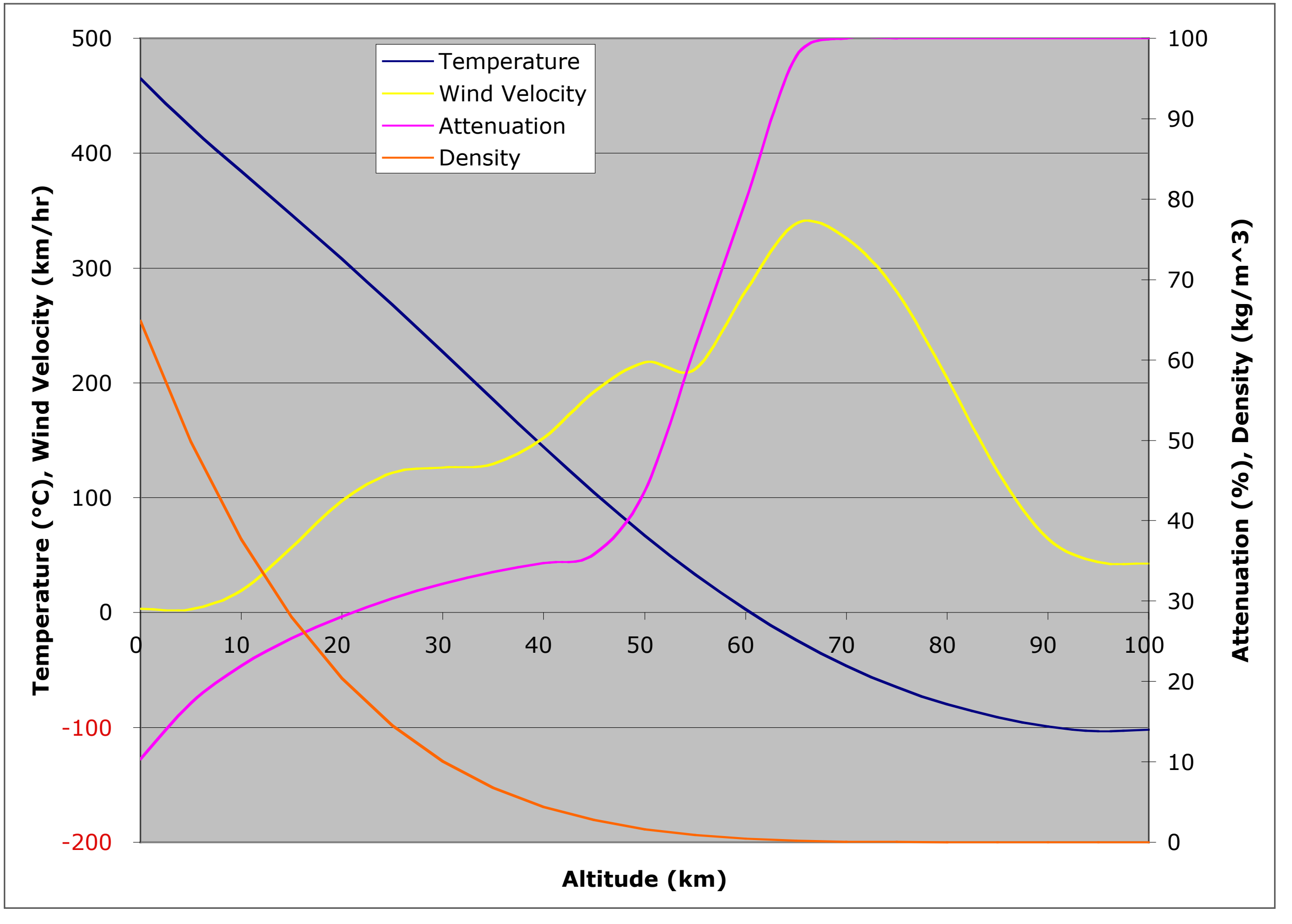
	Earth	Venus
Solar Flux	**1370 W/m^2**	**2600 W/m^2**
Gravity	9.81 m/s^2	8.87 m/s^2
Solar Day	24 hours.	117 days
Surface pressure	1 bar	92 bar
Ave temperature	~0-30 ° C	450° C
Atmosphere	N_2, O_2	CO_2


Venus Atmospheric Structure
80 km
Ice Crystal Haze
-93°C
70km
Thin Smog
-43°C
Sulfuric Acid Cloud Deck
60km
Slow Convection
Circulation
-23°C
50 km
Thick Opaque Clouds, High Sulfuric Acid
67°C
10 to 50 km Atmosphere Convectively
Stable, Global Circulation Patterns
Horizontal With Rising Currents at the
Equator Descending at the Poles
40 km
Haze layer - Thin Likely
Sulfuric Acid Particles
142°C
30 km
210°C
20 km
Atmosphere is
Clear Below 30 km
390°C
Gloomy Red Murk
10 km
Slow Convection
Cells, Low Winds
410°C
0 km
Surface
455°C

National Aeronautics and Space Administration

Environmental Properties on Venus

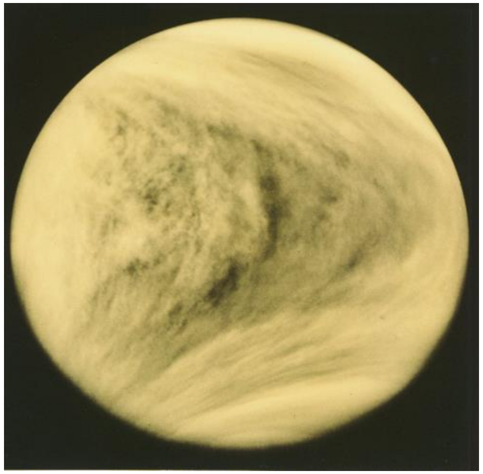
The harsh environment of Venus provides a number of challenges in the operation of equipment and materials. The atmosphere is composed of mainly Carbon Dioxide but does contain corrosive components such as sulfuric acid. The planet has a very thick atmosphere, completely covered with clouds. The temperature and pressure near the surface is 455 ° C at 90 Bar.



Properties of the Venus Atmosphere

www.nasa.gov

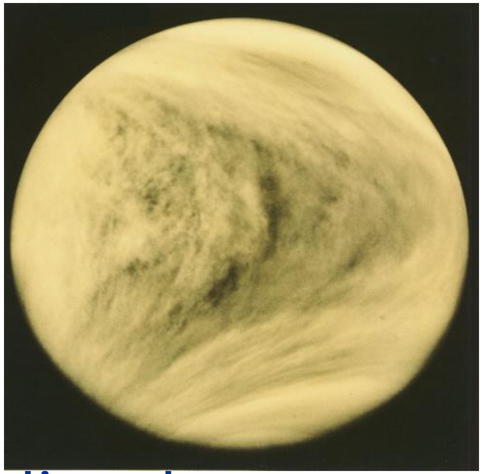
Goal: Science Driven Exploration
Science Questions: Geology



- What process resurfaced the planet in the (geologically recent) past?
- Why doesn't Venus have plate tectonics like Earth?
- Does Venus have active volcanoes?
- Is the interior of Venus similar to the Earth?
- What is the "snow" deposits on the top of Venusian mountains?
- How does the sulfur in the atmosphere interact with the rock?

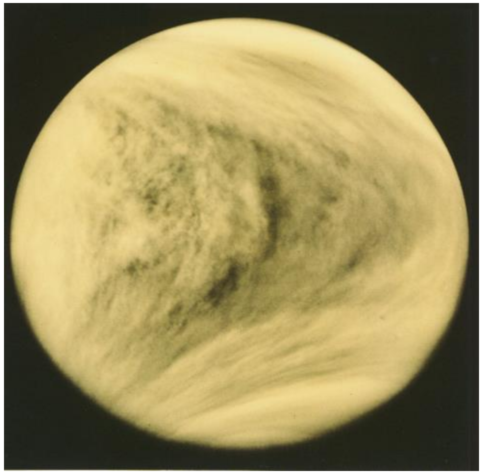
Science Driven Exploration

Science questions: Atmosphere &Climate



- Venus is the **greenhouse planet**: understanding the climate of Venus will teach us about the (past and future) climate of the Earth
- Understand planetary atmospheres by the process of comparison
- What causes the atmospheric super-rotation?
- What are the unknown UV absorbing aerosol particles?
- What was Venus like in the early solar system? How did it lose its hydrogen?

Science-driven Exploration
Science Questions: Astrobiology

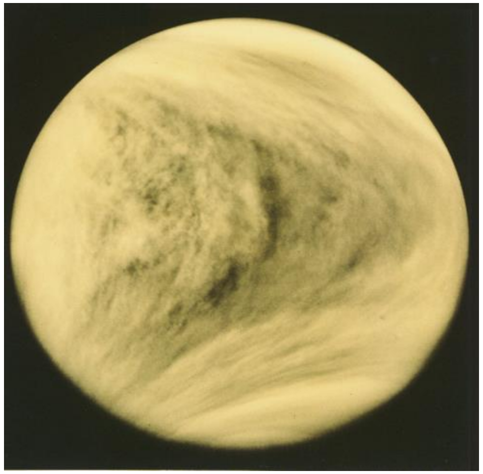


- Did Venus ever have an ocean? Did it once have life?
- What is the history of the chemical evolution of the Venus atmosphere? What can it tell us about the possibility of life starting on earthlike planets?
- Atmosphere of Venus has unexplained deviations from equilibrium: could this be signs of present day life?

(ref: Grinspoon 1997; Sattler *et al* 2001, Schulze-Makuch 2002)

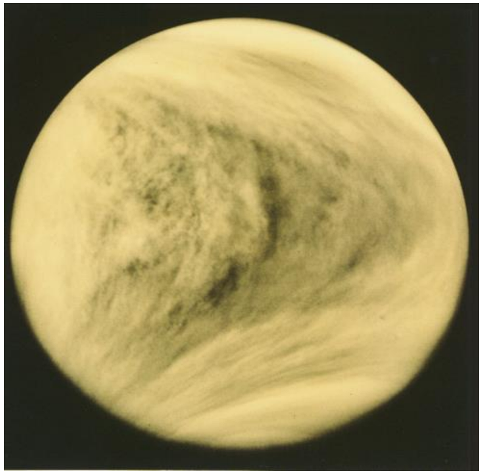
Venus: A Challenge for Exploration

- Solar day is 117 Earth days
- Surface temperature 452° C (850° F)
- Surface pressure 92 bars (equals pressure 1-km under the ocean) carbon dioxide
- Clouds are concentrated sulfuric acid droplets
- Very little solar energy
- Tops of mountains are slightly cooler: top of Maxwell Montes (10.4 km), pressure is 48 bars and temperature is "only" 390 C (725 F)
- **Venus Exploration is a tough challenge!**



Venus in the UV
(viewed from the Pioneer Venus orbiter)

Venus: Long lived mission?



Venus in the UV
(viewed from the Pioneer Venus orbiter)

Longest lived surface lander to date: 2 hrs
Want to produce a longer mission duration!

Two approaches:

- Cooled electronics chamber
- High temperature electronics

Using room-temperature electronics chamber leads to large, expensive mission:

- 400°C of delta-T needed
- Thermal insulation is difficult in 90 bar atmosphere: needs pressure vessel
- Large amount of power required to cool means isotope power system with large number of plutonium bricks
- Leads to a multi-billion dollar “flagship” class mission

Venus: Long lived mission?

The approach of cooling a pressure vessel for the electronics was considered too heavy, risky and expensive for the Venus Flagship mission proposed by the NASA Science and Technology Definition Team, which chose a non-cooled design with a lifetime of 5 hours rather than baseline a cooled system for a two billion + dollar flagship mission.

A rover would be even more difficult!

Venus Wind:

- Atmospheric density: 65 kg/m^3
  - Compares to 1.2 kg/m^3 for Earth sea level
- Wind speed at 50 km: high
- Wind speed at surface: low

- Measured by Venera probes:
  - Average surface wind of **0.6 m/sec**
    - plus or minus 0.3 m/sec

Measured wind speed at surface:

- 0.4 -0.7 m/sec (Venera 9)
- 0.8 -1.3 m/sec (Venera 10)
- 0.3 -0.6 m/sec (Venera 13)
- 0.3 - 0.6 m/sec (Venera 14)

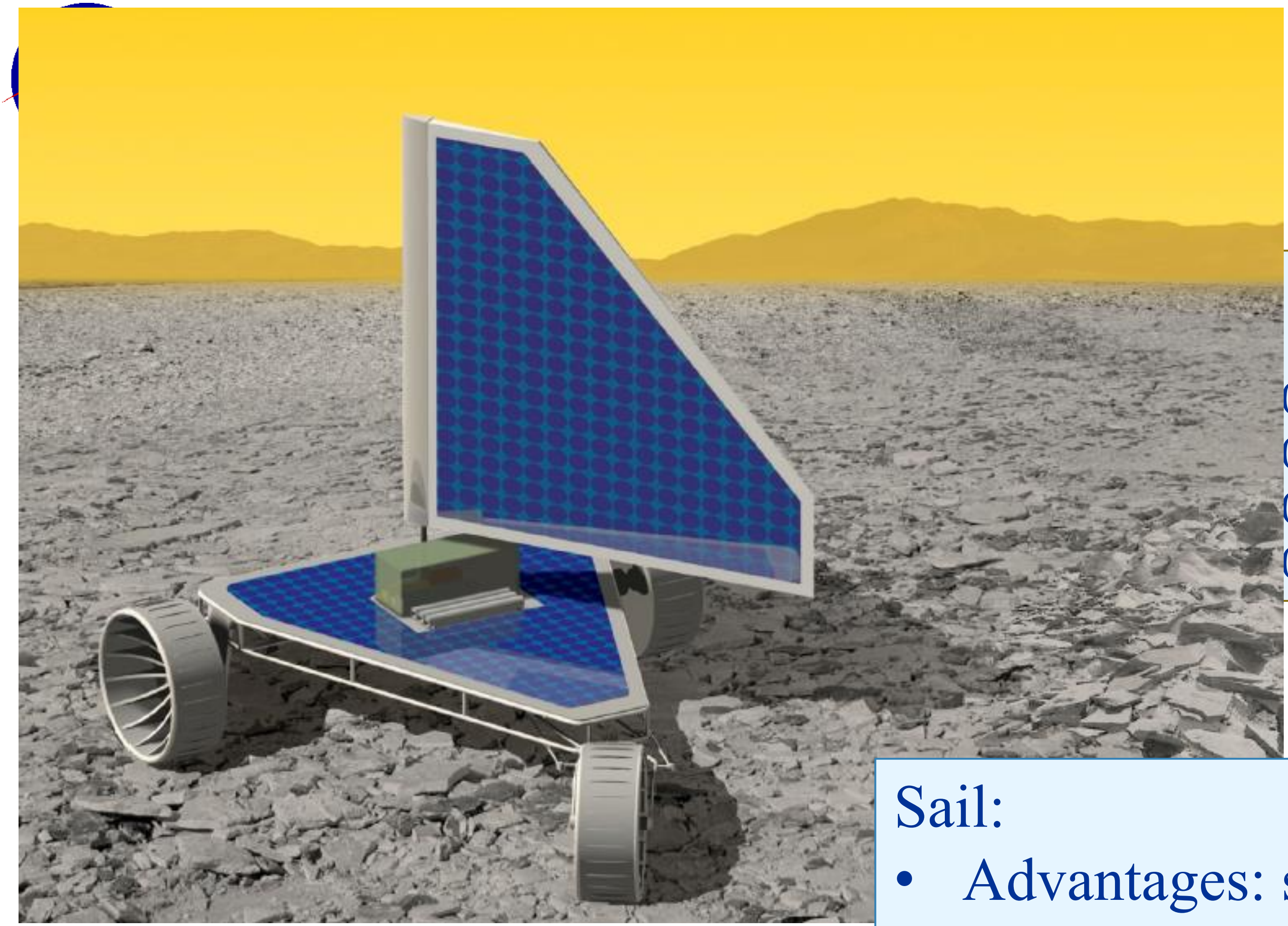
Use the wind as a propulsion force for the rover

- Land-sailing
- Wind turbine

$$\text{Wind force} = \tfrac{1}{2}\,\rho\, C_f A V^2 = 32.5\, C_f A\,(0.6)^2$$

$$\mathbf{11.7\ N/m^2}\ \ (\text{at } C_f \text{ of } 1)$$

C_f = lift or drag coefficient (depending on mode)
Will be near 1 for most operational mode



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0.4 -0.7 m/sec (Venera 9)
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0.3 - 0.6 m/sec (Venera 14)

Sail:

- Advantages: simplicity
- 2 moving parts (sail orientation, steering)
- power needed only for setting sail and steering position; *no power needed to drive*

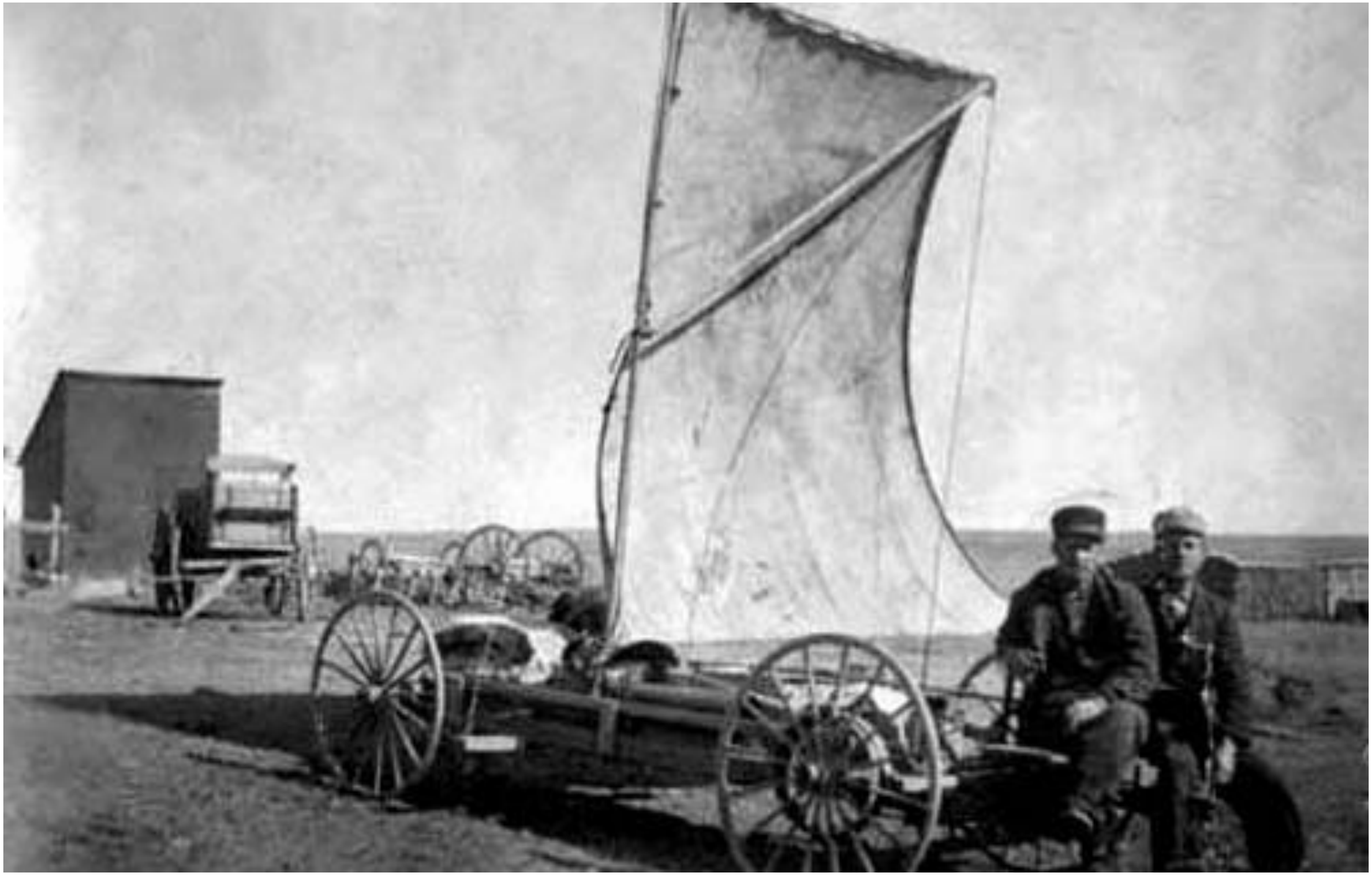
Wind force =

11.

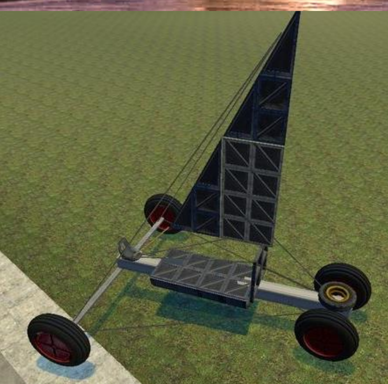
C_f = lift or dr
Will be n

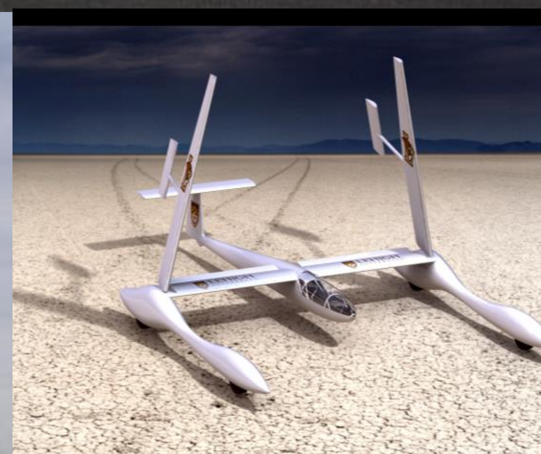
- Looked at both wind turbine and sail concepts
- This study is sail

Kansas “windwagon” from 1860s



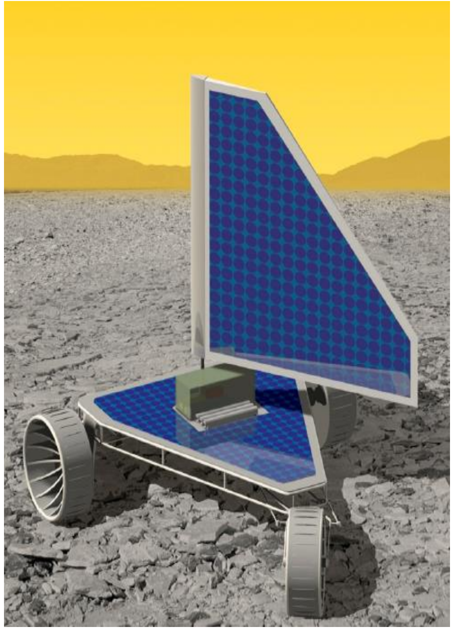
Earth Based Wind Propelled Concepts



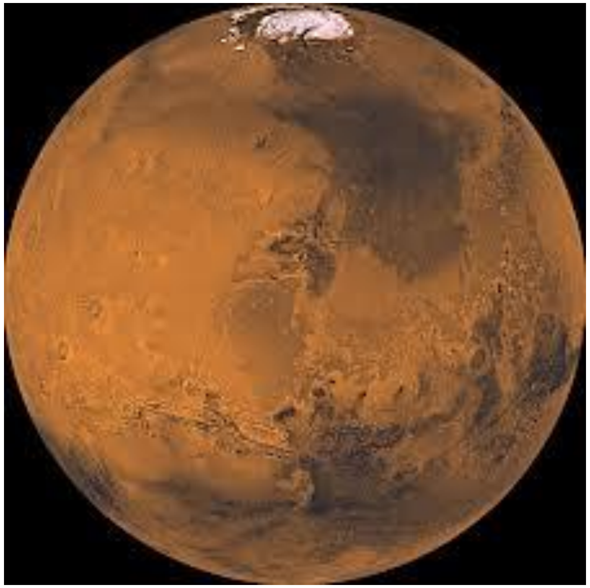


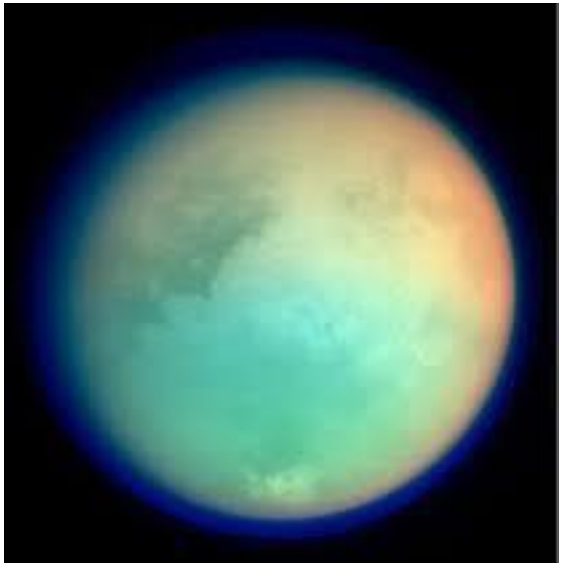
Today… and the future

Today: landsailing for sport on Earth



Next: landsailing for energy-free mobility on Venus





Future?
Mars: thin air, high wind at some locations
Titan: dense atmosphere, known to have wind (but detailed wind not yet measured)

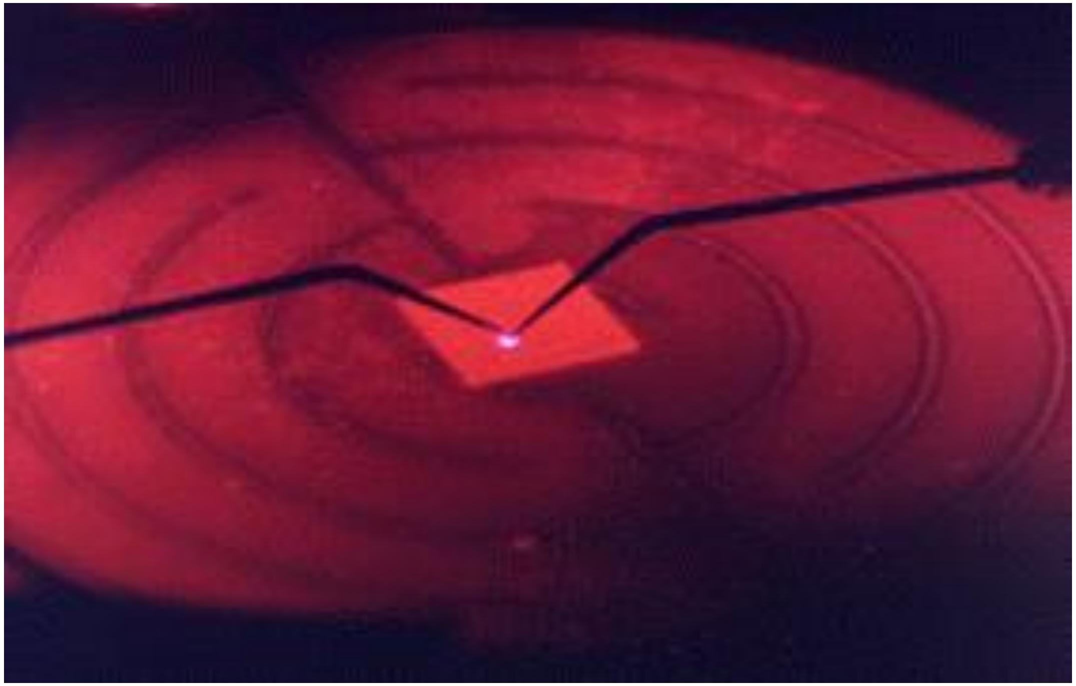
Technology requirements: run all systems at Venus ambient temperature

- Electronics for 450° C:
  - Power system: solar cells
  - Electronics and controls
  - Communications
- Motors
  - Motors and actuators
  - Mechanisms
  - lubrication
- Materials
  - Structure and wheels
  - Insulators
  - Parachute
  - Sail
  - Passivation against environmental corrosion

These are all hard problems
-but:

All of these problems are solvable with technologies currently under development
-no harder than the inside of a jet engine

SiC high-temperature electronics

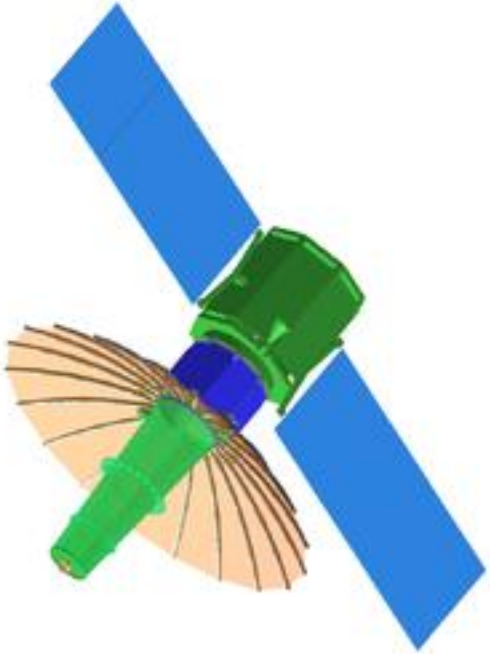


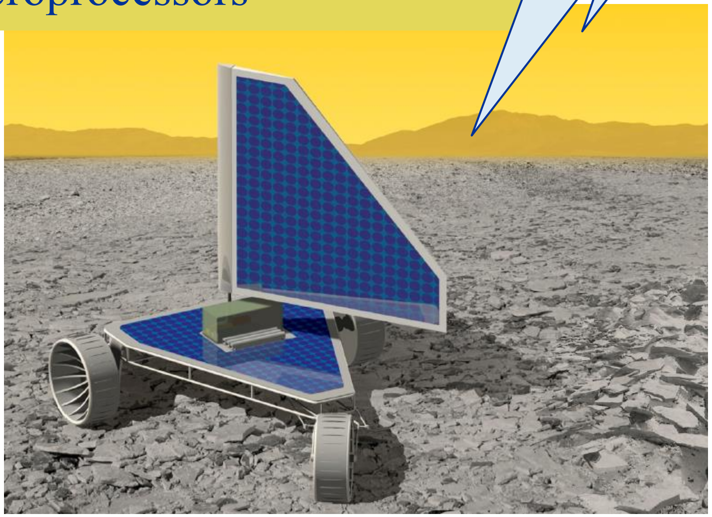
http://www.grc.nasa.gov/WWW/SiC/

The circular heating element and 5 x 5 mm square SiC chip are both glowing red-hot. The diode being tested electroluminesces blue light when forward biased. SiC devices have repeatedly demonstrated proper operation at temperatures as high as 650 C. Silicon-based semiconductor electronics cannot function at these temperatures.

Baseline Concept: Venus ambient temperature electronics on the surface

Silicon carbide and GaN electronics exist and have **demonstrated operation with long life at 500°C**
But:
So far only simple components have been made (*i.e.*, transistors, gates, op amps, integrated circuits of ~100 elements), NOT sophisticated microprocessors

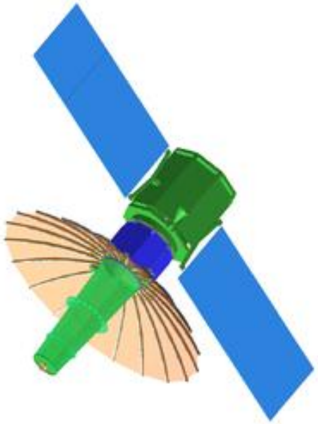




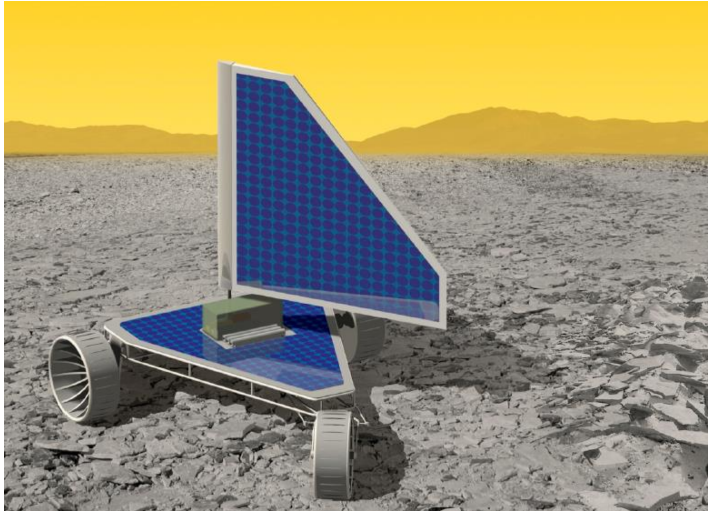
Simple high temperature electronics on board

Approach:
Dumb rover, smart satellite
Communications to UHF relay satellite, which has the computer

Study objective:
Will Landersailing Rover concept work on Venus?



Design study objective:



Use the COMPASS spacecraft design team to do a design study to fill in details of spacecraft design

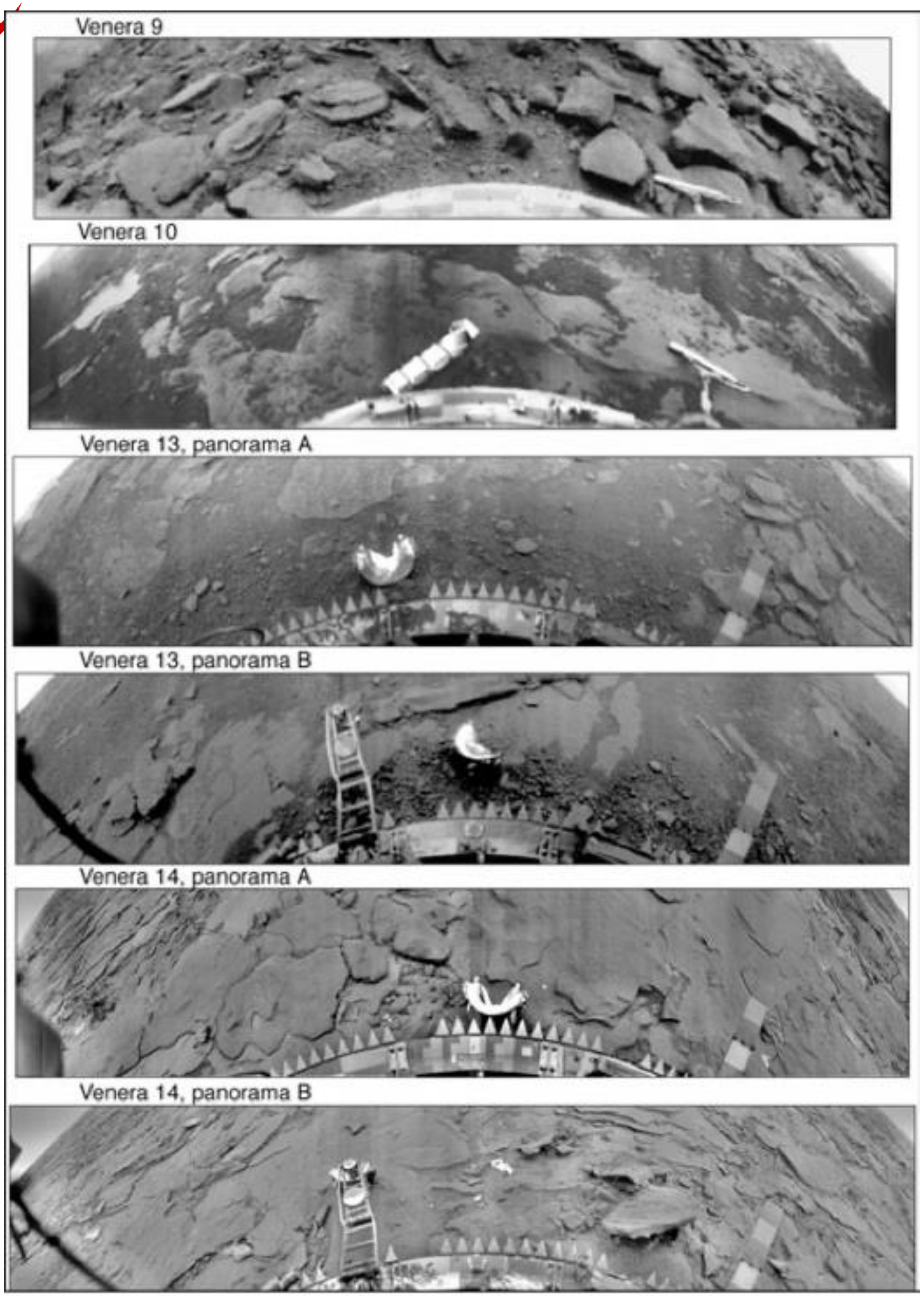
- Include all spacecraft systems, such as structure, communications, launch, orbital mechanics: nothing forgotten
- Include standard growth margins for mass, ΔV, power, cost

Design Study: Strawman Requirements/FOMs

(Strawman requirements are the minimum goal for the mission to be worth flying: would be useful to do better)

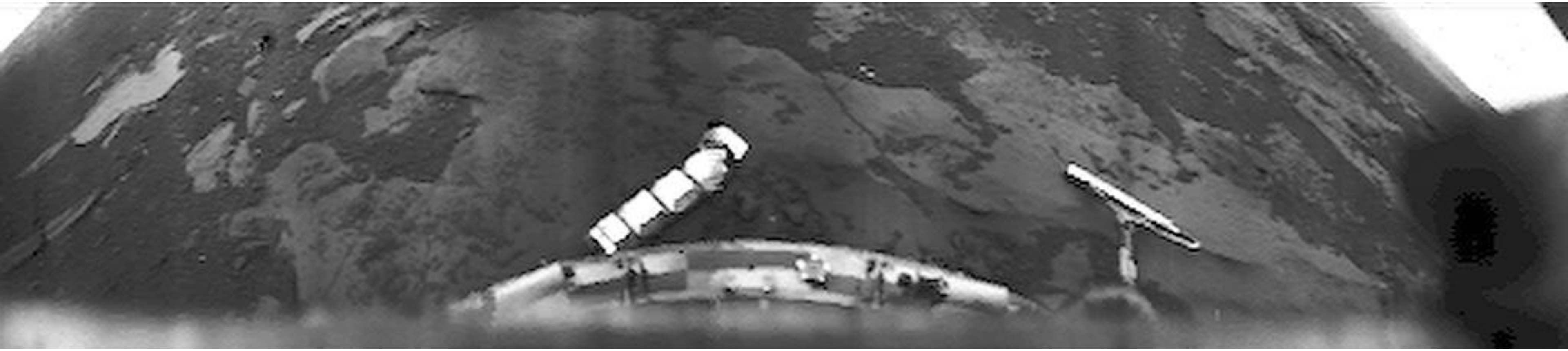
- The land sailer will move a distance of > 1 km
- Lifetime – 29 days on surface (9am to 3pm Venus solar time)
  - average 30 m per day, 15 minutes of sailing per day
- The land sailer will have a science payload capabile of imaging and mineralogy of targetted rocks, plus weather observations
- Nominal mission year: 2025
- Low latitude: flat terrain, 5-70 cm debris
- Largest obstacle height to drive over is 10 cm (TBR)
- Fault tolerance: Zero Fault

Venera Sites and Wind Speeds



- 9: Very Rocky
  - (0.4-0.7 m/s)
- 10: Fairly flat with gravel/regolith
  - (0.8 m/s – 1.3 m/s)
- 13 Similar to 10
  - (0.5 m/s)
- 14 Flat with some rocks – no gravel
  - (0.3-.35 m/s)

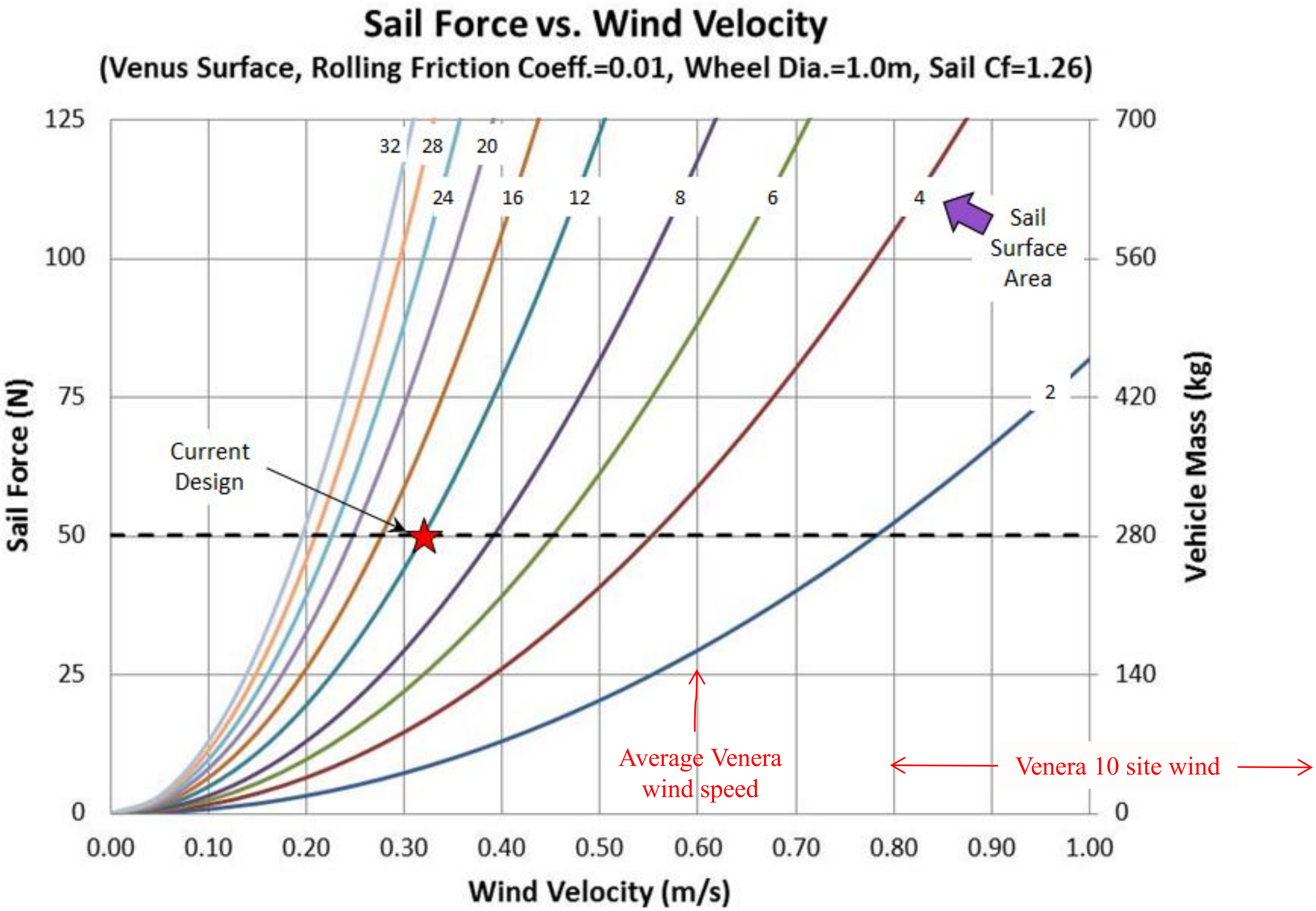
Sailing Terrain



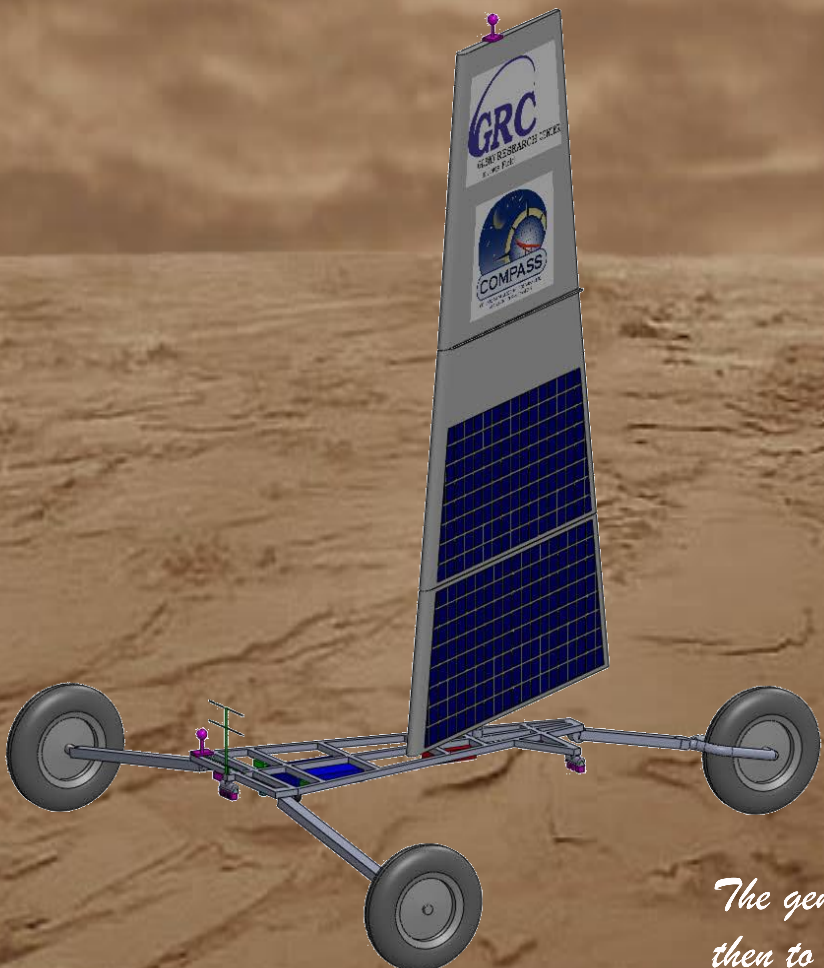
Venera 10 landing site: flat and smooth out to the horizon

Assume ~10cm land irregularities – no problem with 50 cm wheel radius

Sail Performance

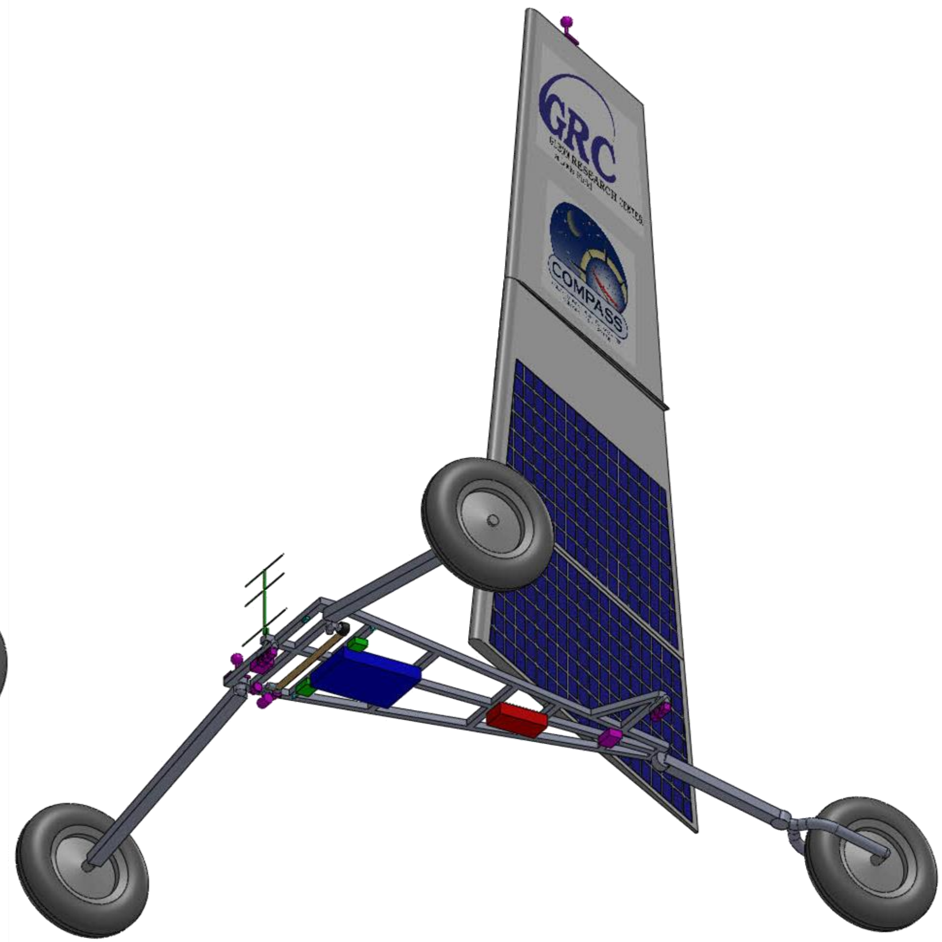


Zephyr:
Conceptual design

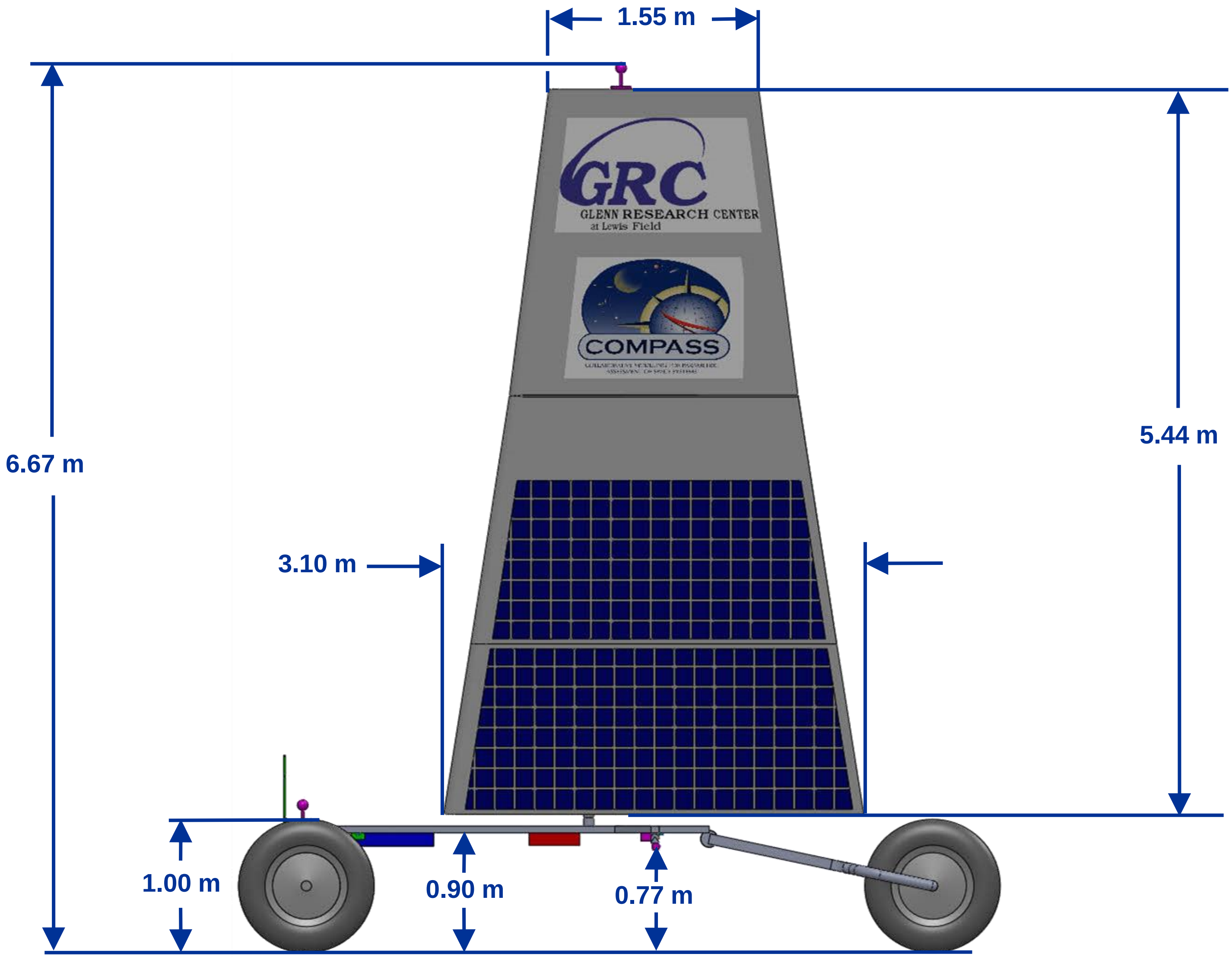


The gentle winds carried Aphrodite across the sea, to Cythera and then to Cyprus, by the god of the west wind, Zephyrus."

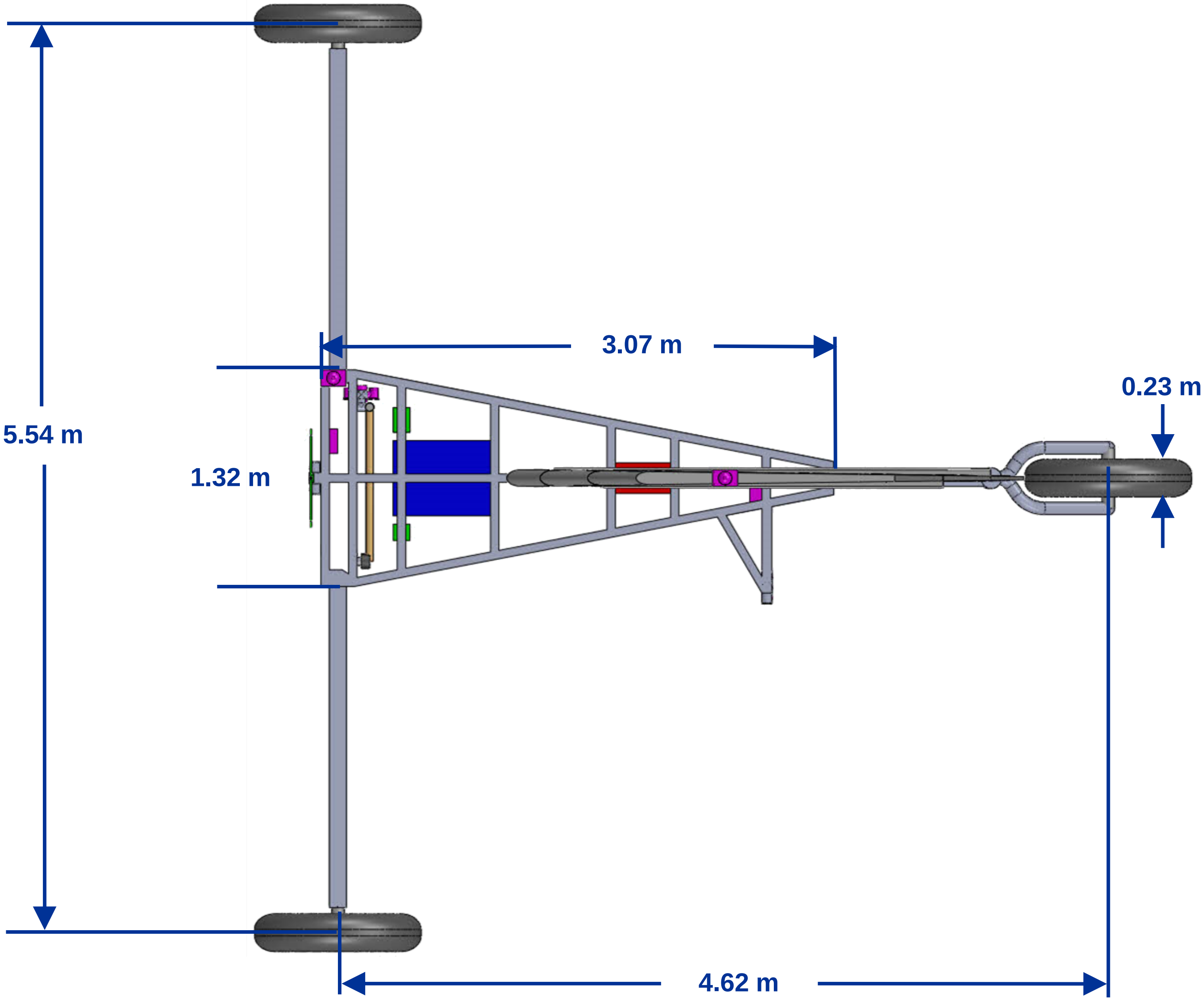
Zephyr Roving Configuration



Zephyr Deployed Dimensions



Zephyr Deployed Dimensions (2/2)



Zephyr Subsystem Components

Subsystems

Communications

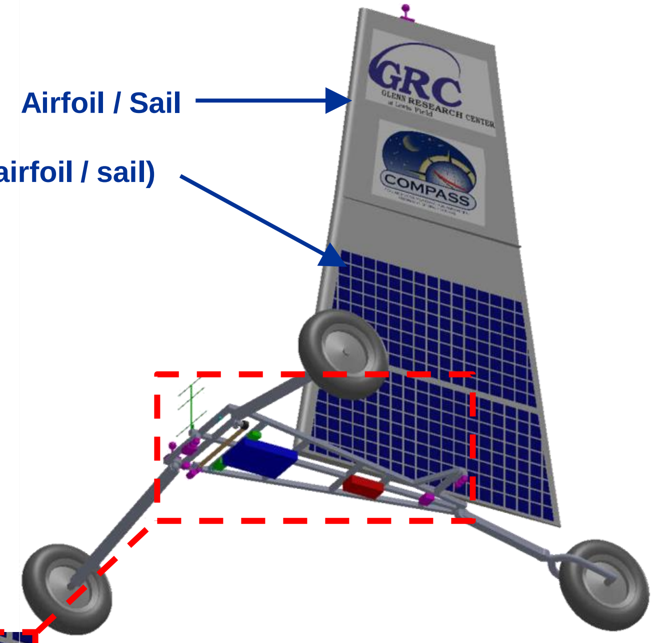
Electrical Power

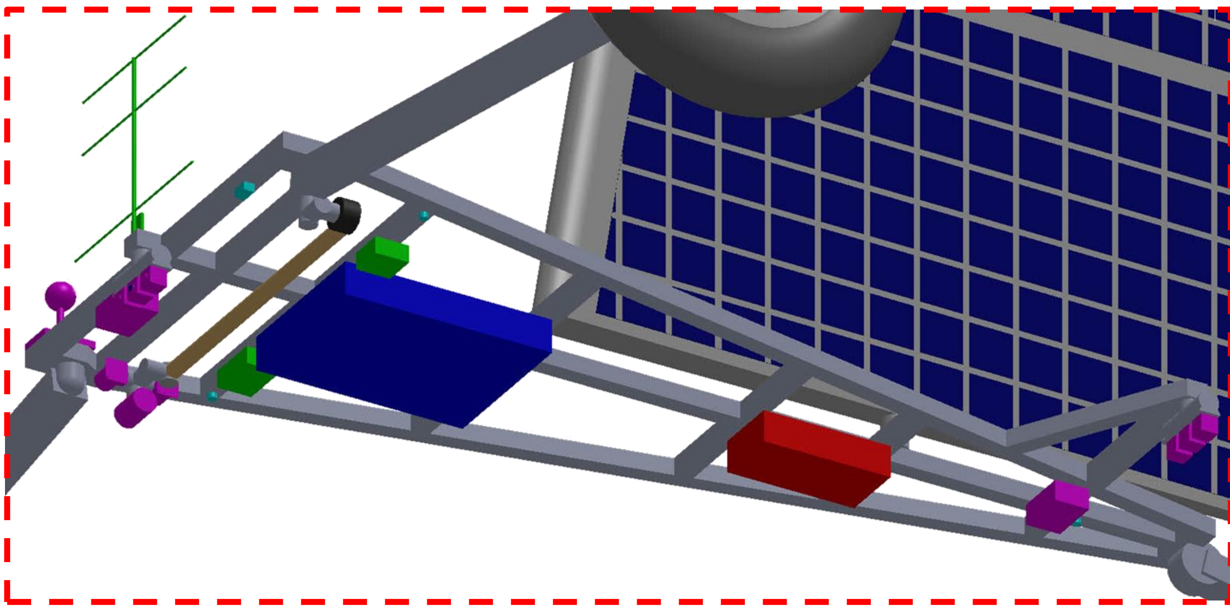
Science

Command and Data Handling

Guidance Navigation and Control

Structures

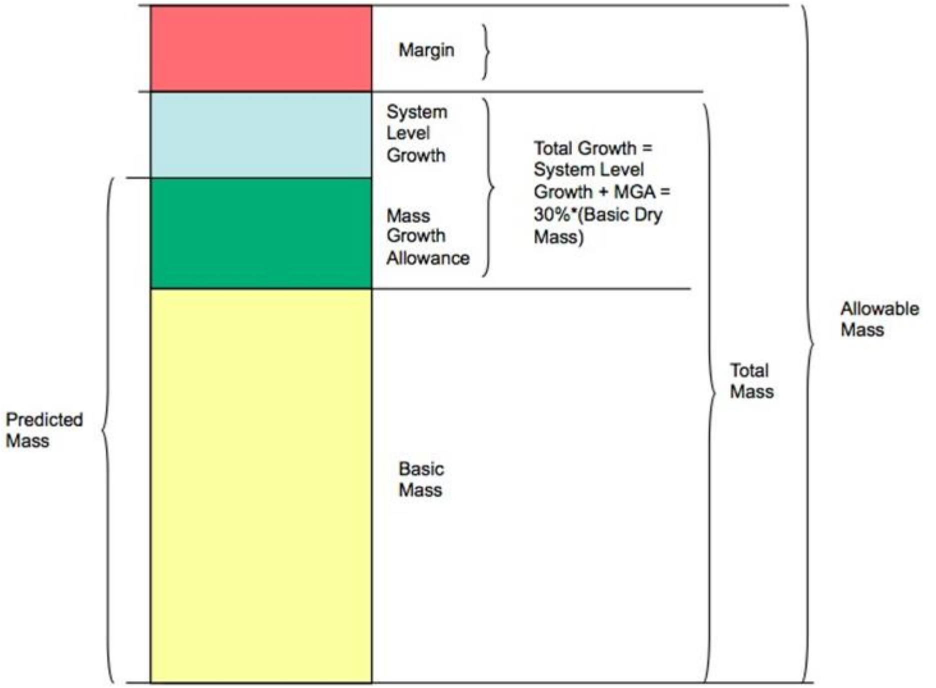




Growth, Contingency and Margin COMPASS Policy and Definitions

Taken from internal COMPASS document CM-2012-01: "COMPASS Concurrent Engineering Team Design Study Requirements and Operations Manual, Version 2"

- ***Basic Mass***
  - *Mass data based on the most recent baseline design. This is the bottoms-up estimate of component mass, as determined by the subsystem leads.*
  - ***Note 1:** This design assessment includes the estimated, calculated, or measured (actual) mass, and includes an estimate for undefined design details like cables, multi-layer insulation, and adhesives.*
  - ***Note 2**: The mass growth allowances (MGA) and uncertainties are not included in the basic mass.*
  - ***Note 3**: COMPASS has referred to this as current best estimate (CBE) in past mission designs.*
  - ***Note 4**: During the course of the design study, the COMPASS Team carries the propellant as line items in the propulsion system in the Master Equipment List (MEL). Therefore, propellant is carried in the basic mass listing, but MGA is not applied to the propellant. Margins on propellant are handled differently than they are on dry masses.*
- ***Mass Growth Allowance (MGA)***
  - *MGA is defined as the predicted change to the basic mass of an item based on an assessment of its design maturity, fabrication status, and any in-scope design changes that may still occur.*
- ***Predicted Mass***
  - *This is the basic mass plus the mass growth allowance for to each line item, as defined by the subsystem engineers.*
  - ***Note** : When creating the MEL, the COMPASS Team uses Predicted Mass as a column header, and includes the propellant mass as a line item of this section. Again, propellant is carried in the basic mass listing, but MGA is not applied to the propellant. Margins on propellant are handled differently than they are handled on dry masses. Therefore, the predicted mass as listed in the MEL is a wet mass, with no growth applied on the propellant line items.*



For the COMPASS process, the desired total percentage on dry mass is 30%

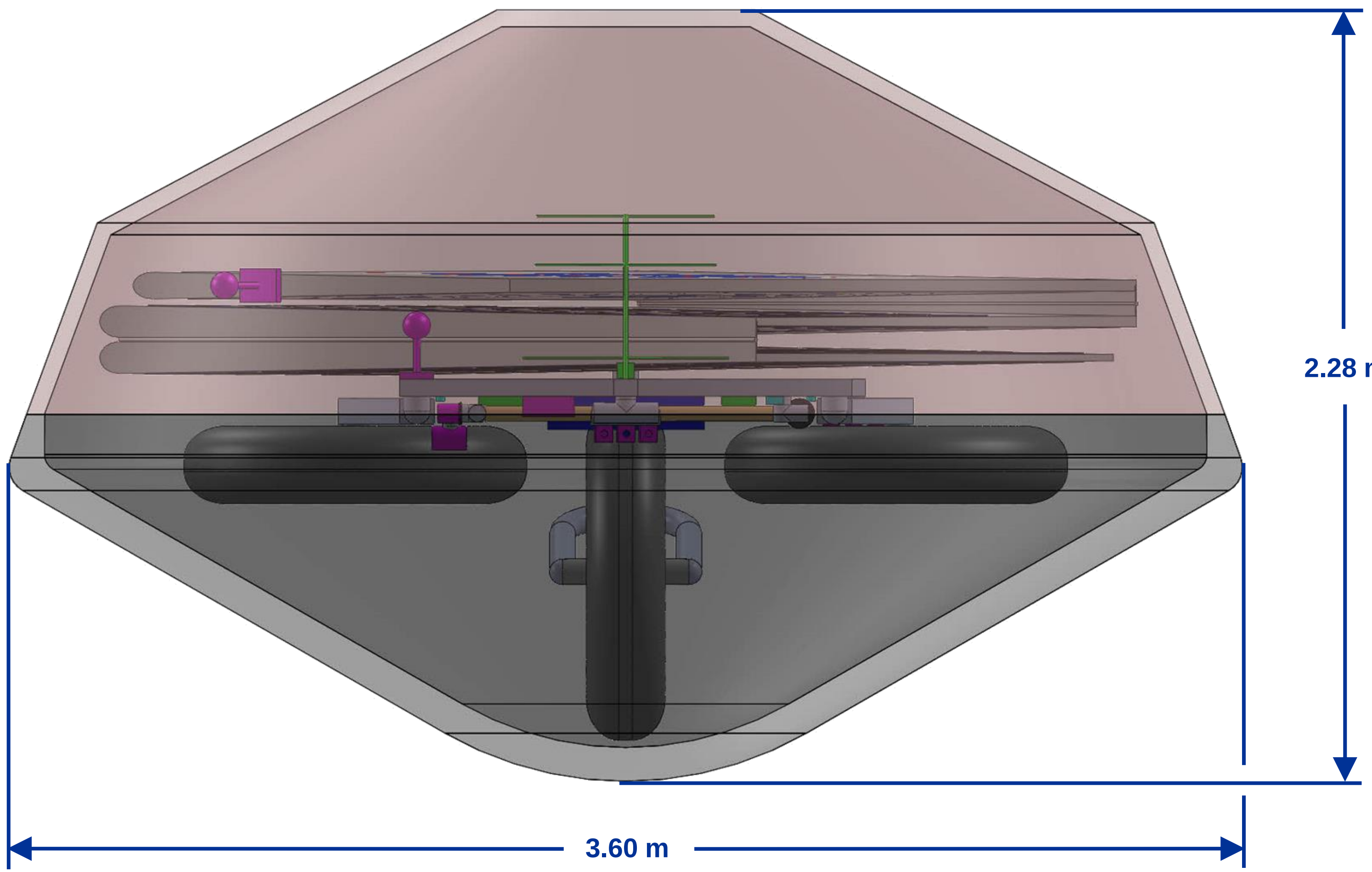
Predicted Mass = Basic Mass + Bottoms up MGA%* Basic Mass

Therefore, Additional System level margin = 30% - Bottoms up MGA%

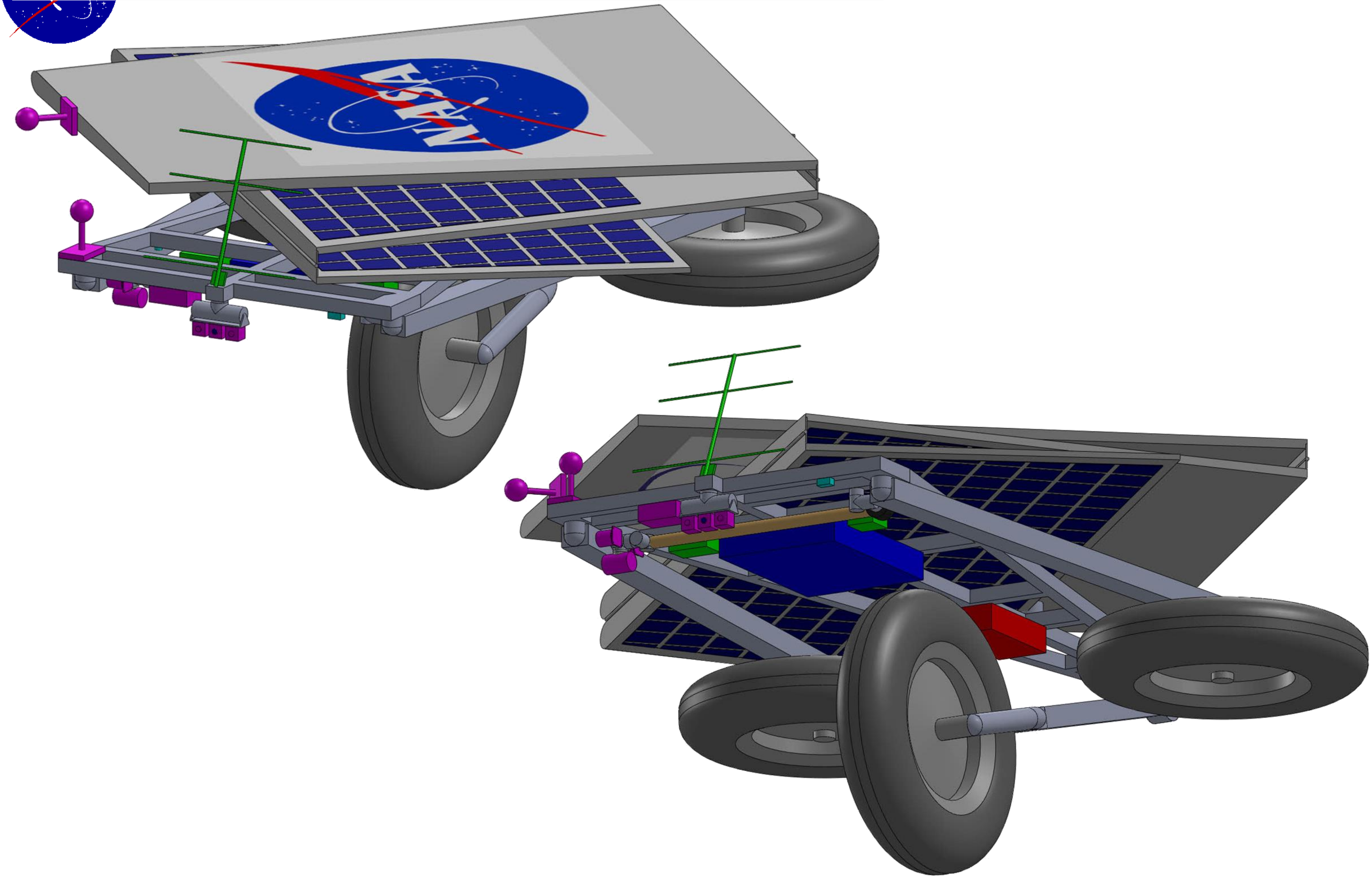
Top Level Venus Landsailer Characteristics

Case #1 Venus Landsailer CD-2013-86			Study Date for this sheet		3/5/2013
GLIDE details:	*VenusLandsailer:Venuslandsailer_1*				
Spacecraft MEL Rack-up (Mass) -Case #1 Venus Landsailer CD-2013-86					
WBS	**Main Subsystems**	**Basic Mass (kg)**	**Growth (kg)**	**Predicted Mass (kg)**	**Aggregate Growth (%)**
06	**Venus Landsailer System**	**1581.0**	**295.7**	**1877**	
06.1	**Landsailer Rover**	***220.1***	***44.9***	**265**	20%
06.1.1	**Science Instruments**	17.9	7.0	**25**	39%
06.1.2	**Attitude Determination and Control**	2.3	0.7	**3**	30%
06.1.3	**Command & Data Handling**	15.3	6.3	**22**	41%
06.1.4	**Communications and Tracking**	4.0	1.3	**5**	33%
06.1.5	**Electrical Power Subsystem**	32.1	4.4	**37**	14%
06.1.6	**Thermal Control (Non-Propellant)**	1.0	0.2	**1**	18%
06.1.7	**Propulsion (Sail System)**	84.2	13.6	**98**	16%
06.1.8	**Propellant (Chemical) (not Used)**	**0.0**		**0**	TBD
06.1.9	**Propulsion (EP Hardware) (Not Used)**	0.0	0.0	**0**	TBD
06.1.10	**Propellant (EP) (Not Used)**	**0.0**		**0**	TBD
06.1.11	**Structures and Mechanisms**	63.2	11.4	**75**	18%
	Element 1 consumables (if used)	**1**		**1**	
	Estimated Spacecraft Dry Mass (no prop,consum)	**220**	45	**264**	**20%**
	Estimated Spacecraft Wet Mass	220	45	265	
System LeveL Growth Calculations Landsailer Rover					**Total Growth**
	Dry Mass Desired System Level Growth	202	61	**263**	**30%**
	Additional Growth (carried at system level)		16		**8%**
	Total Wet Mass with Growth	220	61	**281**	

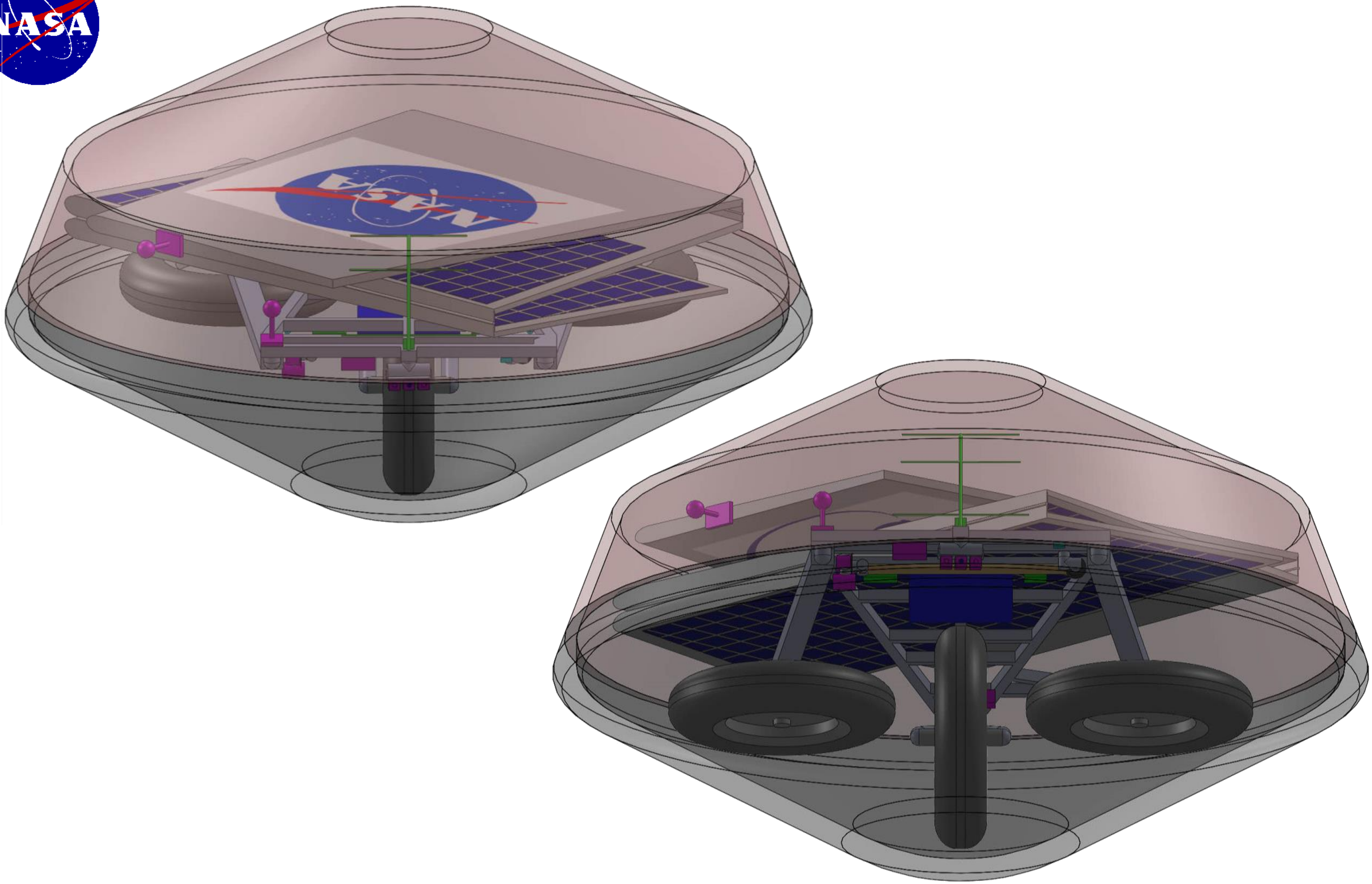
Aeroshell Inside Dimensions



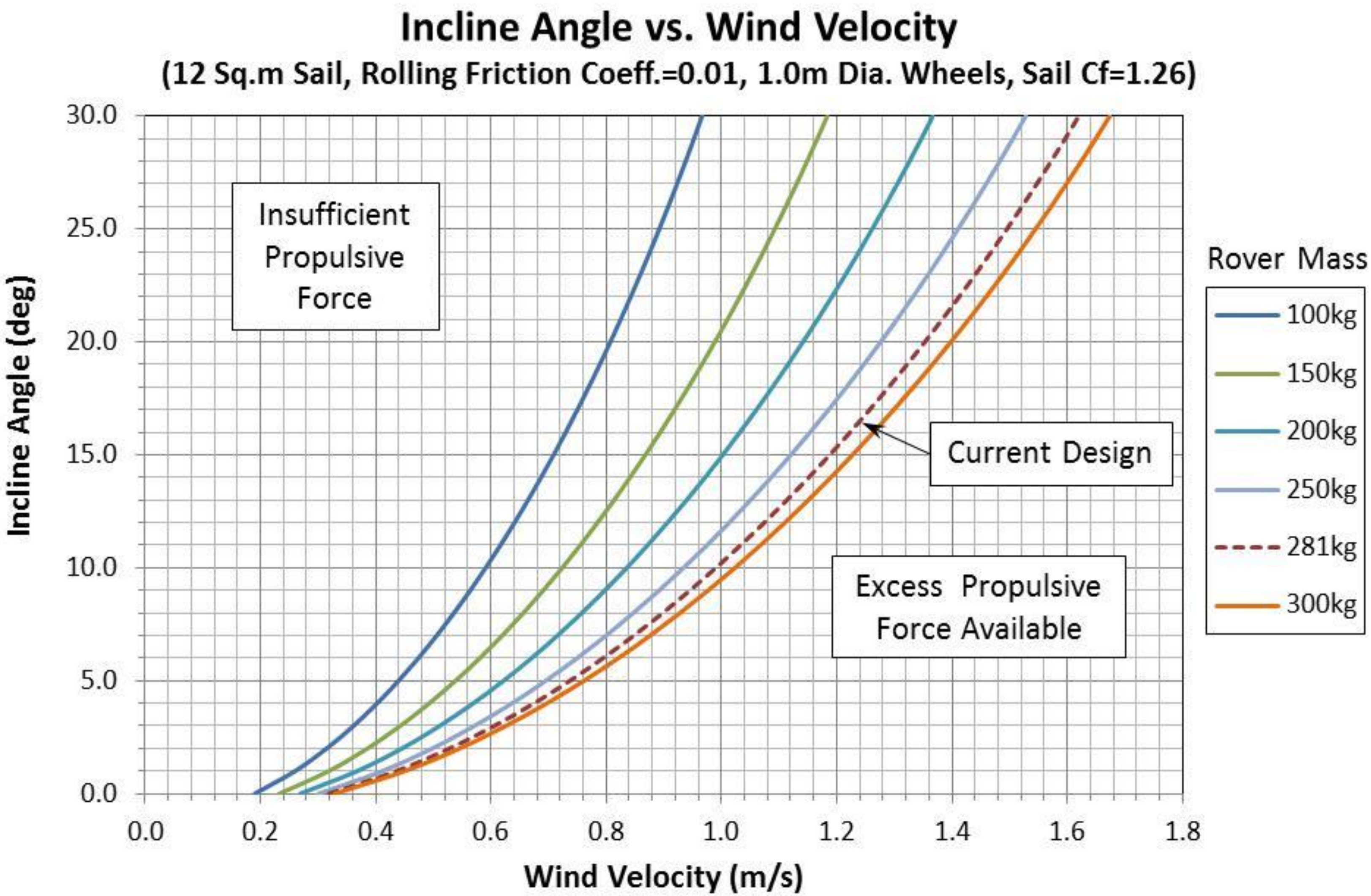
Zephyr Stowed Configuration (3/4)



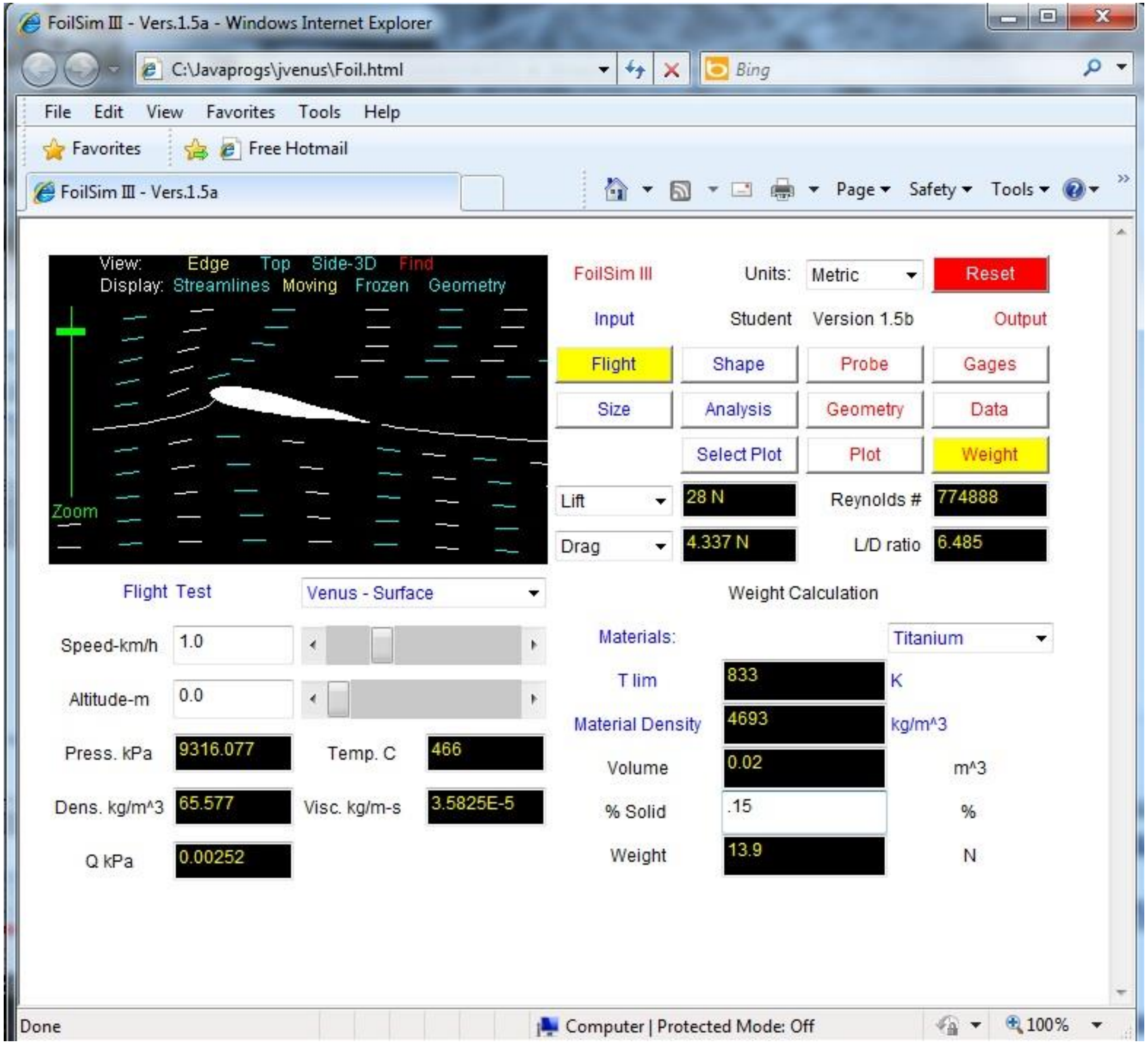
Zephyr Inside Aeroshell



Incline Performance



FoilSim III

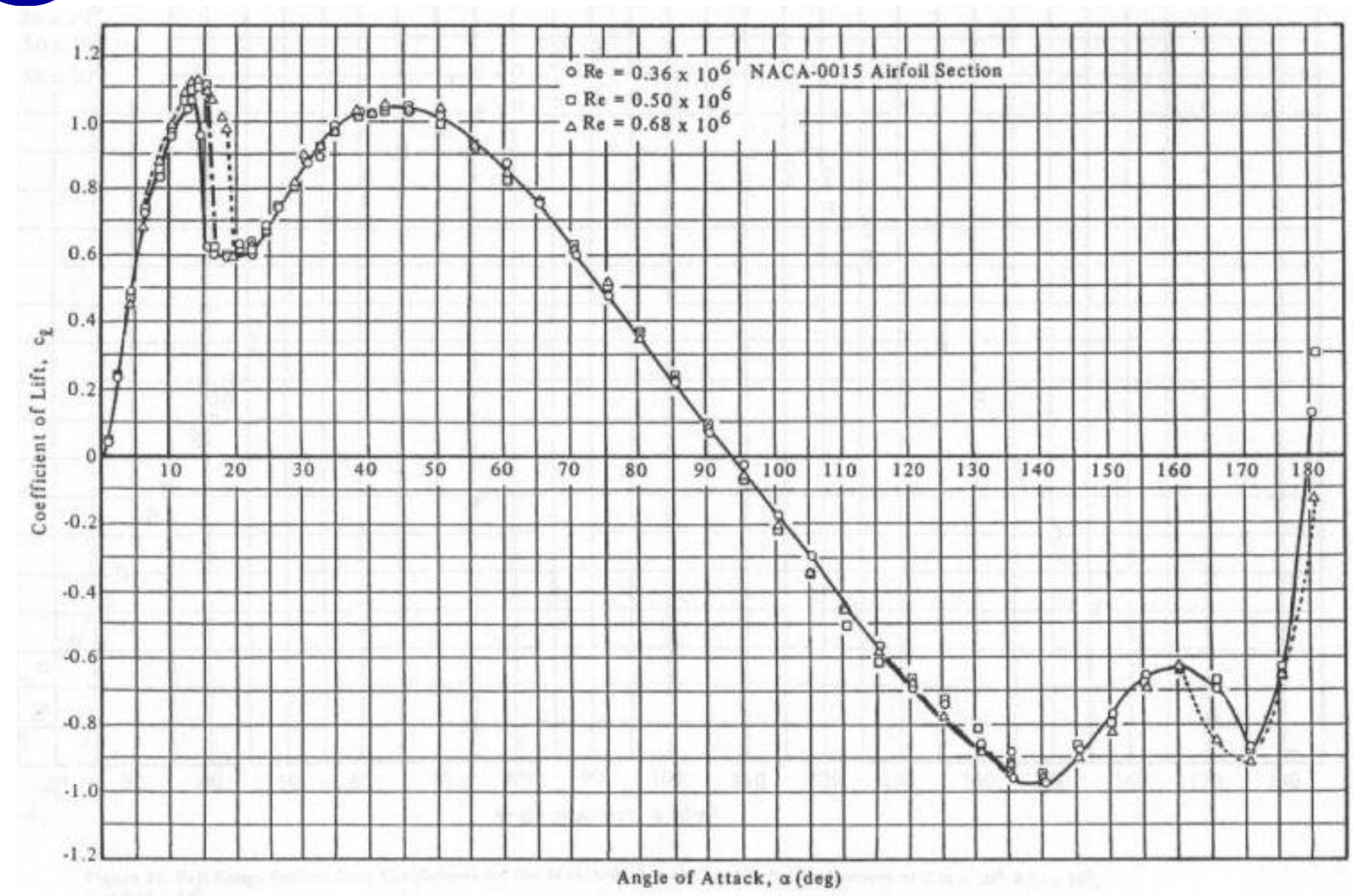


- **Solves 2D Euler Equations for lift coefficient:**
- Kutta-Joukowsky Analysis
- Steady, incompressible, inviscid, instantaneous
- Empirical wing stall model for AoA > 10 degrees

- **Add Venus surface atmosphere**

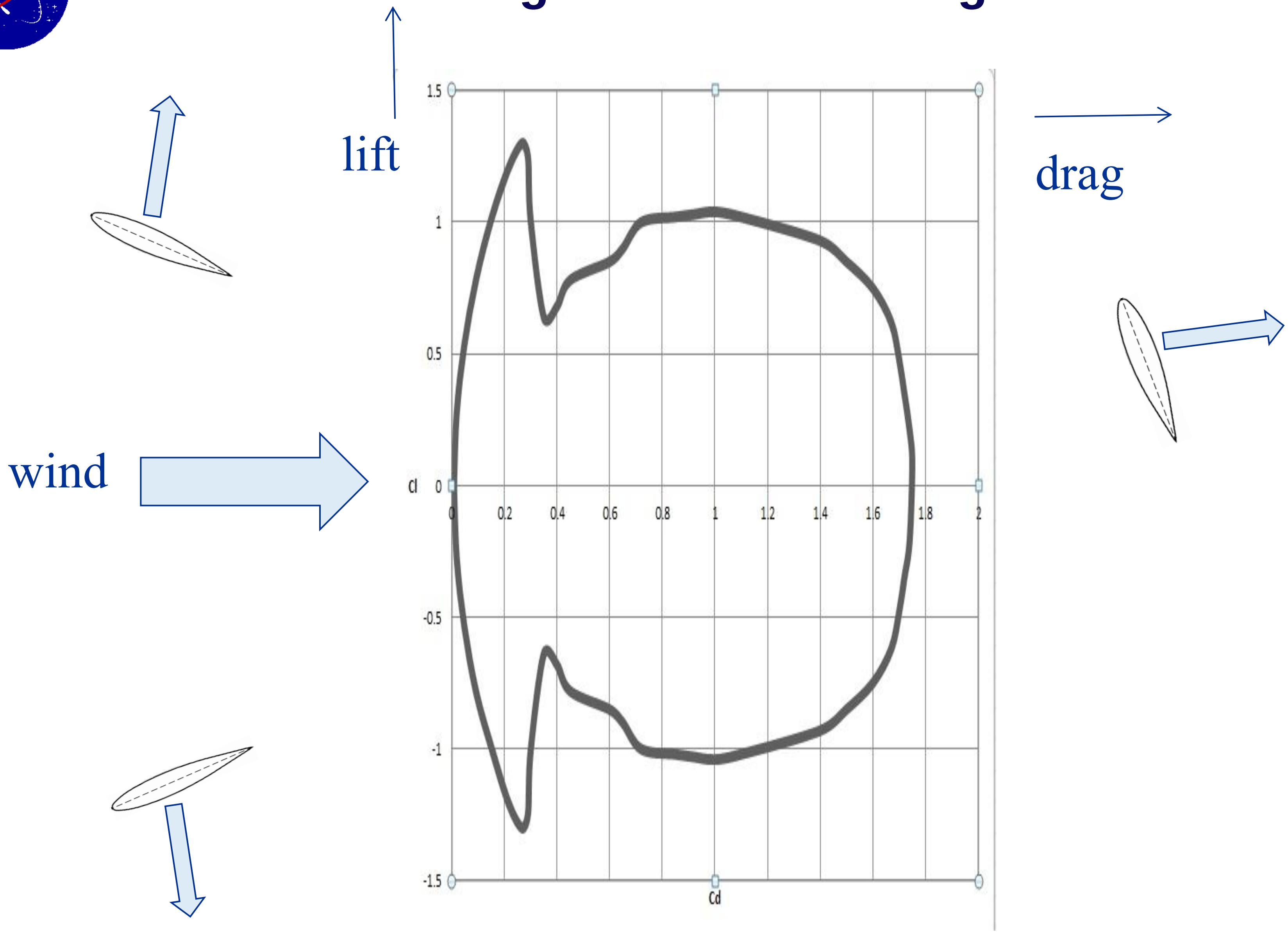
- **Add weight calculation with various materials**
- **Determine that Cl=1.25 is in the proper range**
- **Evaluate solid versus sail wing**

NACA 0015

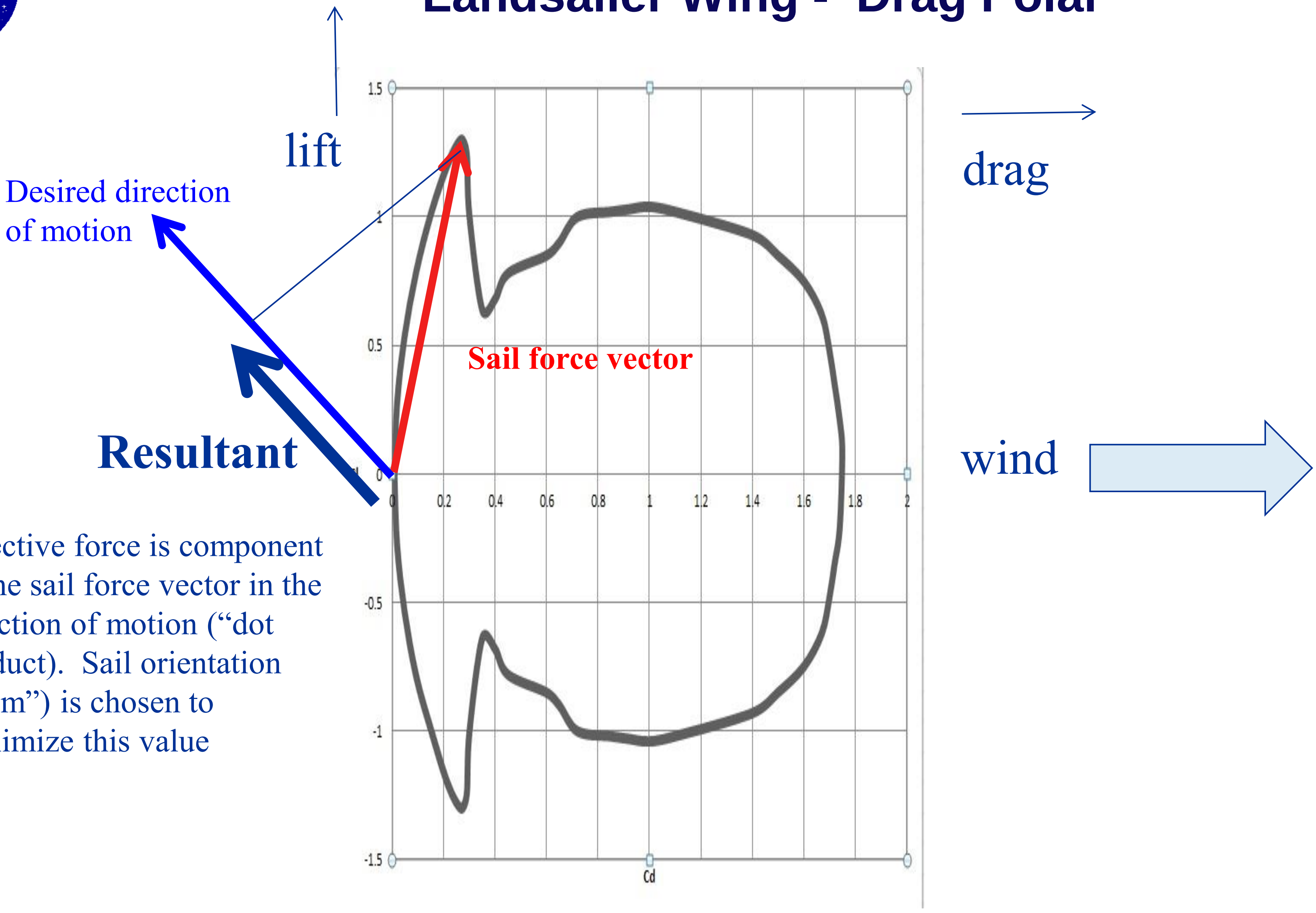


Cl versus alpha

Landsailer Wing - Calculated Drag Polar



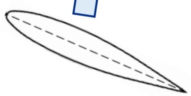
Landsailer Wing - Drag Polar

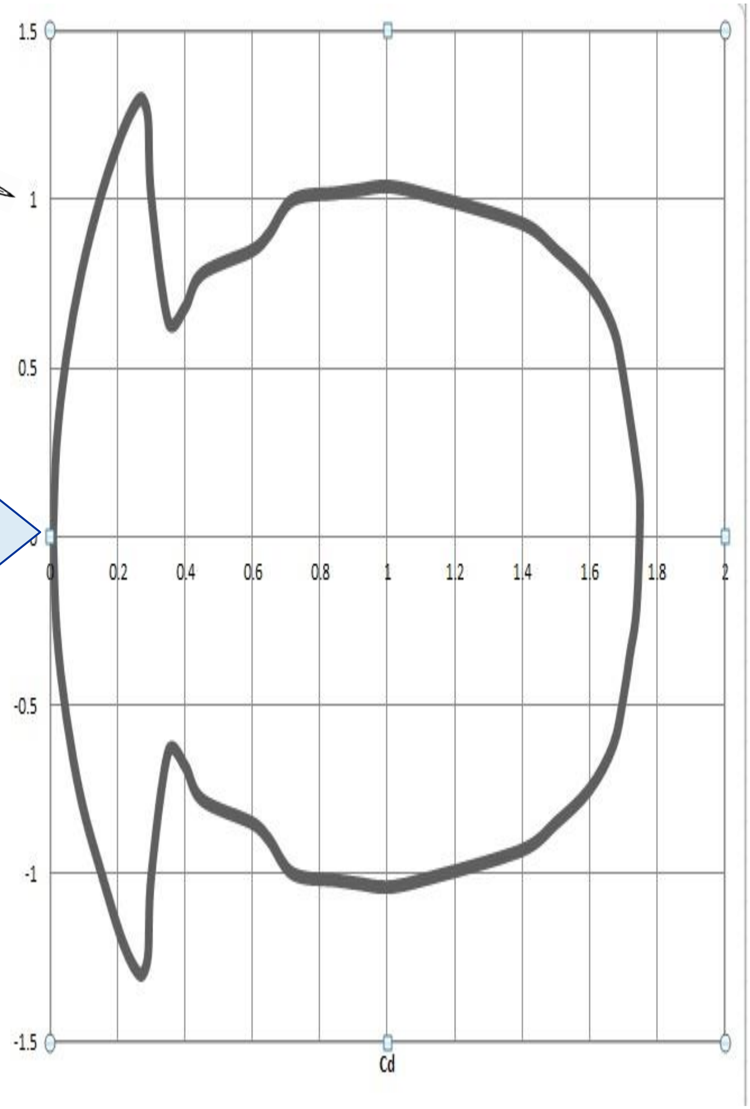


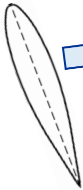
Effective force is component of the sail force vector in the direction of motion ("dot product). Sail orientation ("trim") is chosen to maximize this value

Landsailer Polar

Airfoil primarily lifting







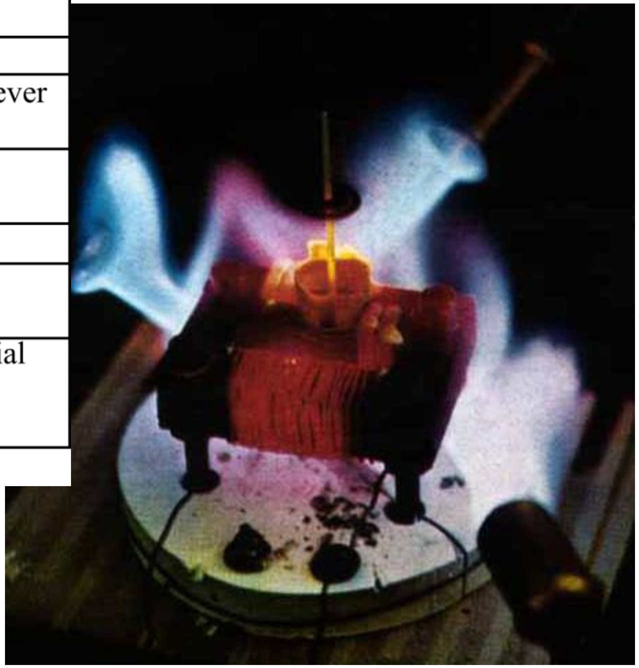
Airfoil primarily drag

wind

Windward arc: propulsion not possible

High Temperature Motor Technology

Motor or actuator	Max operating temperature (C)	status
NASA Glenn switched-reluctance motor	540	demonstrated; 8000 RPM, 27 hours
Honeybee switched reluct.	460	Prototype Venus drill motor
Honeybee brushless	460	prototype Venus motor
Venera drill motor	460	used on Venus for Venera drill
General Electric research	725	Synchronous AC motor "highest ever temperature for a motor"
U. Sheffield Linear actuator	800	technology demonstrator: 1 mm throw, 500N force
In development		
GRC high-temp piezo	360 700	La2Ti2O7 La3Ga5SiO14 In development
NASA Glenn/MSU RAC smart materials: Shape memory alloy actuators	150 500 1000	Shape memory (SMA): commercial SMA: material demonstrated SMA: high temperature goal



GE High Temperature Motor Technology Undergoing Testing While Heated by 3 Ox/Gas Torches

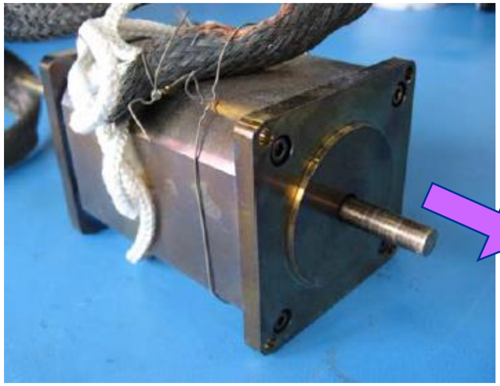
GE High temperature motor:

- NiO-Clad Silver-Palladium Alloy Wire
- 0.762 mm (0.030 in) Diameter Wire
- Poles Made From Laminated 6% Si-Fe
- Sustained Operation at 575^{o}C
- Motor Operated at Temperatures as High as 725^{o}C (Si-Fe Curie Temperature)

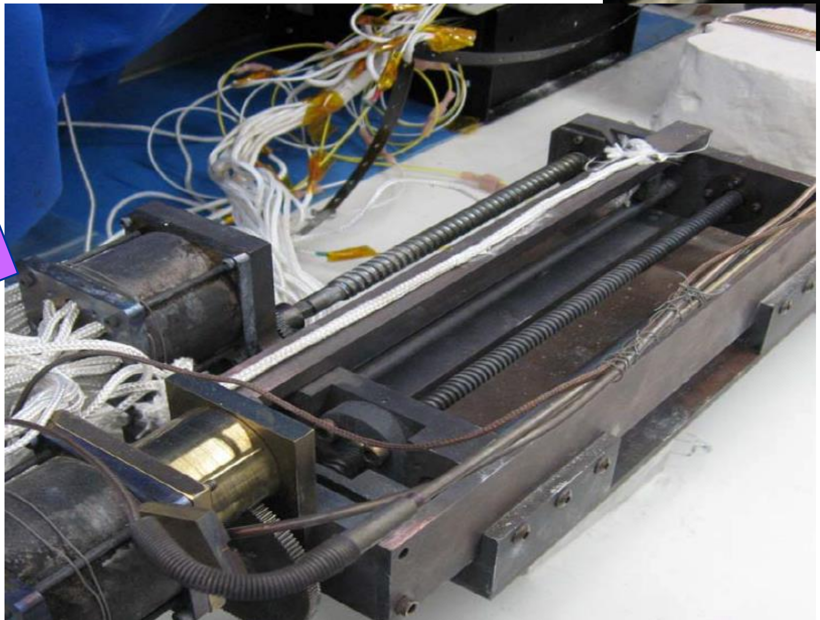
High Temperature Motors

- Developed by Honeybee Robotics based on NASA GRC technology
- Designed to Survive above 460°C in Earth Atmosphere
- Operated Non-Continuously for over 20 Hr in Venus Like Conditions
- Tested in High Temperature Drill Rig
- Require Transmission for low RPM
- Mass: 800 grams

High Temperature Switched Reluctance Motor



Images from Honeybee Robotics, inc



High Temperature Drill Rig

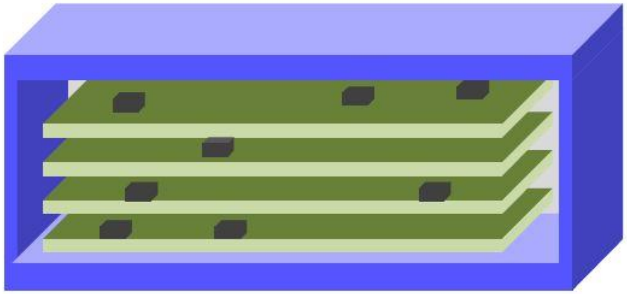
Venus Landsailer
Landsailer Rover System Propulsion (Sail System) MEL

WBS	Description	QTY	Unit Mass	Basic Mass	Growth	Growth	Total Mass
Number	Case #1 Venus Landsailer CD-2013-86		(kg)	(kg)	(%)	(kg)	(kg)
	Power Mode Name Power Mode duration (units tbd)						
06	**Venus Landsailer System**			**1581.03**	**18.7%**	**295.74**	**1876.77**
06.1	**Landsailer Rover**			**220.08**	**20.4%**	**44.86**	**264.94**
06.1.7	**Propulsion (Sail System)**			**84.23**	**16.1%**	**13.58**	**97.82**
06.1.7.a	**Sail System**			52.93	18.0%	9.53	62.46
06.1.7.a.a	*Sail*			48.93	18.0%	8.81	57.74
06.1.7.a.a.a	Steering Mechanism	1.00	7.70	7.70	18.0%	1.39	9.09
06.1.7.a.a.b	Sail Structure	1.00	29.94	29.94	18.0%	5.39	35.33
06.1.7.a.a.c	Deployment Mechanism, Sail	3.00	3.77	11.30	18.0%	2.03	13.33
06.1.7.a.b	*Parachute System*			4.00	18.0%	0.72	4.72
06.1.7.a.b.a	Parachute	1.00	4.00	4.00	18.0%	0.72	4.72
06.1.7.b	**Wheel System**			31.30	13.0%	4.06	35.36
06.1.7.b.a	*Wheels*			31.30	13.0%	4.06	35.36
06.1.7.b.a.a	Wheels	3.00	6.60	19.80	12.0%	2.38	22.18
06.1.7.b.a.b	Brake	2.00	2.50	5.00	18.0%	0.90	5.90
06.1.7.b.a.c	Steering Mechanism	1.00	6.50	6.50	12.0%	0.78	7.28

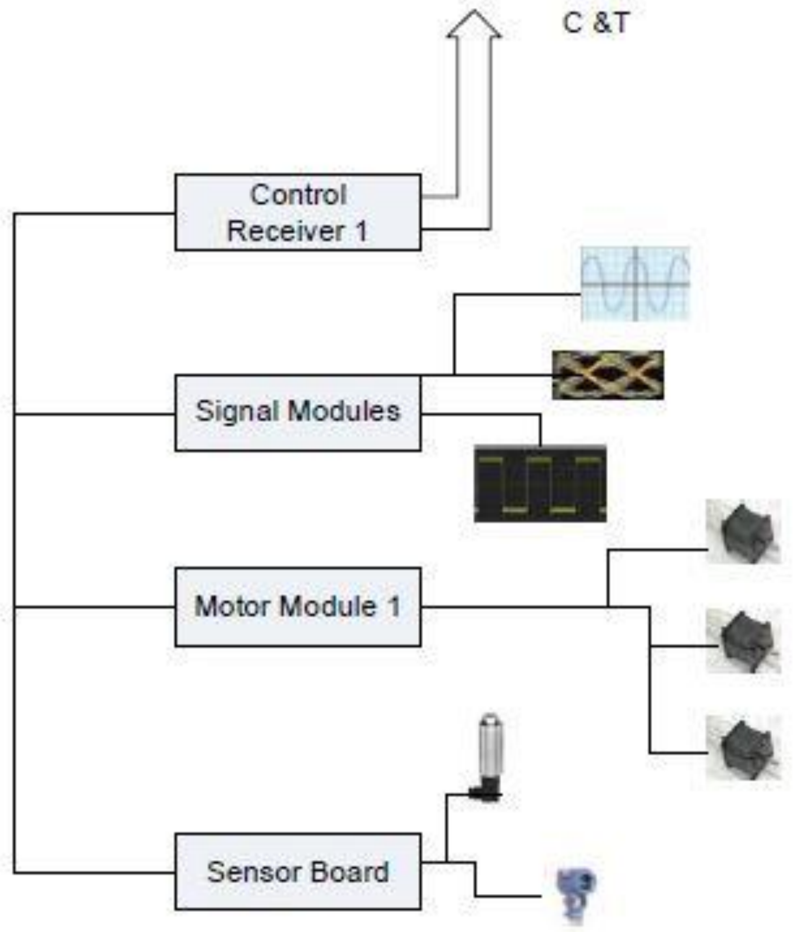
Avionics Overview

- Design Requirements
  - Operate and Survive on the surface of Venus at 462 C, 92 Mpa (92 bar)
  - Accept primitive bit-level commands relayed from orbiter via comm
  - Gather science data via ADC and scanning photodiode imager
  - Transmit data to orbiter via addressable bit-level register dumps
- Assumptions
  - Single string
  - Devoid of software
  - Registered data transferred with multiplexed 1970's style UART data streaming to/from comm
  - Cyclically service all the needed instrumentation (per charts below)
  - Use SiC 1970's RTL-gate integrated circuit design and packaging (TRL 3)
  - Desire lowest possible power per gate/transistor
  - Level of integration several hundred transistors per package
    - ADC, MPU-level integrations, Motor Drivers – all in flat-paks
    - Transistor density comparable to first 4-bit microprocessors of 1971 (2300 transistors).
    - Assume 1970's UART-style instrumentation data flows
    - See charts below for block diagrams
- Design Description
  - Avionics components based on high temperature SiC transistors
  - Assume early 1970's packaging density (e.g. DEC PDP-8 and Data General NOVA minicomputers)
  - Possible ROM/RAM implementations per HP 9100A calculator of 1969.
  - Imaging uses scanning photodiode (similar to Slow Scan TV on Apollo)
  - UART data flows at very low baud rate allow several channels of data in 3 kHz bandwidth if analog
- Concerns, Comments, Recommendations
  - Obvious concern for survivability of transistors, connectors, insulation, integrated circuit packages
  - Development of suitable capacitors and resistors

Avionics Block Diagram



- Avionics enclosure notionally shown with front and back removed and boards in loaded configuration.
- Power lines and connectors not shown.
- Assume gel-filled to prevent corrosion from atmosphere

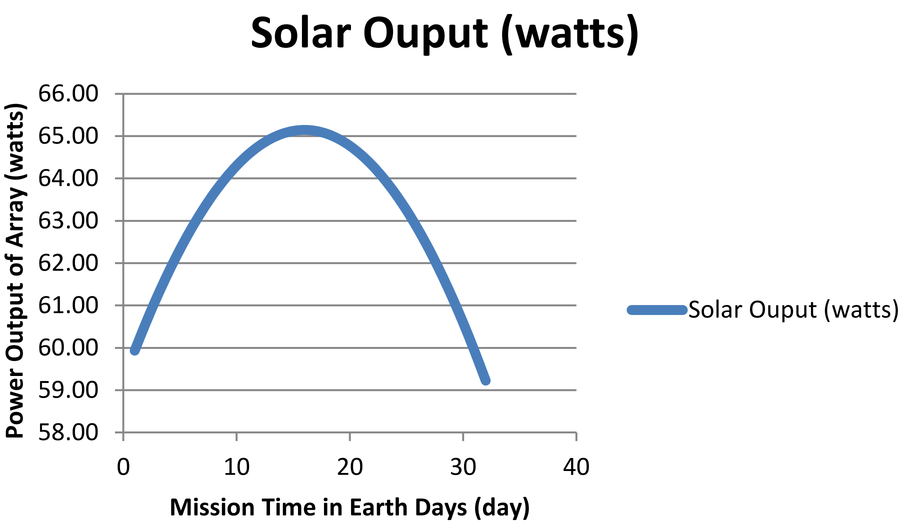


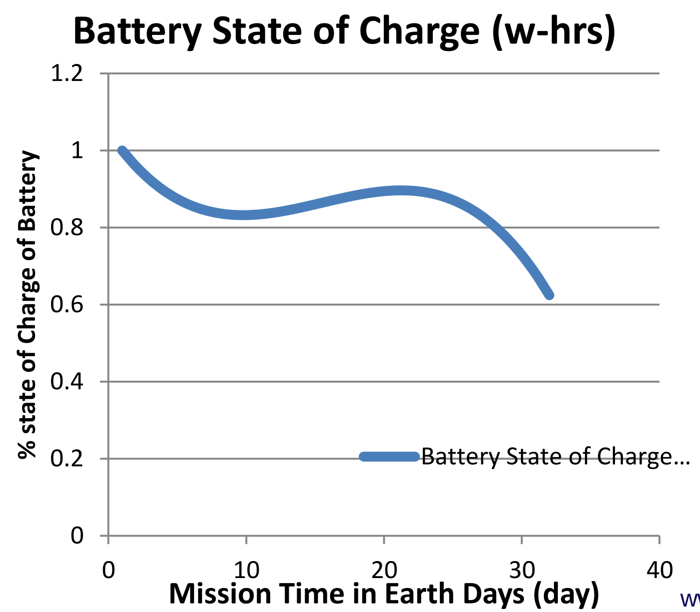
Venus Landsailer
Landsailer Rover System Command and Data Handling MEL

Number	Case #1 Venus Landsailer CD-2013-86		(kg)	(kg)	(%)	(kg)	(kg)
	Power Mode Name Power Mode duration (units tbd)						
06	**Venus Landsailer System**			**1581.03**	18.7%	295.74	1876.77
06.1	**Landsailer Rover**			**220.08**	**20.4%**	**44.86**	**264.94**
06.1.3	**Command & Data Handling**			**15.30**	**40.8%**	**6.25**	**21.55**
06.1.3.a	**C&DH Hardware**			11.30	37.6%	4.25	15.55
06.1.3.a.a	Control Receiver 1	1.00	1.30	1.30	50.0%	0.65	1.95
06.1.3.a.b	Signal Module 1	1.00	1.00	1.00	50.0%	0.50	1.50
06.1.3.a.c	Signal Module 2	0.00	1.00	0.00	50.0%	0.00	0.00
06.1.3.a.d	Motor Module 1	1.00	1.00	1.00	50.0%	0.50	1.50
06.1.3.a.e	Sensor Board	1.00	1.00	1.00	50.0%	0.50	1.50
06.1.3.a.f	Enclosure	1.00	7.00	7.00	30.0%	2.10	9.10
06.1.3.b	**Instrumentation & Wiring**			4.00	50.0%	2.00	6.00
06.1.3.b.b	Data Cabling	1.00	4.00	4.00	50.0%	2.00	6.00

Power System

- Mission lands 15 days before Venus noon
  - 117 earth day daylight period
  - 30 Day Mission starting 15 days before noon (day 58.5)
  - Mission ends at noon + 15 days
- Battery sized for 1 earth-day of energy storage @ 70% DOD
- Battery 100% charged at start of mission
- Array Sized to match daily average power output ~ 65 watts for 15th day (Venus noon) of mission
  - Battery reaches 0% charge on 38th day of mission
  - Battery capable of 1000's of cycles with little change in performance





Power System Summary

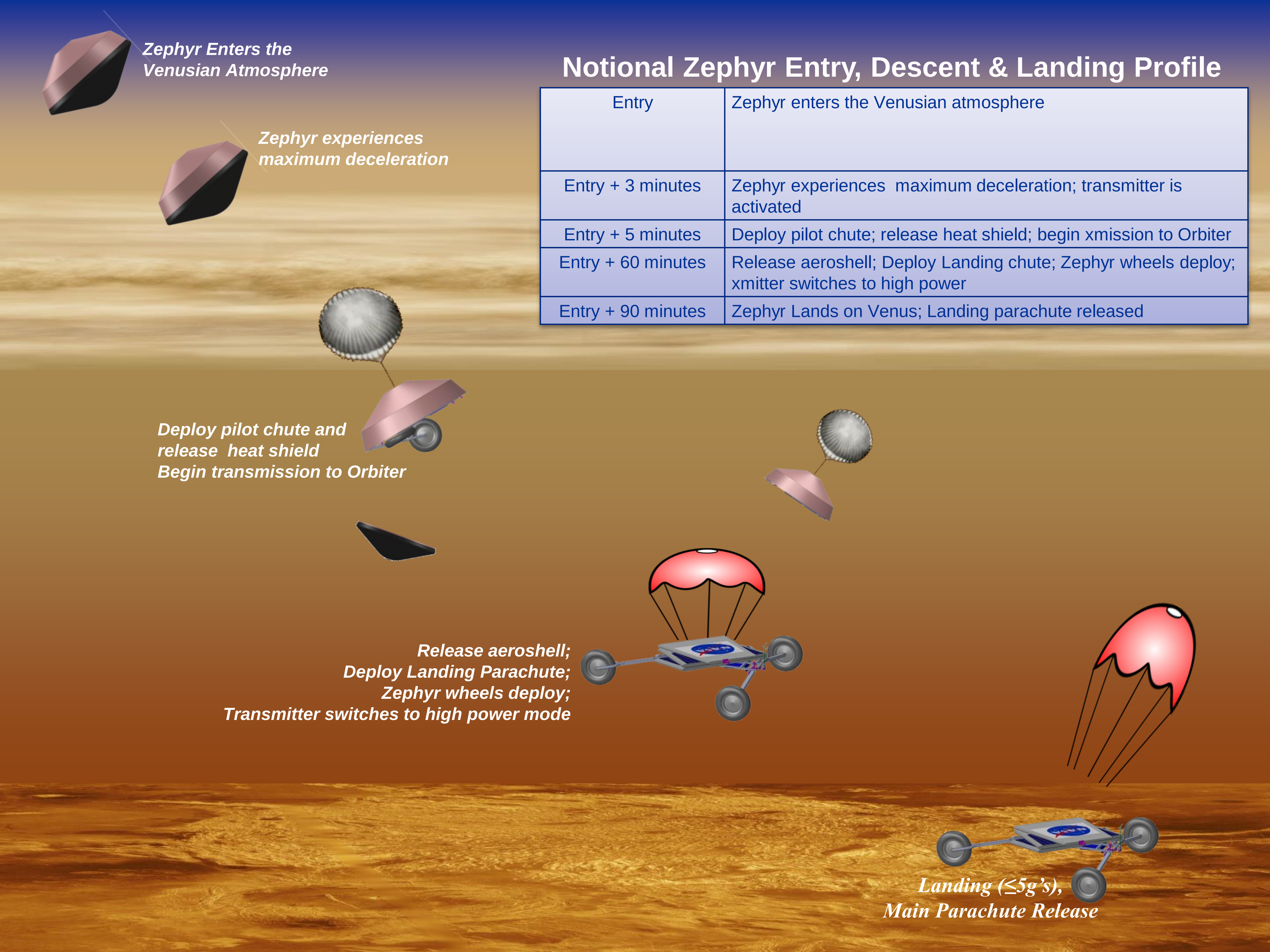
- Summary
  - Solar Array Area – 12 m^2 (6 m^2 on each face of sail)
  - Solar Array Mass – 19.6 kg
  - Battery Mass – 10 kg
  - Battery Volume ~ 4 liters
  - Wiring Harness (bookkept as 6 ft ASRG) – 2.5 kg

Venus Landsailer
Landsailer Rover System Electrical Power MEL

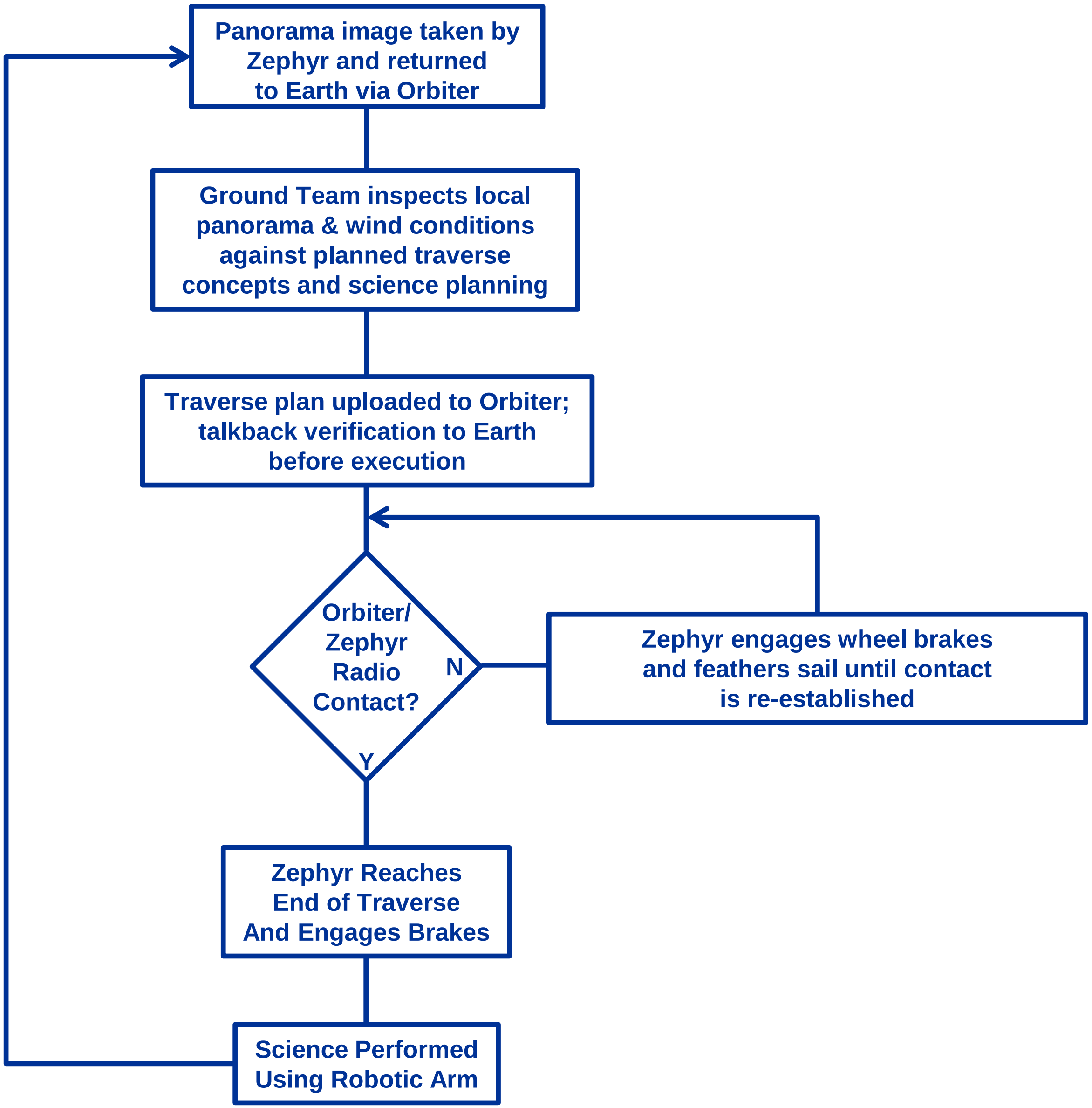
WBS	Description	QTY	Unit Mass	Basic Mass	Growth	Growth	Total Mass
Number	Case #1 Venus Landsailer CD-2013-86		(kg)	(kg)	(%)	(kg)	(kg)
	Power Mode Name Power Mode duration (units tbd)						
06	**Venus Landsailer System**			**1581.03**	**18.7%**	**295.74**	**1876.77**
06.1	**Landsailer Rover**			**220.08**	**20.4%**	**44.86**	**264.94**
06.1.5	**Electrical Power Subsystem**			**32.13**	**13.8%**	**4.44**	**36.57**
06.1.5.a	**Power Conversion**			29.63	15.0%	4.44	34.07
06.1.5.a.a	Solar Arrays	1.00	19.60	19.60	15.0%	2.94	22.54
06.1.5.a.b	Battery System	1.00	10.03	10.03	15.0%	1.50	11.53
06.1.5.b	**Electrical Power Electronics and Control**			2.50	0.0%	0.00	2.50
06.1.5.b.e	Power & Data Cabling	1.00	2.50	2.50	0.0%	0.00	2.50

Notional Zephyr Entry, Descent & Landing Profile

Entry	Zephyr enters the Venusian atmosphere
Entry + 3 minutes	Zephyr experiences maximum deceleration; transmitter is activated
Entry + 5 minutes	Deploy pilot chute; release heat shield; begin xmission to Orbiter
Entry + 60 minutes	Release aeroshell; Deploy Landing chute; Zephyr wheels deploy; xmitter switches to high power
Entry + 90 minutes	Zephyr Lands on Venus; Landing parachute released



Zephyr Traverse Operations



Conclusions

- A new concept for a Venus rover is proposed, using the wind at the primary motive force, and operating at the ambient Venus temperature of ~450°C.
- A design study shows no apparent showstoppers to the mission.
- Technology capable of operation at Venus surface conditions is available, but will need technology development to reach flight readiness level.