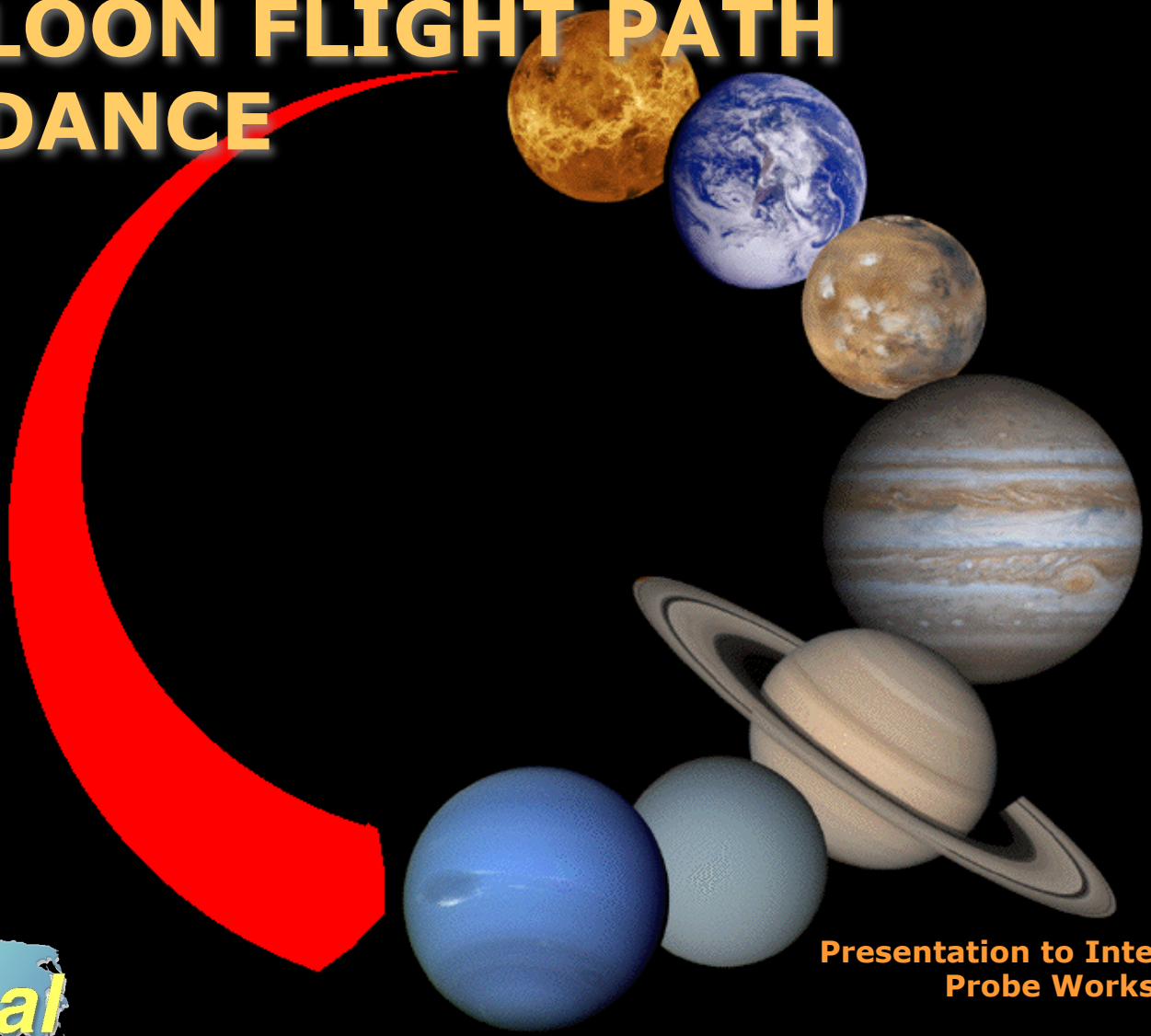
A METHOD FOR PLANETARY BALLOON FLIGHT PATH GUIDANCE



Global Aerospace Corporation

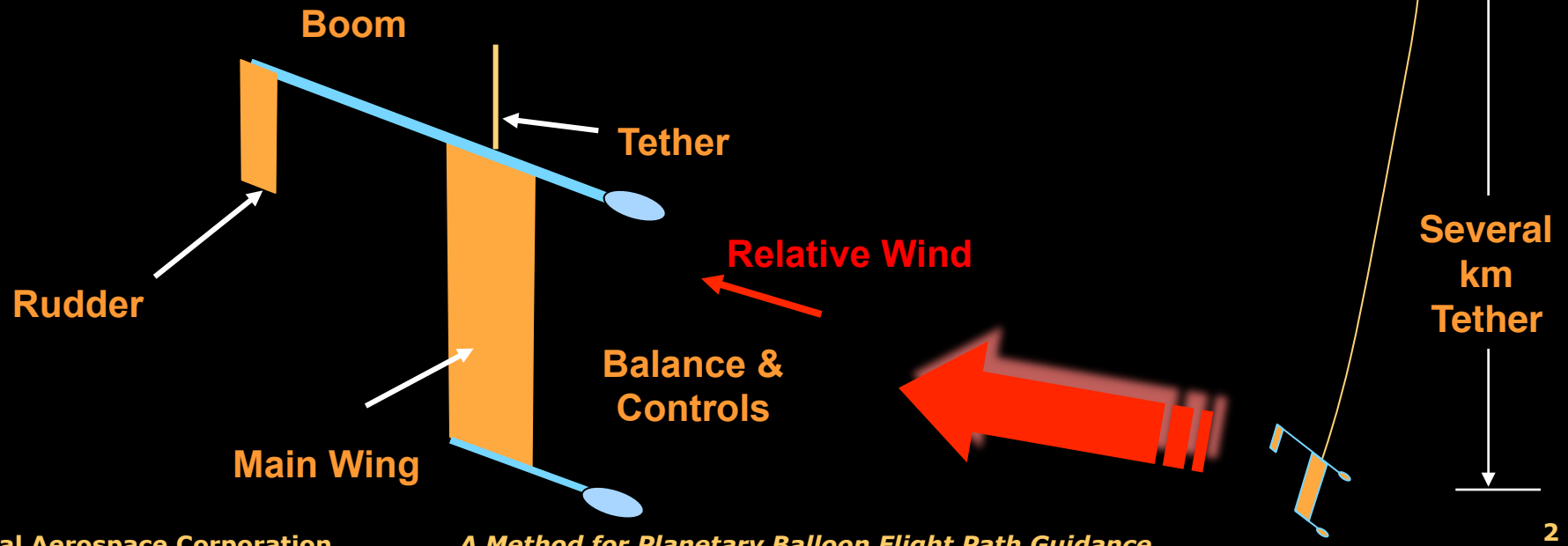
Presentation to International Planetary Probe Workshop, June 29, 2006

K. T. Nock, K. M. Aaron,
M. K. Heun, A. A. Pankine
Global Aerospace Corporation

STRATOSAIL® BALLOON GUIDANCE SYSTEM (BGS)

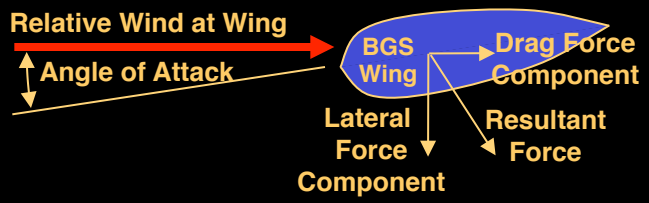
First Generation Balloon Guidance System (BGS)

- Wing hanging vertically on long tether in higher density air below balloon system
- Rudder controls angle of attack
- Relative wind at StratoSail® BGS generates lift force, which alters balloon trajectory



STRATOSAIL® BGS FEATURES

- Passively exploits natural wind conditions
- Operates day and night
- Offers a wide range of control directions regardless of wind conditions
- Can be made of lightweight materials and inflatable structures
- Does not require consumables
- Requires very little electrical power
- Bounded & underactuated control system, therefore cannot stationkeep over a location



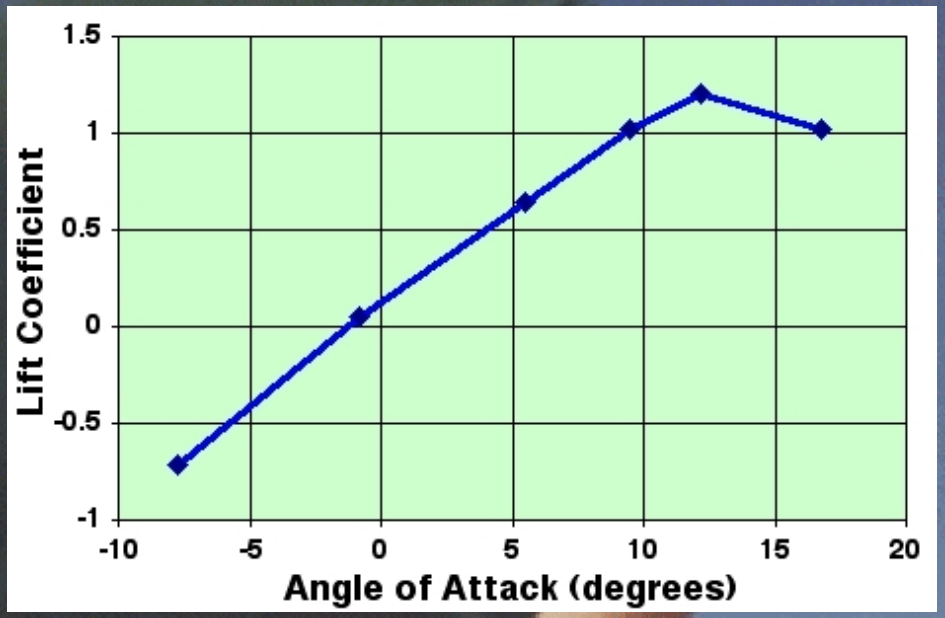
STRATOSAIL® BGS SCALE MODEL TEST

April 2001, **El Mirage Dry Lake, California**

Objectives:

- Acquire quantitative data to verify aerodynamic performance predictions
- Investigate effects of cg location on dynamic behavior
- Validate stability and control requirements
- Gain experience with instrumentation applicable to full scale test

Lift Curve



Instrumentation:

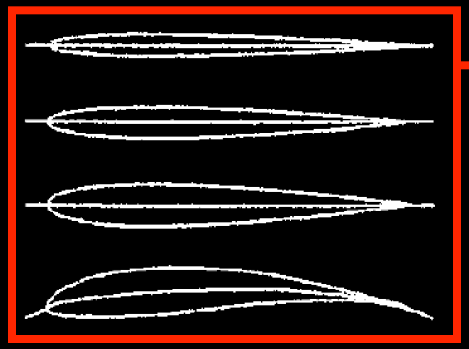
- Hot Film X-probe (velocity and alpha)
- 3-axis tether force transducer (strain gage)
- Accelerometer-based Pitch Roll sensor
- Magnetometers
- Temperature and humidity
- Rudder position encoder
- On board video camera
- Data acquisition and transmission system

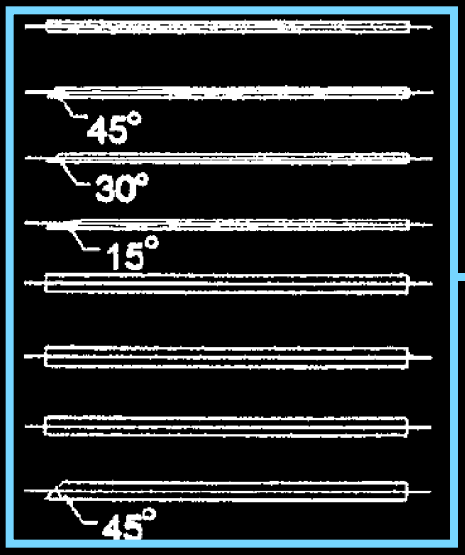
Preliminary Results:

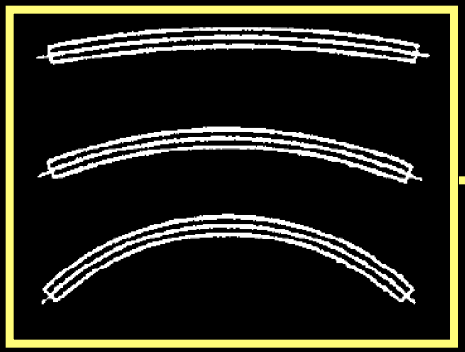
- Aerodynamic performance slightly better than expected
- System is stable
- Preferred center of mass location established
- Instrumentation worked perfectly
- We have confidence that the full scale version will perform as predicted

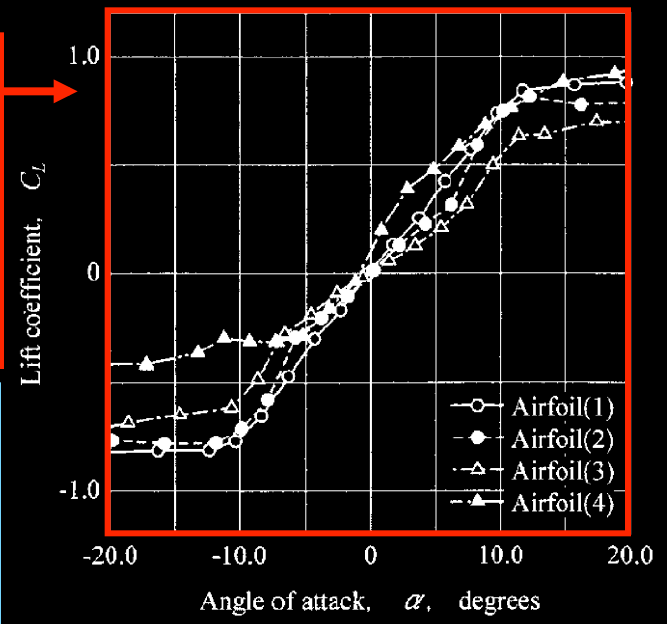
MARS BGS LOW REYNOLDS NUMBER AIRFOILS AND PERFORMANCE

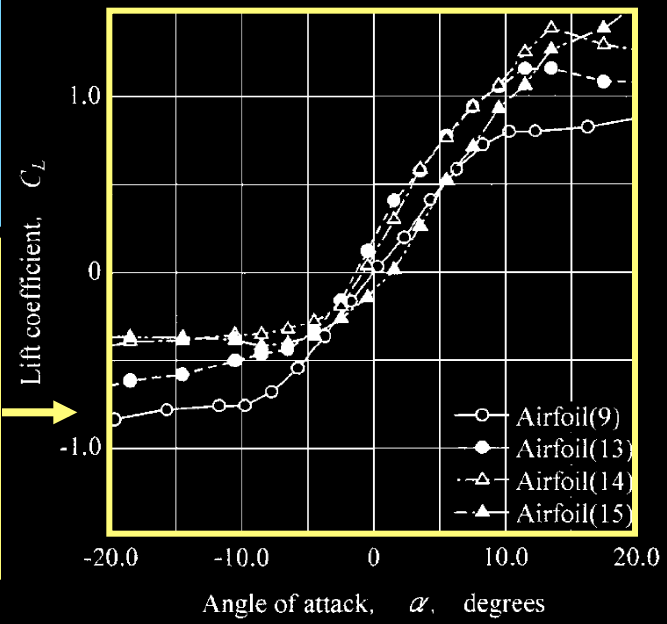
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

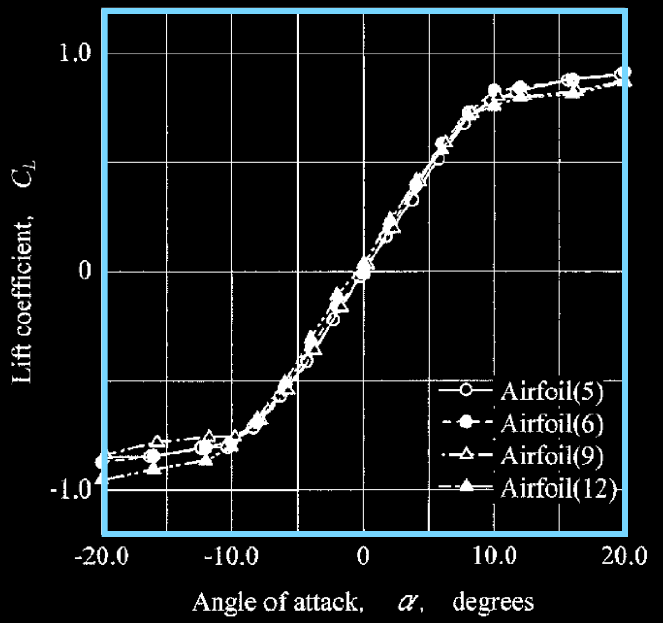










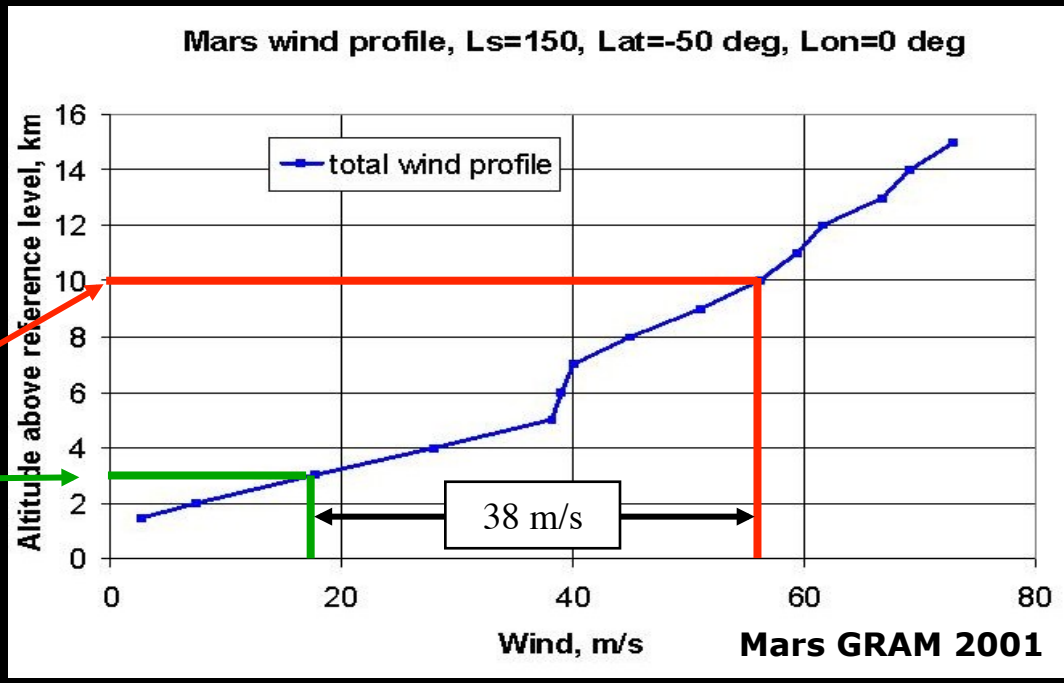


At Mars the Re for the BGS ranges between ~2-4x10^3, hence low-Re airfoils are needed.

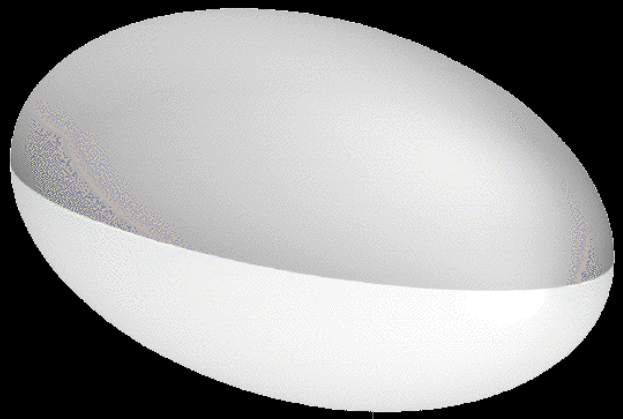
Sunada, S., "Comparison of Wing Characteristics at an Ultralow Reynolds Number," J. Aircraft, Vol. 39, No. 2, March–April 2002 [relevant for Re of 4,000]

MARS WIND PROFILE AND BGS

- Winds vary with altitude
  - Balloon at 10 km
    Density = 0.00645 kg/m³
  - Wing at 3 km
    Density = 0.01186 kg/m³
  - Relative wind velocity
    ~ 38 m/s
- Wing generates lift force
  - "Lift" force is horizontal
  - force is transmitted by tether to balloon
  - balloon drifts relative to local air mass
  - balloon drag ≈ wing lift
- Wing is in denser air than balloon
  - 3 km : 10 km (1.84x)
  - equivalent wing area increased relative to balloon



EXAMPLE MARS Balloon Guidance System



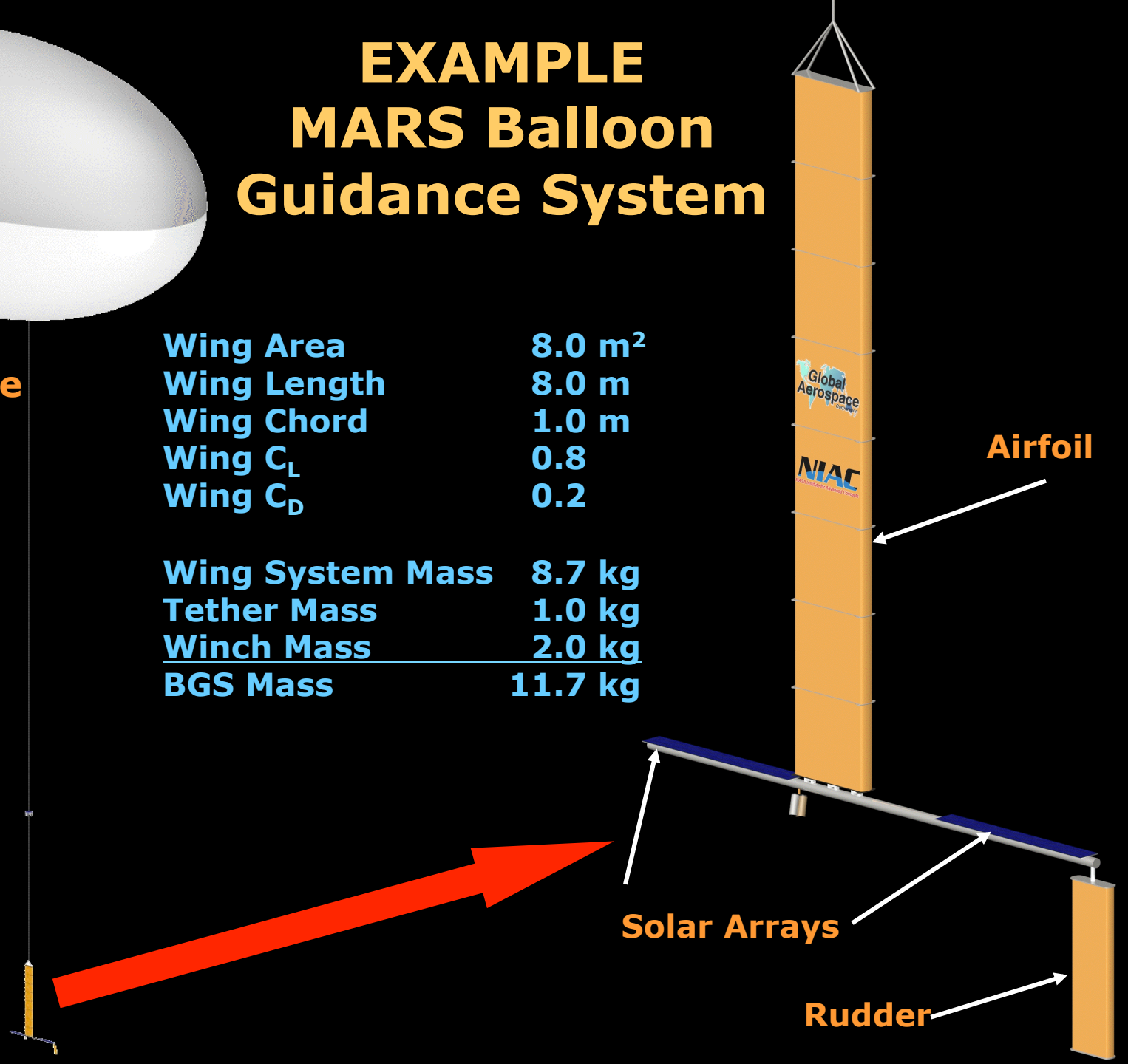
Ellipsoidal Superpressure Balloon

Wing Area	8.0 m^2
Wing Length	8.0 m
Wing Chord	1.0 m
Wing C_L	0.8
Wing C_D	0.2
Wing System Mass	8.7 kg
Tether Mass	1.0 kg
Winch Mass	2.0 kg
BGS Mass	11.7 kg

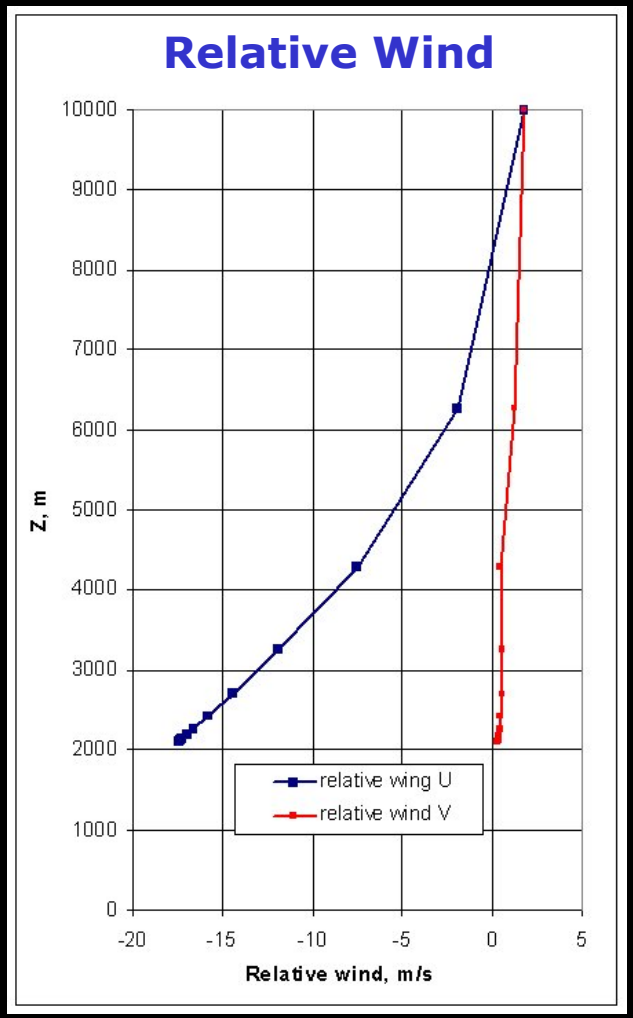
Tether

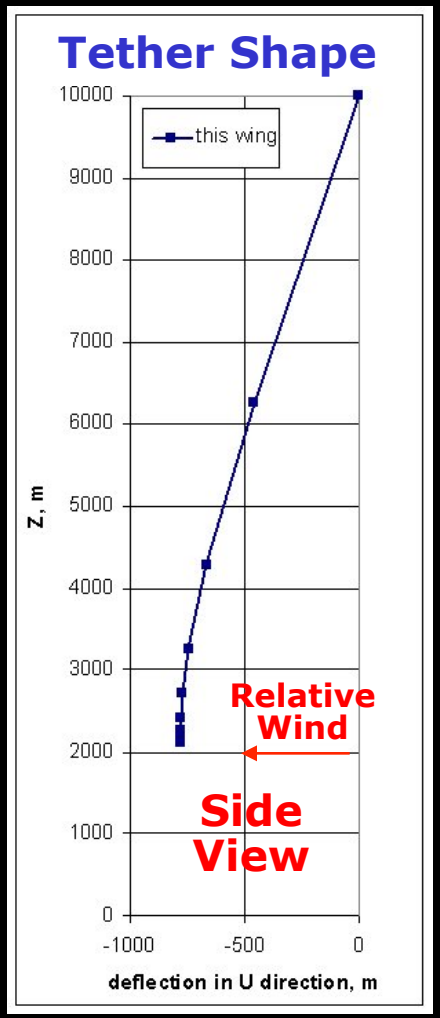
Gondola

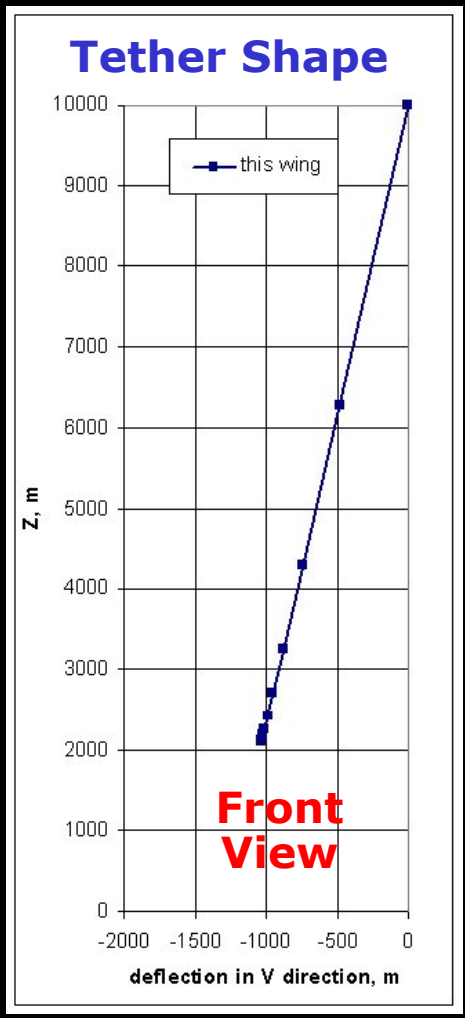
Wing System



BGS PERFORMANCE ANALYSIS: STRONG ZONAL FLOW

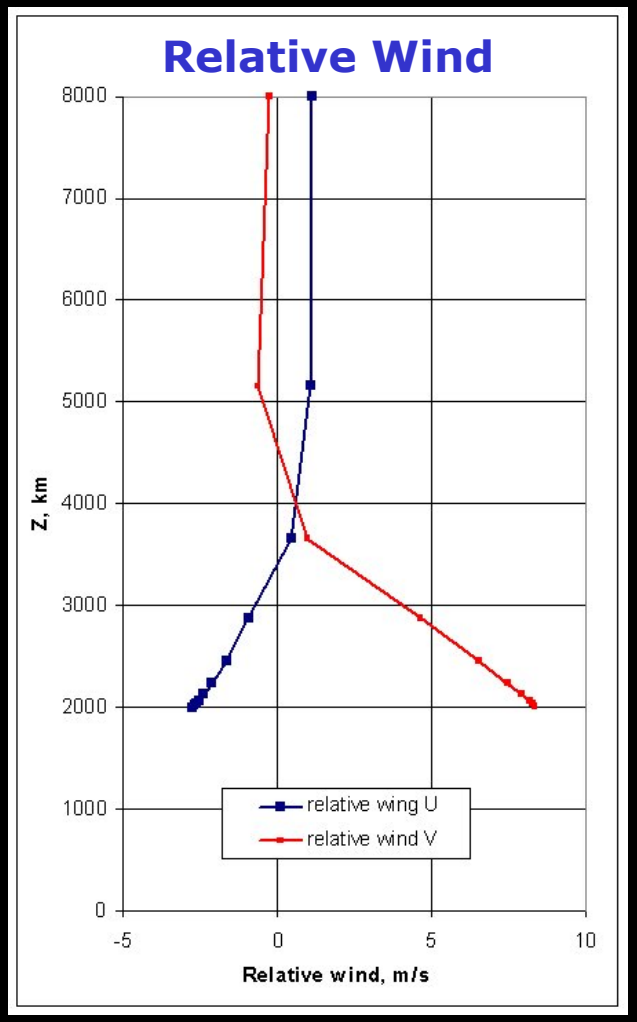


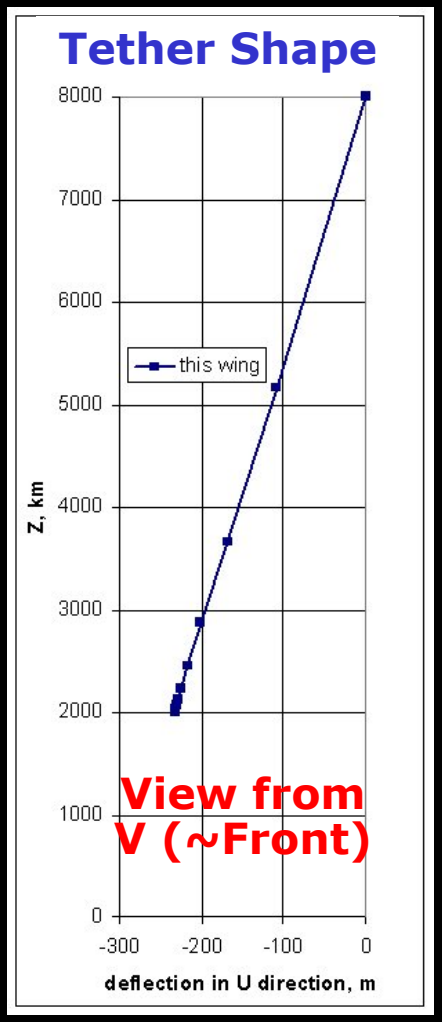


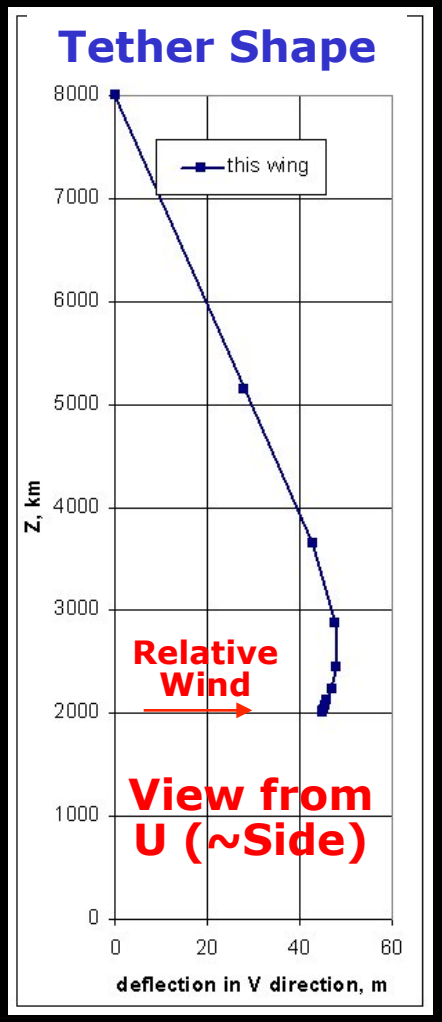


- BGS V_{rel} = -18 m/s
- BGS ΔV = -1.8 m/s

BGS PERFORMANCE ANALYSIS: WEAK FLOW



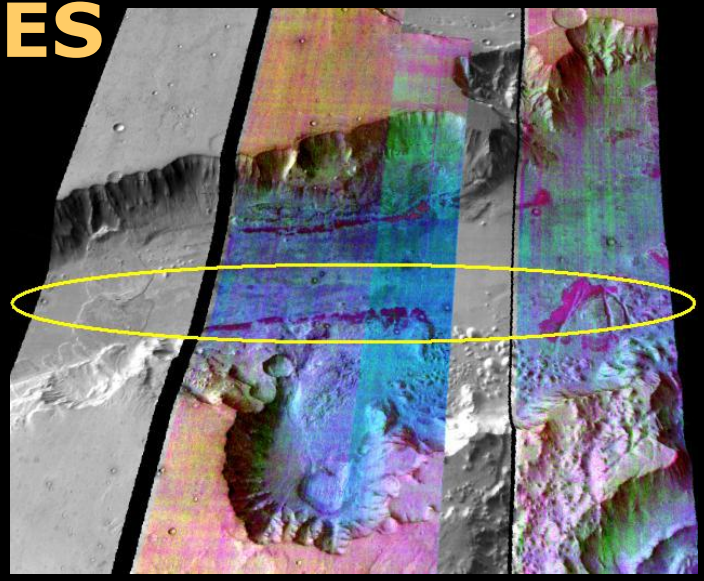




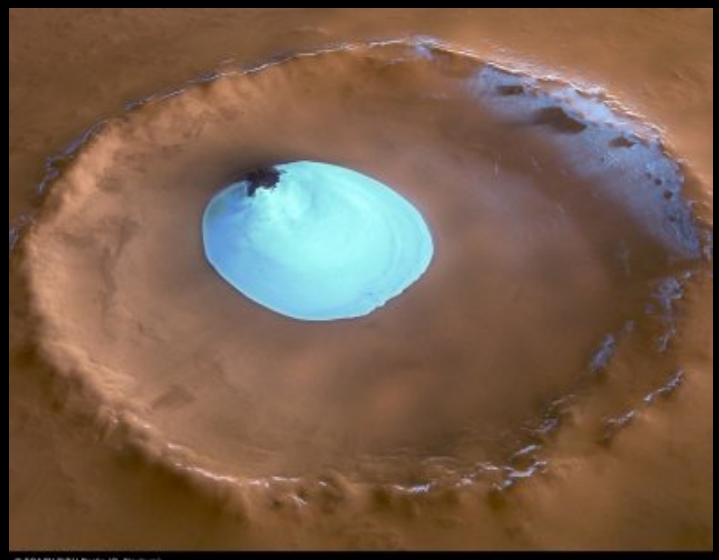
- BGS V_{rel}=9 m/s
- BGS ΔV =1 m/s

EXPLORATION CAPABILITIES

- Global planetary coverage
- Heavy, power-intensive payloads (90 kg and 200 W in 3 to 10 years, 170 kg and 400 W >10 years)
- Long flight duration: 700 days (1 Mars year)
- Autonomous navigation and guidance, target acquisition
- Targeted overflight of surface sites and precise delivery of science probes
- High-resolution imaging, elemental, magnetic and gravity surveys not possible or challenging from orbit
- In situ atmospheric chemistry and circulation
- Landing sites reconnaissance, navigation beacon emplacement

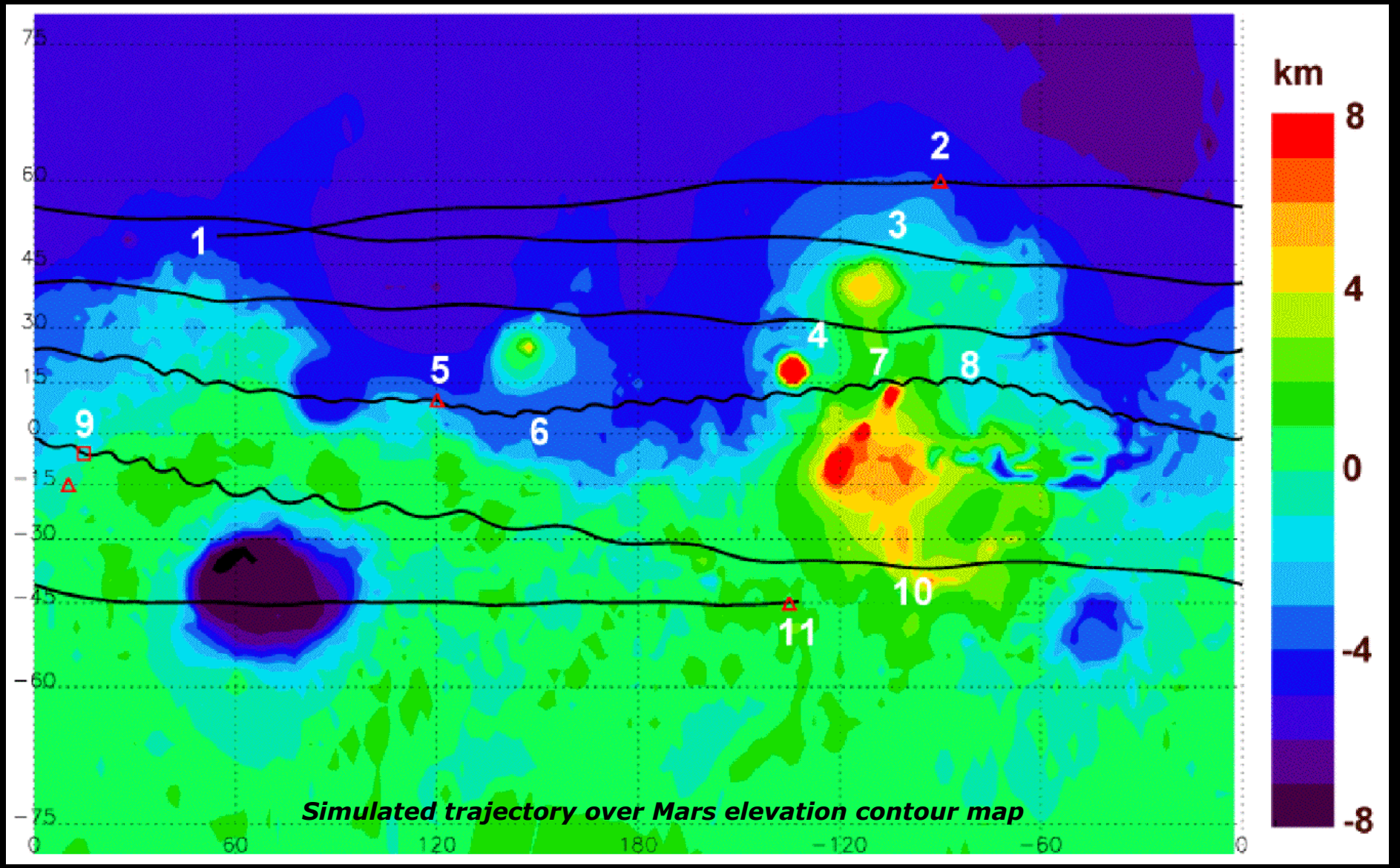


Olivine outcrop and DS-2 landing ellipse (NASA/JPL/ASU)

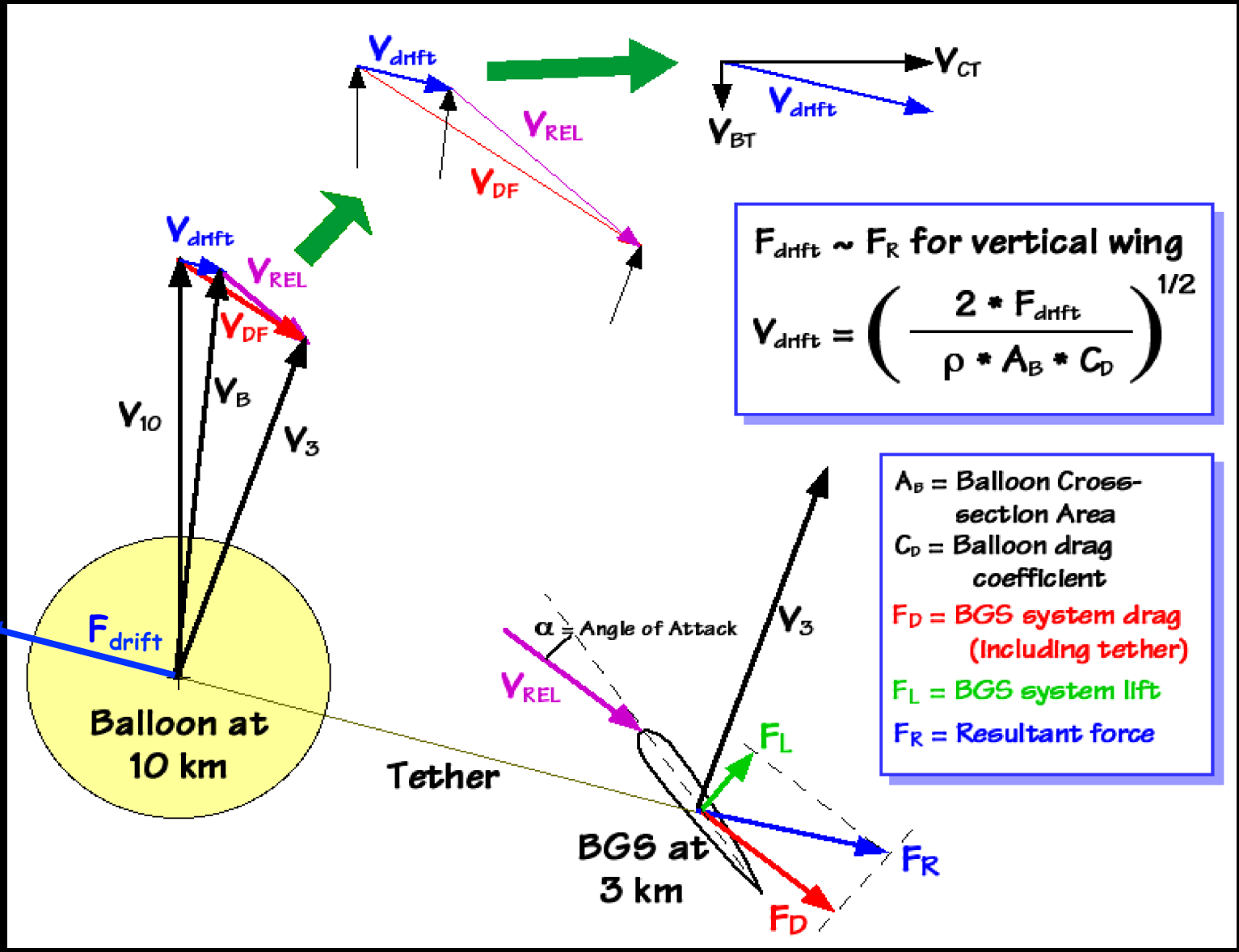


Water ice lake inside a crater on Mars (ESA)

SAILING ACROSS THE MARTIAN EQUATOR



SUMMARY

- Provides flight path control so that balloons can be directed instead of being totally at the mercy of the prevailing winds
- Can be designed and fabricated out of very light materials, including inflatable structures
- Earth-based scale model testing provides high confidence in operation in relevant atmospheric conditions
- Flight operations have been simulated using comprehensive aerodynamic and atmospheric models for Mars and Venus
- Concept appropriate for near-term applications at Mars, Venus and Titan

EXAMPLE BGS OPERATION AT MARS