GIT SMART:
A Feasibility Study of a Mars Scout Vehicle to Study Methane

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Aerospace Systems Design Laboratory
External Advisory Board Meeting, 2 May 2006

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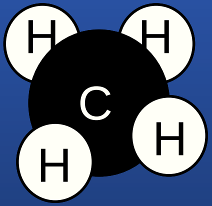
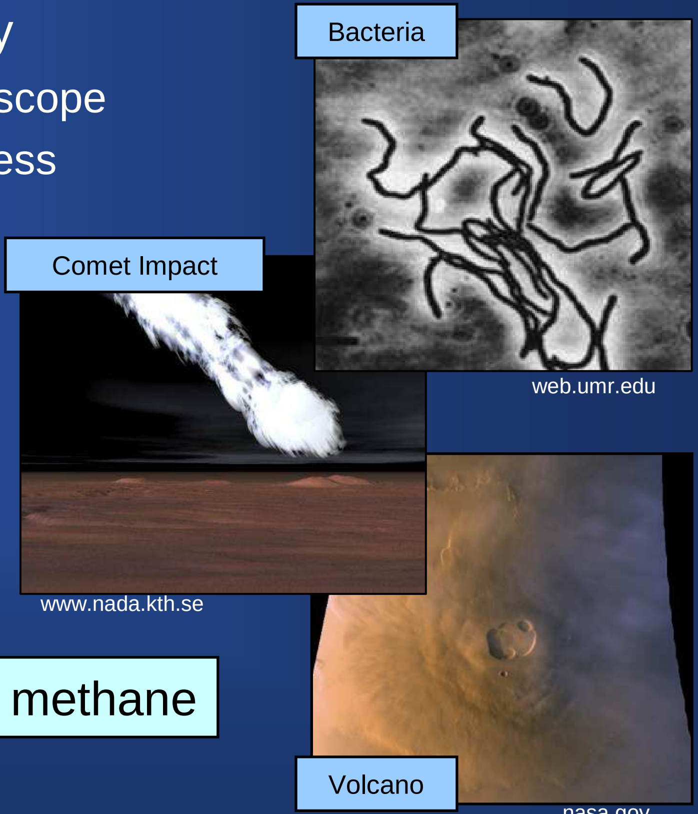
Methane may be evidence of life on Mars

- Methane was found in the Martian atmosphere by
  - The Fourier Transform Spectrometer on CFH Telescope
  - The Planetary Fourier Spectrometer on Mars Express
- Methane is a biomarker
  - Martian methane may be evidence of life on Mars
- Potential sources of methane on Mars:
  - Living organisms
  - Volcanic activity
  - Comet impact





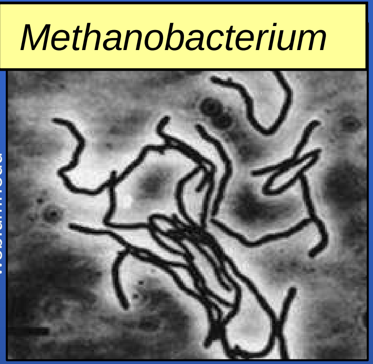
web.umr.edu

www.nada.kth.se

nasa.gov

We need a way to determine the source of the methane

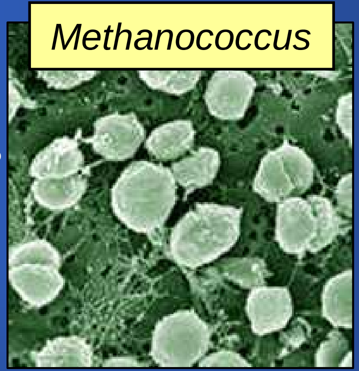
Isotope ratios determine methane source



Methanobacterium

web.umr.edu

$3CO + 2H_2O \rightarrow CH_4 + 2CO_2$



Methanococcus

www.ornl.gov

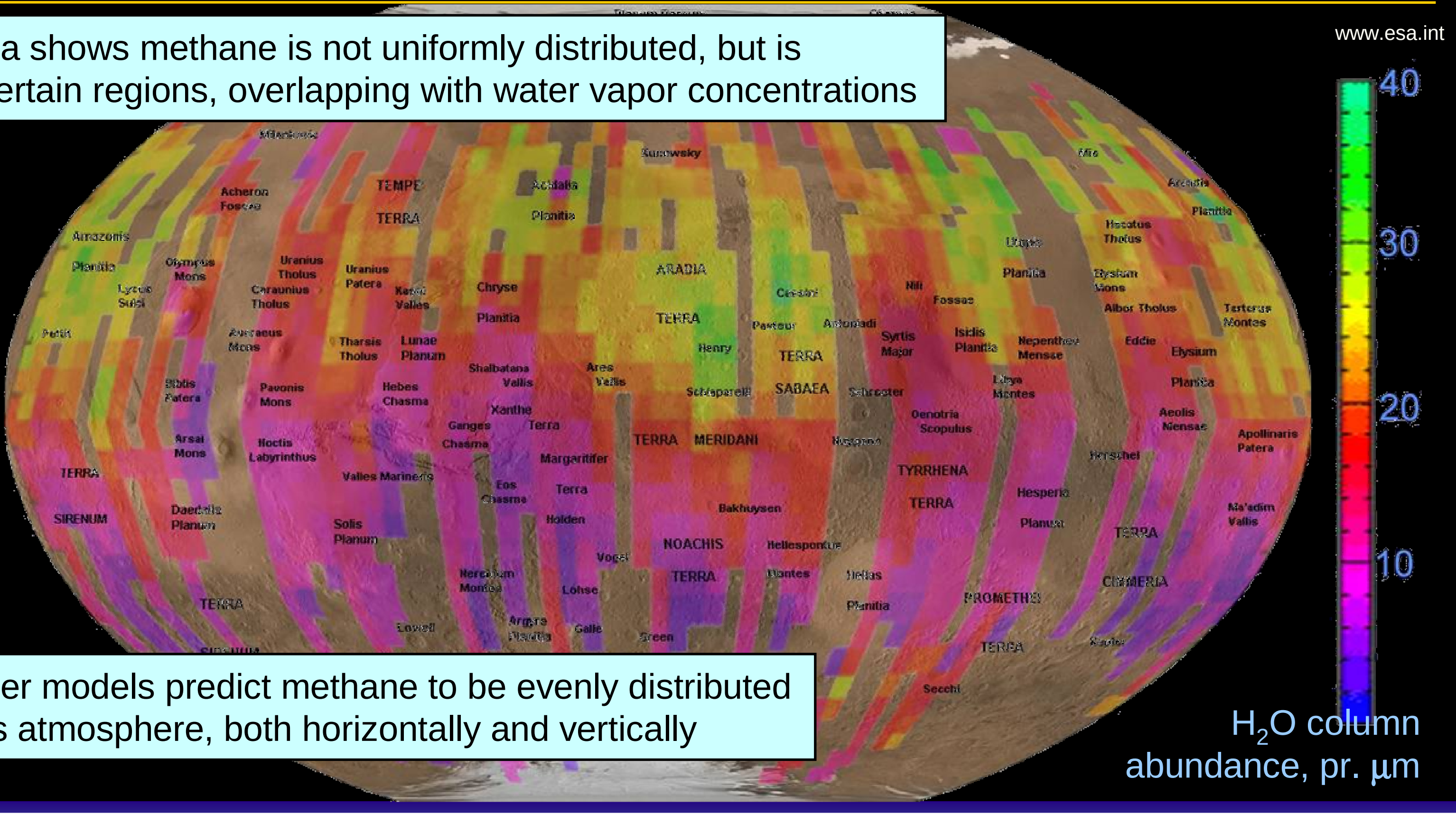
$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$

Isotope ratios can be compared to determine the source of methane

- Methane comes in many isotopes
- Living organisms are less likely to metabolize heavy isotopes because of the increased energy required to break their molecular bonds.
- We can compare the isotope ratios of the methane found on Mars to inorganic reference values of these ratios. Ratios lower than the reference value would indicate a biological source.

Observations suggest methane concentrations near water

Mars Express data shows methane is not uniformly distributed, but is concentrated in certain regions, overlapping with water vapor concentrations



www.esa.int

H_2O column abundance, pr. µm

However, computer models predict methane to be evenly distributed throughout Mars's atmosphere, both horizontally and vertically

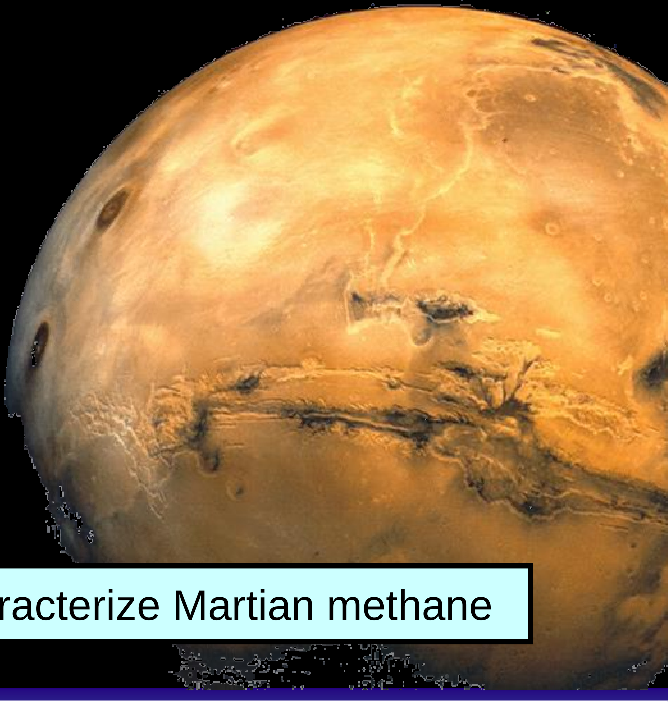
Further studies of Martian methane must be performed

- Martian atmospheric methane needs further study
  - Data needs to be validated at higher resolution
- In order to study methane, a mission will need to:
  - Search for the methane
    - Methane location theory and data conflict
    - Mission will need long endurance, large range, and ability to search multiple altitudes
  - Detect and characterize methane
    - Measurement of isotope ratios requires atmospheric immersion
      - Isotope ratios are small and require concentration of the methane for measurement
  - Characterize atmosphere
    - Measuring pressure, temperature, and wind speed will supplement methane data

Mission objective: characterize the methane in the Martian atmosphere

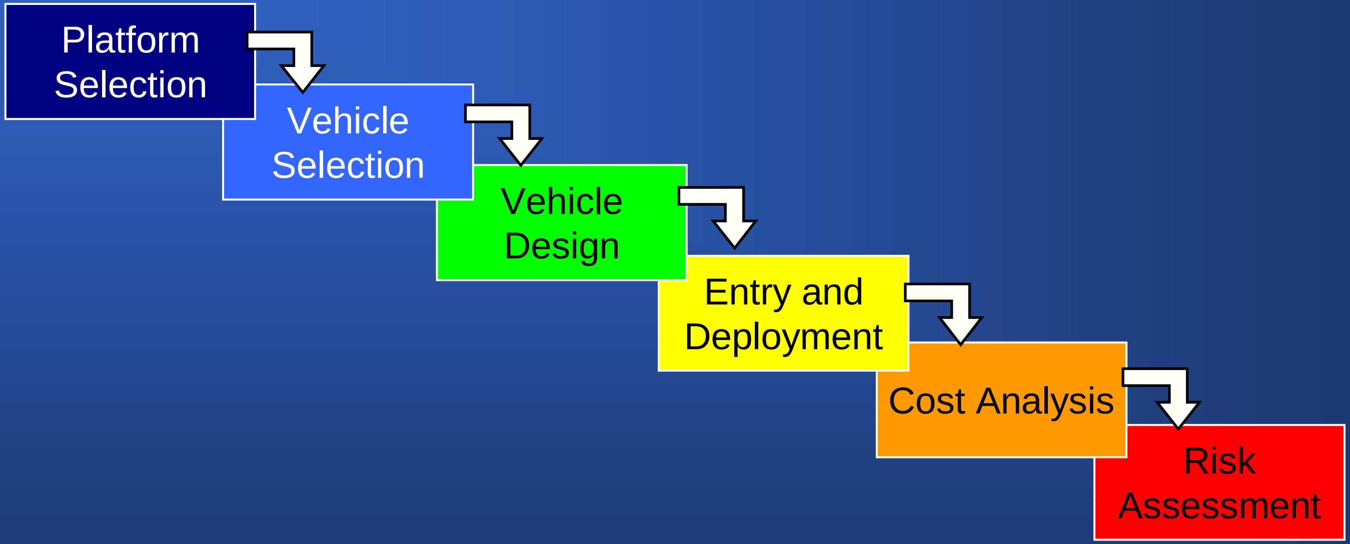
Characterizing methane is perfect for a Mars Scout mission

- Mars Scout 2006
  - Small, simple missions to perform basic science and technology demonstration
  - Missions designed by industry and academia
  - Launch by December 31, 2011
  - $439 million FY06 and launch services provided
- Mars Exploration Program Analysis Group (MEPAG)
  - Goal 1: Determine whether life ever arose on Mars
  - Goal 2: Characterize the climate of Mars
  - Goal 3: Characterize the geology of Mars
  - Goal 4: Prepare for human exploration of Mars



Our project: a feasibility study for a Mars Scout mission to characterize Martian methane

Presentation Outline



Platform Selection

Vehicle Selection

Vehicle Design

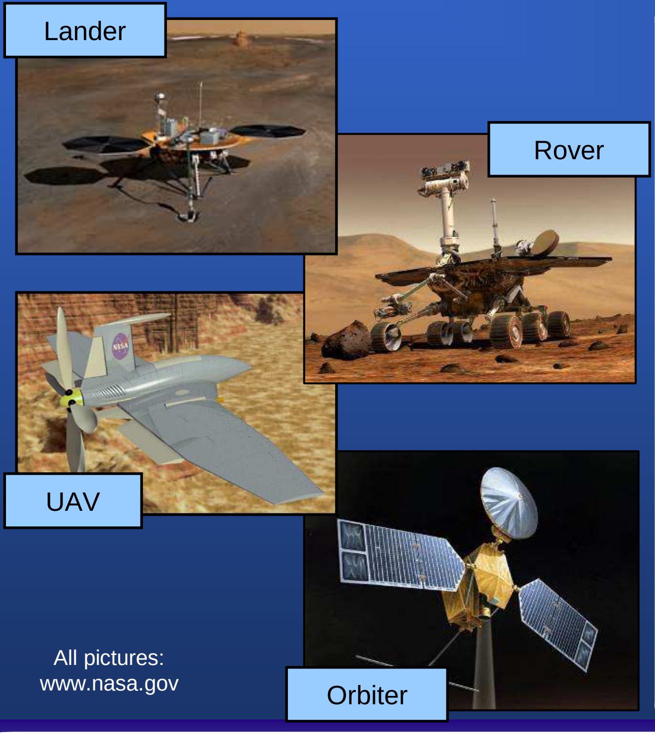
Entry and Deployment

Cost Analysis

Risk Assessment

UAVs have the capabilities necessary for studying methane

Platform Selection | Vehicle Selection | Vehicle Design | Entry and Deployment | Cost Analysis | Risk Assessment



All pictures:
www.nasa.gov

Platform	Platform Capabilities			
	Long Endurance	Large Range	Multiple Altitudes	Atmospheric Immersion
Lander	✓			✓
Rover	✓	✓		✓
UAV	✓	✓	✓	✓
Orbiter	✓	✓	✓	

A Matrix of Alternatives shows all options for a UAV

Platform Selection → **Vehicle Selection** → Vehicle Design → Entry and Deployment → Cost Analysis → Risk Assessment

Over 4600 Concepts!

	Functions	Alternatives			
Vehicle	**Source of lift**	Forward velocity	Rotational velocity	Lighter than air	
	Source of thrust	Propulsion system	Wind driven	Propulsion plus wind	
Flight Profile	**Range**	< 10 km	< 100 km	< 1000 km	> 1000 km
	Endurance	Hours	Days	Months	Years
	Artificial intelligence	None	Low	Medium	High
	Degree of control	No control	Control altitude	Control direction	Control altitude and direction
	Landings	Continuous flight, without landings	Flight with landings		

Vehicle Generation: Fixed Wing Aircraft

Platform Selection | Vehicle Selection | Vehicle Design | Entry and Deployment | Cost Analysis | Risk Assessment

	Functions	Alternatives			
Vehicle	**Source of lift**	[✓ Forward velocity]	Rotational velocity	Lighter than air	
	Source of thrust	[✓ Propulsion system]	Wind driven	Propulsion plus wind	
Flight Profile	**Range**	< 10 km	< 100 km	[✓ < 1000 km]	> 1000 km
	Endurance	Hours	Days	[✓ Months]	Years
	Artificial intelligence	None	Low	Medium	[✓ High]
	Degree of control	No control	Control altitude	Control direction	[✓ Control altitude and direction]
	Landings	[✓ Continuous flight, without landings]	Flight with landings		

Vehicle Generation: Rotorcraft

Platform Selection | **Vehicle Selection** | Vehicle Design | Entry and Deployment | Cost Analysis | Risk Assessment

	Functions	Alternatives			
Vehicle	Source of lift	Forward velocity	[✓ Rotational velocity]	Lighter than air	
	Source of thrust	[✓ Propulsion system]	Wind driven	Propulsion plus wind	
Flight Profile	Range	< 10 km	[✓ < 100 km]	< 1000 km	> 1000 km
	Endurance	Hours	Days	[✓ Months]	Years
	Artificial intelligence	None	Low	[✓ Medium]	High
	Degree of control	No control	[✓ Control altitude]	Control direction	Control altitude and direction
	Landings	Continuous flight, without landings	[✓ Flight with landings]		

Vehicle Generation: Airship

	Functions	Alternatives			
Vehicle	**Source of lift**	Forward velocity	Rotational velocity	[✓ Lighter than air]	
	Source of thrust	Propulsion system	Wind driven	[✓ Propulsion plus wind]	
Flight Profile	**Range**	< 10 km	< 100 km	[✓ < 1000 km]	> 1000 km
	Endurance	Hours	Days	[✓ Months]	Years
	Artificial intelligence	None	[✓ Low]	Medium	High
	Degree of control	No control	Control altitude	[✓ Control direction]	Control altitude and direction
	Landings	[✓ Continuous flight, without landings]	Flight with landings		

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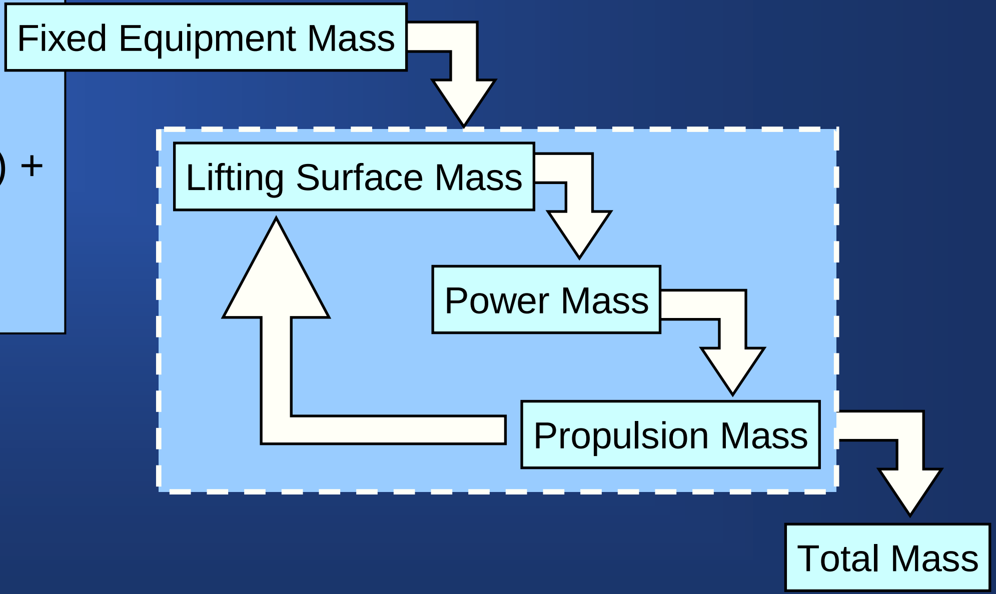
	Degree of control	[✓ No control]	Control altitude	Control direction	Control altitude and direction
	Landings	[✓ Continuous flight, without landings]	Flight with landings		

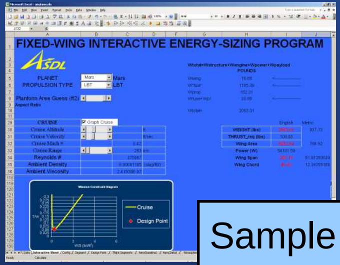
Models were created to size vehicles

Platform Selection | **Vehicle Selection** | Vehicle Design | Entry and Deployment | Cost Analysis | Risk Assessment

- Models created based on first principles and power balance
- Made consistent assumptions across all tools to allow for comparison

Total Mass =
(fixed equipment mass) +
(lifting surface area) * (lifting surface density) +
(power required) * (power density) +
(propulsion required) * (propulsion density)




FIXED-WING INTERACTIVE ENERGY-SIZING PROGRAM

PLANET: Mars
PROPULSION TYPE: LBT
Planform Area Guess (ft2)
Aspect Ratio

CRUISE ☑ Graph Cruise
Cruise Altitude ft
Cruise Velocity ft/sec
Cruise Mach #
Cruise Range nm
Reynolds #
Ambient Density
Ambient Viscosity

Wtotal=Wstructure+Wengine+Wpower+Wpayload
POUNDS

WEIGHT (lbs)
THRUST_req (lbs)
Wing Area
Power (W)
Wing Span
Wing Chord

Sample Vehicle Model

Monte Carlo was used to generate vehicle designs

Platform Selection → **Vehicle Selection** → Vehicle Design → Entry and Deployment → Cost Analysis → Risk Assessment

Vehicle Tool Inputs

	Fixed Wing	Rotorcraft	Airship	Balloon
Fixed Equipment Mass (kg)	5 to 50	5 to 50	5 to 50	5 to 50
Power Subsystem Density (kg/W)	0.015 to 0.25	0.015 to 0.25	0.015 to 0.25	n/a
Lifting Surface Density (kg/m^2)	0.100	0.100	0.020	0.020
Propulsion Subsystem Density (kg/W)	0.005	0.005	0.005	n/a
Altitude (km)	1 to 10	1 to 10	1 to 10	1 to 10
Velocity (m/s)	0 to 200	0 to 200	0 to 200	n/a
Lifting Surface Aspect Ratio	5 to 30	5 to 50	n/a	n/a

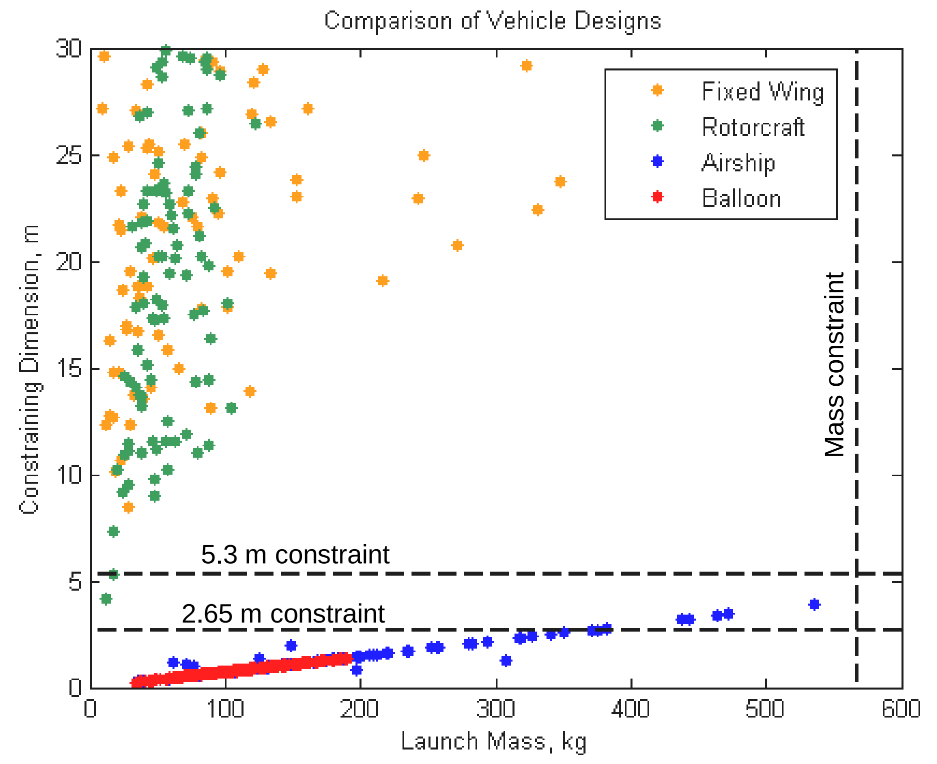
Design space was filled with thousands of designs using Monte Carlo

- Fixed equipment mass based on previous planetary missions
- Densities based on data from existing systems

Vehicle Downselection

- Launch and Entry Constraints:
  - Delta II 7925 is the largest launch vehicle available for Mars Scout missions
    - Max mass to Mars: 568 kg
  - Viking Heritage Aeroshell
    - Max dimension: 2.65 m
      - 5.3 m allowing for one fold

Only airship and balloon designs were able to meet size constraint



Qualitative analysis adds information to vehicle selection

Platform Selection | **Vehicle Selection** | Vehicle Design | Entry and Deployment | Cost Analysis | Risk Assessment

- Figures of Merit:
  - Vehicle Complexity
  - Probability of Success
  - Control
  - Feasibility
  - Scientific Capability
- Pugh matrices suggest that a balloon offers similar scientific capabilities with less complexity

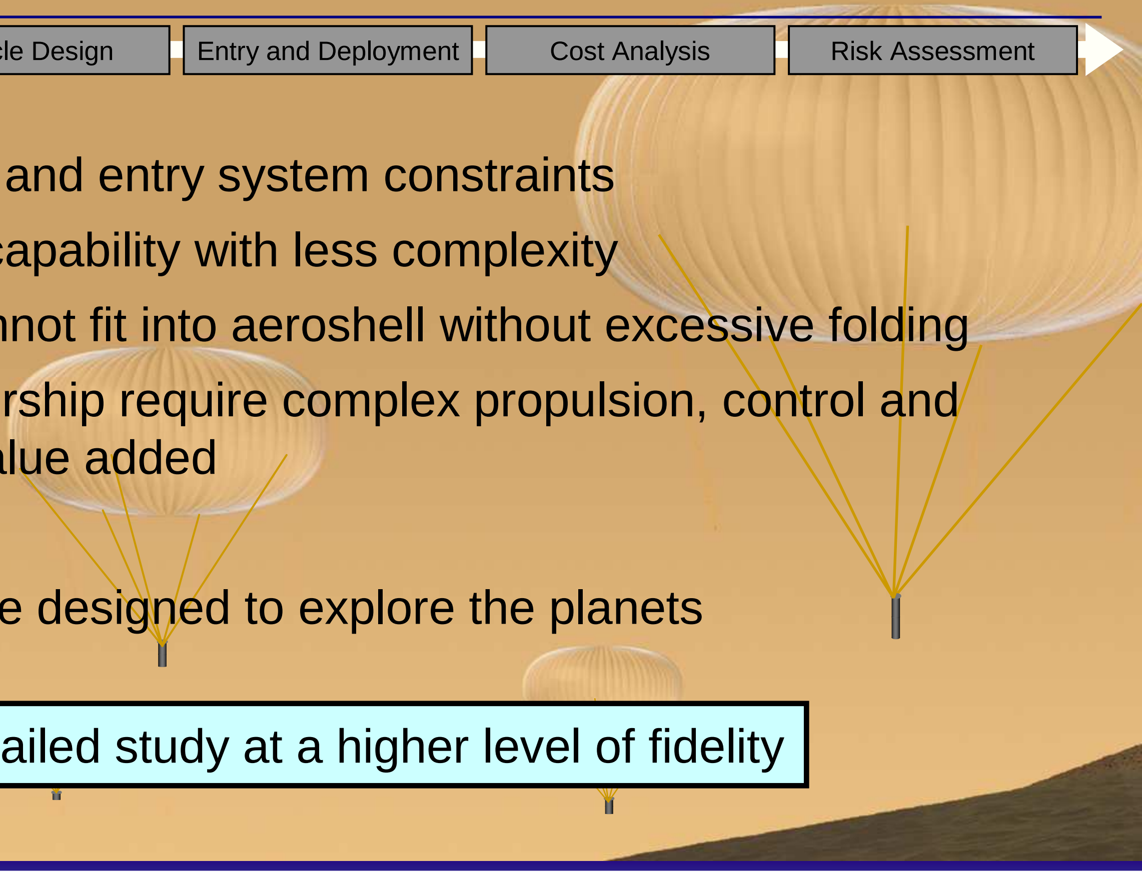
Sample Pugh Matrix

	Fixed Wing	Rotorcraft	Airship	Balloon
Vehicle Complexity	0	Baseline	+	+
Probability of Success	–		0	+
Control	+		0	–
Feasibility	0		+	+
Scientific Capability	0		0	0
Sum +	1		2	3
Sum –	1		0	1
Sum 0	3		3	1

Balloon has similar science capability with less complexity

The Balloon is the best vehicle for this mission

Platform Selection | **Vehicle Selection** | Vehicle Design | Entry and Deployment | Cost Analysis | Risk Assessment

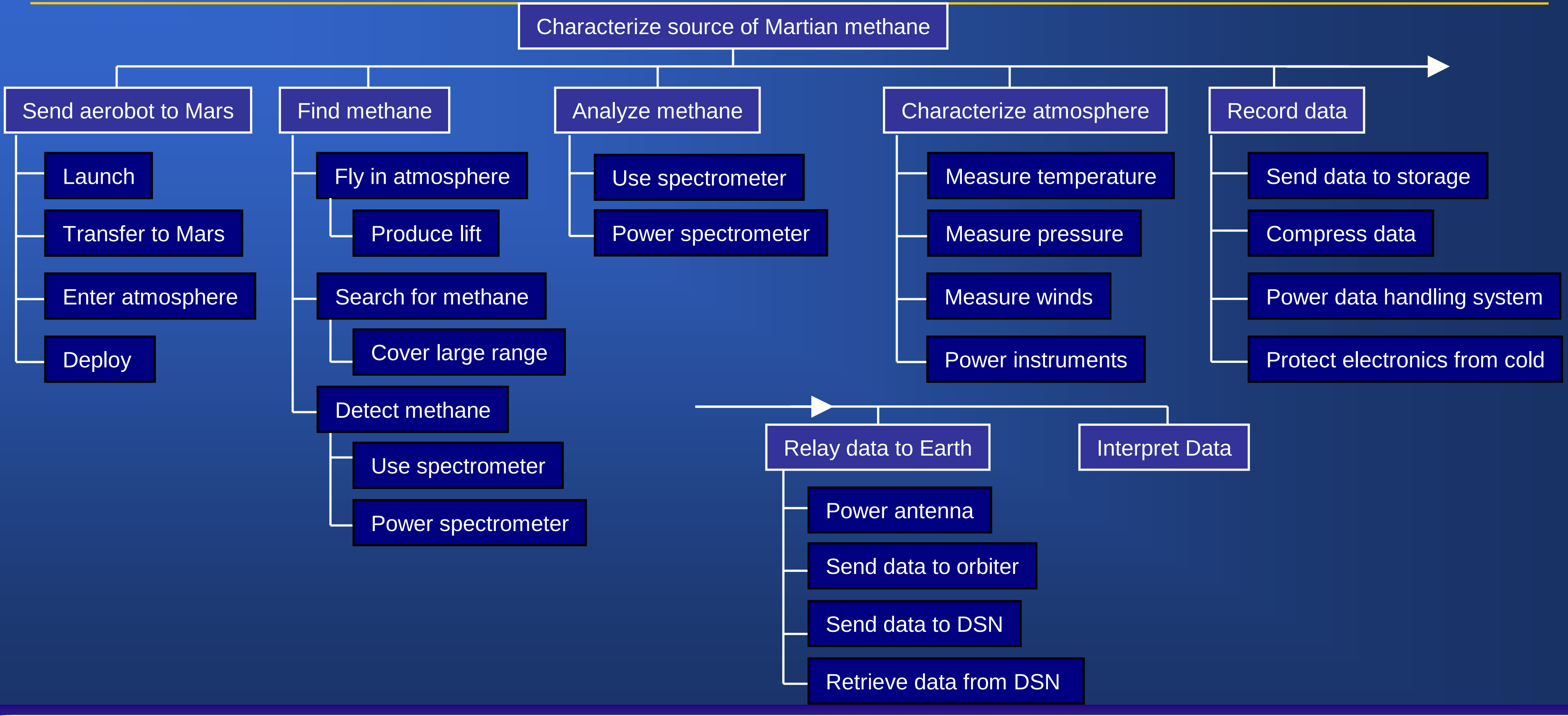


- The balloon meets the launch and entry system constraints
- The balloon has comparable capability with less complexity
- Fixed Wing and Rotorcraft cannot fit into aeroshell without excessive folding
- Fixed Wing, Rotorcraft, and Airship require complex propulsion, control and artificial intelligence with no value added

- Aerobot: lighter than air vehicle designed to explore the planets

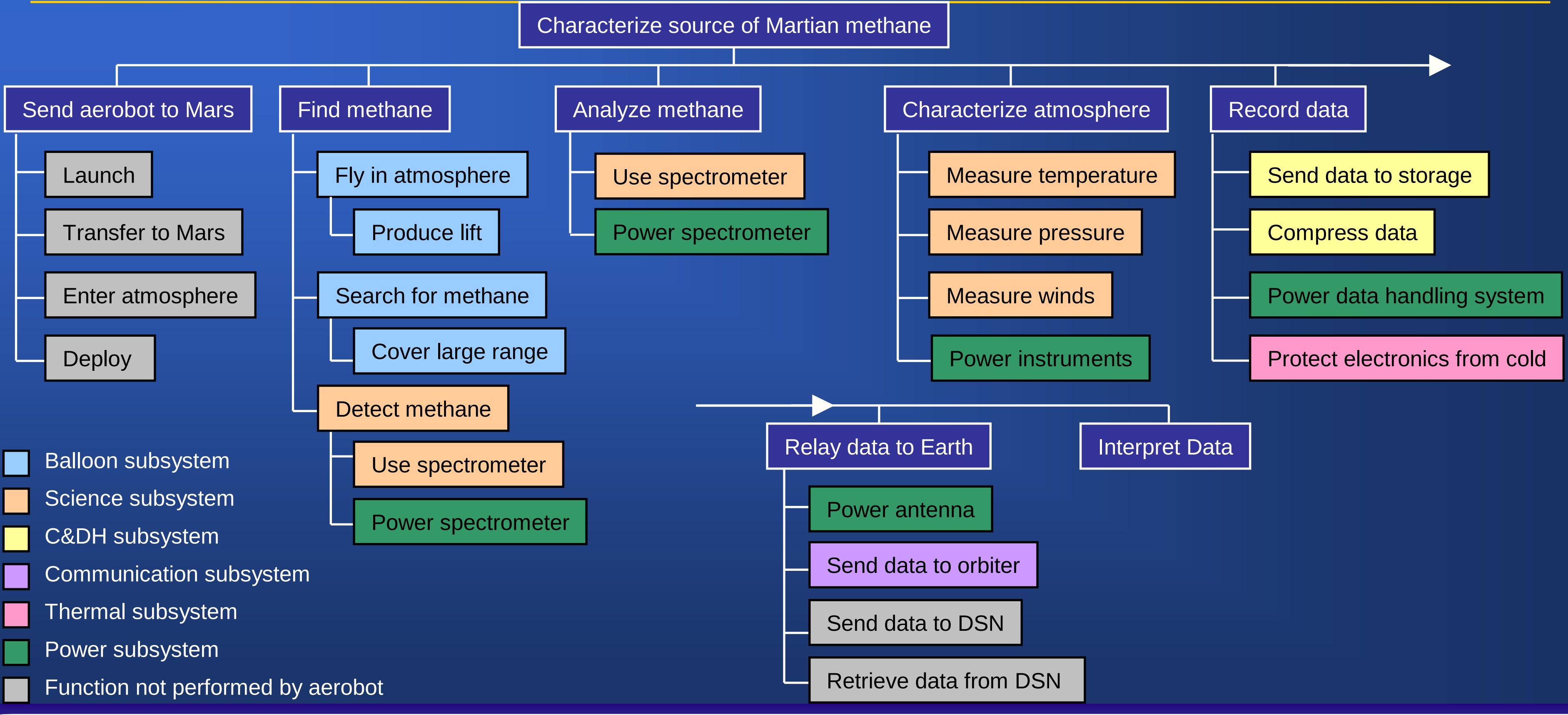
These results warrant a more detailed study at a higher level of fidelity

Aerobot Functional Decomposition



- Characterize source of Martian methane
  - Send aerobot to Mars
    - Launch
    - Transfer to Mars
    - Enter atmosphere
    - Deploy
  - Find methane
    - Fly in atmosphere
      - Produce lift
    - Search for methane
      - Cover large range
    - Detect methane
      - Use spectrometer
      - Power spectrometer
  - Analyze methane
    - Use spectrometer
    - Power spectrometer
  - Characterize atmosphere
    - Measure temperature
    - Measure pressure
    - Measure winds
    - Power instruments
  - Record data
    - Send data to storage
    - Compress data
    - Power data handling system
    - Protect electronics from cold
  - Relay data to Earth
    - Power antenna
    - Send data to orbiter
    - Send data to DSN
    - Retrieve data from DSN
  - Interpret Data

Subsystem Identification



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      - Cover large range
    - Detect methane
      - Use spectrometer
      - Power spectrometer
  - Analyze methane
    - Use spectrometer
    - Power spectrometer
  - Characterize atmosphere
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    - Send data to DSN
    - Retrieve data from DSN
  - Interpret Data

🟦 Balloon subsystem

🟧 Science subsystem

🟨 C&DH subsystem

🟪 Communication subsystem

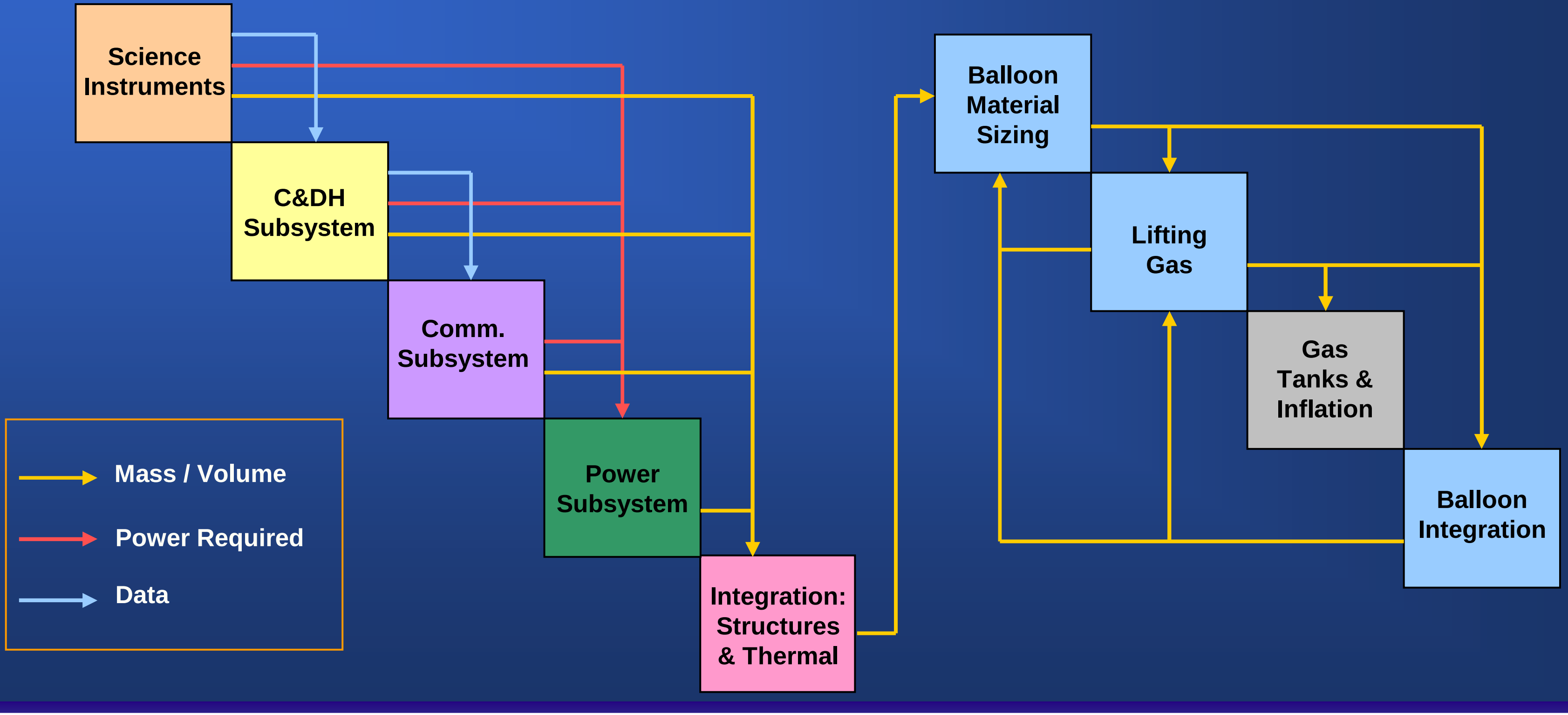
🟥 Thermal subsystem

🟩 Power subsystem

⬜ Function not performed by aerobot

Integrated Environment

Platform Selection | Vehicle Selection | Gondola Design | Balloon Design | Entry and Deployment | Cost Analysis



Science Instruments

C&DH Subsystem

Comm. Subsystem

Power Subsystem

Integration: Structures & Thermal

Balloon Material Sizing

Lifting Gas

Gas Tanks & Inflation

Balloon Integration

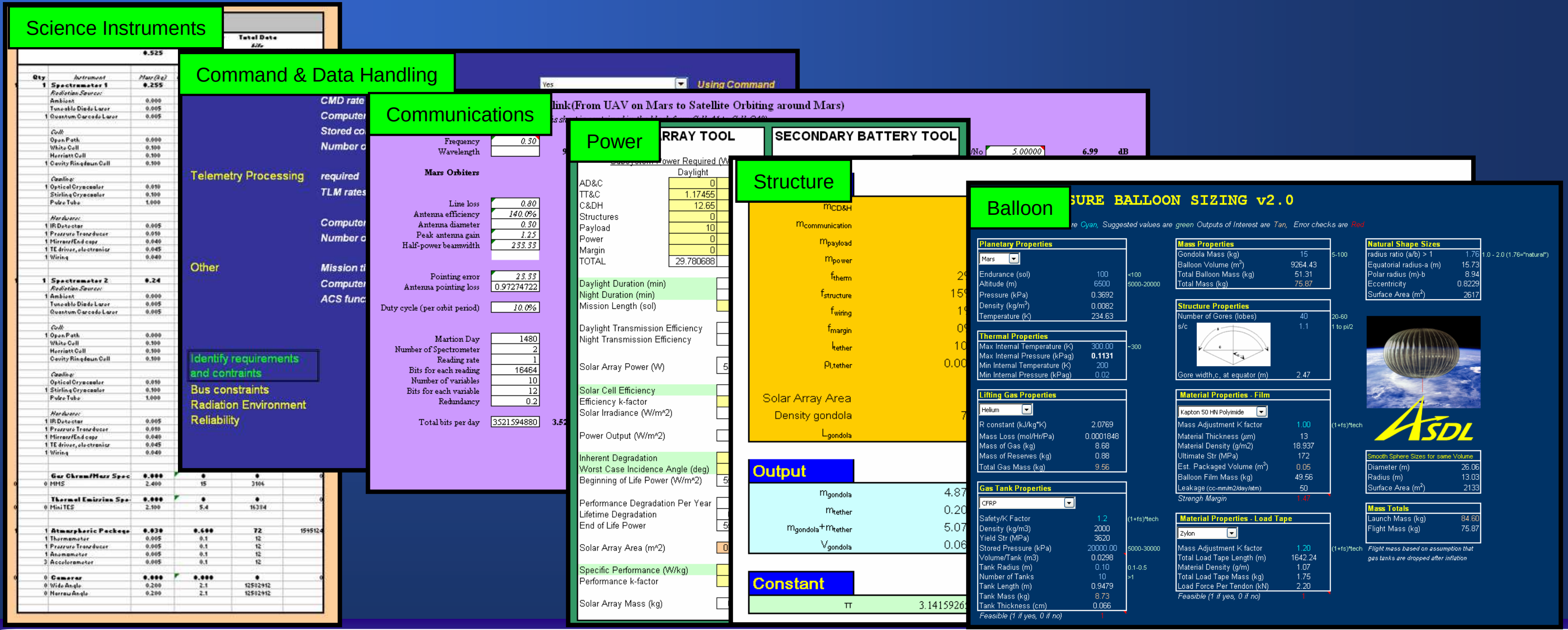
→ Mass / Volume

→ Power Required

→ Data

Tools Created to Size Subsystems

- Platform Selection
- Vehicle Selection
- Gondola Design
- Balloon Design
- Entry and Deployment
- Cost Analysis



Science Instruments

Qty	Instrument	Mass (kg)			
		0.525			
1	**Spectrometer 1**	0.255			
	Radiation Source:				
	Ambient	0.000			
	Tuneable Diode Laser	0.005			
1	Quantum Cascade Laser	0.005			
	Cell:				
	Open Path	0.000			
	White Cell	0.100			
	Herriott Cell	0.100			
1	Cavity Ringdown Cell	0.100			
	Cooling:				
1	Optical Cryocooler	0.010			
	Stirling Cryocooler	0.100			
	Pulse Tube	1.000			
	Hardware:				
1	IR Detector	0.005			
1	Pressure Transducer	0.010			
1	Mirrors/End caps	0.040			
1	TE driver, electronics	0.045			
1	Wiring	0.040			
1	**Spectrometer 2**	0.24			
	Radiation Source:				
1	Ambient	0.000			
	Tuneable Diode Laser	0.005			
	Quantum Cascade Laser	0.005			
	Cell:				
1	Open Path	0.000			
	White Cell	0.100			
	Herriott Cell	0.100			
	Cavity Ringdown Cell	0.100			
	Cooling:				
	Optical Cryocooler	0.010			
1	Stirling Cryocooler	0.100			
	Pulse Tube	1.000			
	Hardware:				
1	IR Detector	0.005			
1	Pressure Transducer	0.010			
1	Mirrors/End caps	0.040			
1	TE driver, electronics	0.045			
1	Wiring	0.040			
	Gas Chrom/Mass Spec	0.000	0	0	
0	MMS	2.400	15	3106	
	Thermal Emission Spe	0.000	0	0	
0	Mini TES	2.100	5.4	16384	
1	**Atmospheric Package**	0.030	0.600	72	1595124
1	Thermometer	0.005	0.1	12	
1	Pressure Transducer	0.005	0.1	12	
1	Anemometer	0.005	0.1	12	
3	Accelerometer	0.005	0.1	12	
0	**Cameras**	0.000	0.000	0	
0	Wide Angle	0.200	2.1	12582912	
0	Narrow Angle	0.200	2.1	12582912	

Total Data Size

Command & Data Handling

Yes | Using Command

CMD rate
Computer
Stored co
Number o

Telemetry Processing | required
TLM rates
Computer
Number o

Other | Mission ti
Computer
ACS func

Identify requirements and contraints
Bus constraints
Radiation Environment
Reliability

Communications

link(From UAV on Mars to Satellite Orbiting around Mars)

Frequency	0.30
Wavelength	
Mars Orbiters	
Line loss	0.80
Antenna efficiency	140.0%
Antenna diameter	0.30
Peak antenna gain	1.25
Half-power beamwidth	233.33
Pointing error	23.33
Antenna pointing loss	0.97274722
Duty cycle (per orbit period)	10.0%
Martion Day	1480
Number of Spectrometer	2
Reading rate	1
Bits for each reading	16464
Number of variables	10
Bits for each variable	12
Redundancy	0.2
Total bits per day	3521594880

/No 5.00000 6.99 dB

Power

RRAY TOOL | SECONDARY BATTERY TOOL

Power Required (W)	Daylight
AD&C	0
TT&C	1.17455
C&DH	12.65
Structures	0
Payload	10
Power	0
Margin	0
TOTAL	29.780688

Daylight Duration (min)
Night Duration (min)
Mission Length (sol)
Daylight Transmission Efficiency
Night Transmission Efficiency
Solar Array Power (W)
Solar Cell Efficiency
Efficiency k-factor
Solar Irradiance (W/m^2)
Power Output (W/m^2)
Inherent Degradation
Worst Case Incidence Angle (deg)
Beginning of Life Power (W/m^2)
Performance Degradation Per Year
Lifetime Degradation
End of Life Power
Solar Array Area (m^2)
Specific Performance (W/kg)
Performance k-factor
Solar Array Mass (kg)

Structure

$m_{CD\&H}$
$m_{communication}$
$m_{payload}$
m_{power}
f_{therm}
$f_{structure}$
f_{wiring}
f_{margin}
l_{tether}
$\rho_{l,tether}$
Solar Array Area
Density gondola
$L_{gondola}$

Output

$m_{gondola}$	4.87
m_{tether}	0.20
$m_{gondola}+m_{tether}$	5.07
$V_{gondola}$	0.06

Constant

π	3.1415926

Balloon

SURE BALLOON SIZING v2.0

re Cyan, Suggested values are green Outputs of Interest are Tan, Error checks are Red

Planetary Properties		
Mars		
Endurance (sol)	100	<100
Altitude (m)	6500	5000-20000
Pressure (kPa)	0.3692	
Density (kg/m^3)	0.0082	
Temperature (K)	234.63	

Thermal Properties		
Max Internal Temperature (K)	300.00	~300
Max Internal Pressure (kPag)	0.1131	
Min Internal Temperature (K)	200	
Min Internal Pressure (kPag)	0.02	

Lifting Gas Properties	
Helium	
R constant (kJ/kg*K)	2.0769
Mass Loss (mol/Hr/Pa)	0.0001848
Mass of Gas (kg)	8.68
Mass of Reserves (kg)	0.88
Total Gas Mass (kg)	9.56

Gas Tank Properties		
CFRP		
Safety/K Factor	1.2	(1+fs)*tech
Density (kg/m3)	2000	
Yield Str (MPa)	3620	
Stored Pressure (kPa)	20000.00	5000-30000
Volume/Tank (m3)	0.0298	
Tank Radius (m)	0.10	0.1-0.5
Number of Tanks	10	>1
Tank Length (m)	0.9479	
Tank Mass (kg)	8.73	
Tank Thickness (cm)	0.066	
Feasible (1 if yes, 0 if no)	1	

Mass Properties		
Gondola Mass (kg)	15	5-100
Balloon Volume (m^3)	9264.43	
Total Balloon Mass (kg)	51.31	
Total Mass (kg)	75.87	

Structure Properties		
Number of Gores (lobes)	40	20-60
s/c	1.1	1 to pi/2
Gore width,c, at equator (m)	2.47	

Material Properties - Film		
Kapton 50 HN Polyimide		
Mass Adjustment K factor	1.00	(1+fs)*tech
Material Thickness (μm)	13	
Material Density (g/m2)	18.937	
Ultimate Str (MPa)	172	
Est. Packaged Volume (m^3)	0.05	
Balloon Film Mass (kg)	49.56	
Leakage (cc-mm/m2/day/atm)	50	
Strengh Margin	1.47	

Material Properties - Load Tape		
Zylon		
Mass Adjustment K factor	1.20	(1+fs)*tech
Total Load Tape Length (m)	1642.24	
Material Density (g/m)	1.07	
Total Load Tape Mass (kg)	1.75	
Load Force Per Tendon (kN)	2.20	
Feasible (1 if yes, 0 if no)	1	

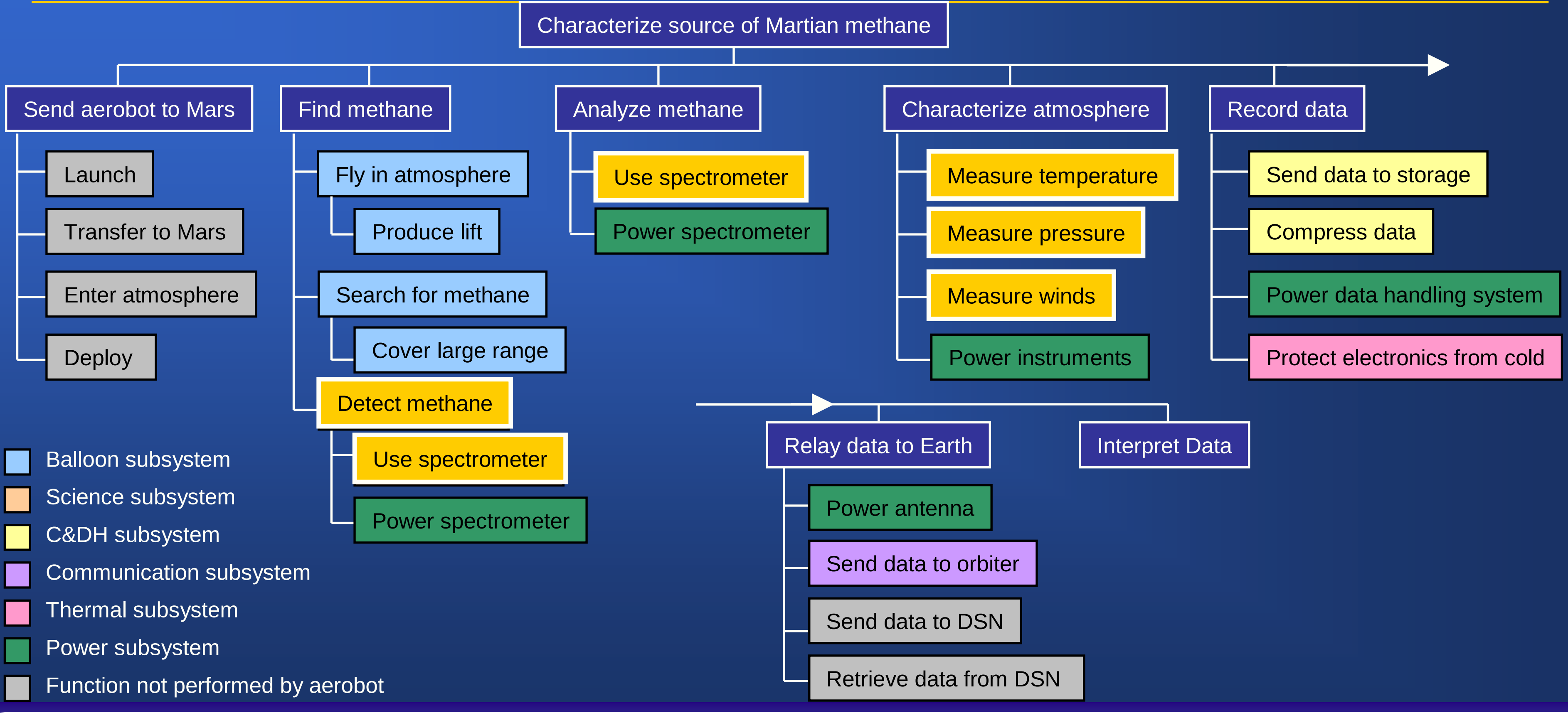
Natural Shape Sizes		
radius ratio (a/b) > 1	1.76	1.0 - 2.0 (1.76="natural")
Equatorial radius-a (m)	15.73	
Polar radius (m)-b	8.94	
Eccentricity	0.8229	
Surface Area (m^2)	2617	

Smooth Sphere Sizes for same Volume	
Diameter (m)	26.06
Radius (m)	13.03
Surface Area (m^2)	2133

Mass Totals	
Launch Mass (kg)	84.60
Flight Mass (kg)	75.87

Flight mass based on assumption that gas tanks are dropped after inflation

Science Functions



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    - Send data to DSN
    - Retrieve data from DSN
  - Interpret Data

🟦 Balloon subsystem
🟧 Science subsystem
🟨 C&DH subsystem
🟪 Communication subsystem
🟥 Thermal subsystem
🟩 Power subsystem
⬜ Function not performed by aerobot

Science Instruments Subsystem

Needs:

- Small mass
- Small volume
- Low power requirements
- Sensitivity

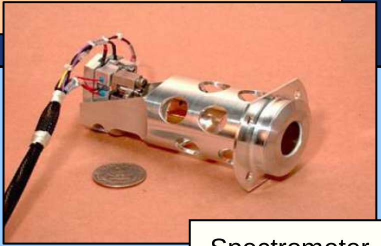
Why 2 QCL spectrometers and atmospheric package?

- Minimum required instruments to fulfill mission
- Each spectrometer can provide different functions
- Other instruments needlessly increased mass and power requirements
- Redundancy and decreased risk

Methane Detection Devices	Mass (kg)	Power (W)	Data (bits)
Quantum Cascade Laser Spectrometer	0.25	3	320
Tunable Diode Laser Spectrometer	0.24	3	320
Gas Chromatography/Mass Spectrometer	2.4	15	320

Other Instruments of Interest	Mass (kg)	Power (W)	Data (bits)
Thermal Emission Spectrometer	2.1	5.4	320
Atmospheric Package	0.03	0.6	72
Cameras (1 wide angle and 1 narrow angle)	0.4	4.2	25165824

Sized Subsystem:



Spectrometer

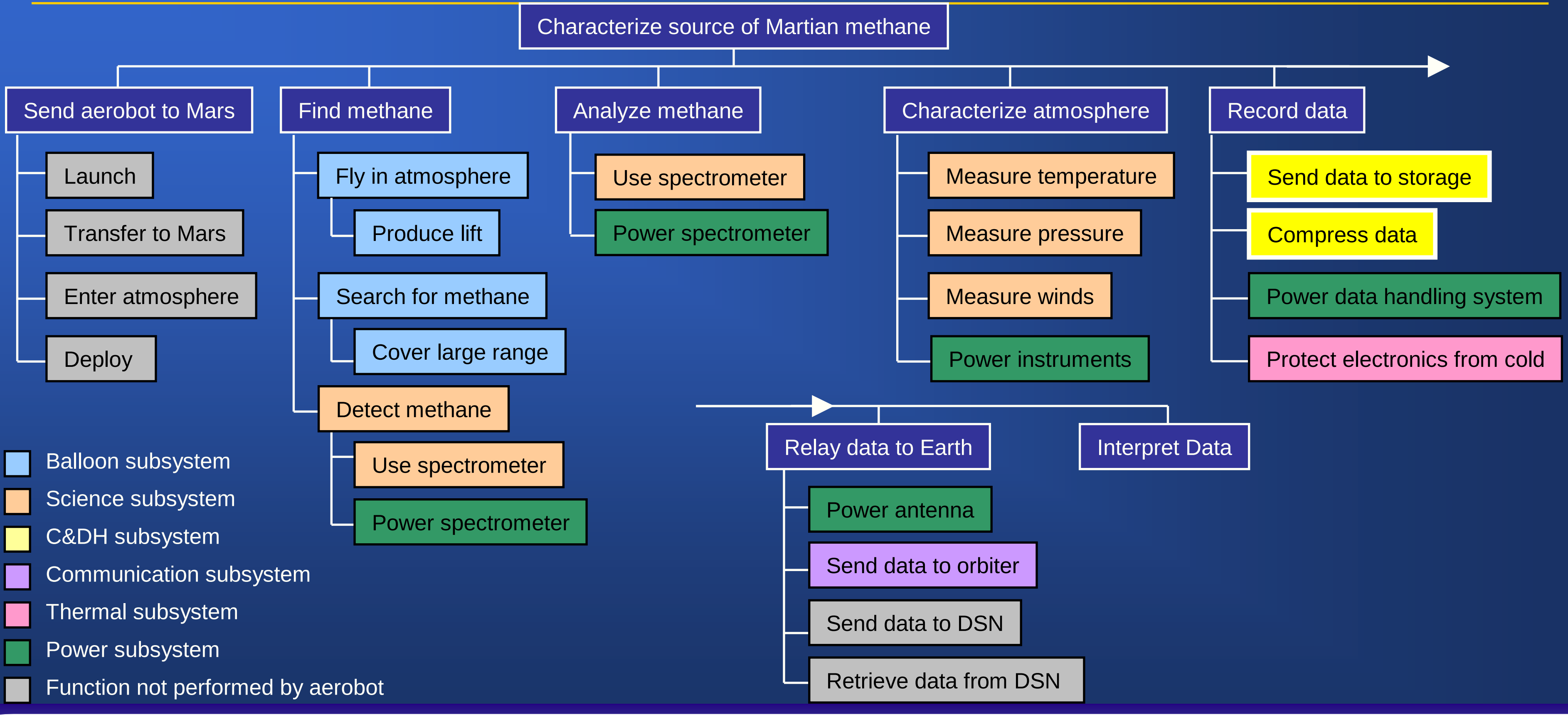
Components:

- 2 QCL spectrometers
- 1 Atmospheric package
  - 1 Thermometer
  - 1 Pressure Transducer
  - 1 Anemometer
  - 3 Accelerometers

Specifications:

- Mass: 0.53 kg
- Volume: 0.002 m^3
- Power: 6.6 W (day), 0.6 W (night)
- Data/day: 6.2 Mbits

Command and Data Handling Functions



Characterize source of Martian methane

- Send aerobot to Mars
  - Launch
  - Transfer to Mars
  - Enter atmosphere
  - Deploy
- Find methane
  - Fly in atmosphere
    - Produce lift
  - Search for methane
    - Cover large range
  - Detect methane
    - Use spectrometer
    - Power spectrometer
- Analyze methane
  - Use spectrometer
  - Power spectrometer
- Characterize atmosphere
  - Measure temperature
  - Measure pressure
  - Measure winds
  - Power instruments
- Record data
  - Send data to storage
  - Compress data
  - Power data handling system
  - Protect electronics from cold
- Relay data to Earth
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Command & Data Handling Subsystem

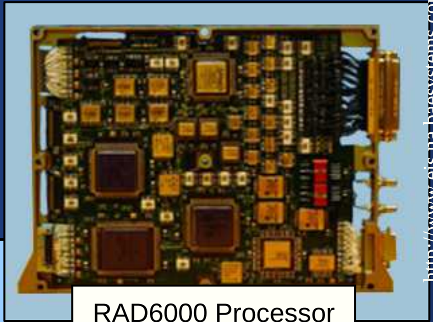
Needs:

- Historical precedence
- Small mass
- Small volume
- Low power requirements
- Processing ability

Company	CPU Options
BAE Systems	RAD750
BAE Systems	RAD6000
Sandia National Laboratories	Rad-hard variant of Intel Pentium
Honeywell Aerospace	RH32
Honeywell Aerospace	PowerPC 603e
Sun Microsystems	SPARC V8
GEC-Plessey	RG1750
Harris Corporation	RH3000
Boeing Company	Rad-hard variant of PowerPC 750

Why RAD6000?

- Flown on past missions
  - Mars Exploration Rovers
  - Mars Pathfinder
  - Mars Odyssey
- LOW RISK
- Sufficient capability to perform mission



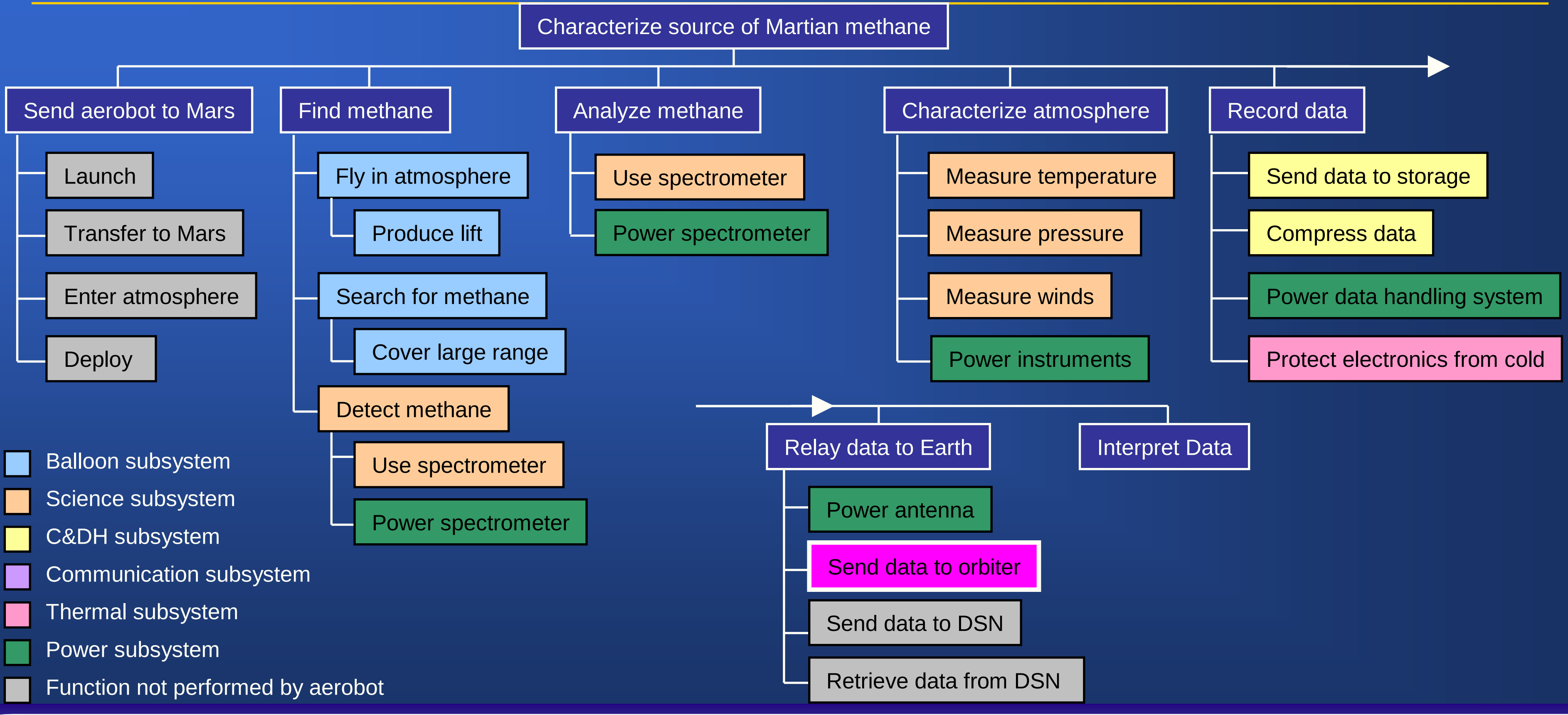
RAD6000 Processor

http://www.eis.na.baesystems.com

Sized Subsystem:

Components:	Specifications:
•RAD6000 CPU	•Mass: 3 kg
•Backup RAD6000	•Volume: 0.0023 m^3
•256 MB flash memory	•High Power: 7.5 W
•Data acquisition board	•Low Power: 3.1 W
	•Dose: < 1 Mrad

Communication Functions



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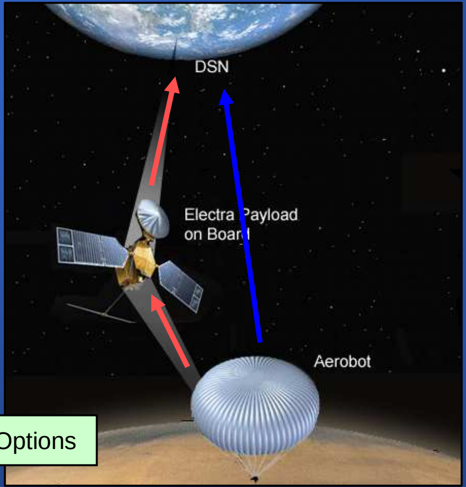
Communication Subsystem

Needs:

- Historical precedence
- Small mass
- Small volume
- Low power requirements
- Electra compatibility



Communications Options

Company	UHF Transceiver Options
L3 Communications Cincinnati Electronics	C/TT– 505, C/TT– 508, C/TT– 510
Avalon RF	TX518M, TX618M
Yaesu	FT– 1802M, FT– 2800M, FT– 7800R, FT– 8800R, FT– 8900R
Kenwood	TM–271A, TM–D700A, TM–G707A, TM–V708A

Why communicate to orbiter instead of Earth?

- Aerobot control and science data are not time critical
- Communications system is much smaller, lighter, and uses less power

Why C/TT–505?

- Flown on past missions
  - Mars Exploration Rovers
- LOW RISK
- Electra compatible

Sized System:

Components:

- UHF transceiver
- Monopole antenna

Specifications:

- Mass: 2.4 kg
- Volume: 0.0025 m^3
- Transmitting power: 45.5 W
- Receiving power: 6 W
- Frequency range: 400 to 500 MHz
- Data rate: 128 kbps
- Communication window: 2 minutes

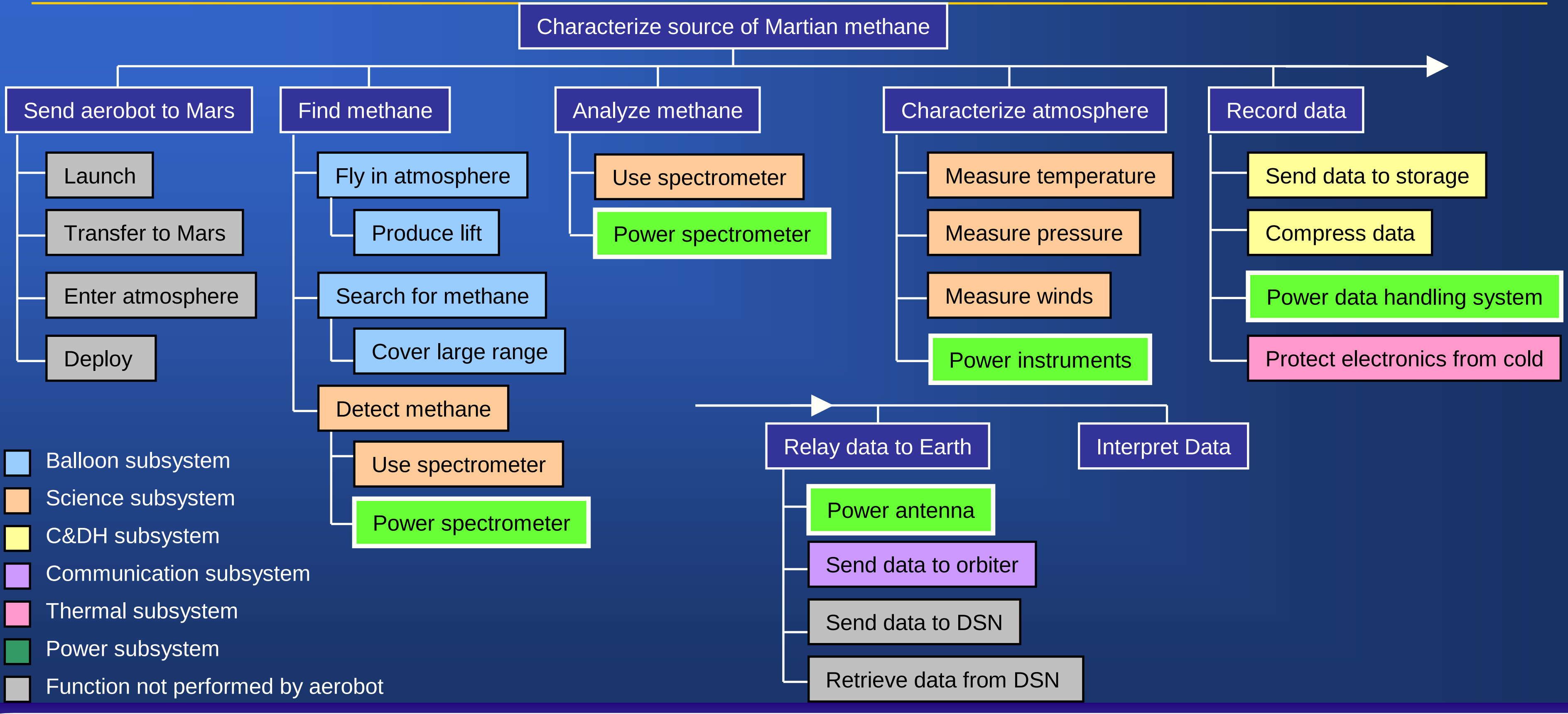
C/TT-505

http://www.cinele.com

Monopole Antenna

Mars Exploration RoversTelecommunications

Power Functions



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Power Subsystem

Needs:

- Historical precedence
- Small mass
- Small volume
- Long mission life (renewable power source)

Power Generation Options:

Characteristic	Solar Array	Radioisotope	Fuel Cell
Specific Performance (W/kg)	25 to 300	5 to 20	275
Fuel Availability	Unlimited	Very limited	Limited

Power Storage Options:

	Nickel-Cadmium	Nickel-Metal-Hydride	Lead-acid	Lithium-ion	Lithium-ion-polymer	Reusable Alkaline
Energy Density (Wh/kg)	45 to 80	60 to 120	30 to 50	110 to 160	100 to 130	80

Why solar arrays and Li-Ion batteries?

- Solar arrays provide renewable power
- Solar arrays have high specific performance
- GaAs arrays used on Mars Exploration Rovers
- Li-Ion provides extremely high energy density

Sized System:

Components:

- Triple junction gallium arsenide solar cells
- Lithium Ion rechargeable batteries
- Power control unit
- Regulators/Converters
- Wiring

Specifications:

- Mass: 2.4 kg
- Average power: 3.43 W
- Generated power: 77.4 W
- Solar array area: 2.72 m^2
- Battery capacity: 3.5 Ahr

Triple Junction GaAs Solar Cell

Gondola Design Summary

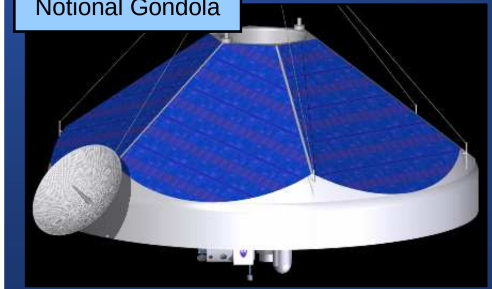
Design Budgets

Subsystem	Mass (kg)	Power Required (W)
Science Instruments	0.53	6.6 (day) 0.6 (night)
Command &Data Handling	3.00	7.5 (day) 3.1 (night)
Communications	2.40	45.5 (transmitting) 6 (receiving)
Thermal	0.23	—
Power	3.43	3.7 (day) 0.9 (night)
Structure	1.70	—
TOTAL	**11.6 kg**	**77.4 W (average)**

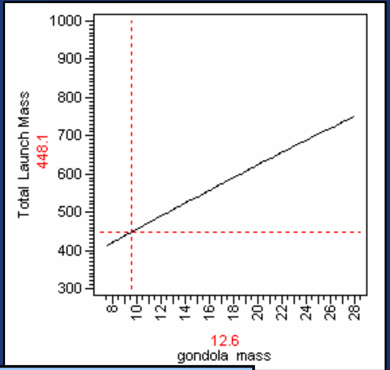
Gondola Dimensions:

- Diameter: 0.4 m
- Packaged Height: 1.1 m
- Deployed Height: 2.2 m
- Volume: 0.1382 m^3
- Mass: 11.6 kg

Notional Gondola

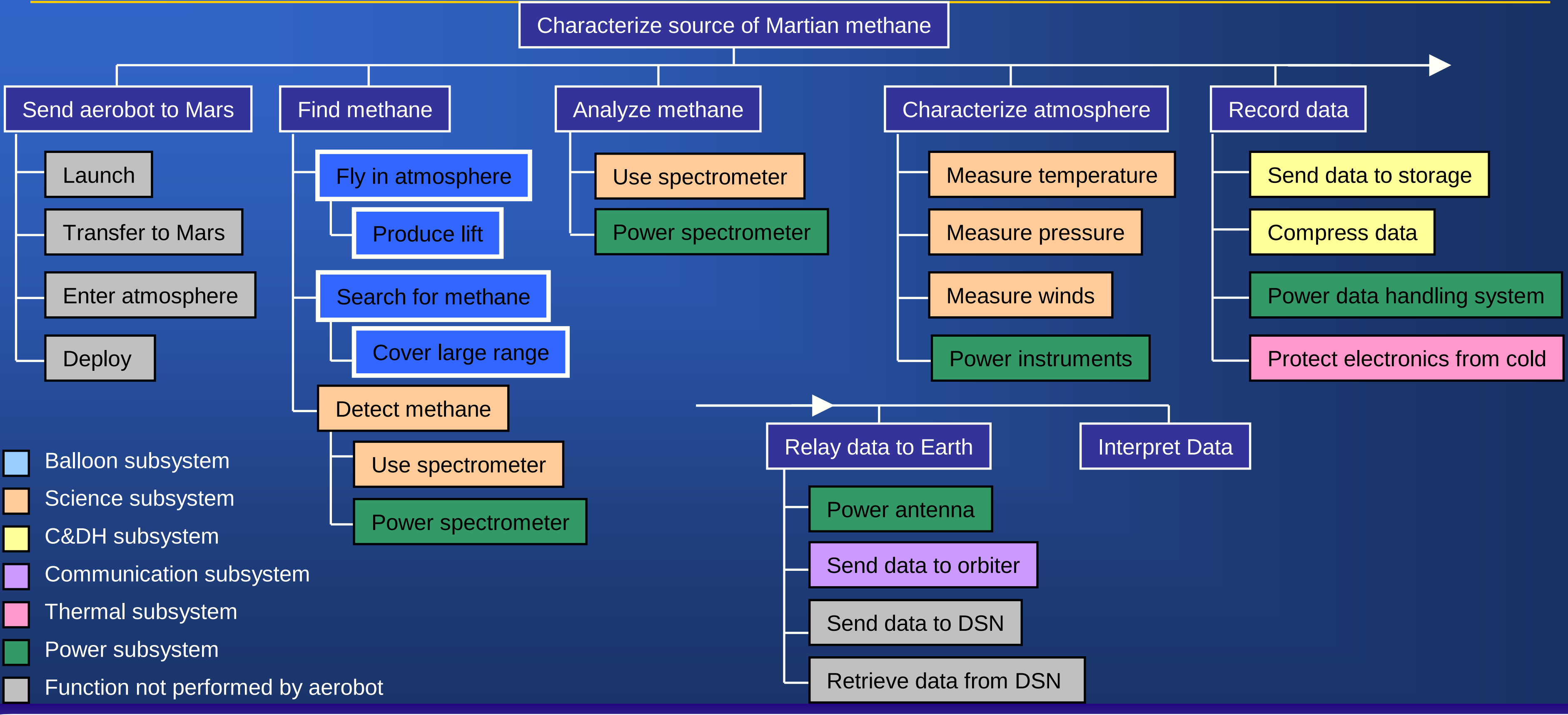


www.ae.gatech.edu



Gondola Mass Growth

Balloon Functions



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Balloon Subsystem

Type and structure needs:

- Low risk
- Low mass
- Long mission life

Balloon Type and Structure:

	Alternatives		
Balloon Type	Zero–pressure	[✓ Superpressure]	––
Balloon Structure	Spherical	[✓ Natural]	Cylindrical

Why superpressure?

- Long endurance
- Can be designed to remain at safe altitude to avoid terrain
- Not as risky as zero-pressure, which rises and falls

Why natural shape?

- Best possible stress distribution

Lifting gas needs:

- High lifting potential
- Low leakage rate
- Low inflation system mass

Lifting Gas:

Gas	Lifting Potential (kg/m^3)	Leakage Rate (cc-mm/m2-24hr-atm)	Inflation System Mass (not including tanks) (kg)	Possibility of Explosion?
[✓ Hydrogen]	0.00821	23	14	Yes
Helium	0.00781	53	75	No

Why hydrogen?

- Required inflation/storage system offers significant mass reduction over He
- Lower leakage rate
- Lighter weight

Balloon Subsystem Continued

Vehicle Selection | Gondola Design | **Balloon Design** | Entry and Deployment | Cost Analysis | Risk Assessment

Material needs:

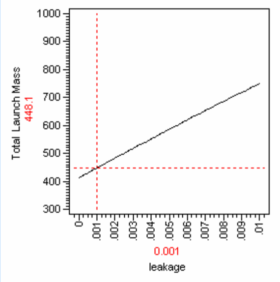
- Low density
- High strength
- High gas retention
- UV resistant

Envelope Material:

Material	Density (g/cc)	Thickness (µm)	Ultimate Stress (MPa)
Sclairfilm mpp-1	0.918	25	82.7
Vectra coextrudable	1.4	10	182
Mylar OB12AF	1.4	13	241
Kapton 50 HN Polymide	1.42	13	172
Tedlar PVF	1.37	12.5	90

Why a vectra-kevlar coextrusion?

- Vectra has extraordinary gas retention
- Kevlar provides resistance to tear propagation
- Kevlar does not degrade when exposed to UV



Material Leakage Trade Study

Load tape and tether criteria needs:

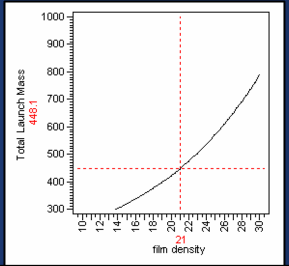
- Low density
- High strength

Load Tape and Tether Material:

Material	Density (g/cc)	Tenacity (N/tex)	Ultimate Strength (MPa)	Ultimate Load (kN)
Kevlar (aramid)	1.44	2.08	3000	2.81
Spectra 2000	0.97	3.44	3000	2.65
Zylon	1.56	3.71	5800	2.64
Vectran	1.40	2.38	2840	2.64

Why zylon?

- Best tenacity



Material Density Trade Study

Balloon Design Summary

Balloon Summary	
Balloon type	Superpressure
Load tape material	Zylon
Envelope material	Vectra-Kevlar composite
Number of gores	80
Tether material	Zylon
Lifting gas	Hydrogen
Lifting gas tanks	6 tanks Mass of each tank: 1.35 kg Radius of each tank: 0.1 m Height of each tank: 0.55 m
Inflation system mass	14 kg

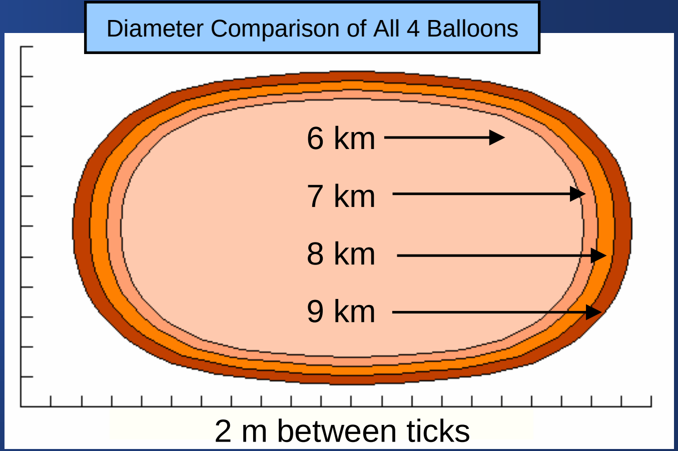
Final Balloon Design

Aerobot Design Summary

- 4 Aerobots
  - Each designed to fly at a different altitude: 6, 7, 8, and 9 km
  - Identical gondolas

	Aerobot Summary						
Altitude	Balloon Mass (kg)	Gas Mass (kg)	Tank Mass (kg)	Inflation Mass (kg)	Gondola/ Tether Mass (kg)	Volume (m^3)	TOTAL MASS (kg)
6 km	54.2	4.9	12.9	14	12.6	8600	99
7 km	61.6	5.4	13.4	14	12.6	10500	107
8 km	69.9	6.0	14.0	14	12.6	12700	117
9 km	79.7	6.6	14.8	14	12.6	15400	128
TOTAL MASS (kg)	265	23	55	56	50	– –	**451**

Diameter Comparison of All 4 Balloons



451 kg meets the launch vehicle constraint of 568 kg!

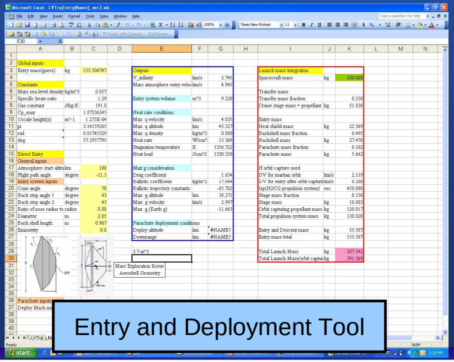
GIT SMART aerobot is comparable to Martian aerobot baselines

System	Mars '96	MAP	MABS	GIT SMART
Shape	Cylinder	Sphere	Sphere	Natural
Diameter (m)	13.2x43	18	27.2	15.4/16.4/17.5/18.6
Volume ($m^3/10^3$)	5.5	3	10.5	8.6/10.5/12.7/15.4
Payload (kg)	28.5	9.3	15	12.6
Balloon Mass (kg)	30.5	15.3	55.3	54.2/61.6/69.9/79.7
Altitude (km)	2 to 4	6	6.5	6/7/8/9
Material	Mylar	Nylon-6	My/Kv/PE	Vec/Kev
Area Dens (g/m^2)	7.7	11.5	20	21
Max Diff. Press (Pa)	40	214	238	92
Stress Level (N/m)	854	976	1617	1515

Entry and Deployment Systems

Vehicle Selection | Gondola Design | Balloon Design | **Entry and Deployment** | Cost Analysis | Risk Assessment

- Constraint: total launch mass must be less than launch vehicle limit (1022 kg)
  - Delta II 7925 is largest launch vehicle available for scout missions
- Aerial deployment was selected to reduce risk of tangling/tearing that could occur during ground deployment
- Entry and deployment system includes:
  - Transfer vehicle
  - Heat shield
  - Backshell
  - Parachute



Global inputs		
Entry mass(guess)	kg	155.506747
Constants		
Mars sea-level density	kg/m^3	0.057
Specific heats ratio		1.29
Gas constant	J/kg-K	191.8
Cp_max		1.87336245
1/scale height(x)	m^-1	1.275E-04
pi		3.14159265
rad		0.01745329
deg		57.2957795
Direct Entry		
General inputs		
Atmosphere start altitu	km	100
Flight path angle	degree	-11.5
Entry system inputs		
Cone angle	degree	70
Back step angle 1	degree	43
Back step angle 2	degree	43
Ratio of nose radius to radius		0.88
Diameter	m	2.65
Back shell length	m	0.967
Emissivity		0.8
Parachute inputs		
Deploy Mach nu		

Outputs		
V_infinity	km/s	2.745
Mars atmosphere entry veloc	km/s	4.945
Entry system volume	m^3	9.220
Heat rate conditions		
Max. q velocity	km/s	4.035
Max. q altitude	km	45.327
Max. q density	kg/m^3	0.000
Heat rate	W/cm^	15.369
Stagnation temperature	K	1356.722
Heat load	J/cm^2	1330.350
Max g consideration		
Drag coefficient		1.654
Ballistic coefficient	kg/m^2	17.044
Ballistic trajectory constants		-65.782
Max. g altitude	km	38.271
Max. g velocity	km/s	2.997
Max. g (Earth g)		-11.663
Parachute deployment conditions		
Deploy altitude	km	#NAME?
Downrange	km	#NAME?

3.7 m^3

Launch mass integration		
Spacecraft mass	kg	100.000
Transfer mass		
Transfer mass fraction		0.250
Cruise stage mass + propellant	kg	51.836
Entry mass		
Heat shield mass	kg	22.369
Backshell mass fraction		0.495
Backshell mass	kg	27.476
Parachute mass fraction		0.102
Parachute mass	kg	5.662
If orbit capture used		
DV for martian orbit	km/s	2.119
DV for entry after orbit capturi	km/s	0.200
Isp(H2/O2 propulsion system)	sec	450.000
Stage mass fraction		0.150
Stage mass	kg	18.003
Orbit capturing propellant mass	kg	120.017
Total propulsion system mass	kg	138.020
Entry and Descent mass	kg	55.507
Entry mass total	kg	155.507
Total Launch Mass	kg	207.342
Total Launch Mass(orbit captur	kg	391.369

Mars Exploration Rover Aeroshell Geometry

Entry and Deployment Tool

Component	Weight (kg)
Total aerobot mass (including tanks)	451
Transfer vehicle	205
Heat shield	67
Backshell	82
Parachute	17
Total Launch Mass	**822**

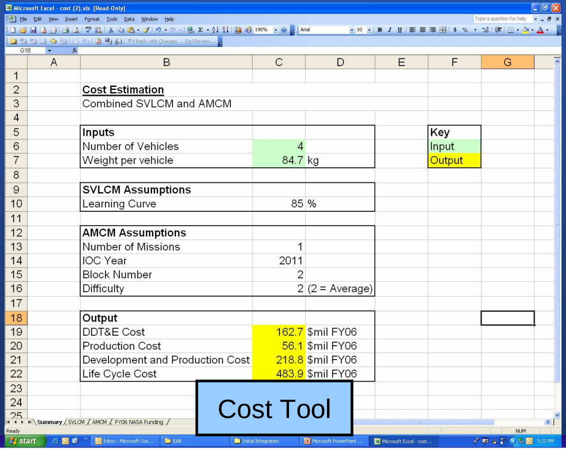
822 kg is under the 1022 kg limit!

Aerobot Aerial Deployment

Cost estimates within budget

Vehicle Selection | Gondola Design | Balloon Design | Entry and Deployment | **Cost Analysis** | Risk Assessment

- Constraint: cost must be less than Mars Scout budget
  - $439 million (FY06)
- Cost tools
  - Spacecraft/Vehicle Level Cost Model (SVLCM)
  - Advanced Missions Cost Model (AMCM)



Microsoft Excel - cost (2).xls [Read-Only]

	A	B	C	D	E	F	G
1							
2		**Cost Estimation**					
3		Combined SVLCM and AMCM					
4							
5		**Inputs**				**Key**	
6		Number of Vehicles	4			Input	
7		Weight per vehicle	84.7	kg		Output	
8							
9		**SVLCM Assumptions**					
10		Learning Curve	85	%			
11							
12		**AMCM Assumptions**					
13		Number of Missions	1				
14		IOC Year	2011				
15		Block Number	2				
16		Difficulty	2	(2 = Average)			
17							
18		**Output**					
19		DDT&E Cost	162.7	$mil FY06			
20		Production Cost	56.1	$mil FY06			
21		Development and Production Cost	218.8	$mil FY06			
22		Life Cycle Cost	483.9	$mil FY06			
23							
24							

Cost Tool

Cost Type	Cost ($mil FY06)	Model
Design, Development, Testing & Evaluation Cost	162.7	SVLCM
Production Cost	56.1	SVLCM
Life Cycle Cost	483.9	AMCM
Launch Cost	55.0	AIAA Reference
Principal Investigator Cost	**428.9**	LCC minus Launch Cost

Actual Principal Investigator Cost = $428.9 million (FY06)

Risk Mitigation Plan

Criteria:

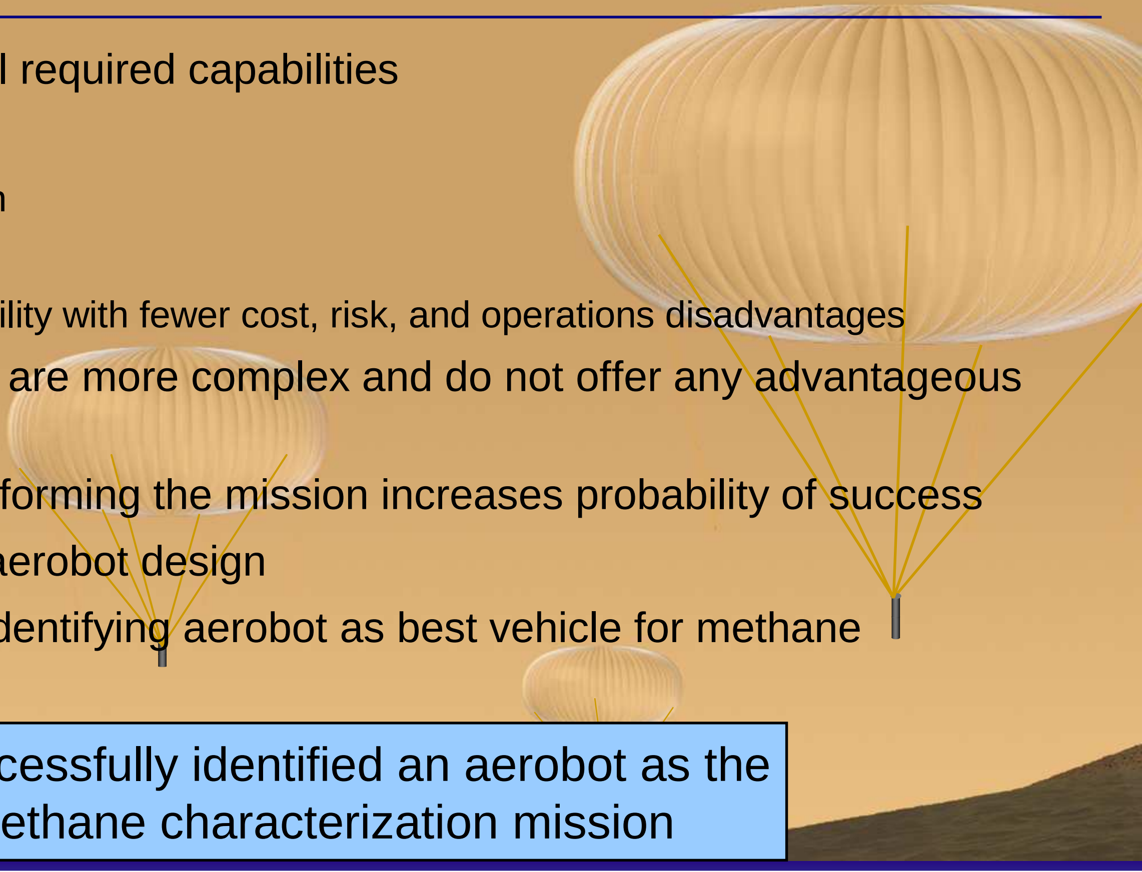
- A design that performs mission at an acceptable level of risk
- Lowest level of risk possible

Risk Assessment:

Mission Events	Probability of Success
Launch	94%
Transit to Mars	71%
Entry	83%
Deployment	Unknown
Locating the methane	Unknown
Science instruments operate	Unknown
All other subsystems operate	Unknown
Transmitting data from UAV to orbiter	Unknown
Transmitting data from orbiter to DSN	~100%

- Goal: mitigate all unknown and high risk events in our control
- Risk Mitigation Plan:
  - Incorporate redundancy
    - Four balloons
    - Four altitudes
    - Two CPUs
    - Two spectrometers
  - Reliable, proven hardware
    - All subsystem hardware (except spectrometers) successfully flown on previous Mars missions
  - Simplicity
- Largest risk: deployment
  - Perform more research concerning envelope material properties and packing

Aerobot is the best vehicle for methane characterization mission



- UAV is only platform that fulfills all required capabilities
- Aerobot is most feasible UAV
  - Simplicity of design and operation
  - Easily fits inside aeroshell
  - Offers competitive science capability with fewer cost, risk, and operations disadvantages
- Fixed wing, rotorcraft, and airship are more complex and do not offer any advantageous capabilities over aerobot
- Four aerobots simultaneously performing the mission increases probability of success
- Risk mitigation incorporated into aerobot design
- Feasibility study is successful in identifying aerobot as best vehicle for methane characterization mission

Our feasibility study successfully identified an aerobot as the best vehicle for a methane characterization mission