5.0 Aerodynamic and Propulsive Decelerator Systems

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Presentation Outline

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Part I - Introduction

- Capability Breakdown Structure
- Decelerator Functions
- Candidate Solutions

Part II - Performance and Technology

- Capability State-of-the-Art
- Performance Needs
- Candidate Configurations

Part III - Possible Technology Roadmaps

- Capability Roadmaps

Capability Breakdown Structure

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Human Planetary Landing Systems CRM # 7

Aerodynamic and Propulsive Decelerators 5.0

- **5.1 Supersonic Aerodynamic Decelerators**
- **5.2 Subsonic Aerodynamic Decelerators**
- **5.3 Supersonic Propulsive Decelerators**
- **5.4 Systems Design, Development, Testing, and Qualification**

Decelerator Functions

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Decelerators typically provide one or more of the following functions in planetary landing systems:

- Deceleration from supersonic to subsonic speed
- Controlled acceleration
- Minimize descent rate
- Provide specified descent rate
- Provide stability (parachute drogue function)
- System deployment (parachute pilot function)
- Provide difference in ballistic coefficient for separation events
- Provide height
- Provide timeline
- Provide specific state (e.g., altitude, location, speed for precision landing)

Aerodynamic and Propulsive Decelerator Capabilities for Mars - Integrated Mission Architecture

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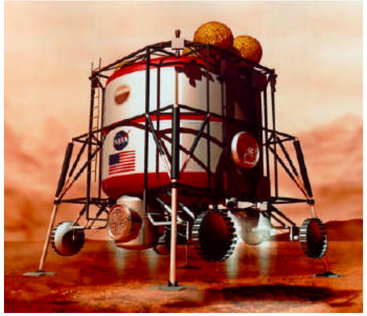
Options for Hypersonic Decelerators

Parachutes

Inflatable Decelerators



Propulsion

Options for Supersonic & Subsonic Decelerators

Options for Terminal Descent Systems

5.0 Aerodynamic and Propulsive Decelerator Candidate Solutions

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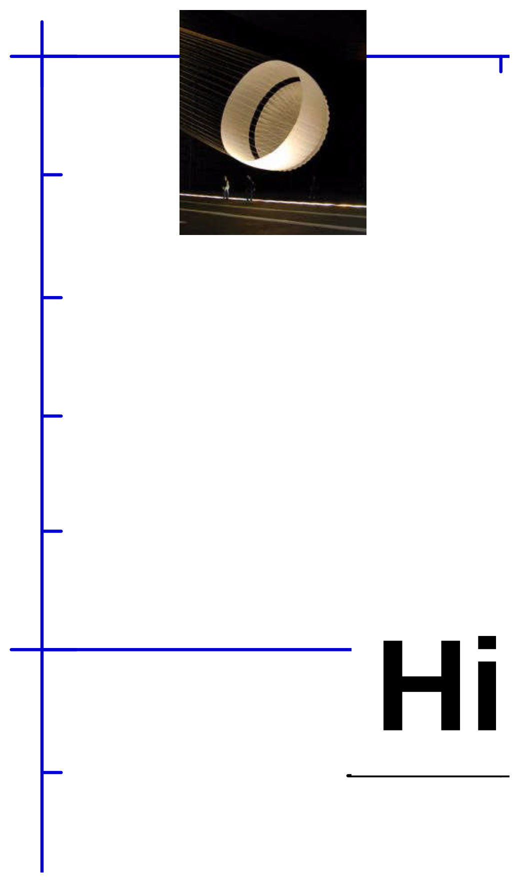
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

	Candidate Mission Scenario	Candidate Solutions
Mars Descent	**Mars human and cargo landing**	**Supersonic parachutes, subsonic parachute clusters** **Inflatable decelerators** **Supersonic and subsonic propulsion** **Combination**
Earth Return (Mars)	**Human direct entry or landing from orbit**	**Subsonic parachute cluster** **Parafoils** **Lifting body/wings**
Earth Return (Lunar)	**Human direct entry or landing from orbit**	**Subsonic parachute cluster** **Parafoils** **Lifting body/wings**

Supersonic Parachutes

- Disk-Gap-Band (DGB) heritage parachutes
- Deployment at Mach number M • 2.1 (Viking heritage)
- Deployment at dynamic pressure q • 800 Pa (MER heritage)
- Nominal diameter, D_0 • 16.15 m (Viking heritage)
- Maximum drag area, $C_D S$ • 108 m^2 (approximate for Viking parachute with D_0 = 16.15 m at M = 2.1)
- No reefing, clustering, or glide control
- Mortar deployment

Viking DGB Parachute Drag Model



Subsonic Parachutes

- DGB heritage parachutes (see supersonic parachutes)
  - Maximum drag area, C_DS • 139 m^2
- Ringsail heritage parachutes
  - Beagle 2, MTP Subsonic Parachute, extensive Earth-flight experience (e.g.,Mercury, Gemini, Apollo)
  - Deployment at Mach number M • 0.8 (MTP Subsonic Parachute)
  - Nominal diameter, D_0 • 33.5 m (MTP Subsonic Parachute)
  - Maximum drag area, C_DS • 679 m^2
  - Reefing
  - No clustering or glide control

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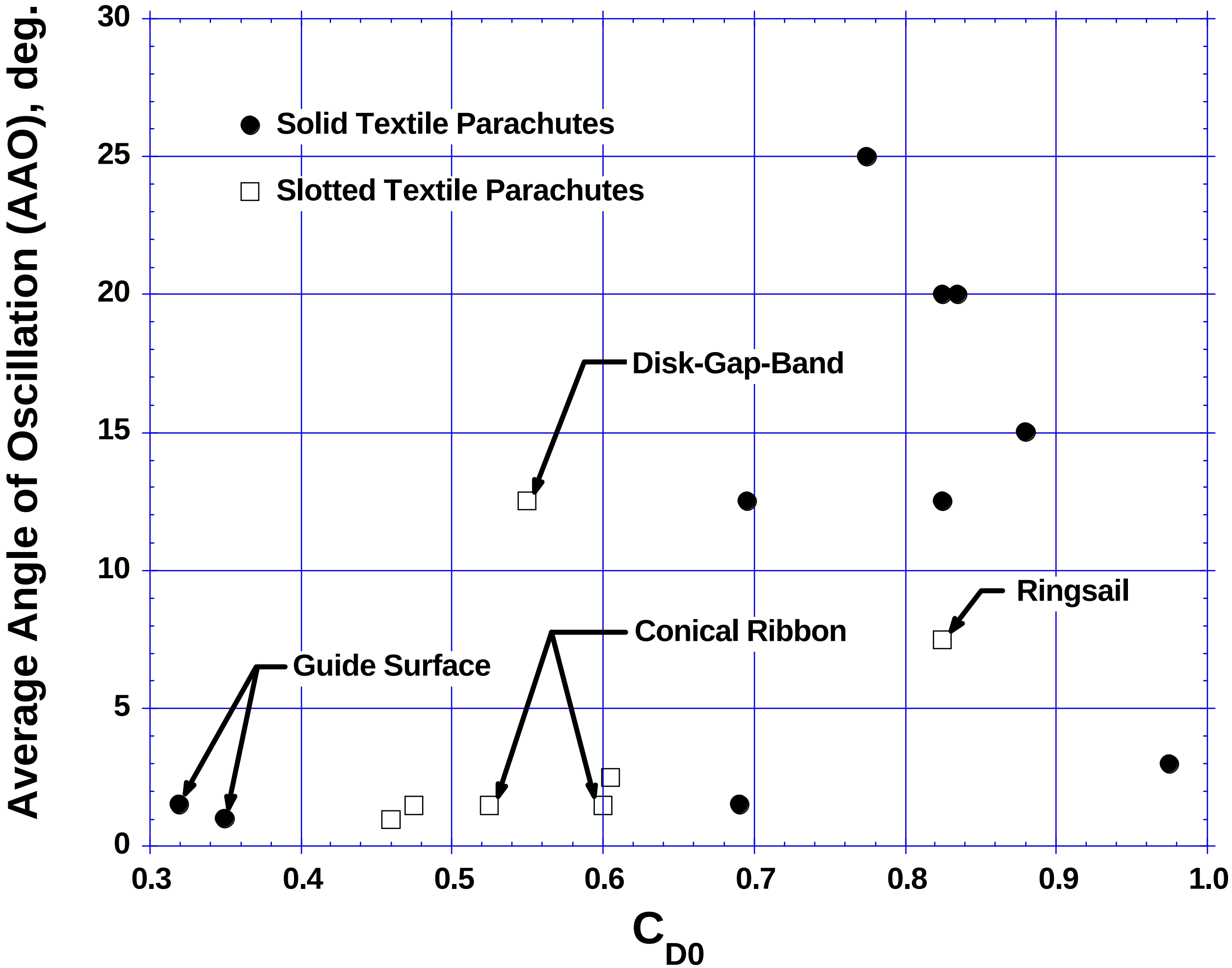
Drag vs Stability Comparison



Inflatable Supersonic Decelerators

- No inflatable supersonic decelerators have been flown in planetary exploration missions
- Several concepts proposed, some tested
- Some concepts show promise

Materials

- Kevlar, Nylon, Polyester (Dacron) are “qualified” materials
- Vectran, Spectra, Technora, Nextel, Zylon now used in some “qualified” applications
- Coated materials (impermeable, ablative) have been used for munitions programs

Analysis Methods

- Current methods have a significant empirical component (need data to calibrate)
- First-principle methods (e.g., Fluid Structures Interaction analyses) are available but validation is lacking
- Scaling of results (physical size and test conditions) possible but poorly understood

Test Methods

- Need improvements in our ability to adjust results of all testing to other scales and different conditions
- Wind tunnel testing (sub-scale and full-scale)
  - Available facilities at risk of closing
- Low altitude flight testing (subsonic)
- High altitude flight testing (supersonic and subsonic)
  - Sounding rocket
  - Balloon
  - Balloon/Rocket

Current Earth and Mars Aerodynamic Decelerator Technology Capabilities and Limitations

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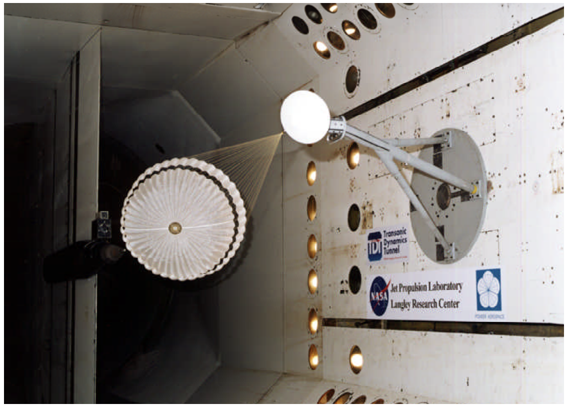
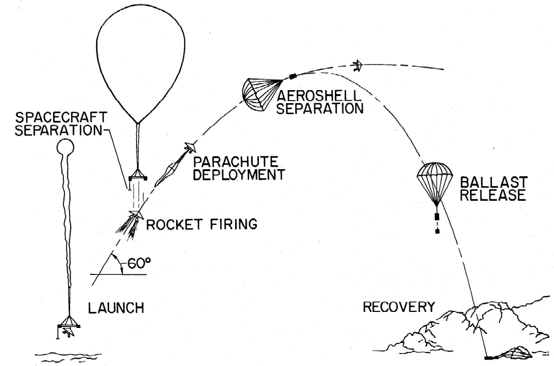
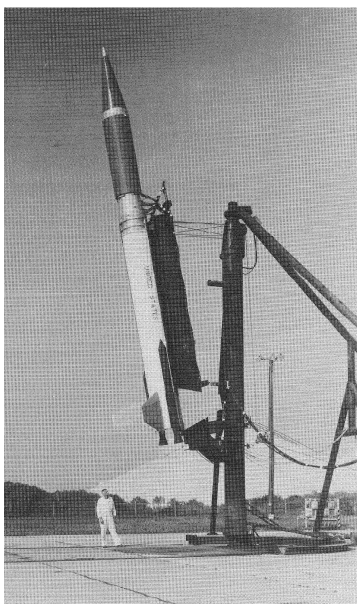


Sub-Scale Wind Tunnel Testing

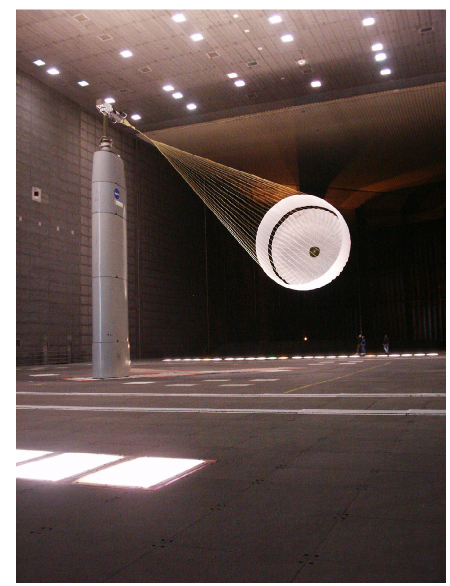
Full-Scale Flight Testing



Balloon/Rocket



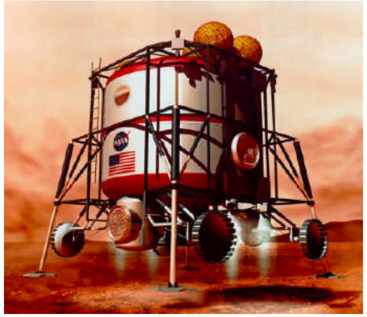
Sounding Rocket

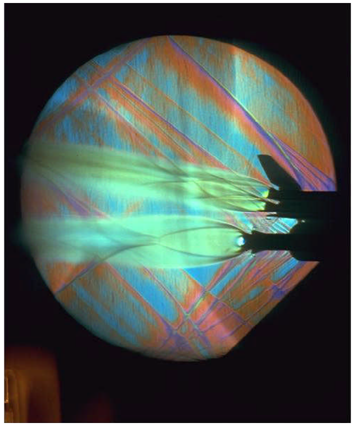


Full-Scale Wind Tunnel Testing

Mars Propulsive Decelerators

- Supersonic deceleration at Mars may require a propulsive component
  - An aerodynamic-decelerator only solution may not be realistic (extremely large parachutes)
- Use of retrorockets to decelerate from supersonic to subsonic speeds has issues
  - Initiation of thrusting is likely to require blow-out covers in TPS
    - MER TIRS motor covers are a primitive example
  - Thermal protection must be provided while vehicle is enveloped in high enthalpy recirculating exhaust
  - Plume / freestream interaction will be fundamentally unsteady
    - Freestream Mach number and dynamic pressure change rapidly
    - Rapidly changing aerodynamic forces on aeroshell will require significant control authority, especially in the transonic regime
- Development of modeling capability for this “inverse base flow” problem will be likely require subscale wind tunnel tests and flight testing.





Mars: Performance Needs

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Supersonic-to-Subsonic Deceleration

- Larger aero decelerator drag area ($C_D S$) at supersonic speeds
- Aero decelerator drag area control at supersonic speeds (loads and trajectory)
- Aero decelerator deployment at Mach number > 4
- Propulsive supersonic deceleration

Subsonic Terminal Descent

- Larger aero decelerator drag area ($C_D S$) at subsonic speeds
- Large propulsive descent system

Pinpoint Landing Capability

- Ability to make parachute glide in a chosen direction
- Propulsive descent system guidance and hazard avoidance

Earth and Mars: Aerodynamic Decelerators Technology Needs

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Fluid-Structures Interaction Analyses

- Joining of Computational Fluid Mechanics (CFD) with structural Finite Element Methods (FEM)
- Allows for numerical design optimization
- Can yield insight on scaling of test results (physical size and test conditions)
- Can yield values of quantities usually obtained by test (e.g., C_{D0})
- Can yield values of quantities that are difficult to obtain by test (e.g., dynamic aero coefficients - C_{mq})
- Has possibility of reducing testing and qualification costs by decreasing number of tests
- Works with trend of cheaper computing
- In need Verification (are we solving the equations right?) and Validation (are we solving the right equations?) to obtain level of trust suitable for exploration missions
- <u>Must-have technology</u>

Earth and Mars: Aerodynamic Decelerators Technology Needs

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Scaling

- **Ability to scale test results to the system size and test conditions**
- **May allow for relevant sub-scale testing of systems in flight at supersonic conditions**
- **<u>Must-have technology for large Mars systems</u>**

Testing

- **Adequate wind tunnel and flight test (e.g., high-altitude balloons, sounding rockets) capabilities must be <u>retained</u> and in some cases expanded**
- **Capability to flight test supersonic systems will become a necessity for Mars systems**

Materials

- **Development of new space-qualified materials will have a significant impact on aerodynamic decelerator design (i.e., mass to drag area ratio)**
- **Materials with high temperature capabilities for parachutes (M > 2.5) and inflatable decelerators will be required**

Earth and Mars: Aerodynamic Decelerators Technology Needs

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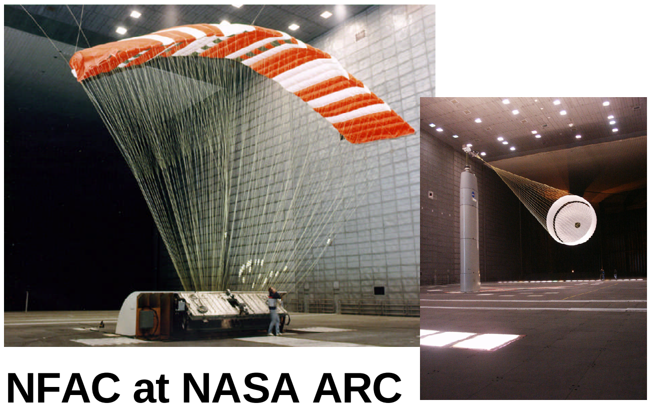
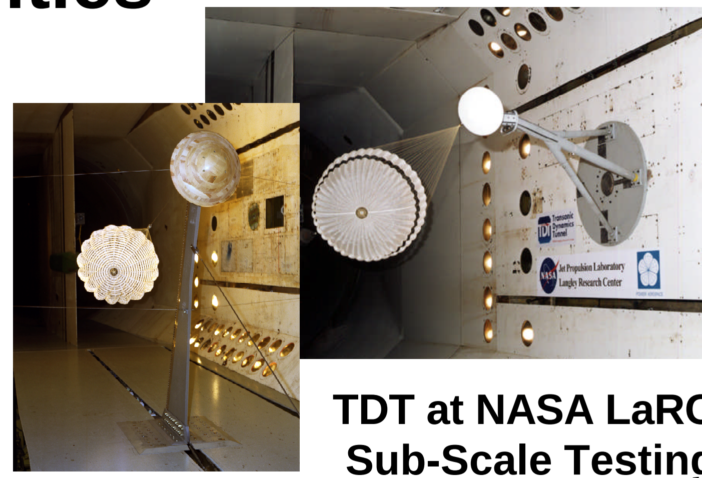
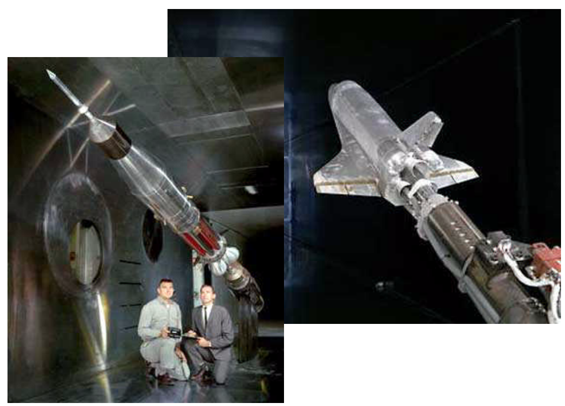
Key Wind Tunnel Testing Facilities



NFAC at NASA ARC
Full- and Sub-Scale Testing
Subsonic



TDT at NASA LaRC
Sub-Scale Testing
Subsonic and Transonic



10’ x 10’ Supersonic at NASA GRC
Sub-Scale Testing Supersonic

Possible Mars Configurations

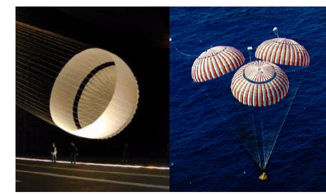
2 Metric Ton Entry Mass Level

Disk-Gap-Band Supersonic Parachute
Ringsail Subsonic Parachute (single canopy)

4 Metric Ton Entry Mass Level

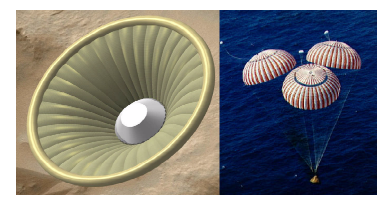
Disk-Gap-Band Supersonic Parachute (reefed)

Ringsail Subsonic Parachute (cluster)



10 Metric Ton Entry Mass Level

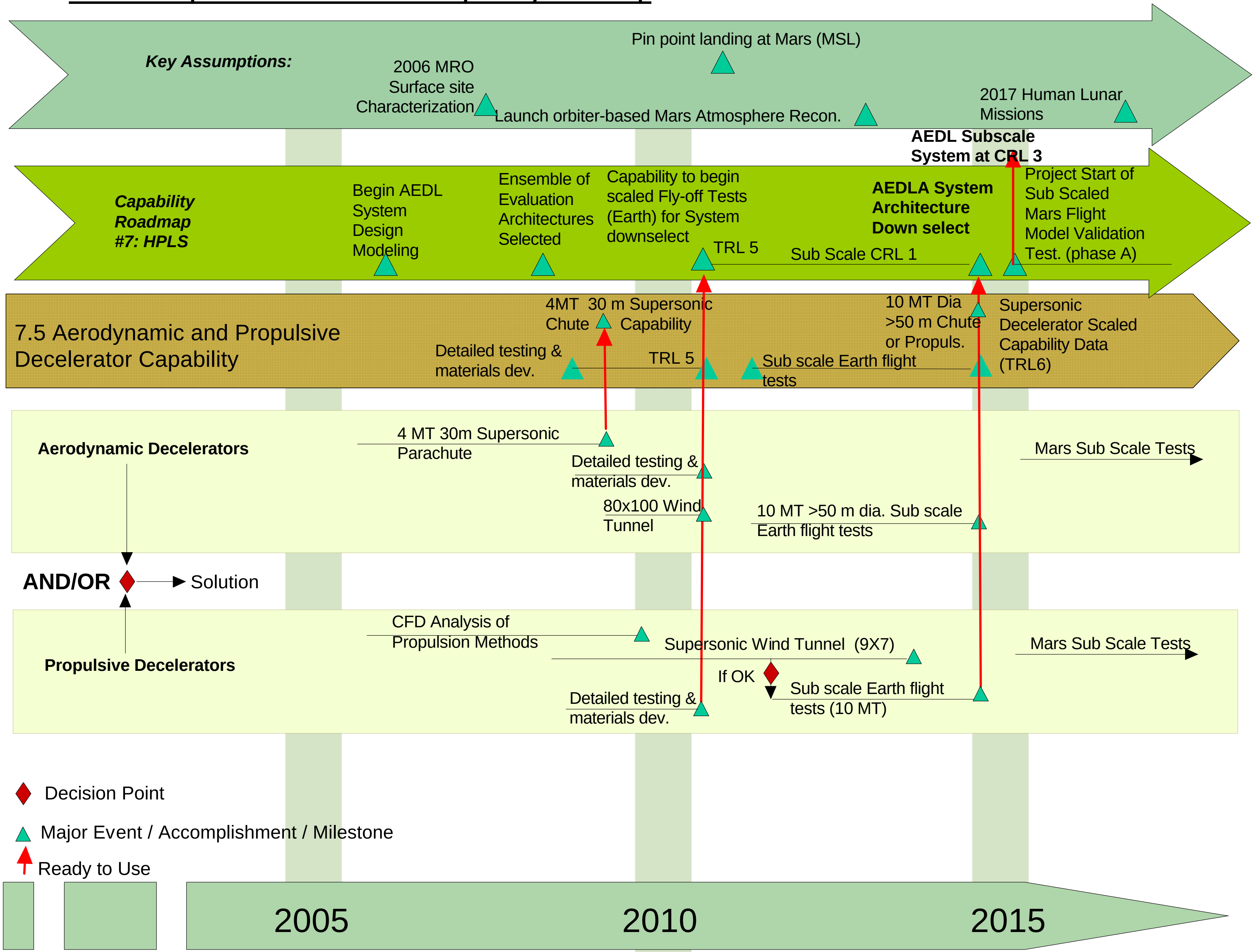
Inflatable Supersonic Decelerator
Ringsail Subsonic Parachute (cluster)



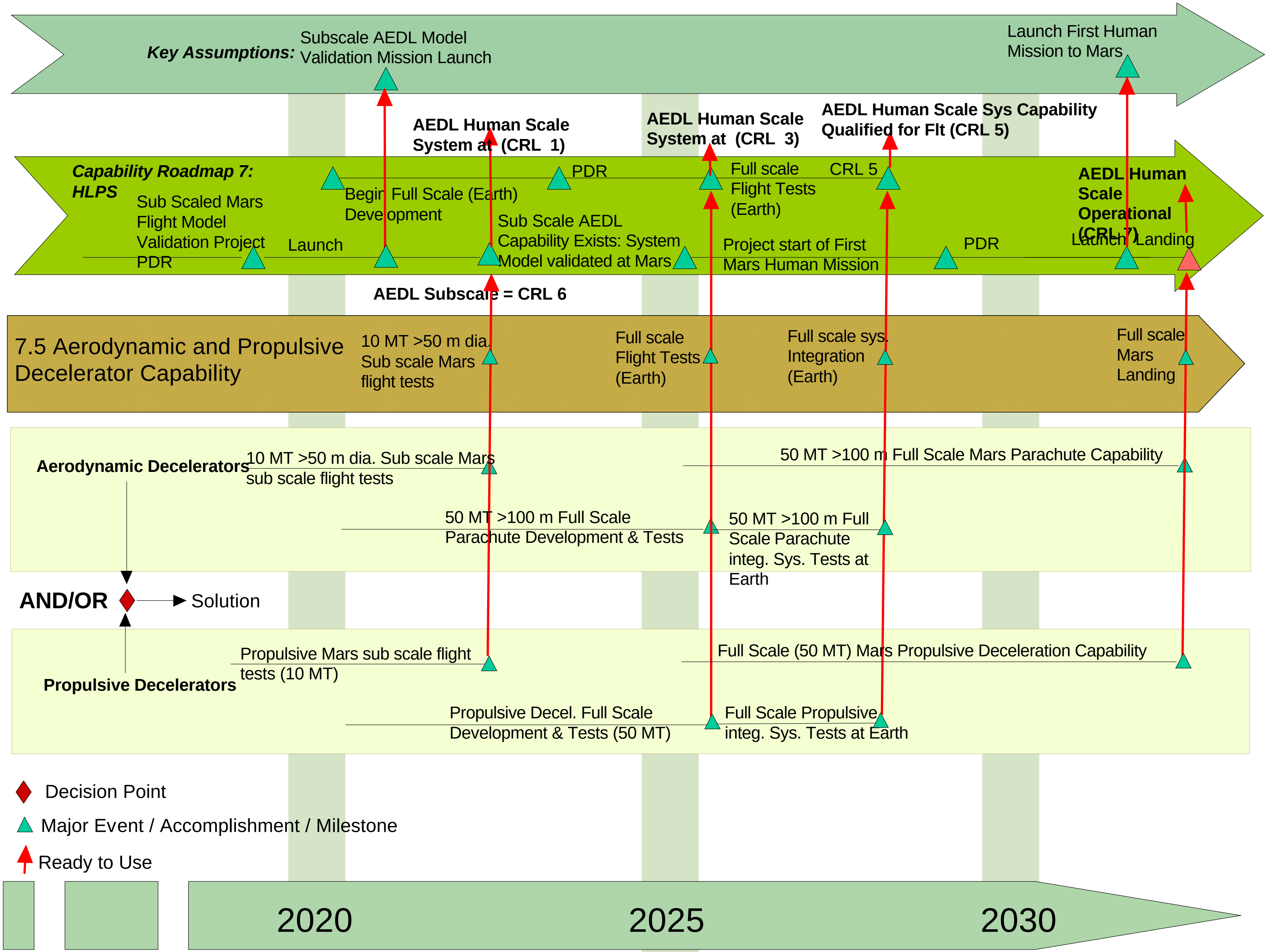
50 Metric Ton Entry Mass Level (Human)

Inflatable Supersonic Decelerator
Ringsail Subsonic Parachute (cluster)
Propulsion Assisted Deceleration

Team 7: Supersonic Decelerators Capability Roadmap



Team 7: Supersonic Decelerators Capability Roadmap



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Backup Material

Symbols and Acronyms

Symbols

C_{D0}	drag coefficient
C_DS	drag area
C_{mq}	derivative of pitching moment with respect to pitch rate
D_0	nominal diameter
M	Mach number
q	dynamic pressure

Acronyms

AAO	Average Angle of Oscillation
ARC	Ames Research Center
CFD	Computational Fluid Dynamics
DGB	Disk-Gap-Band
FEM	Finite Element Method
FSI	Fluid Structures Interaction
GRC	Glenn Research Center
LaRC	Langley Research Center
MER	Mars Exploration Rover
MT	Metric Ton
MTP	Mars Technology Program
NFAC	National Full-Scale Aerodynamics Complex
TDT	Transonic Dynamics Tunnel
V&V	Verification and Validation
WT	Wind Tunnel