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Application of Auto-Rotation for Entry, Descent and Landing on Mars

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All the space you need

Presentation Outline

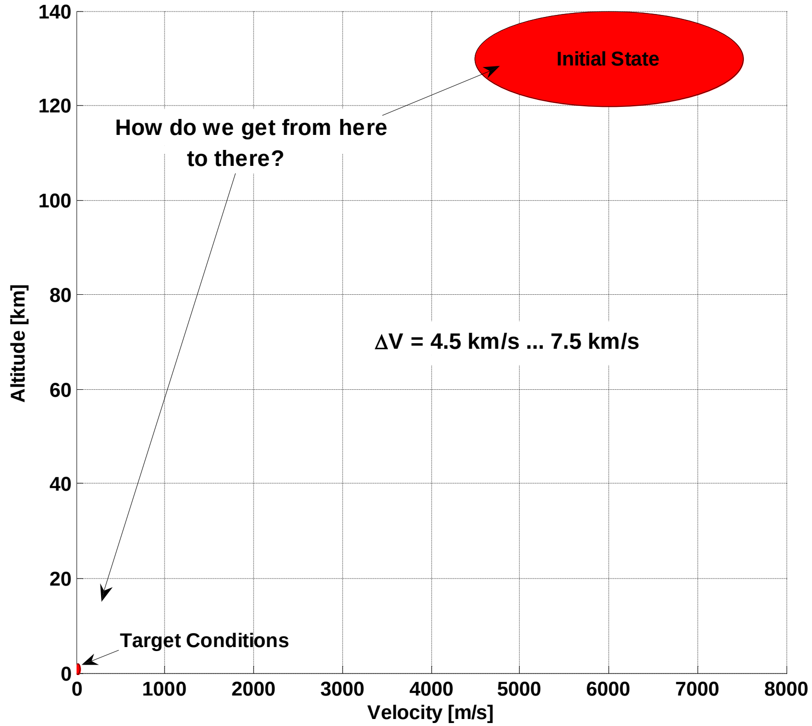
- Study Requirements and Assumptions
- Entry, Descent and Landing on Mars
  - Challenges & Solutions
- Auto-Rotation
  - General Considerations
  - Specific Design Challenges of Auto-rotation Systems for Mars
- An Auto-Rotation System Concept for EDL on Mars
  - EDL Sequence
  - Proposed System
  - System Performance
- Conclusions

Study Requirements and Assumptions

- The work described here was performed within an ESA contract entitled “Autorotation in Martian Descent and Landing”
- The study aims at developing an alternative landing approach for Mars exploration missions
- It is based on the following requirements:
  - the probe to be landed shall follow a **ballistic** entry trajectory,
  - the probe shall have a Viking-like aeroshell,
  - the probe shall be landed at altitudes below 2000 m,
  - the probe shall be landed at a vertical descent velocity of less than 20 m/s,
  - the landing vehicle shall be capable of **maneuvering** close to the surface prior to touchdown, and
  - the landed mass shall be between 20 and 200 kg.

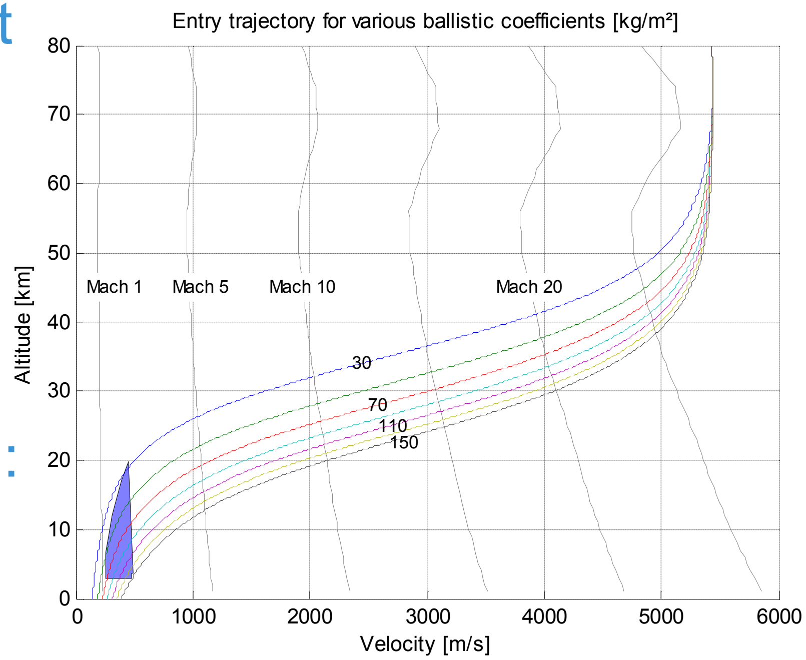
Entry, Descent and Landing on Mars

- Most of the kinetic energy from arrival is removed during entry
- The atmosphere of Mars requires:
  - Use of large decelerators after entry
  - Additional terminal descent means (e.g. MER retro-rockets)
- High energy/velocity at entry:
  - Thermal protection during entry required
- Density uncertainty of upper atmosphere leads to conservative system and mission design reducing possible performance



Entry, Descent and Landing on Mars

- EDL Performance within this context is defined as
  - Landed mass
  - Landing site elevation
  - Landing precision
- Traditional missions/concepts apply several descent and landing s/s, e.g:
  - Parachutes
  - Powered descent
  - Vented & unvented airbags
- Also complex, but reducing the number of required EDL subsystems, is use of an auto-rotative decelerator



Auto-Rotation

General Considerations

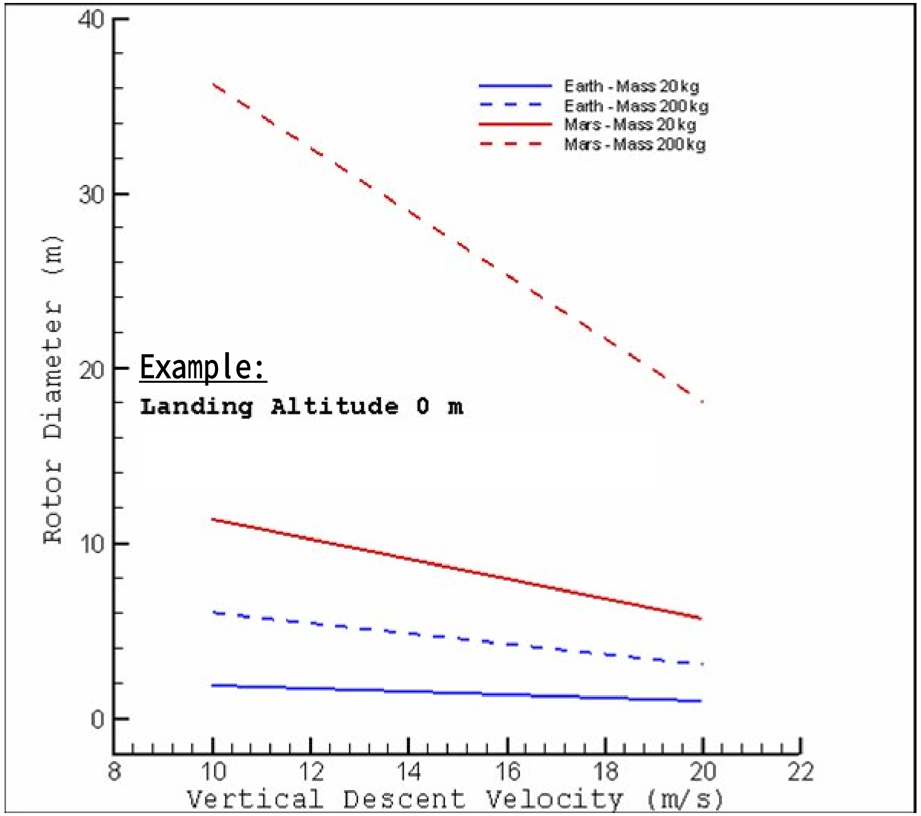
- Auto-Rotation is used to perform un-powered landings of helicopters in an emergency mode after failure of the power plant
- During auto-rotation the rotor is not engine-driven, but rotated by the upward airflow while the vehicle is descending
- This can provide about as much equivalent ‘drag’ as a circular parachute of the same diameter,
- The rotor can then be used as a control device to perform manoeuvres during the last stages of the descent and landing
- Employment of such a concept on a Mars lander is being studied with the object of using the lander’s descent kinetic energy so as to perform manoeuvres otherwise requiring the use of fuel

Auto-Rotation

- Preliminary sizing of the rotor diameter assuming purely vertical descent:

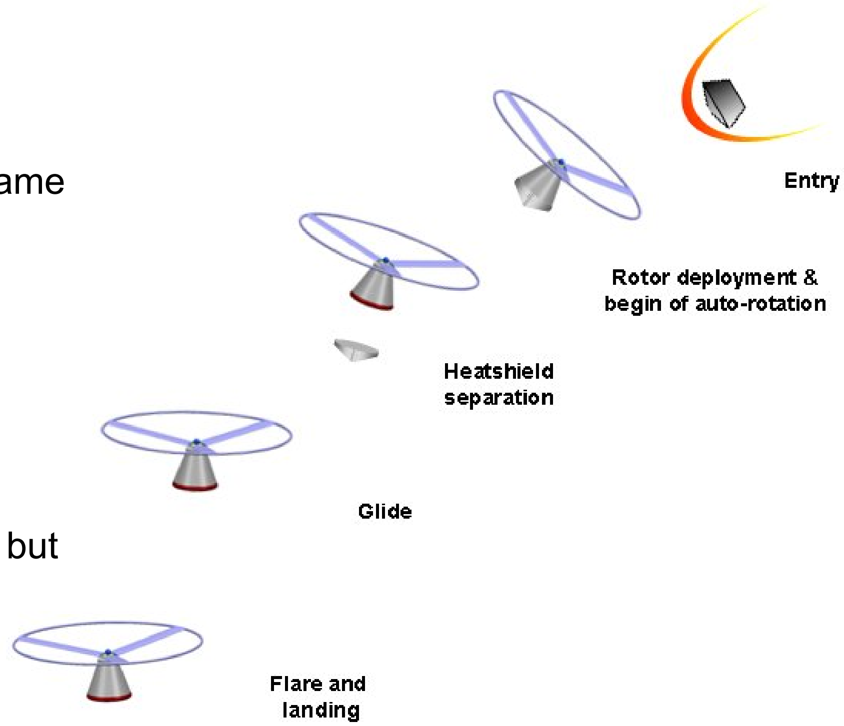
$$D = \sqrt{\frac{8 \cdot m \cdot g}{C_D \cdot \rho \cdot \pi \cdot V^2}}$$

- On Mars, roughly 6 times the rotor diameter is required to achieve a given vertical auto-rotation speed for a given landing mass !



Auto-Rotation System Concept for Mars

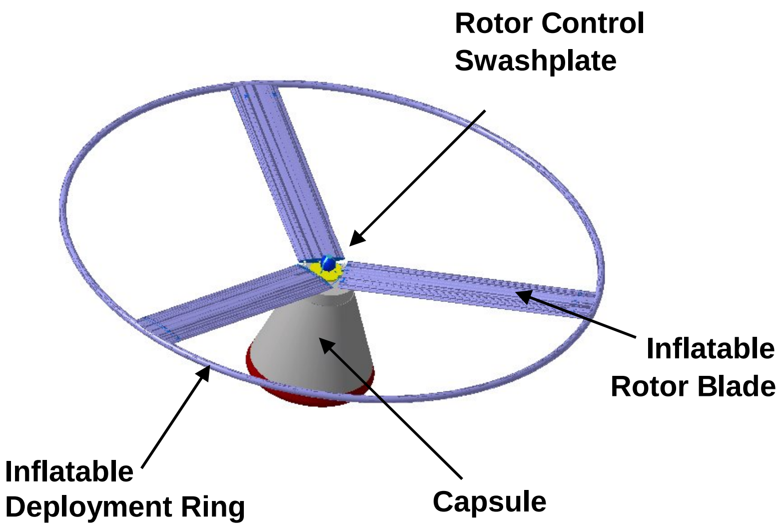
- The EDL sequence for an auto-rotative system is:
  - Entry
    - Assumed to be ballistic
  - Rotor deployment and transition
    - Assumed to take place within the same range of dynamic pressure as DGB parachutes, but possibly could be extended to higher Mach numbers (Ma 1.8 .. 2.5)
  - Heatshield separation
  - Glide
    - Provides the downrange capability, but
    - Is influenced by Wind effects
  - Flare and Landing

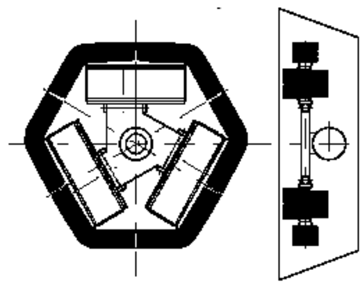


Auto-Rotation System Concept for Mars

- Proposed concept:
  - based on an inflatable rotor system
  - Inflatable ring to assist and stiffen the rotor during deployment
  - Swash plate enables attitude and trajectory control by shifting the COG relative to the rotor
  - Roll control of the capsule by cold gas engines or fins
  - Compared to rigid systems the concept results in a light weight system

Inflatable Rotor System



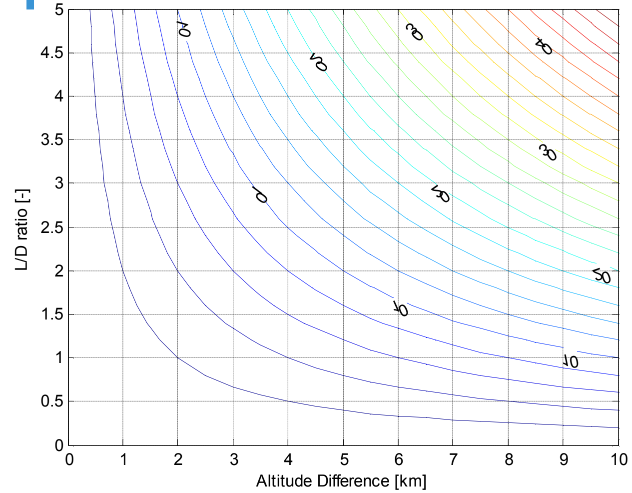


Auto-Rotation System Concept for Mars

- Aerodynamic considerations:
  - Aerodynamic performance of Martian rotor systems analysed using well-proven momentum theory and blade element theory methods
  - Rotor system key parameters taken into account:
    - Known aerodynamic rotor blade aerofoil section characteristics in terms of section lift and drag vs. blade angle-of-attack
    - Pitch angle of the rotor blades including its variation with radius
    - Rotor solidity = total blade area/rotor disc area
  - Outputs of the Analysis
    - Rotor lift, drag and angle-of-attack
    - Limiting flight conditions for auto-rotation operation of the rotor (i.e. largely stalled operation of rotor blades, rotor blade tip speeds approaching sonic velocity)

Auto-Rotation System Concept for Mars

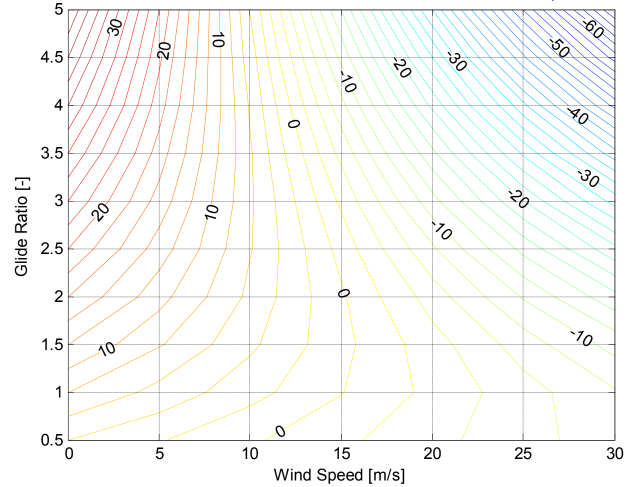
- Glide Ratio: $$E = \frac{C_L}{C_D} = \frac{1}{\tan(\gamma_a)}$$



- Index ‘a‘ denotes ‘wrt air‘
- Performance during gliding:

$$V_a = \sqrt{\frac{8 \cdot m \cdot g}{C_D \cdot \rho \cdot \pi \cdot D^2} \cdot \sin(\gamma_a)}$$

Downrange Capability [km] vs Wind Speed and Glide Ratio (ΔH = 8 km, β = 0.8 kg/m²)



- Selected glide ratio depends on mission requirements (sometimes fast descent preferable)
- But: total velocity is limited by maximum blade tip speed (Ma ≤ 0.8)

Auto-Rotation System Concept for Mars

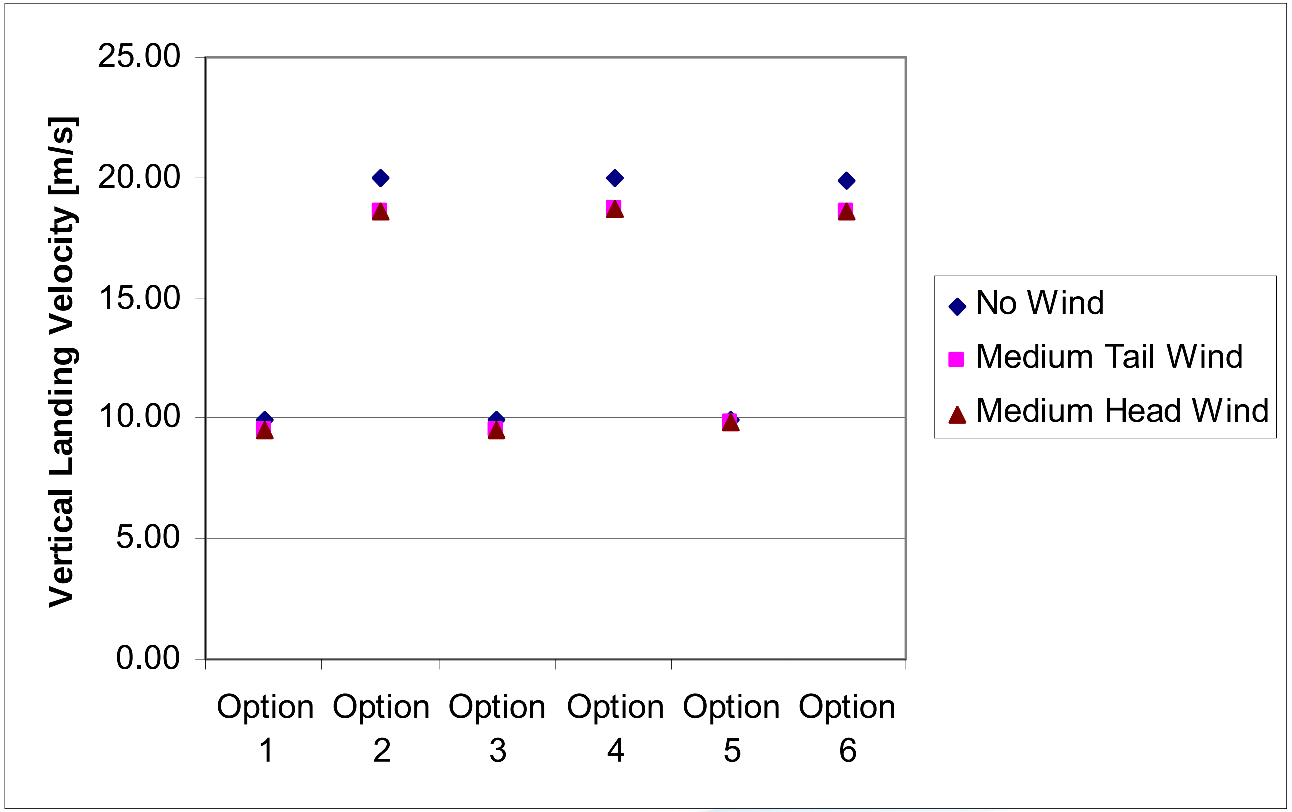
System Evaluation

- Common rotor system deployment condition:
  - Altitude:10041 m
  - Flight path velocity: 383.45 m/s
  - Flight path angle: 28.4 deg
- Design options for system evaluation:

		Landed Mass [kg]		
		20	100	200
Landing Velocity [m/s]	10	Option 1 (D=14.9m, m=35kg)	Option 3 (D=32.6m, m=168kg)	Option 5 (D=47.1m, m=351kg)
	20	Option 2 (D=6.2m, m=25kg)	Option 4 (D=13.5m, m=118kg)	Option 6 (D=19.2m, m=235kg)

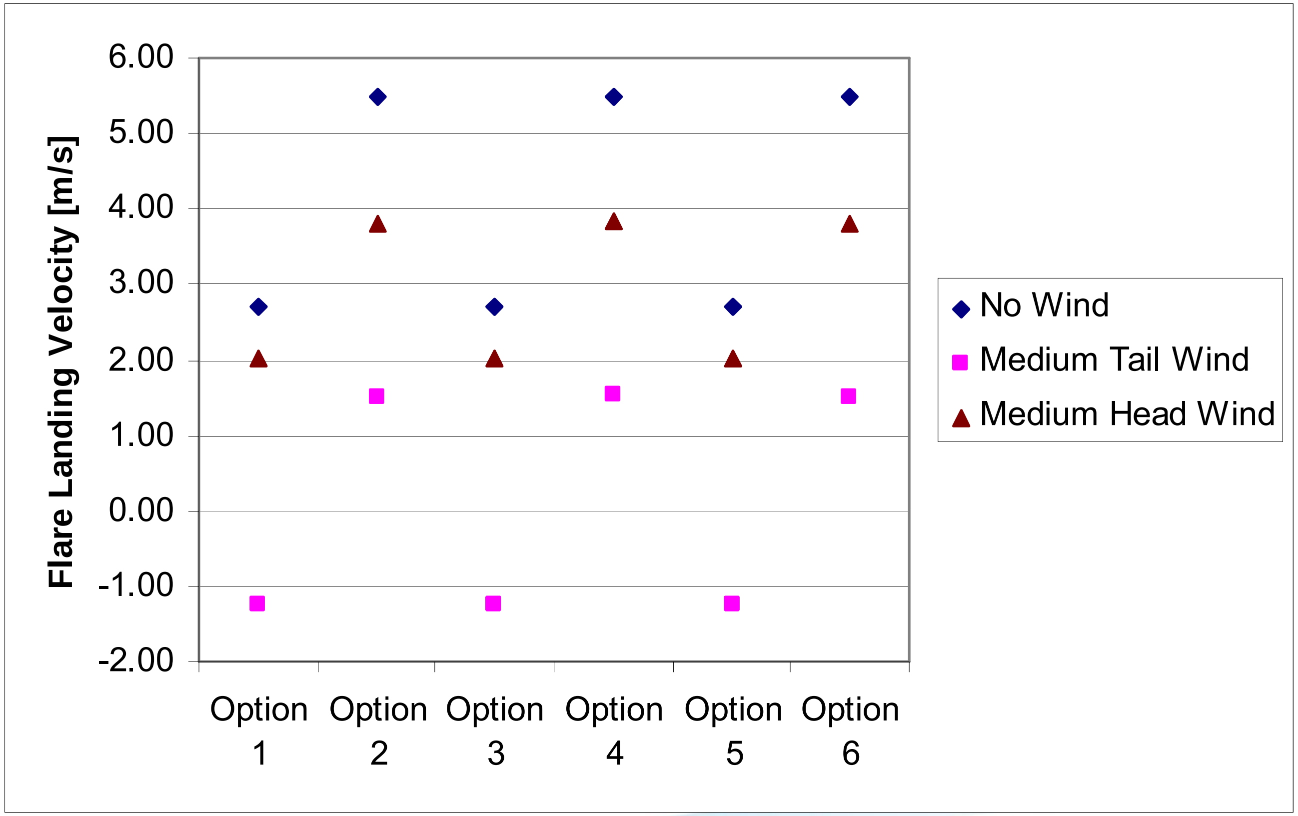
Auto-Rotation System Concept for Mars

- Resulting conditions at landing: Vertical Landing Velocity



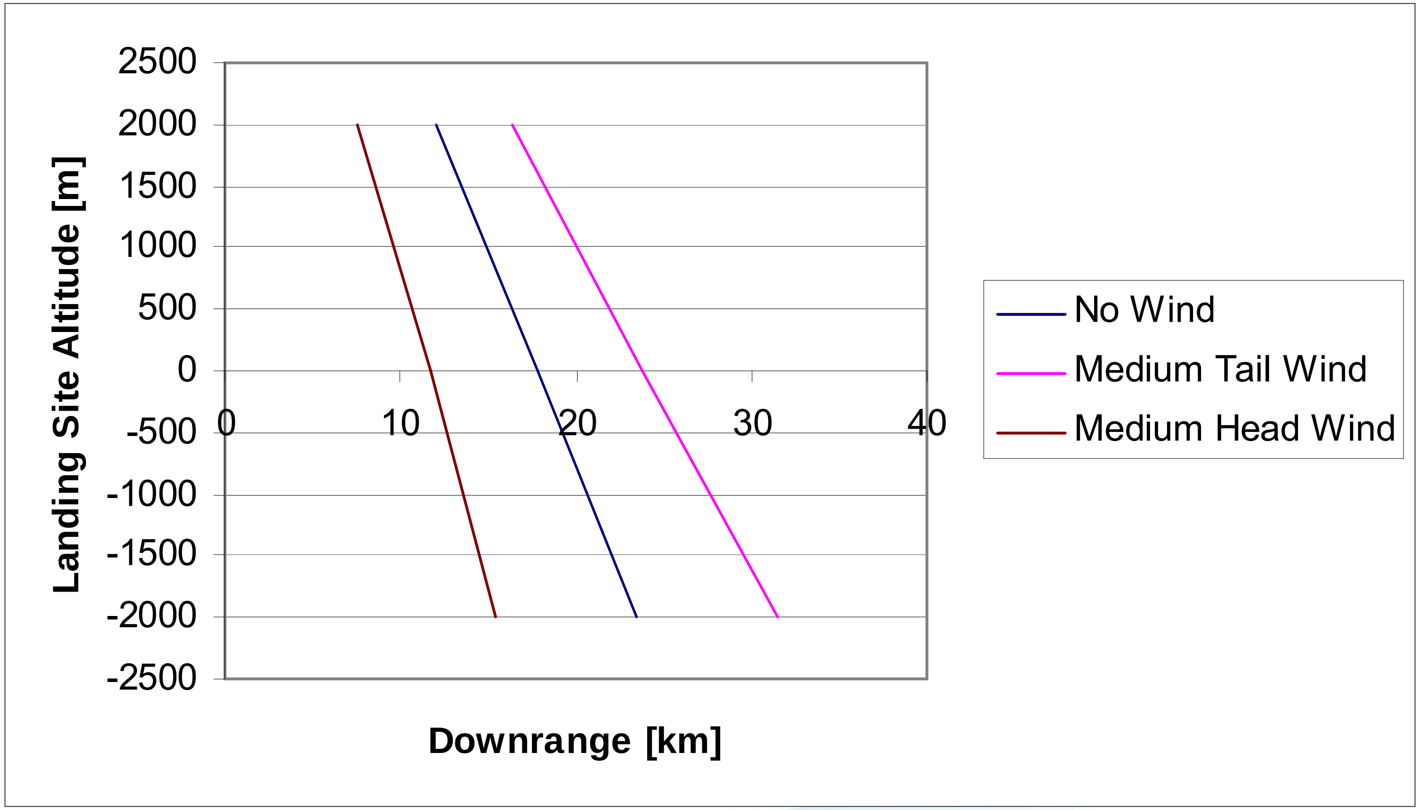
Auto-Rotation System Concept for Mars

- Resulting conditions at landing: Flare Landing Velocity



Auto-Rotation System Concept for Mars

- Resulting conditions at landing: Downrange vs. LSA (Option 6)



Auto-Rotation System Concept for Mars

- System performance
  - Landing Site Elevation
    - Elevation is strongly dependent on rotor deployment altitude
    - Operational constraints allow for shorter timelines compared to conventional parachute & rocket based EDL systems
    - Descent time can be traded against time for gliding flight (altitude traded against downrange capability)
  - Downrange/precision
    - Typical ballistic missions achieve error ellipses of 80 to 150 km
    - Depending on wind conditions and deployment altitude these ellipses can be reduced by up to 25 km
    - Combining guided entry with Auto-Rotation even precision landing is possible
  - The inflatable auto-rotation system offers hazard avoidance capability if equipped with the appropriate sensor suite

Conclusions

- Auto-Rotation descent & landing offers an alternative approach to meet the EDL challenges
  - Potential of precision landing and hazard avoidance
  - High altitude landings
- Though rigid AR systems are state-of-the-art for Earth applications they tend to be heavy systems if applied to Mars
- Inflatable Auto-Rotation systems appear to be a feasible option to overcome this limitation
- The system performance of inflatable AR systems makes them an interesting alternative for Mars EDL missions