

The Mars Science Laboratory EDL Mode Commander

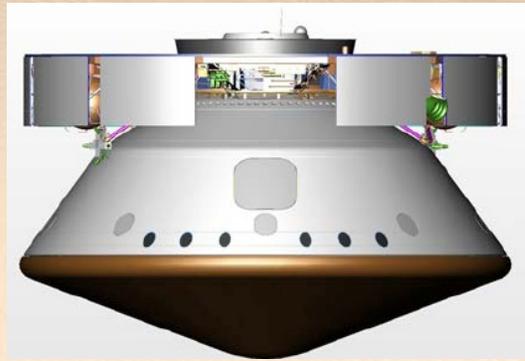
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Fred Serricchio and Gurkupal Singh

Jet Propulsion Laboratory, California Institute of Technology





MSL Mission Overview



CRUISE/APPROACH

- 8 to 9-month cruise
- Arrive August 6-20, 2012



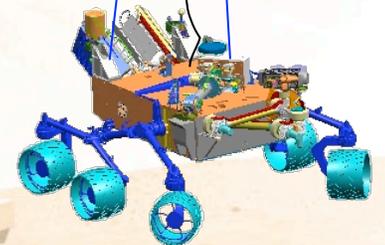
ENTRY, DESCENT, LANDING

- Guided entry and powered “sky crane” descent
- 20×25-km landing ellipse
- Access to landing sites $\pm 30^\circ$ latitude, < 0 km elevation
- 900-kg rover



SURFACE MISSION

- Prime mission is one Mars year (687 days)
- Latitude-independent and long-lived power source
- Ability to drive out of landing ellipse
- 72 kg of science payload
- Direct (uplink) and relayed (downlink) communication
- Fast CPU and large data storage



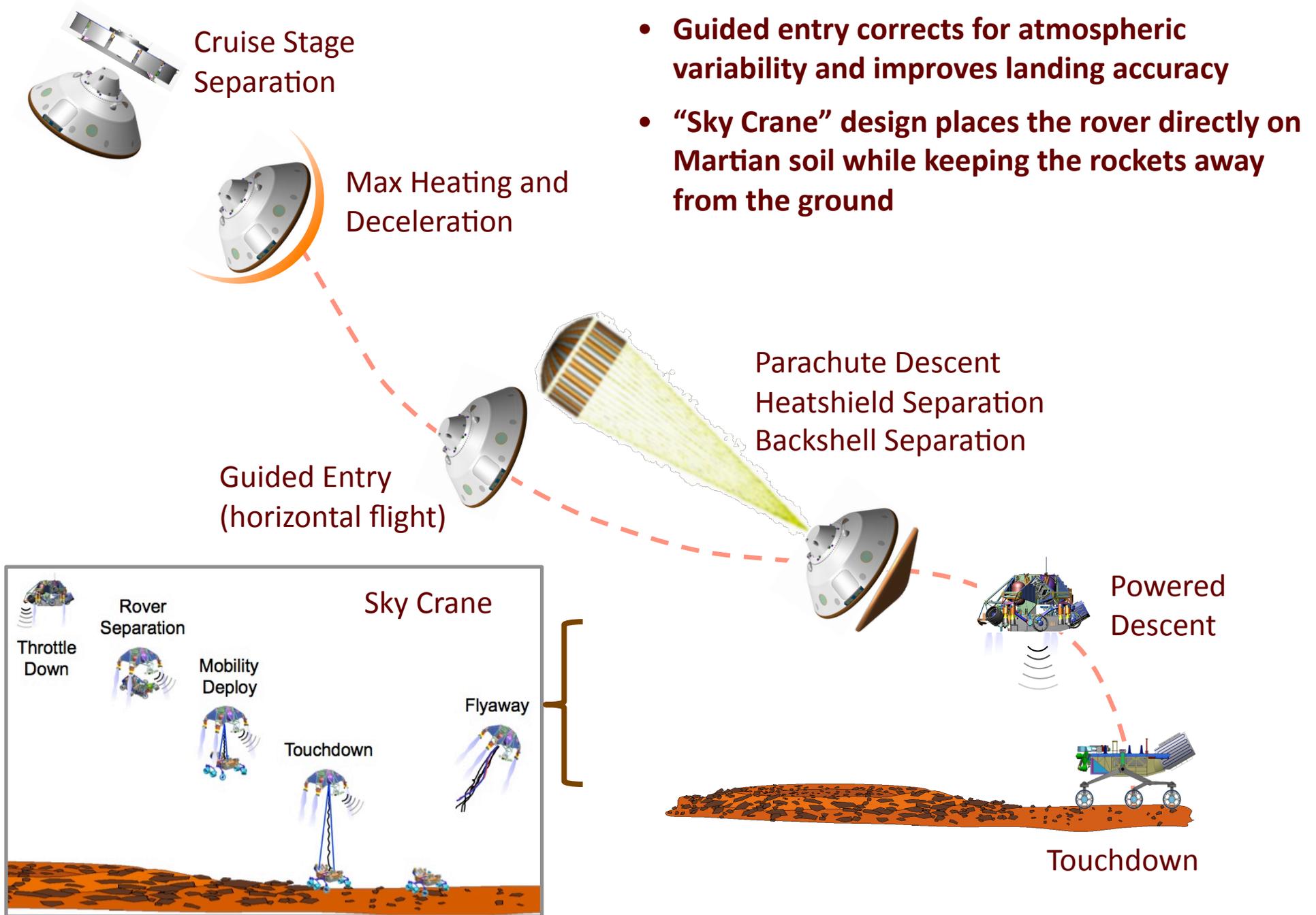
LAUNCH

- Window is Nov. 25 to Dec. 18, 2011
- Atlas V (541)





MSL Entry, Descent, and Landing





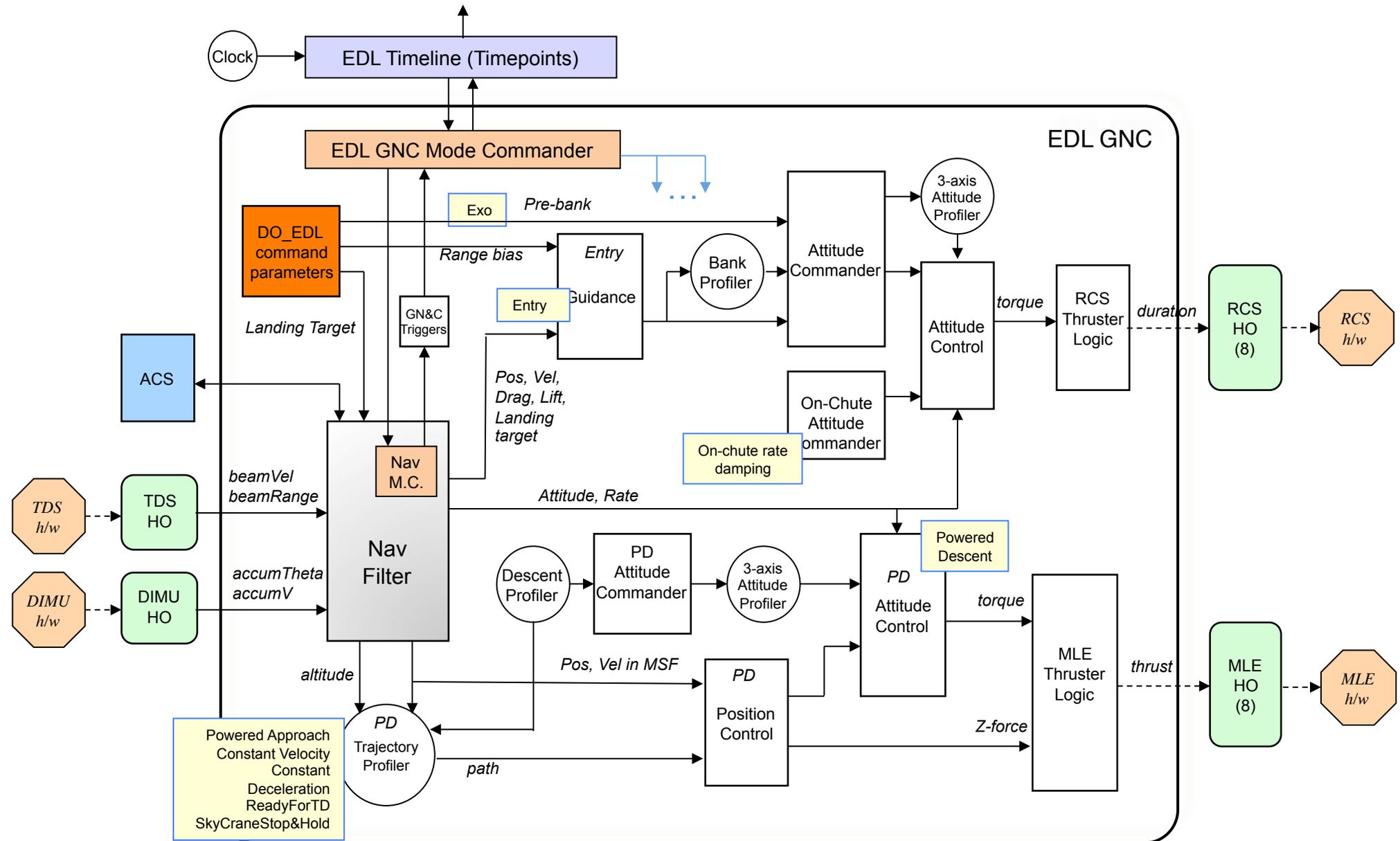
How does the EDL system actually do it?

- The EDL system has three main components:
 1. A timeline engine to prepare and coordinate all the events
 2. A Navigation Mode Commander to manage the estimation of the vehicle position and orientation from the Descent Inertial Measurements Units and the Terrain Descent Sensor (radar)
 3. An EDL Mode Commander to reconfigure the vehicle and guide-and-control the vehicle to a safe landing.
- This talk will describe this last component, the EDL Mode Commander, which is the executive that orchestrates:
 - Hardware reconfigurations (balance mass ejections, heatshield and backshell jettisons, parachute opening, rover separation, etc.)
 - Guidance Navigation & Control functions (position and attitude estimation, entry guidance, RCS attitude control until powered descent starts, powered descent guidance, powered descent position and attitude control).
- We will describe the EDL modes of operation, the vehicle reconfigurations, the GN&C functions performed at each mode, and the navigational and temporal triggers used to transition between modes.





EDL GN&C Block Diagram





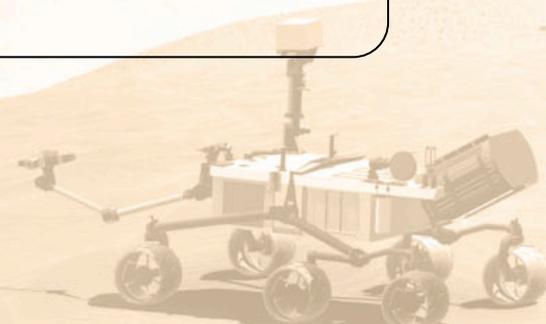
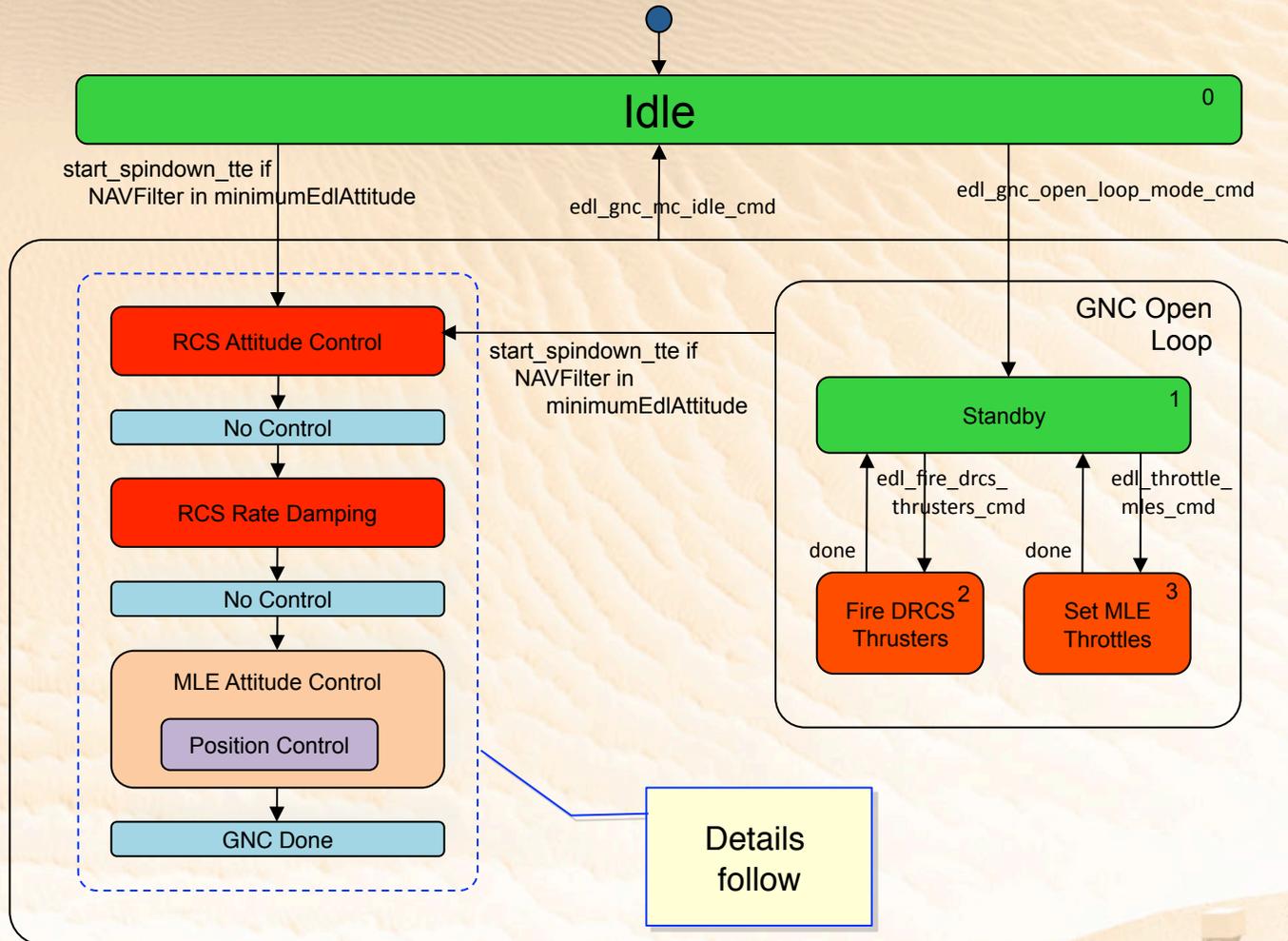
How does the Mode Commander works?

- The EDL GN&C mode commander is a state machine that precisely defines the behavior of the EDL GN&C system. It specifies which GN&C functions are performed at each mode and the conditions to transition between modes.
- Mode Triggers:
 - Timepoint triggers: to, CBM ejection, Entry interface (pressurize RCS), EBM ejections, uninhibit RCS, start TDS nav. Init, warm MLE, PD detumble, rover separation, done.
 - GNC profiled triggers: De-spin, Turn to entry, Bank reversals, Heading alignment slew, Radar attitude slew, PD powered approach, PD constant velocity, PD constant deceleration, PD throttle down, PD SkyCrane constant velocity,
 - Navigated state triggers: Guidance start trigger, Heading alignment start trigger, SUFR trigger, Chute deploy trigger, Heatshield ejection, prime MLE, Backshell Separation, and Touchdown trigger.
- The EDL GN&C mode commander has 38 modes that describe the main functions of the EDL-GN&C system
- It interfaces with the Timeline Engine and the Navigation Mode Commander
- It manages parameters, dynamic states, RCS and MLE command requests, telemetry and real time communication data products



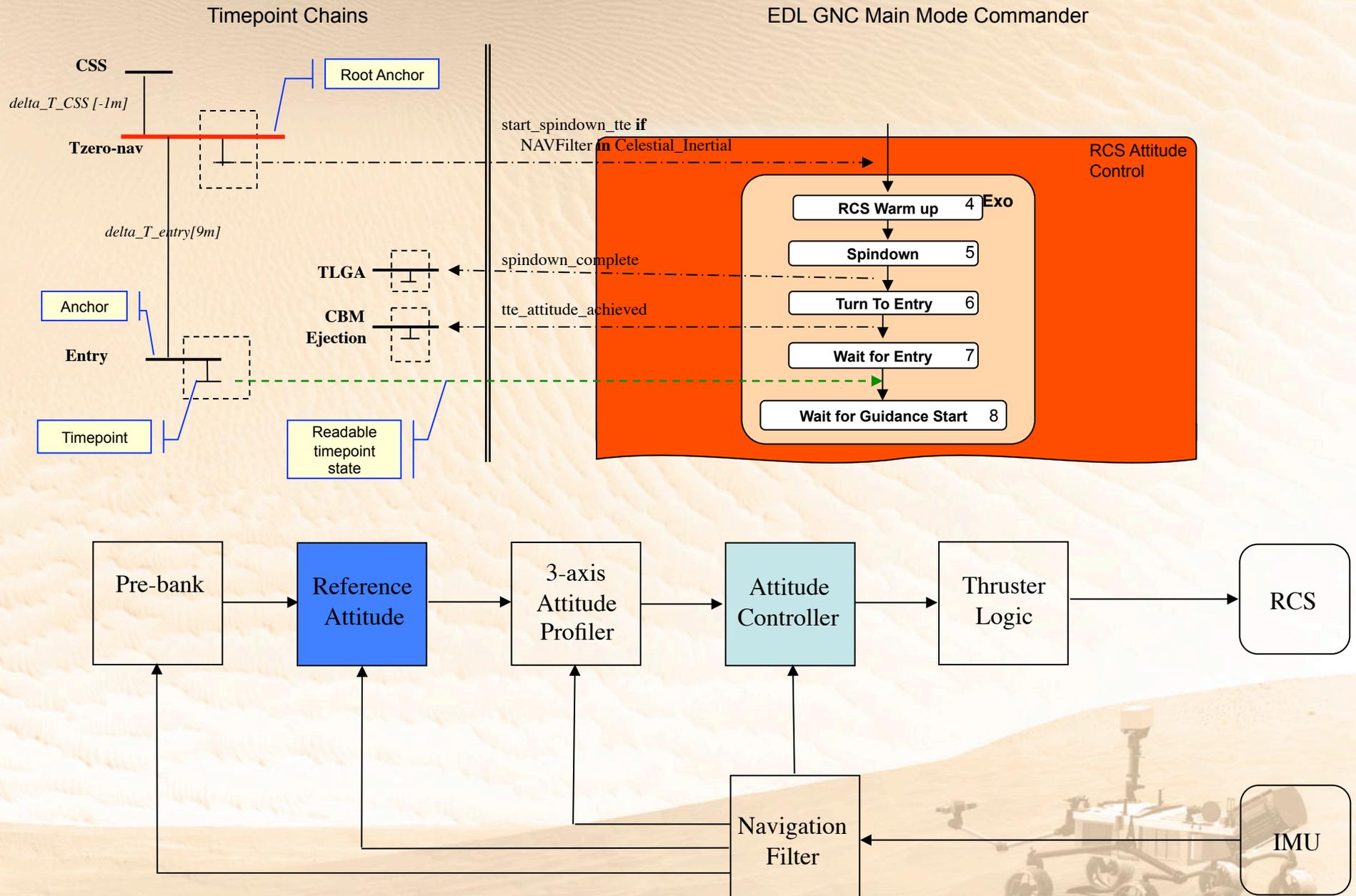


EDL GN&C Main Mode Commander: - Open Loop Test Modes





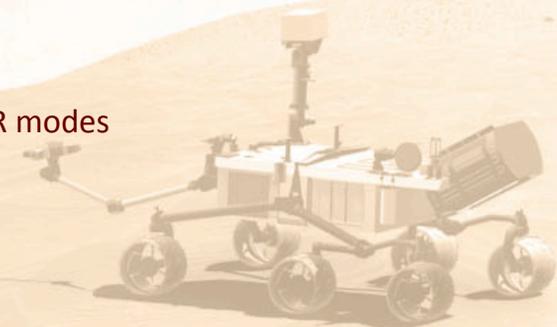
EDL GNC Main Mode Commander: Exo-atmospheric phase





Navigated State Triggers

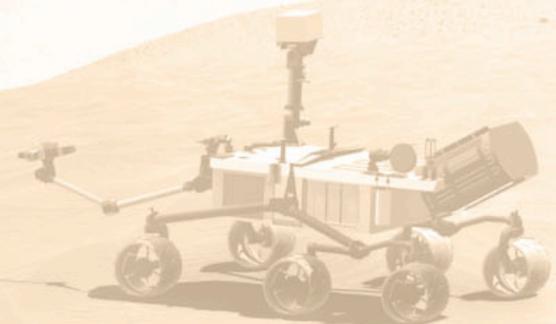
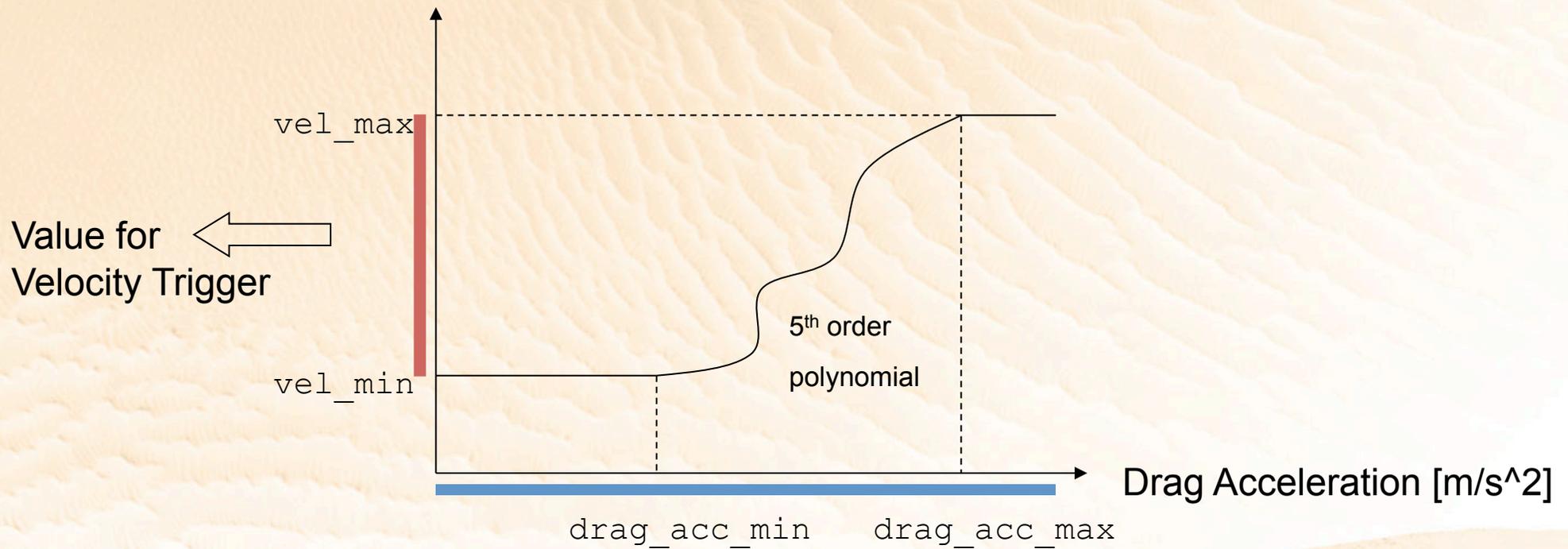
- Guidance start trigger:
 - Drag acceleration trigger
 - Fired if
 - GNC Mode = `WAIT_FOR_GUIDANCE_START`;
 - estimated drag acceleration > 0.2 Earth-g.
- Heading Alignment start trigger
 - Velocity trigger
 - Fired if
 - GNC Modes = Anytime during Range Control phase
 - Estimated atmospheric relative speed < 1100 m/s
- SUFR/Slew to RADAR Attitude start trigger
 - Velocity/Acceleration trigger
 - Fired if
 - GNC Modes = Anytime Heading Alignments phase
 - Estimated atmospheric relative speed < 545 m/s
- Parachute deploy trigger
 - Velocity/Acceleration trigger
 - Fired if
 - GNC Modes = Anytime during Slew to Radar Attitude/SUFR modes
 - Estimated atmospheric relative speed < 485 m/s





Velocity/Acceleration Trigger

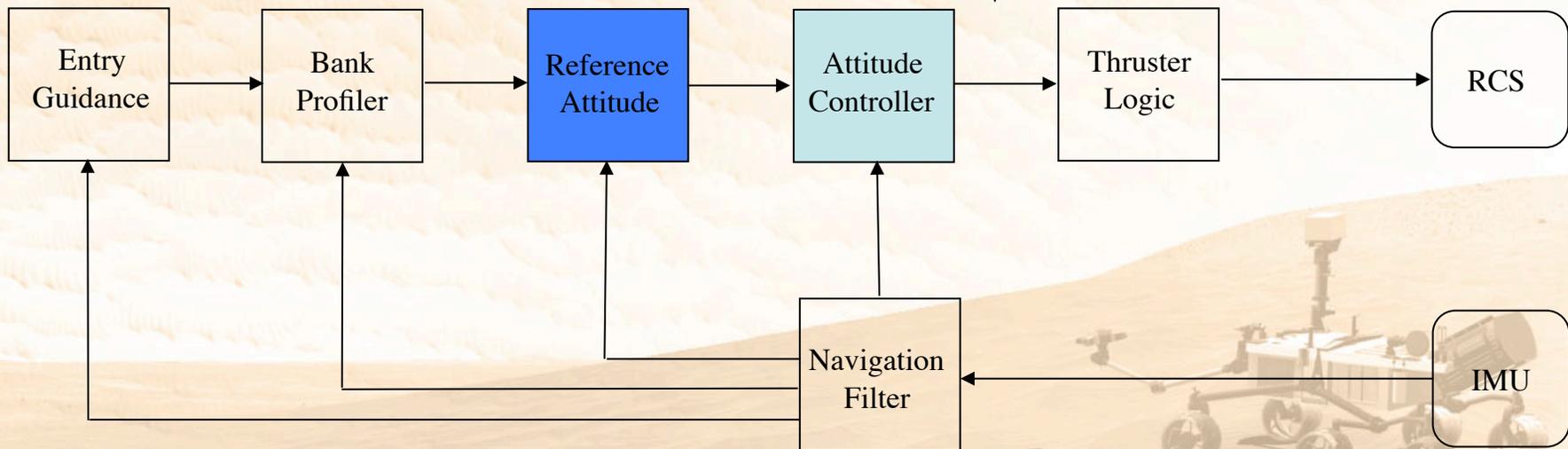
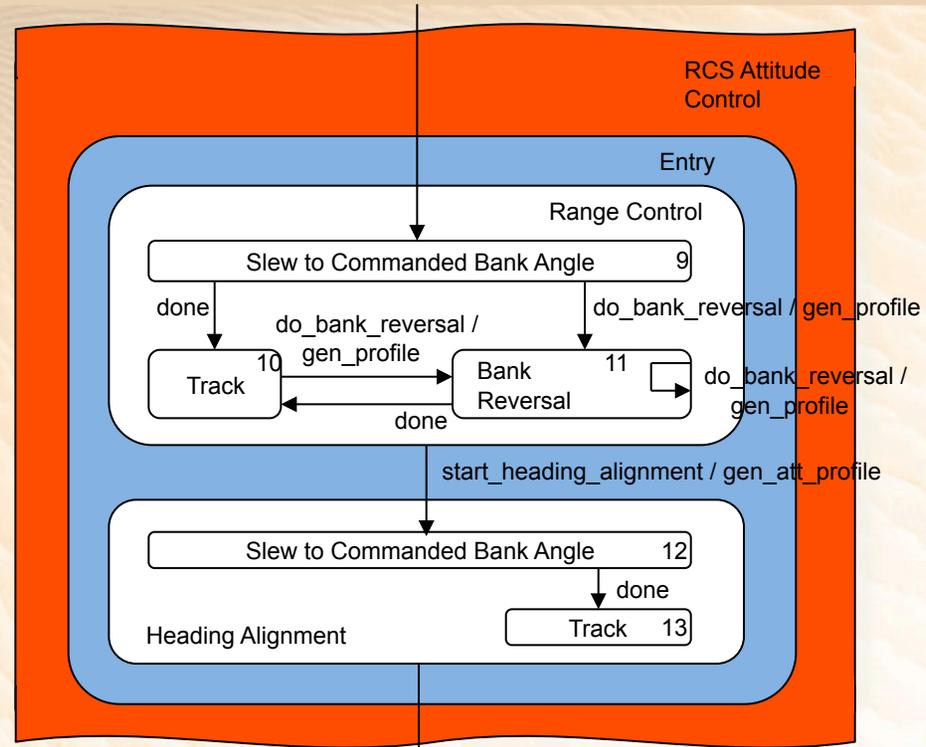
Atmospheric Relative Speed [m/s]





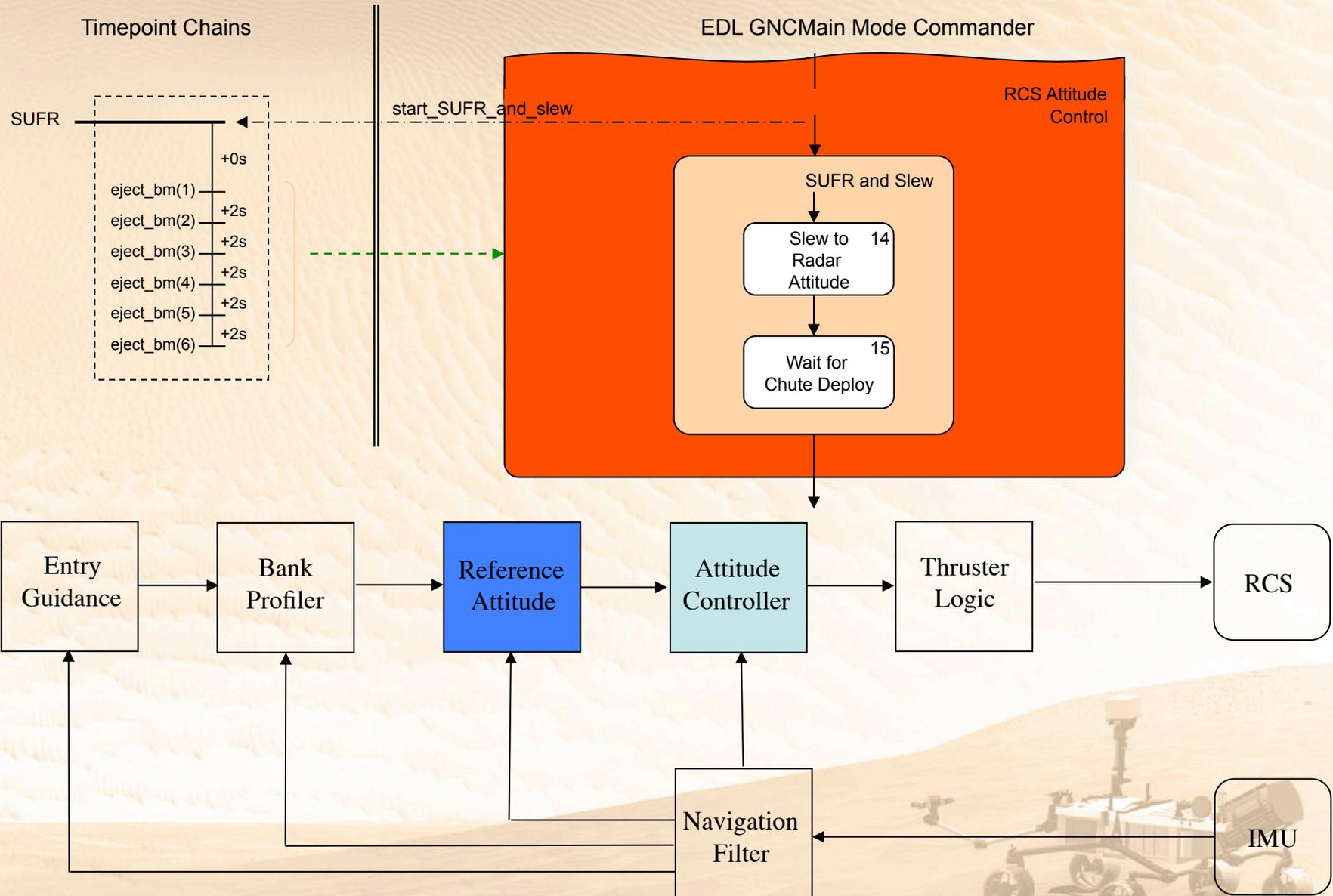
EDL GNC Main Mode Commander: Entry phase

Timepoint Chains



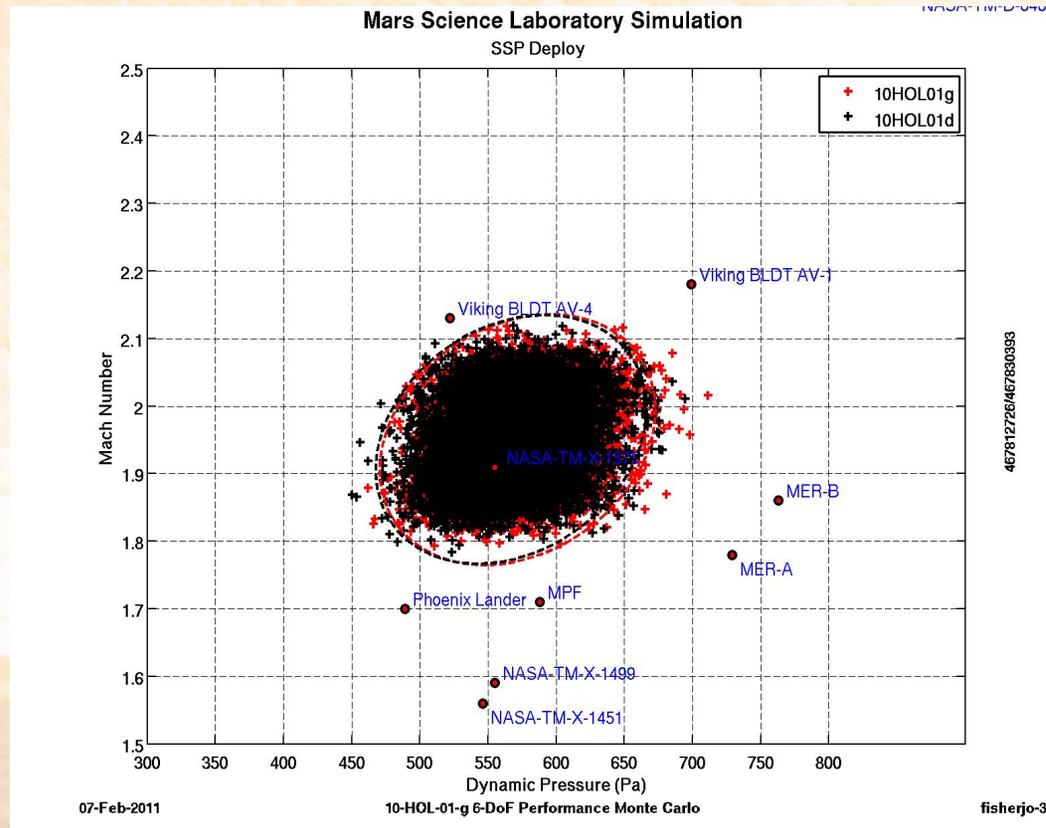
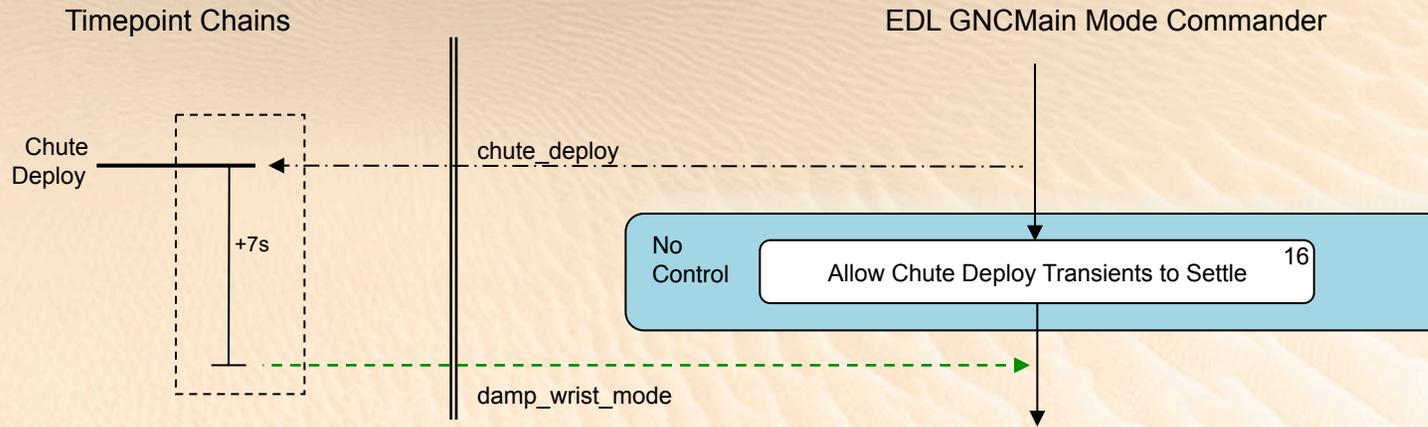


EDL GNC Main Mode Commander: Straighten Up and Flight Right and Roll Slew





EDL GNC Main Mode Commander: Chute Deploy Trigger

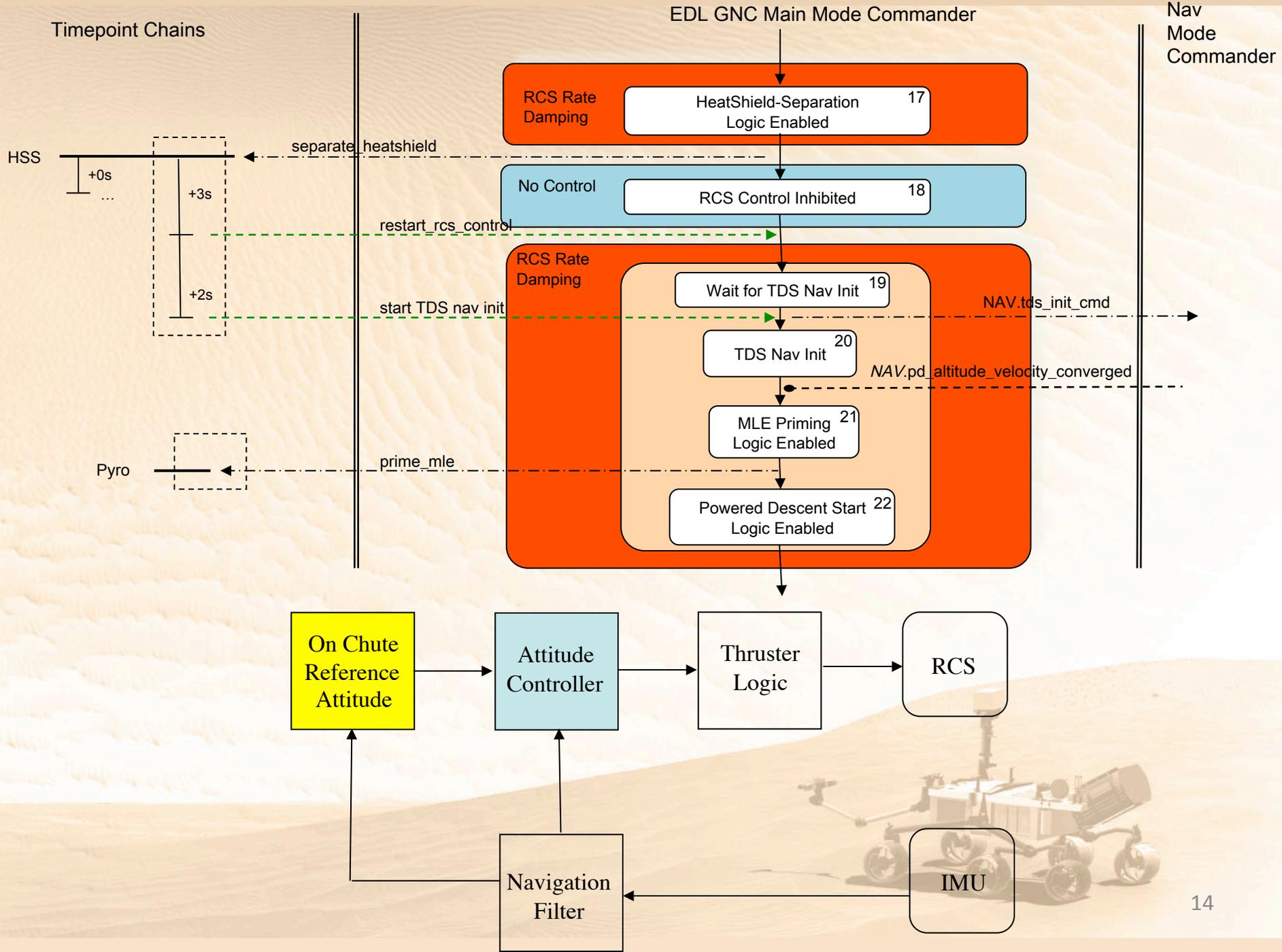


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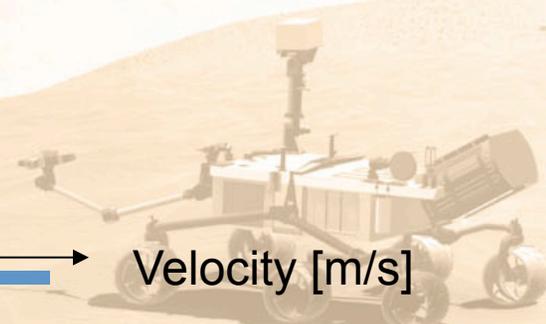
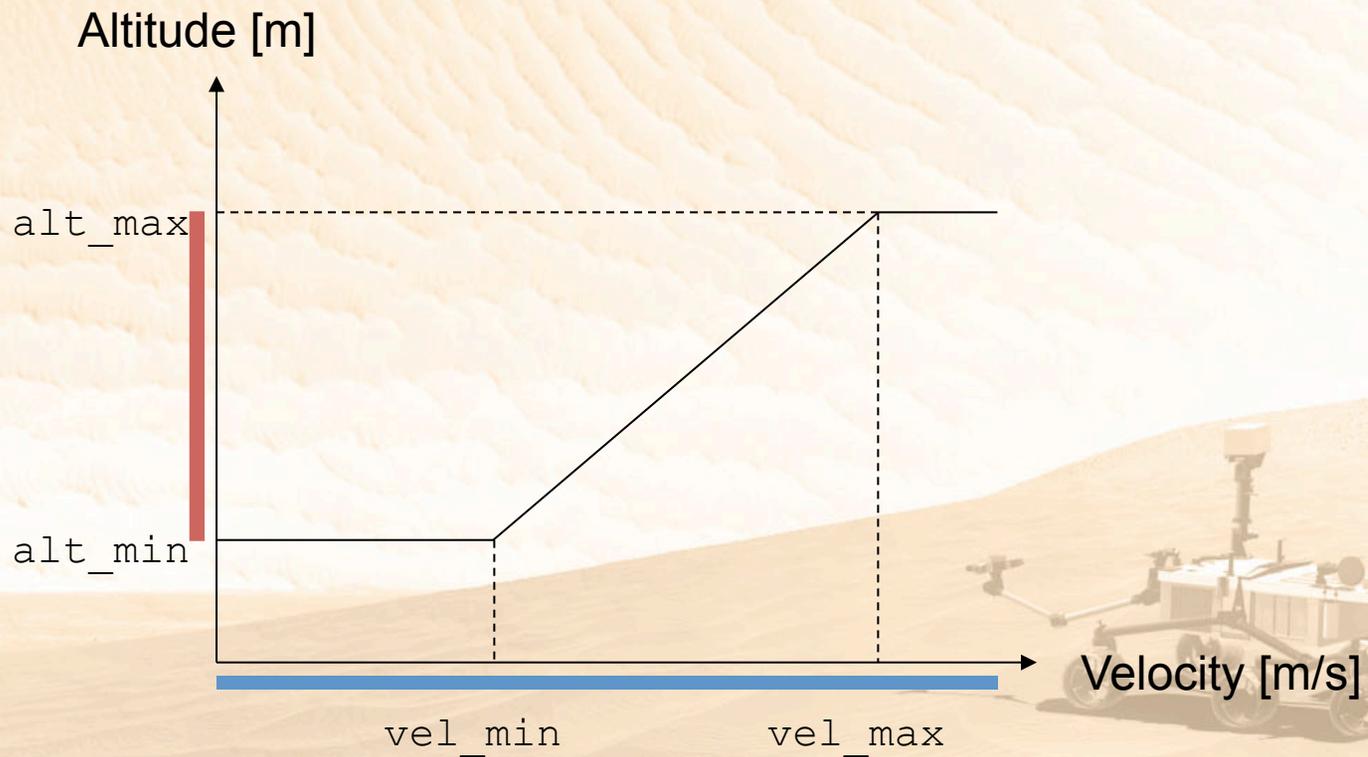
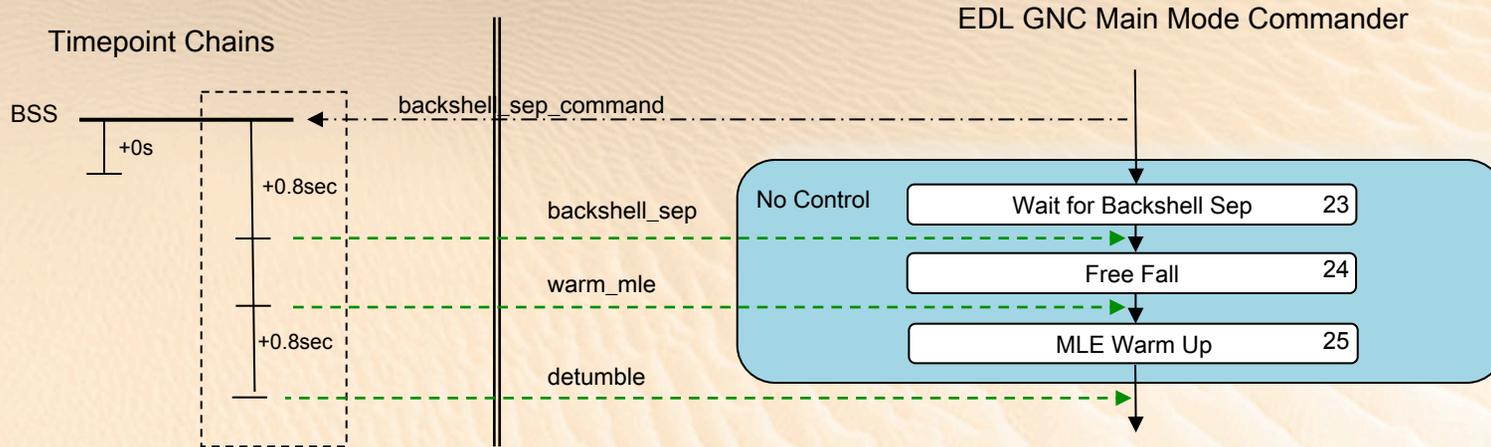


EDL GNC Main Mode Commander: Parachute phase



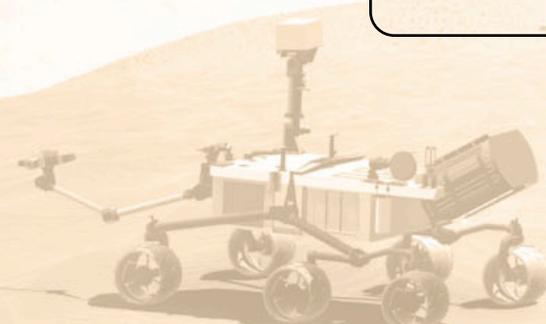
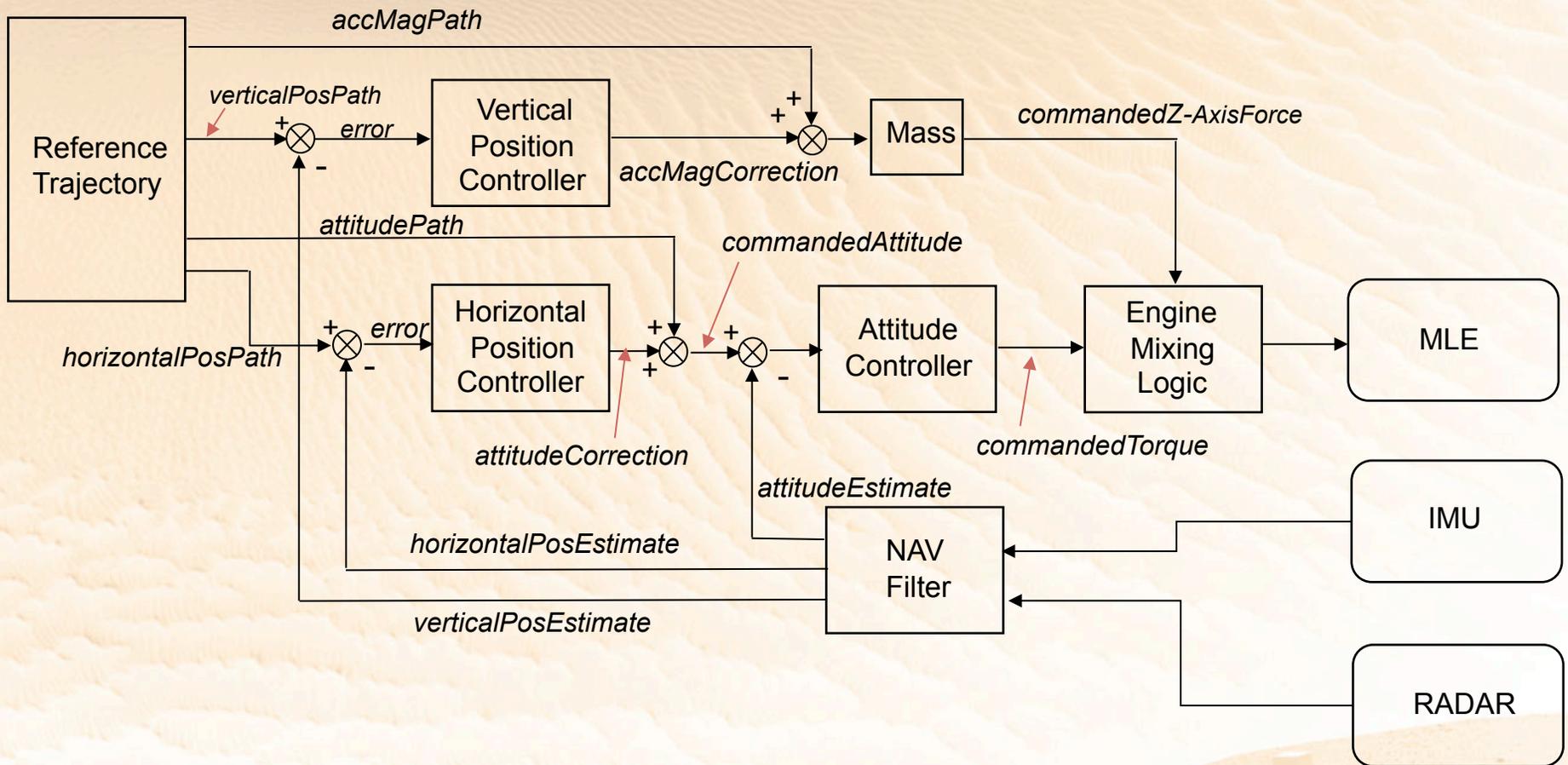


EDL GNC Main Mode Commander: Backshell separation





MSL Entry, Descent, and Landing



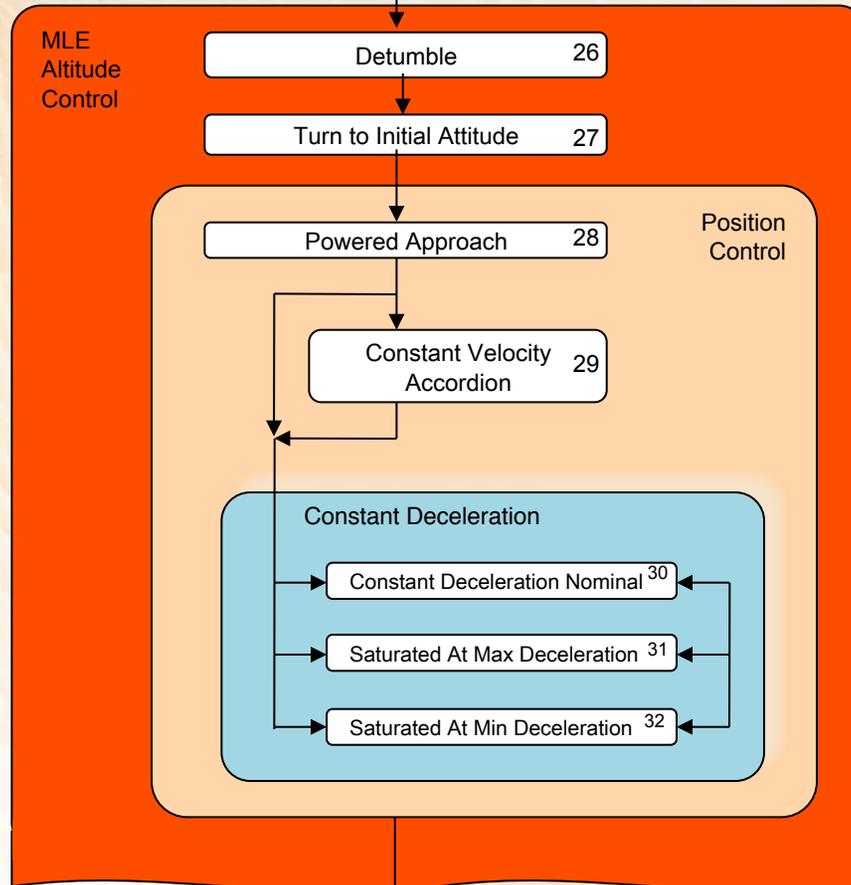


EDL GNC Main Mode Commander: Powered Descent phase

Timepoint Chains

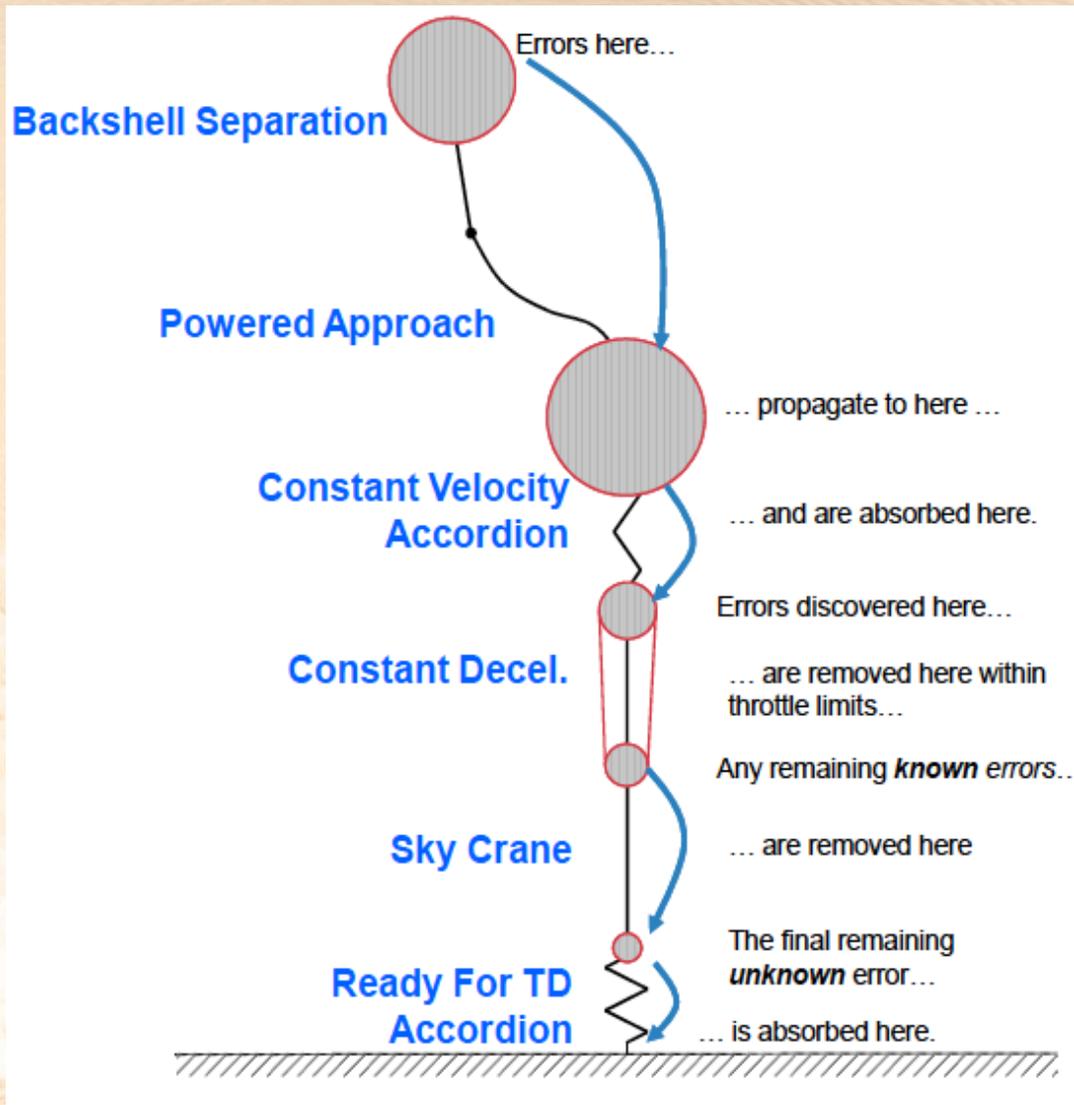
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EDL GNC Main Mode Commander





MSL Powered Descent Altitude Error Strategy

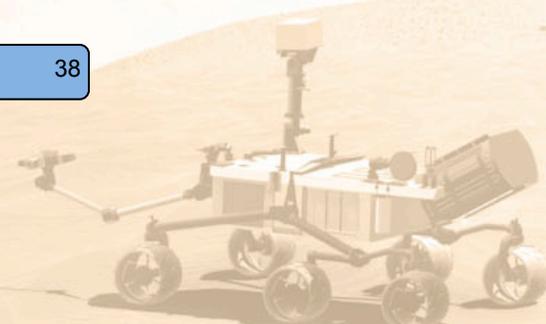
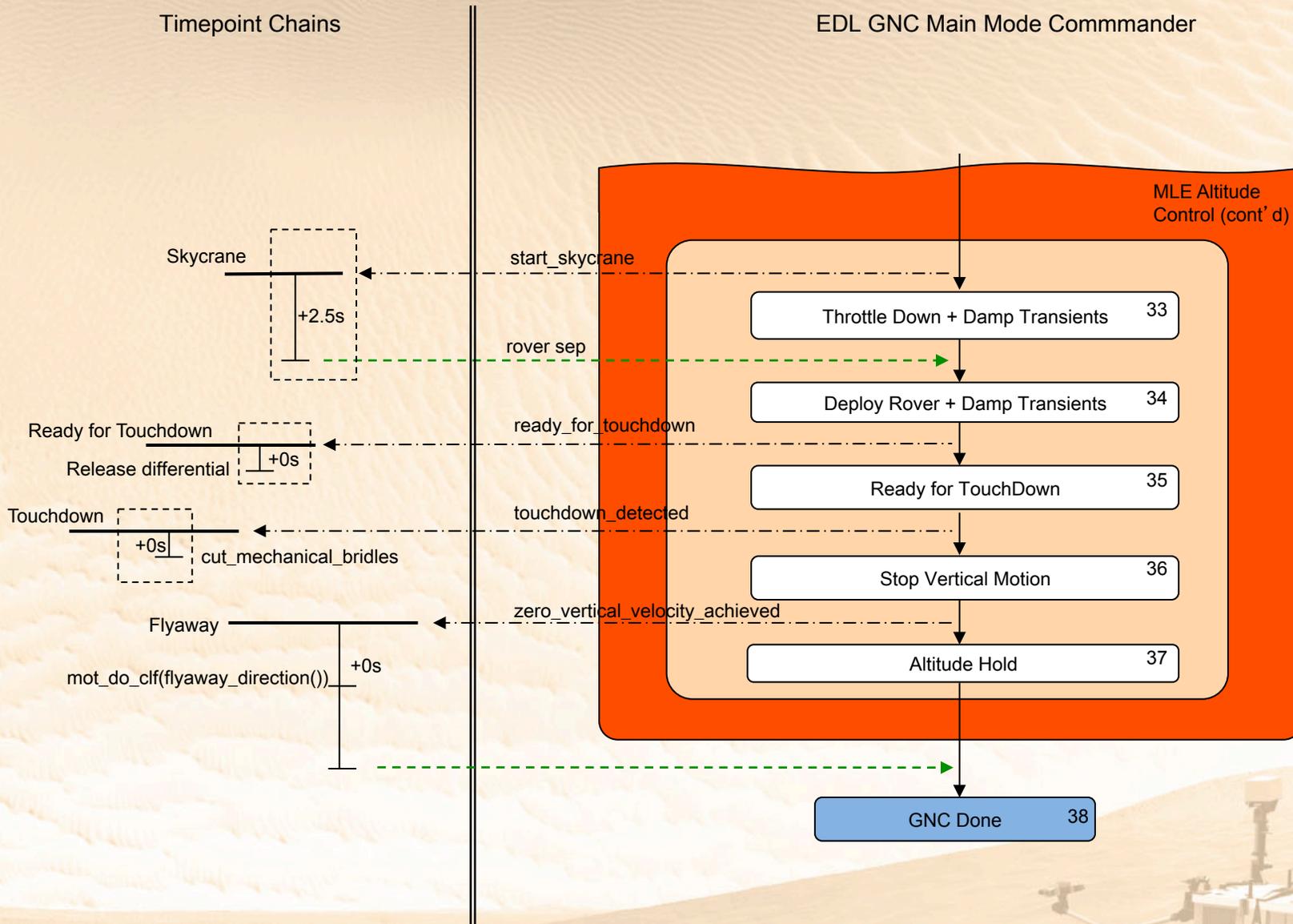


- **Altitude errors are due to:**
 - Radar measuring the terrain in the vicinity of the landing site.
 - Radar measurement errors
- **Errors are corrected via trajectory replanning capability**
 - **At mode transitions (nominal)**
 - **When large errors are encountered (off-nominal)**



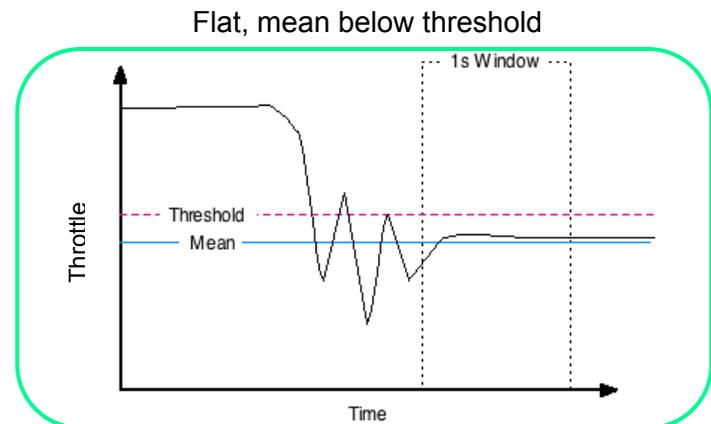
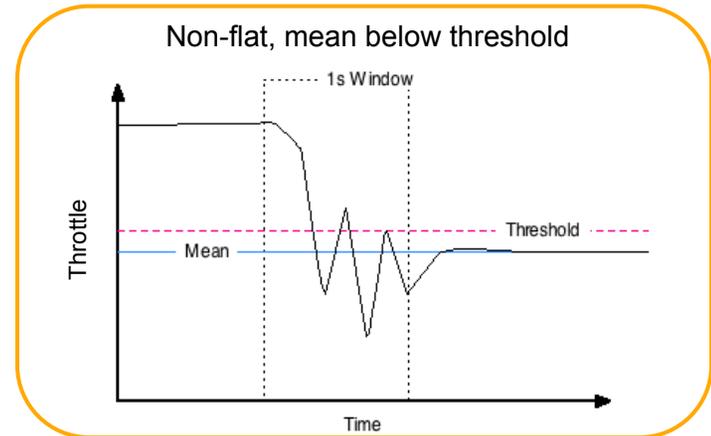
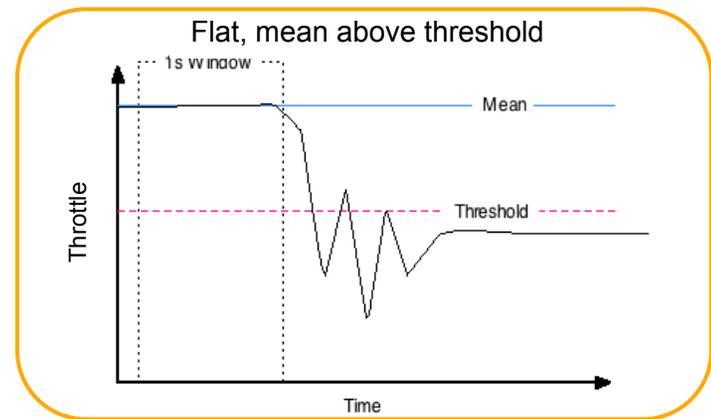
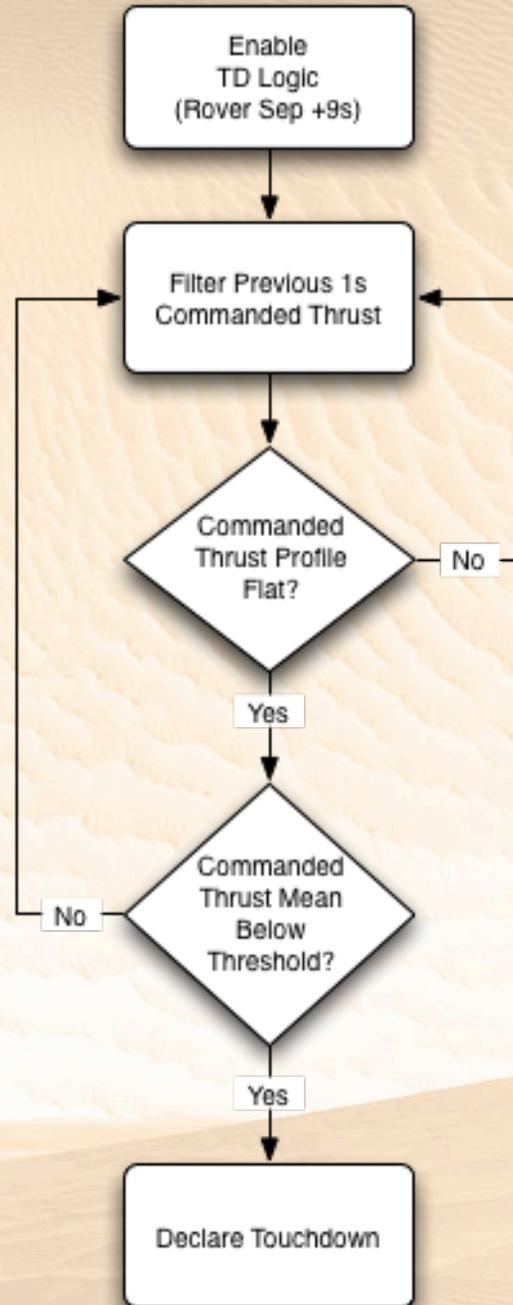
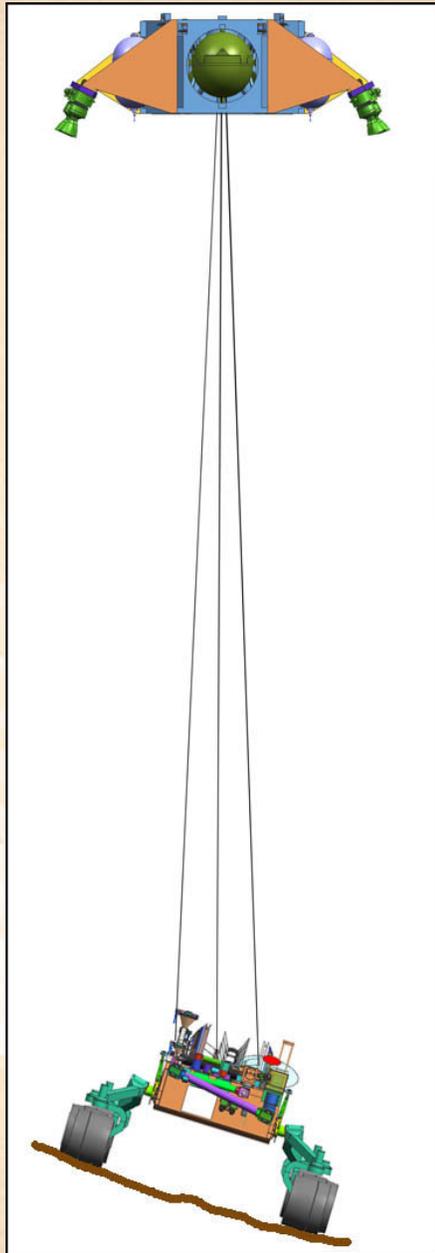


EDL GNC Main Mode Commander: SkyCrane phase





EDL GNC Main Mode Commander: Touchdown Trigger





References

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Mars Science Laboratory

<http://mars.jpl.nasa.gov/msl>

Mission Video

<http://www.jpl.nasa.gov/video/index.cfm?id=979>



Liftoff 11.25.2011*
Landing 8.6.2012*



*predicted