Mars Science Laboratory EDL Terminal Descent Strategy and Challenges

Steven W. Sell

Jet Propulsion Laboratory

California Institute of Technology

Pasadena, CA USA

7th International Planetary Probe Workshop

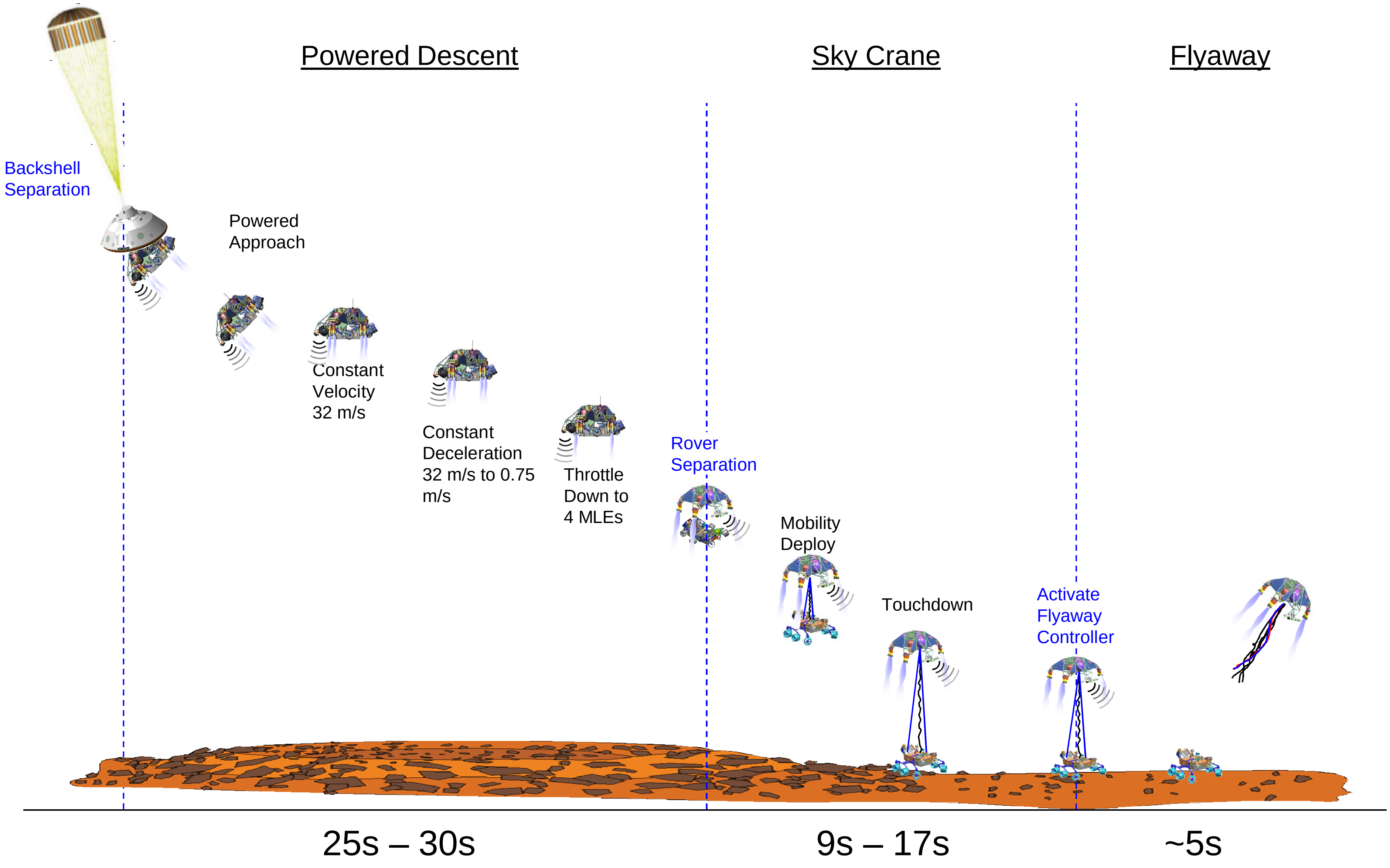
14-18 June 2010

Barcelona, Spain

Introduction / Descent Methodology

- The MSL Terminal Descent strategy divides terminal descent into deterministic and more easily analyzable segments
- Implements a Mid-Point Correction style guidance
  - Errors are cleaned up in distinct locations (accordions) which can be bounded by error budgets
- The implemented style allows graceful degradation

MSL Terminal Descent



Powered Descent Overview

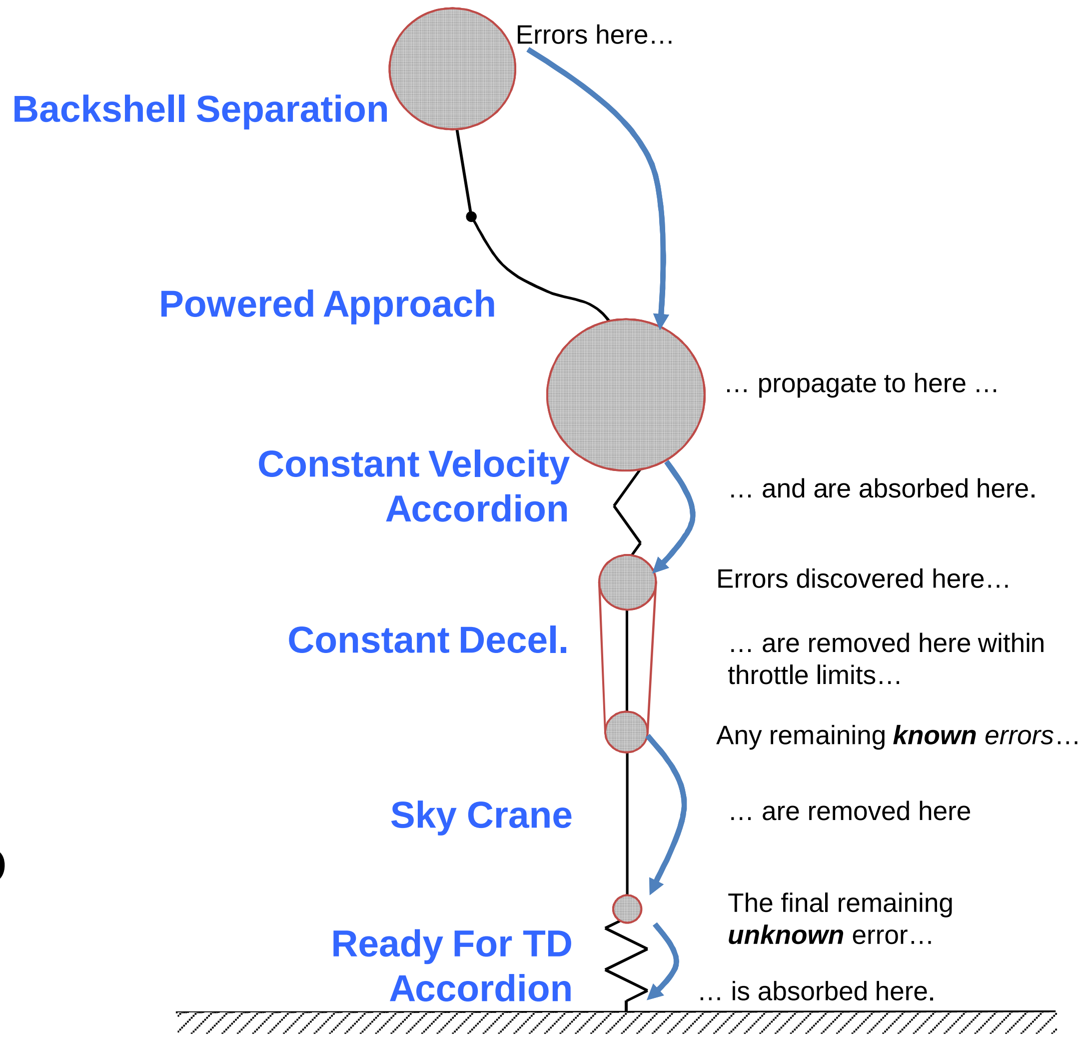
- Powered descent begins at backshell separation
  - Land engine priming begins ~10s prior to backshell separation
- Consists of four sub-segments
  - Powered Approach
    - Uses radar for velocity only (i.e., stop looking for the ground)
    - Polynomial 2-point boundary value guidance trajectory
    - Includes a 300 m divert maneuver for backshell avoidance
    - Brings the PDV to vertical flight at 32 m/s
  - Constant Velocity
    - Use radar altimetry
    - Adjusts for ±100 m altitude error at BSS
  - Constant Deceleration
    - Slow to Skycrane velocity of 0.75 m/s
      - Velocity maintained throughout skycrane
  - Throttle Down
    - Throttle 4 “inboard” MLEs to near-shutdown (1% throttle)
    - After throttle down allow 2.5 s of settling time
- Powered Descent ends at rover separation from the Descent Stage

Sky Crane / Flyaway Overview

- Sky Crane begins at the command for rover separation issued by the GNC mode commander
- Descent Stage maintains 0.75 m/s vertical descent rate throughout Sky Crane segment
- Rover is lowered on the BUD to 7.5 m below the Descent Stage
- Rover mobility deployed while rover being lowered on BUD
- DS continues descent until post-touchdown state is detected
- After touchdown is declared, transition to Flyaway begins
  - DS slows to 0 m/s
  - Control transferred to DMCA
  - Umbilical is cut
  - Flyaway starts
- EDL ends when all Flight System components have zero Kinetic Energy

PD Error Correction Methodology

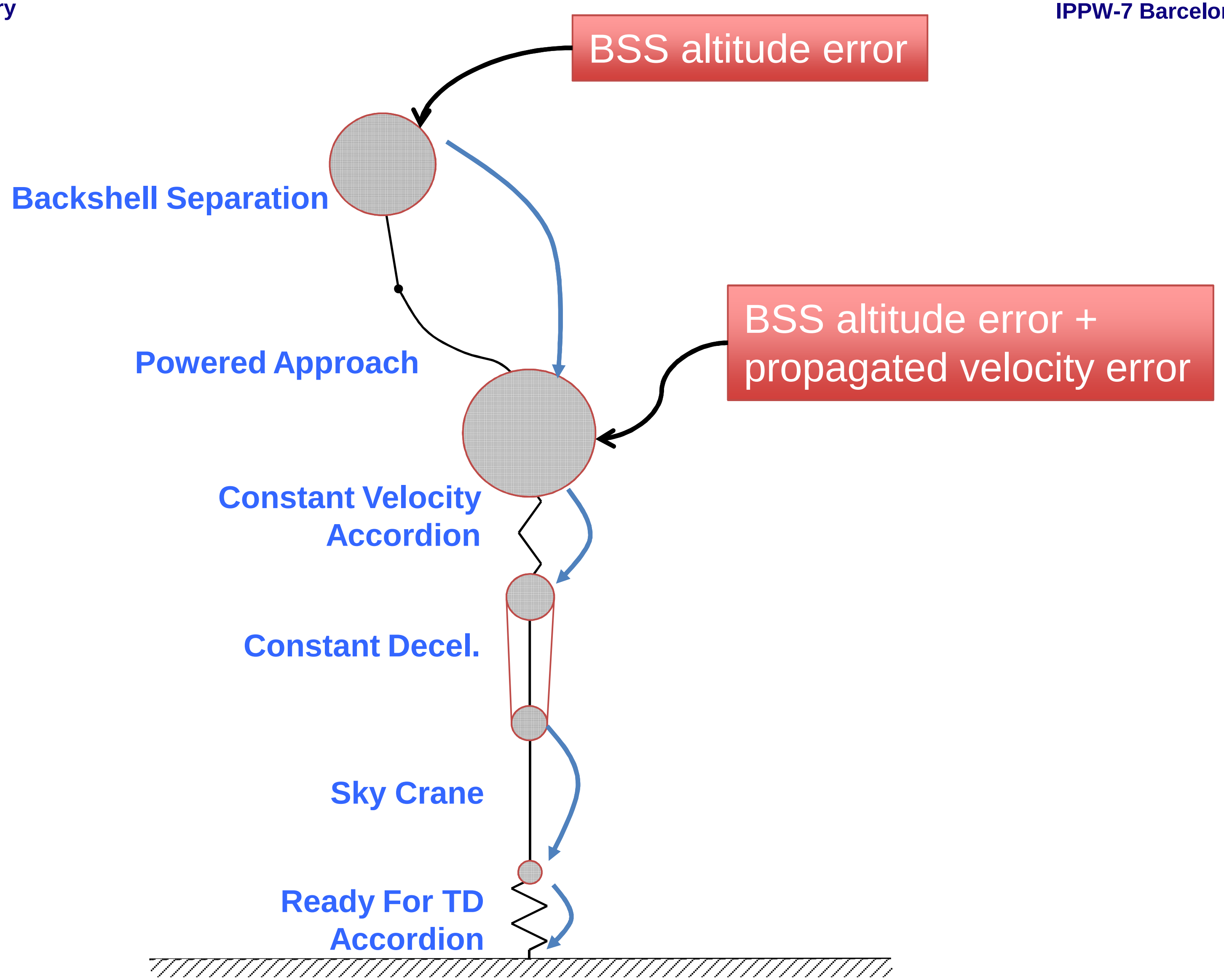
- During Powered Descent, altitude errors are absorbed in two accordions
  - Constant Velocity accordion to correct for errors at BSS
  - Ready for TD to correct for altitude errors at Sky Crane start
- Each accordion is sized based on the expected errors from the preceding segment(s)
- Additionally, errors discovered during Constant Deceleration are corrected in within CD and Sky Crane phases



Backshell Separation Errors

- The constant velocity accordion absorbs the altitude error that existed at backshell separation as well as the propagated velocity error throughout powered descent
- The size of the CV accordion is comprised of two sources of error
  - TDS
    - Velocity & Slant Range measurement
    - Antenna Alignment
  - Terrain
    - Terrain relief between TDS illumination spots and the eventual touchdown point
      - Flight path angle
      - Wrist Mode
- The accordion is sized to handle both the case where the surface is closer or farther away by the error amount

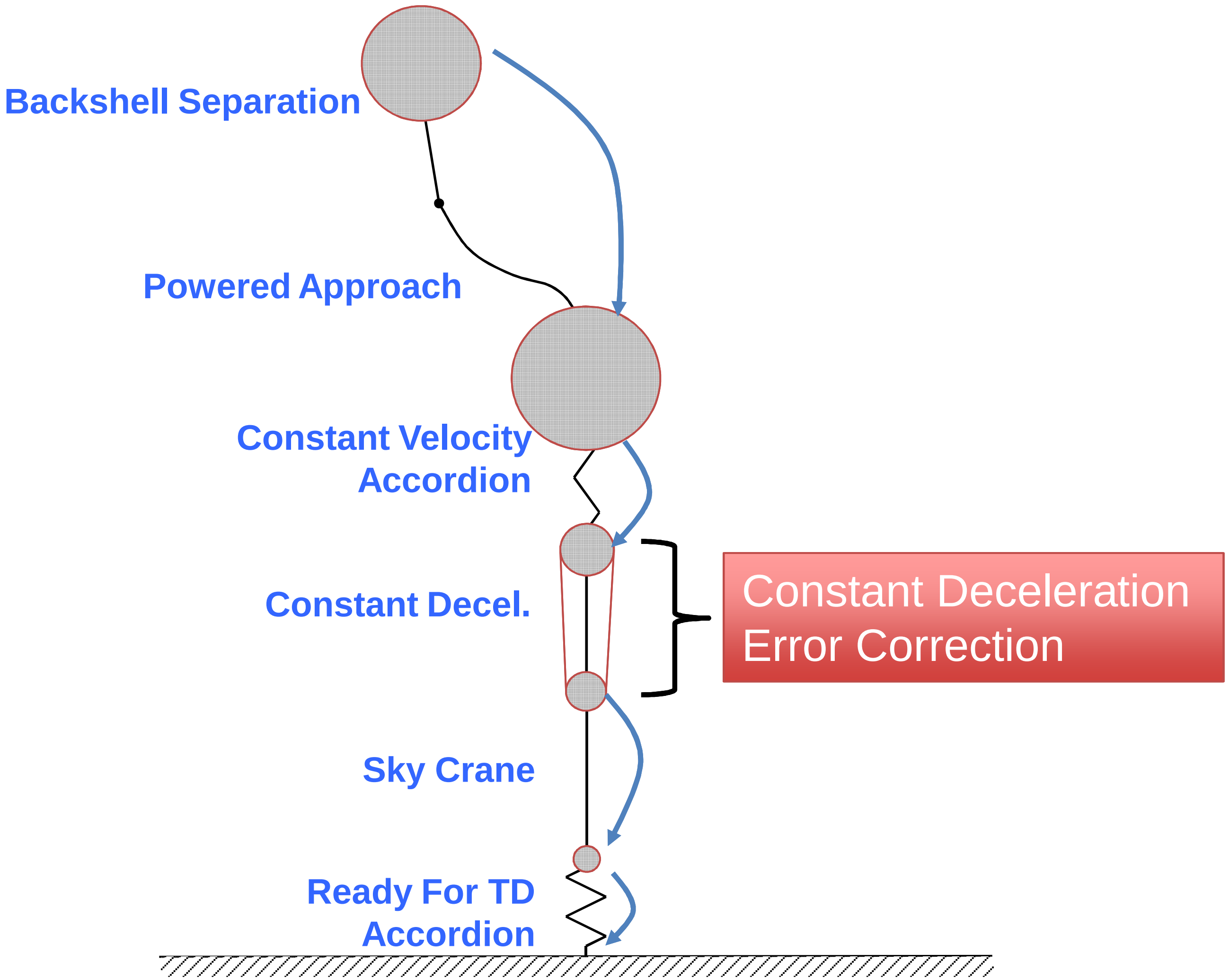
PD Error Correction Methodology



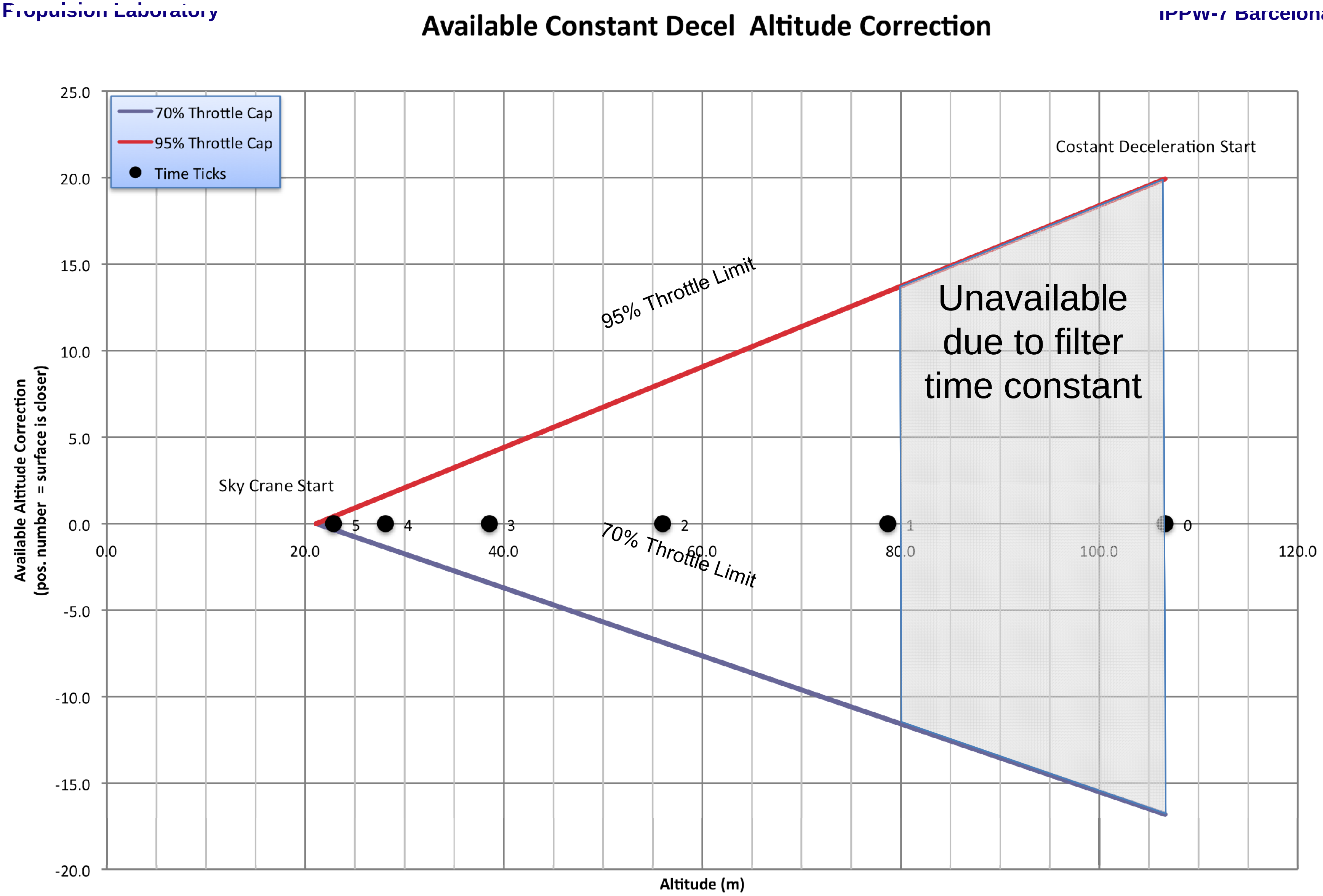
Constant Deceleration

- The exit from CV to CD phase is on an altitude trigger
- There will be errors in the altitude estimate due to TDS performance and look angle
  - These are maximized when the end of powered approach phase results in little or no CV phase
    - Attitude of the PDV is changing from the divert maneuver
- To handle this situation, the CD phase incorporates the ability to replan the remainder of CD when the surface estimate changes by more than a prescribed amount (flight parameter)
- CD is planed nominally at 80% throttle, the replanning would be allow to use between 70% and 95%
- If replanning would require throttle setting outside of this range, the remainder of the error is handled in Sky Crane

PD Error Correction Methodology



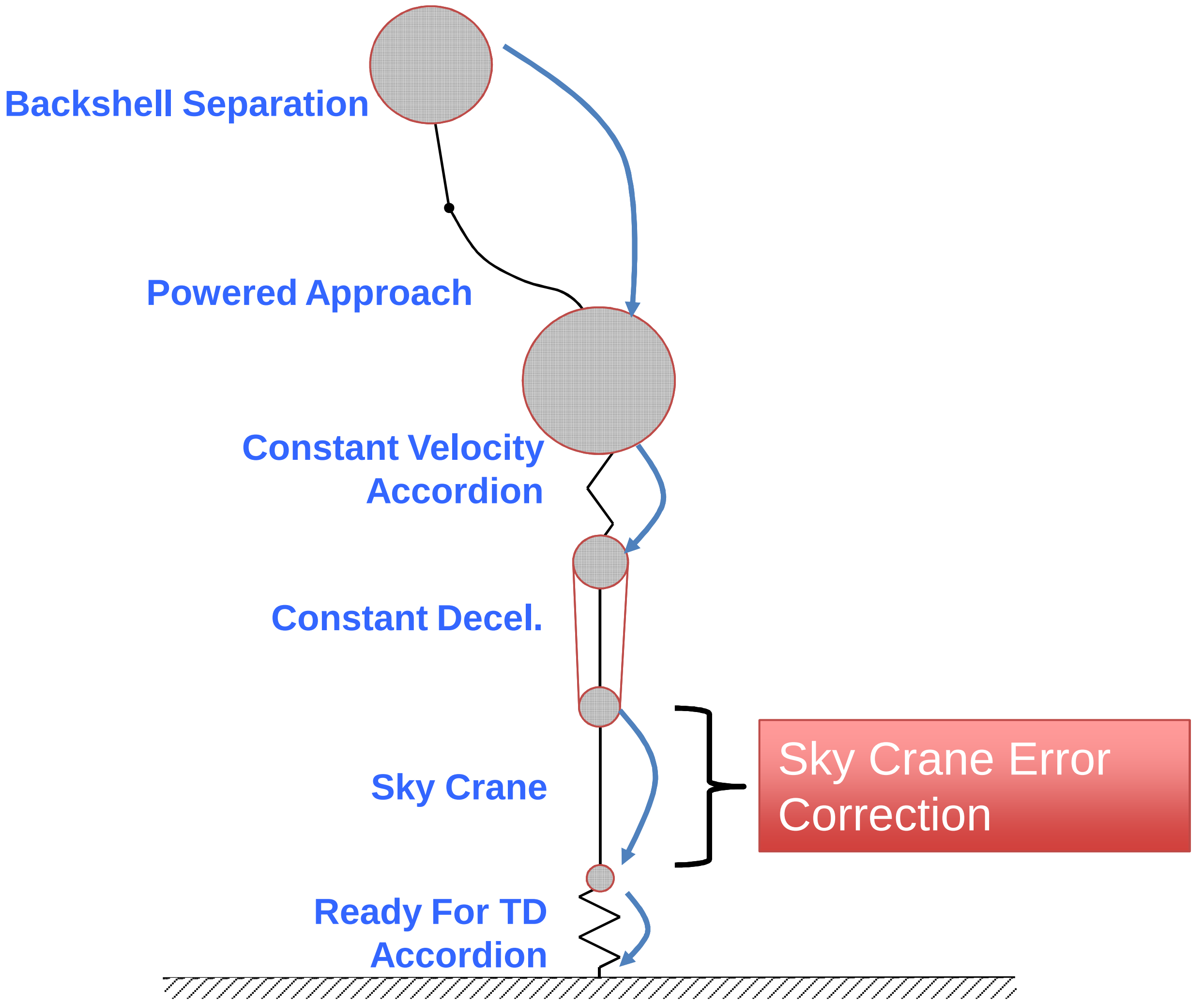
How much error can be corrected?



Sky Crane

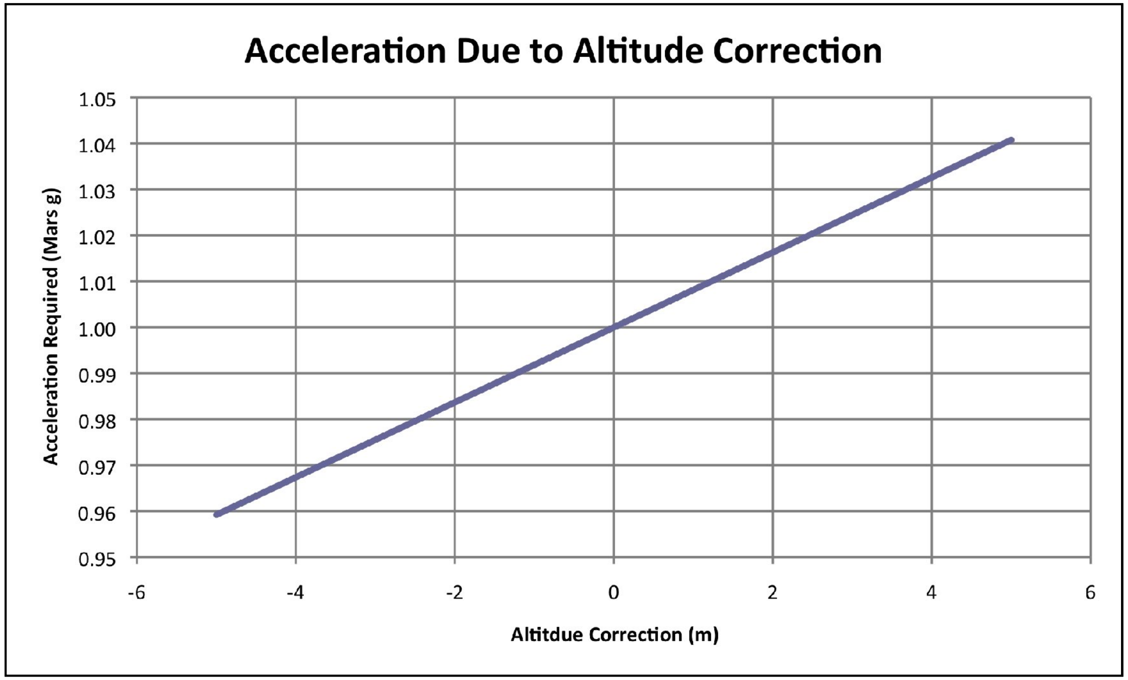
- Sky Crane nominally starts at an altitude of 21m and maintains a constant vertical velocity of 0.75 m/s targeting a “Ready for TD” condition 3m above the surface
- In the case where a *known* altitude error exists at Sky Crane Start, a profiled trajectory can be used to correct this altitude error and meet the “Ready for TD” condition 3m above the surface
- The impact of this profile to the system is a few percent deviation in the sensed acceleration

PD Error Correction Methodology

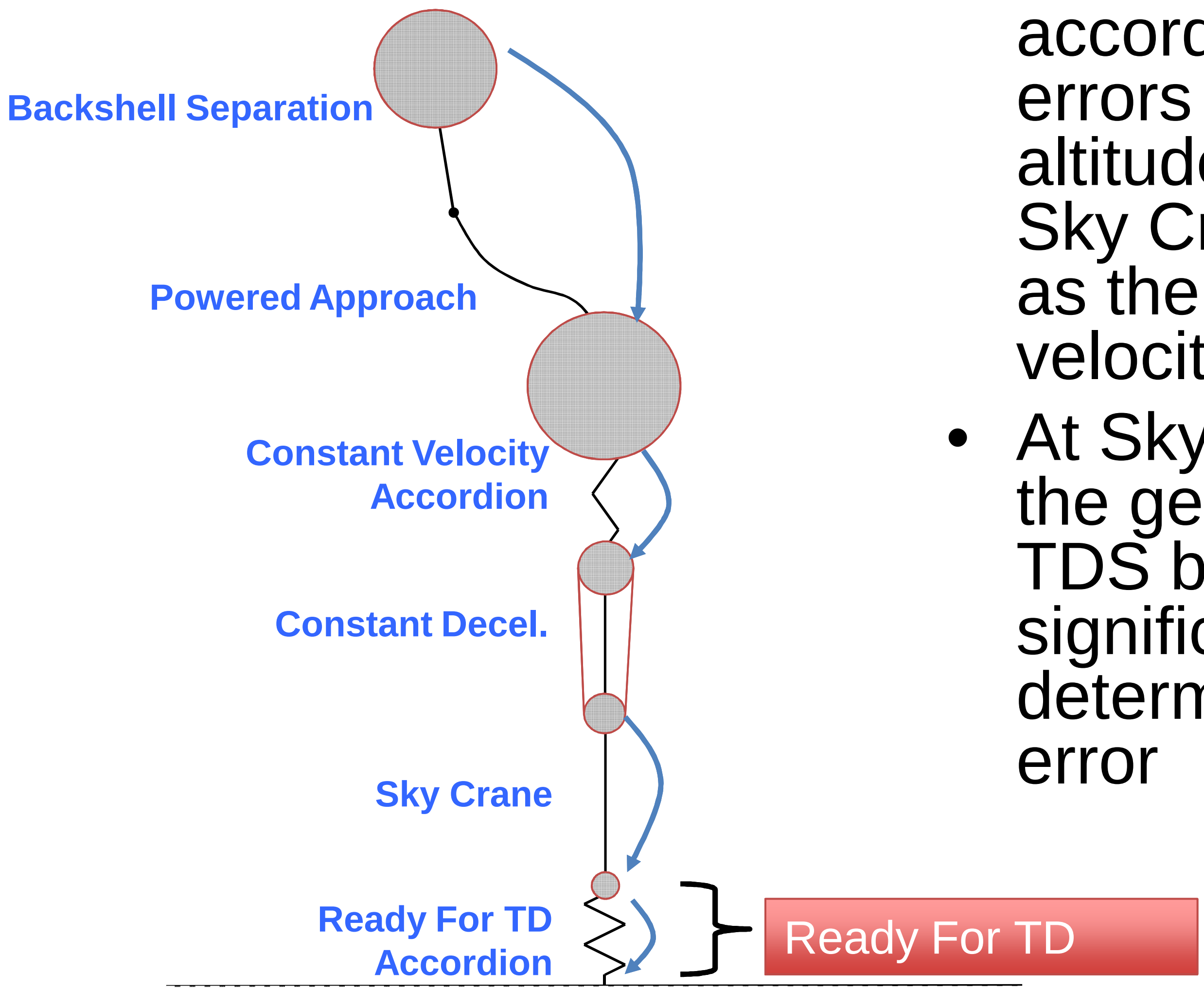


Known SC Altitude Error Correction

- The amount of error correction available has minimal impact on system sensed acceleration
- For example, can correct 5m of error with less than 4% change in g-level

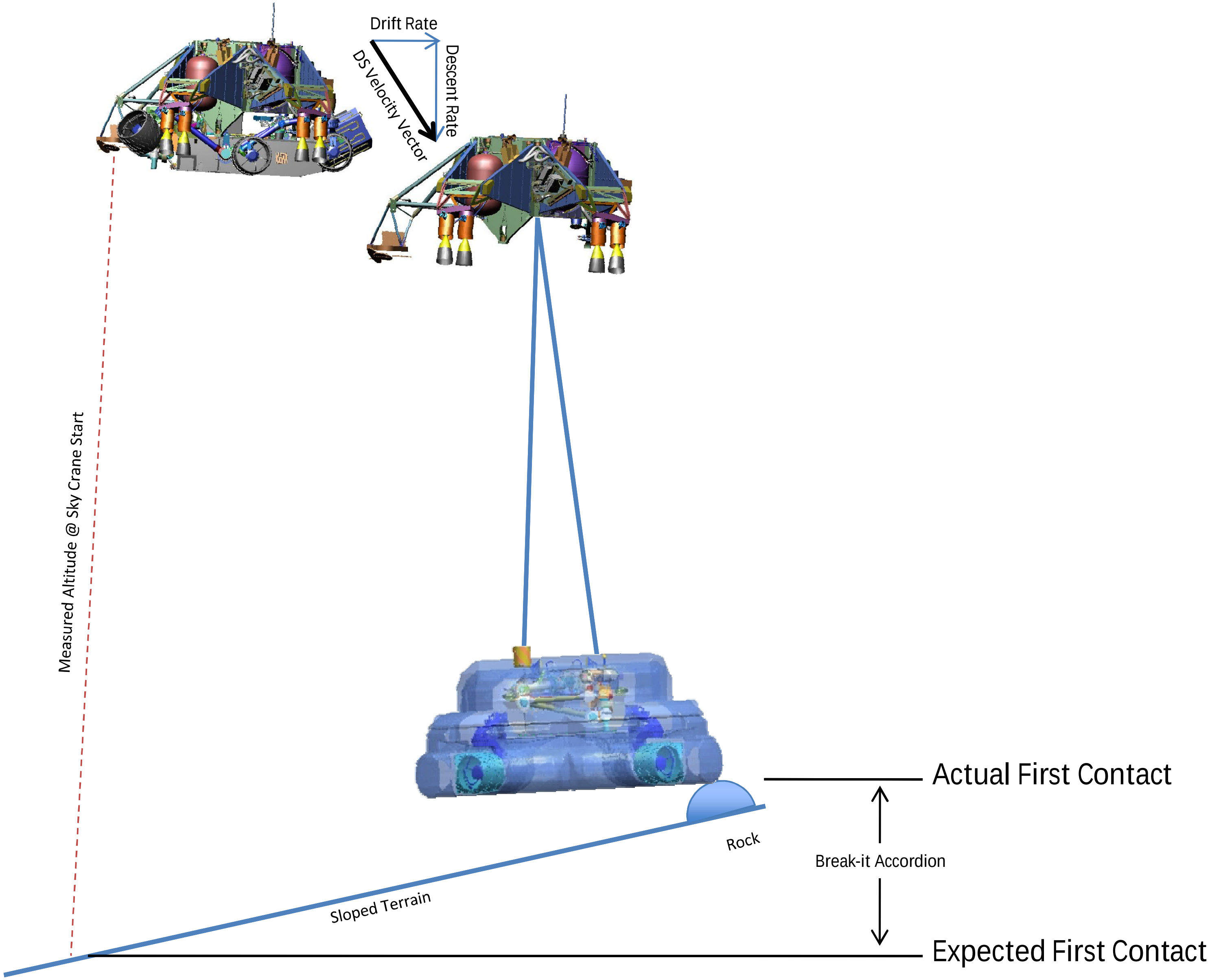


Ready for TD Accordion

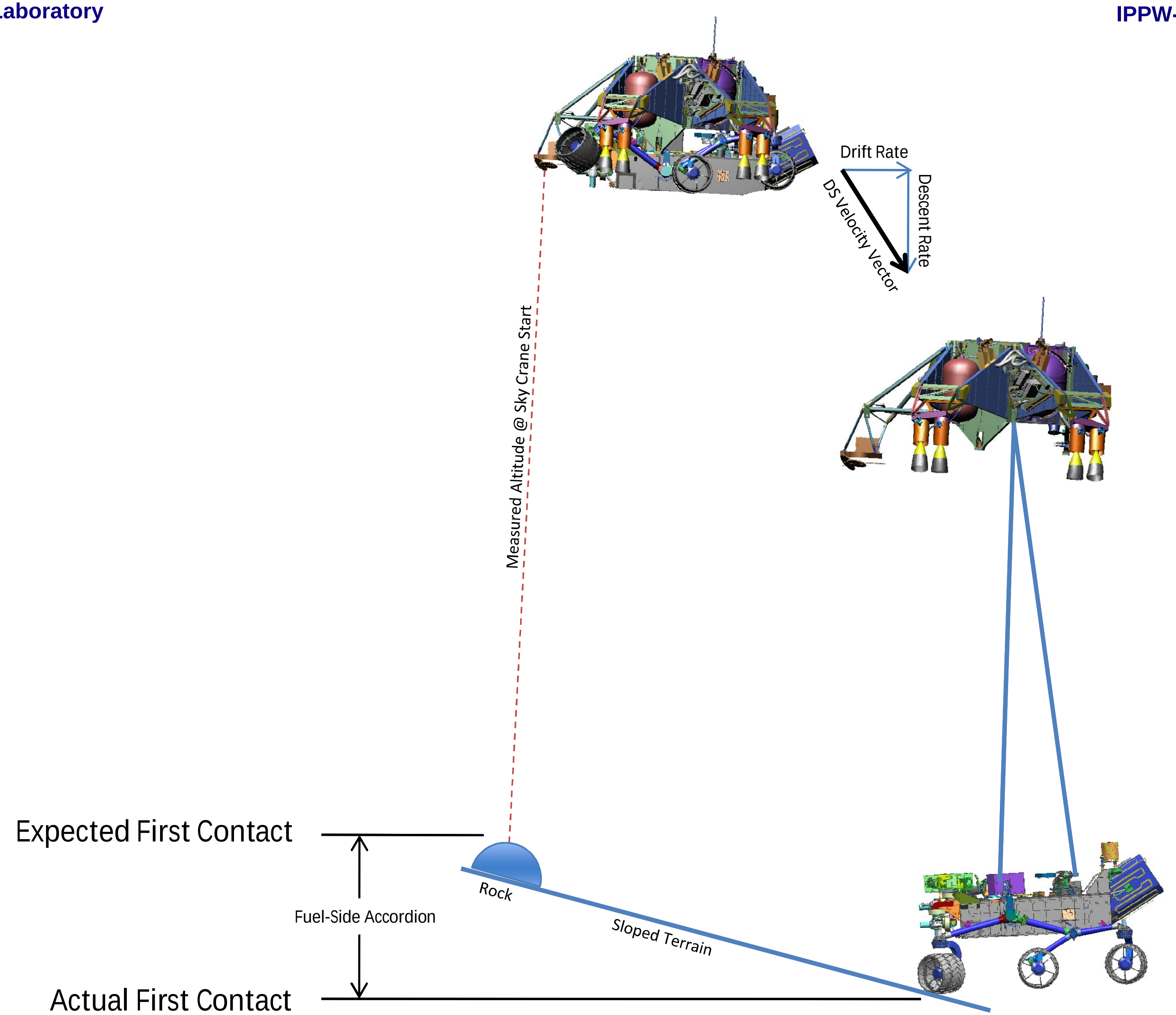


- The ready for TD accordion absorbs the errors that exist in altitude knowledge at Sky Crane start as well as the propagated velocity error
- At Sky Crane altitudes the geometry of the TDS becomes significant in determining the altitude error

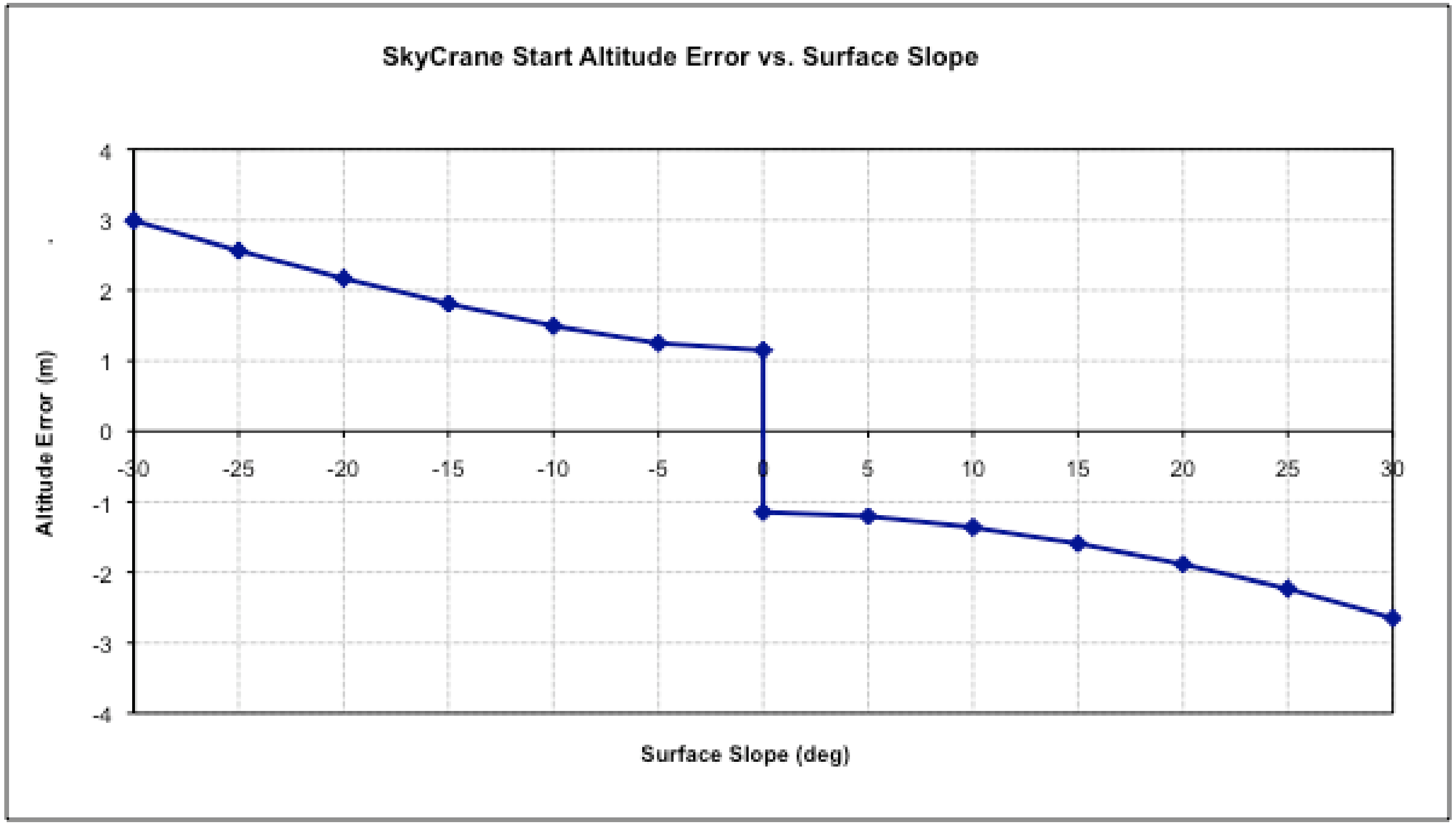
Early Touchdown Geometry



Long Accordion Geometry



Ready for TD Accordion Sizing



Conclusions

- The MSL Terminal Descent strategy divides the descent into deterministic and more easily analyzable segments
  - Risk can be traded between the segments depending on the risk posture of the project
- Errors are cleaned up in distinct locations (accordions) which can be bounded by error budgets
- For errors which are not handled in the accordions, the system shows graceful degradation