



Approach and Entry, Descent, and Landing Operations

Allen Chen, Martin Greco, Tomas Martin-Mur,
Brian Portock, and Adam Steltzner

AIAA/AAS Space Flight Mechanics Meeting
February 13, 2013

...didn't this thing land itself?

Three primary objectives for approach/EDL operations:

- Get the spacecraft ready to do EDL
- Get to the right place at the right time
- Tell the spacecraft what it needs to know



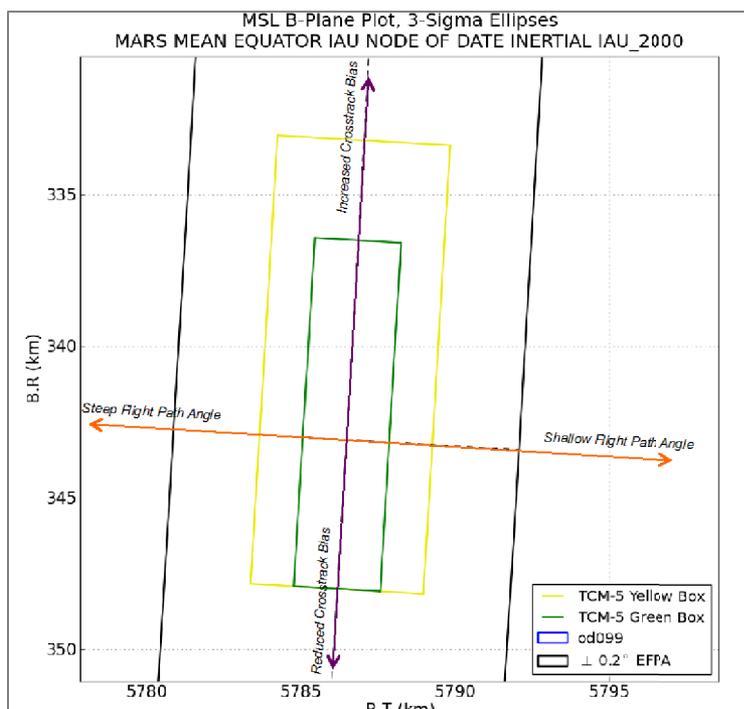


Getting the Spacecraft Ready



- Layered EDL preparation activities on top of “normal” cruise activities during the last month
- Performed hardware checkouts: radar, throttle valves, etc.
- Conducted cold boot activities
 - Cleared flash memory and perform cold processor resets of both strings
 - Intended to match ground test conditions in flight
- Loaded flight parameters: EDL and early surface
- Started power and thermal conditioning for EDL
 - Charged batteries
 - Warmed up propulsion system

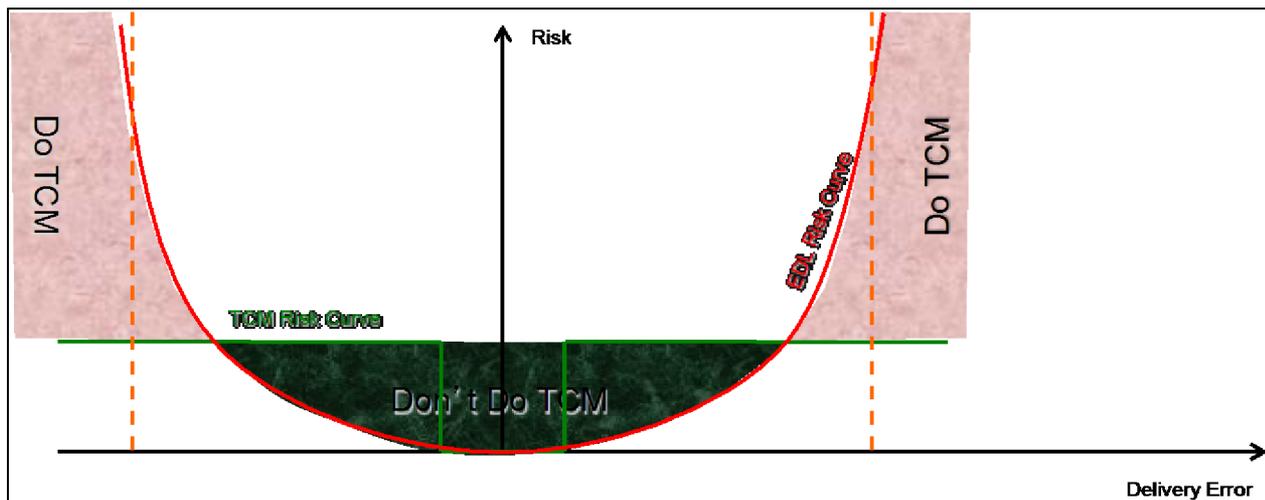
- Although MSL has guided entry, it's still sensitive to delivery error
 - Entry guidance control authority isn't unlimited
 - Altitude and landing precision impacted
 - Can increase cruise stage recontact risk



Error	EDL System Impact
Steep Flight Path Angle	<ul style="list-style-type: none"> • Reduced entry guidance control authority • Increased guidance prediction error • Risk of guidance saturation • Loss of altitude/timeline margin • Reduced testing experience
Shallow Flight Path Angle	<ul style="list-style-type: none"> • Reduced entry guidance control authority • Increased guidance prediction error • Reduced testing experience
Reduced Crosstrack Bias	<ul style="list-style-type: none"> • Increased cruise stage recontact risk • Reduced testing experience
Increased Crosstrack Bias	<ul style="list-style-type: none"> • Reduced testing experience • Slightly reduced entry guidance control authority

- Also, closer to target = closer to majority of tested/simulated conditions

- Trajectory Correction Maneuvers (TCMs) during approach are used to put the spacecraft back on target
- Executing TCMs incurs operational risks
 - Potential for human error, spacecraft hardware failures, etc.
 - Need to consider spacecraft health and flight team readiness in evaluating TCM risk
 - Typically not a function of maneuver size
- EDL risks increase non-linearly with delivery error





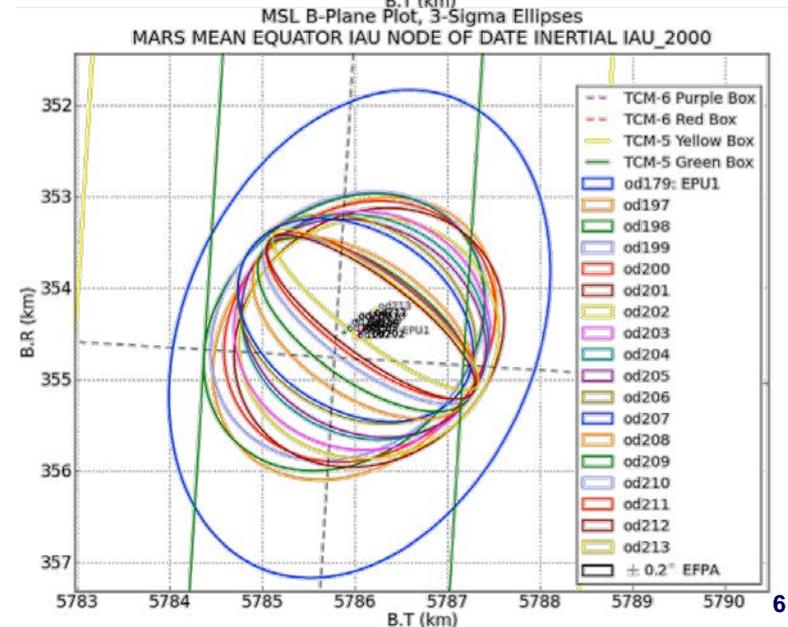
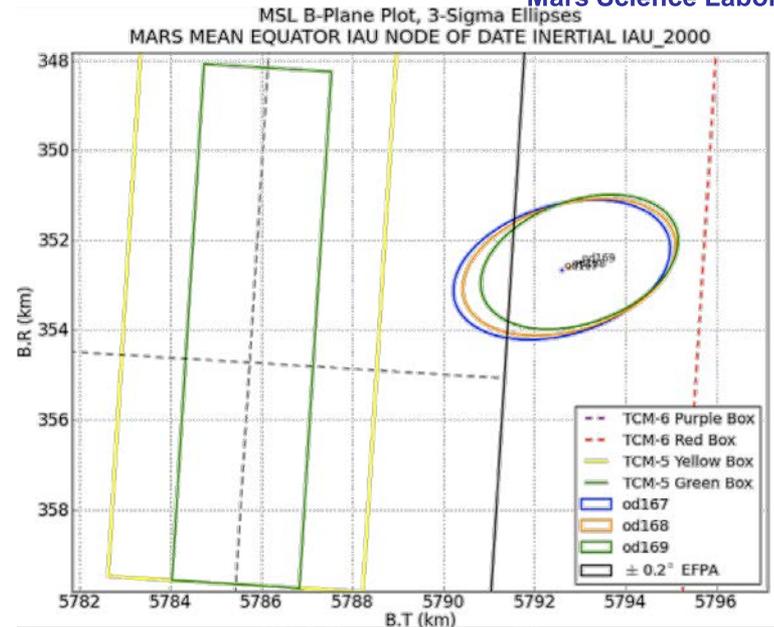
Getting to the Right Place on August 5th, 2012



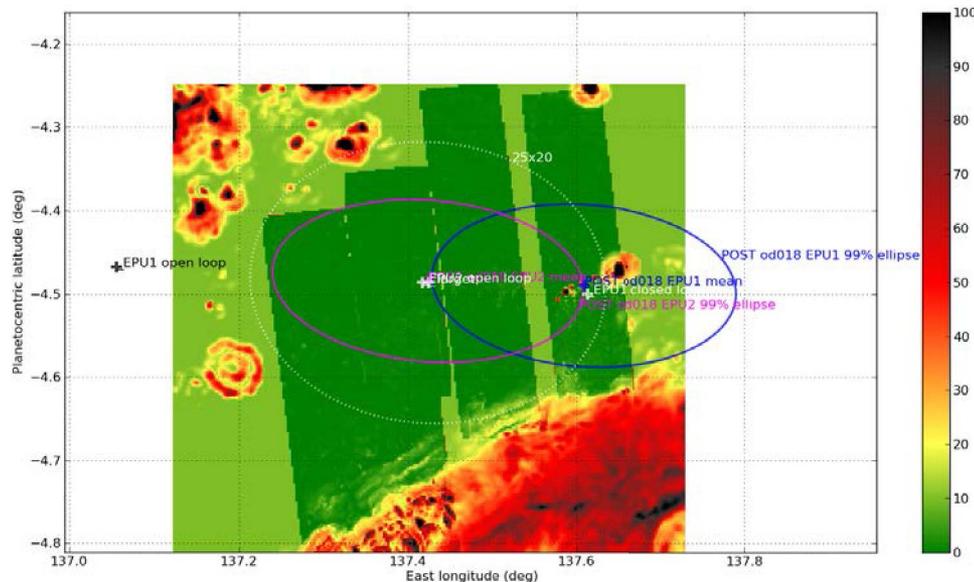
Mars Science Laboratory

EDL Team

- Conditions leading up to TCM-4 at E-8 days made the decision relatively simple
 - Clearly outside of established TCM criteria
 - Stable navigation solutions
 - Healthy spacecraft and well rested operations team
- Excellent TCM-4 execution and exceptional stability of navigation solutions afterwards made subsequent decisions simple
 - No further TCMs needed
- Very little residual delivery error for EDL to fly out

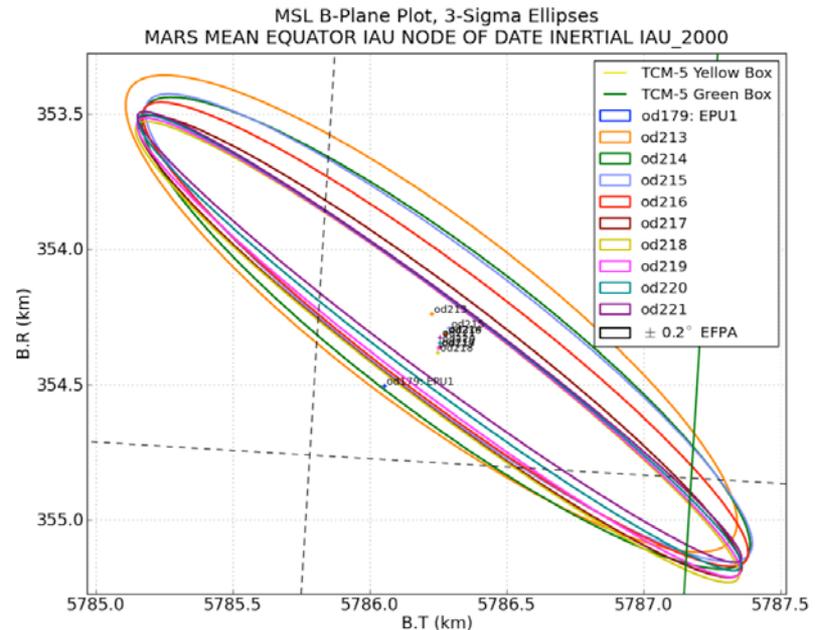
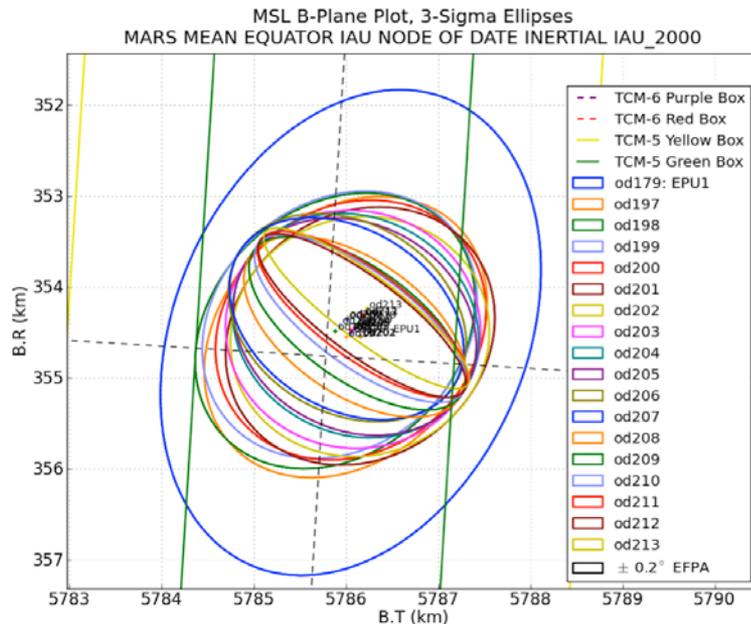


- Inclusion of entry guidance significantly increases the importance of good onboard state knowledge
 - Vehicle propagates from ground provided initial state
 - “Lying” to entry guidance directly impacts precision performance
- Best estimate of initial state from ground based navigation evolves with number of measurements, time, and proximity
- State errors usually result in shifts in landing ellipse, which may increase failure risk



- Team was prepared to build and uplink late state updates, if needed

- Navigation solutions were extremely stable following TCM-4, 8 days prior to entry
- Team was prepared to make all planned parameter updates, only one parameter load after TCM-4 was necessary
- State estimate uplinked to vehicle six days prior to entry only ~200 m from post flight reconstructed state!





Conclusion



- Flight team achieved its primary approach/EDL operations goals in weeks and days leading up to August 5
 - Vehicle readied for entry
 - TCM and parameter update decisions made using pre-gamed criteria
- Key decisions balanced spacecraft operational risk with future risk to be incurred during EDL
- Exceptional TCM execution and navigation performance greatly simplified approach activities
 - Team was prepared for much worse
- Executing the operations plan put in the spacecraft in a good position to succeed