A Recipe for Improving Landing Accuracy at Mars for Missions After MSL

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MSL System and EDL Flight Characteristics - 2012

Design Characteristics

- 4.5 m aeroshell
- Bank-angle Apollo aero-guidance
- Chute deploy based on velocity
- Lift/drag: .24
- Chute diameter: 21.5 m
- Chute mach #: 2.1
- Descent engines (8) mono prop. ISP = 225 sec
- Flight Profile Table (approx.)

	Altitude (m)	Speed (m/s)	fpa (deg)	Time (sec)
Entry	128,000	5,667	-16	0
Heading Alignment	15,500	1,100	+1	144
Chute Deploy	10,400	456	-16	253
Heat Shield Jettison	6,900	117	-52	292
Ignition	1900	86	-87	360
Touchdown	0	0	-90	375

- Radio navigation on approach

MSL 2012 Landing Accuracy Overview

- Fundamental MSL Landing Accuracy 2012 (3σ)
  - 10,000 to 12,000 m from nominal target
- Major independent contributing error sources (in order of magnitude)
  - Winds 6000 m
  - IMU orientation initialization error (.25°) 5000 m
  - Aero response uncertainties (aeroshell and chute) 3000 m
  - Atmospheric condition uncertainties 2500 m
  - Entry state errors 2500 m
  - IMU measurement noise 1000 m
- Fundamental Rover mass capability*
  (for a landing at MOLA – 1,460m) ~950 kg

(ROT-Based)+ Rover mass capability at zero MOLA landing ~770 kg
Expected+ Rover mass capability at zero MOLA in 2018 970 kg
*There may be margin in this value, but we will assume the margin to be zero
+ROT = Rule of Thumb

Steps for Improvement of Landing Accuracy
(in order of highest expected improvement factor/per rover mass impact)

Step (1)
Develop a program to improve the IMU attitude initialization error (at entry) by a factor of about 5, from ~.25° (3σ) to ~.05° (3σ).

The program needs to consist of analysis derived steps to be taken during mission development, ground testing, and flight testing phases. It may require a co-mounting of the IMU with a star tracker or celestial sensor, and in-flight imaging of fixed stars with celestial angular positions known to accuracies far better than .05°.

Anticipate accuracy gain:
This step should reduce the landing error contribution of the IMU attitude initialization error by a factor of 5, from about 5,000 m to about 1,000 m, leaving other errors to accumulate to about 8000 m.

Step (2)
Apply down range distance (instead of only velocity) to trigger parachute deployment.

Anticipated accuracy Gain:
Horizontal dispersions at landing decrease as the dependency on range triggering is increased and velocity dependence is decreased, improving touch down accuracy to about 3000 m as a full range trigger chute deploy scheme is approached. We assume here that the IMU orientation improvement step (Step 1) has been taken.

Step (3) (Accuracy Gains TBD)

(1) Refine Apollo guidance and chute triggering to optimize landing accuracy and elevation potential
(2) Look closely at MSL flight results including MEDLI measurements for data which might lead to error source model improvements
(3) Consider potential of other design changes
    a. Horizontally guided parachutes
    b. Met station on future landers to measure winds at future landing site
    c. Adjustments in EDL design, lift, chute diameter, mach #, reefing, etc.

Anticipated Gains Largely TBD

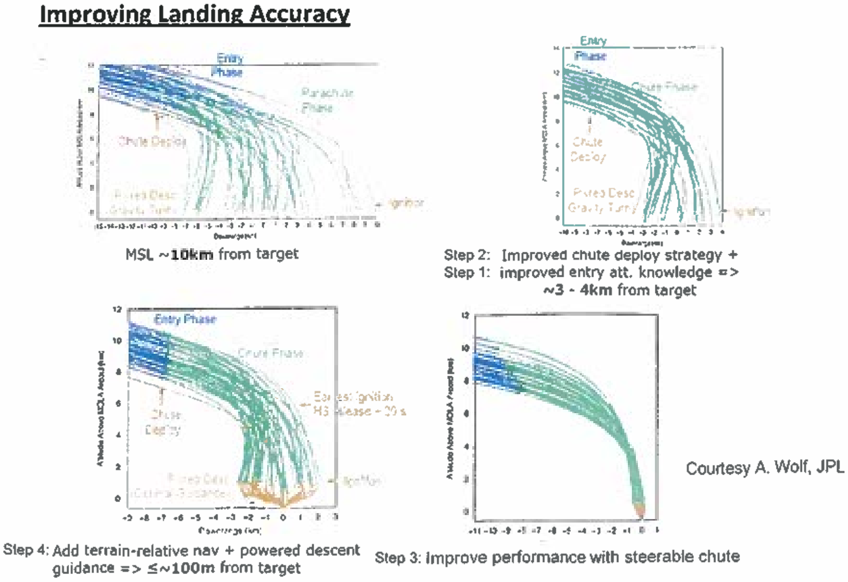
Step (4), after Steps 1 and 2
Apply additional fuel and horizontal thrusting during powered descent.

Anticipated Accuracy Gain:
This step has the potential to reduce the landing uncertainty from 3,000 meters to a negligible value, depending on the amount of additional fuel which is applied. Preliminary analysis indicates that pinpoint accuracy can be achieved with about 300 extra kilograms of fuel and associated fuel tank size and propulsion system increases. This can reduce the maximum rover mass for a MOLA = zero landing elevation to about 600 kg, unless going from Step 3 is realized.

__**Additional Possible Enhancement Steps**__

The previous four steps have provided a recipe for the path from today's 10-12 km landing accuracy in 2012 to pinpoint landing in the future. Partial accuracy improvement is of course possible with the taking of partial steps – e.g. partial fuel loading. These steps represent a straight-forward approach employing only must-do steps. Contributors to the recipe include Joel Benito, Jordi Casoliva, and Aron Wolf.

__**Improving Landing Accuracy**__



MSL ~**10km** from target

Step 2: Improved chute deploy strategy +
Step 1: improved entry att. knowledge =>
~**3 - 4km** from target

Step 4: Add terrain-relative nav + powered descent guidance => ≤~**100m** from target

Step 3: Improve performance with steerable chute