Jet Propulsion Laboratory
California Institute of Technology

The Future of Landing

Terrain Relative Navigation from Prototype to Mars 2020

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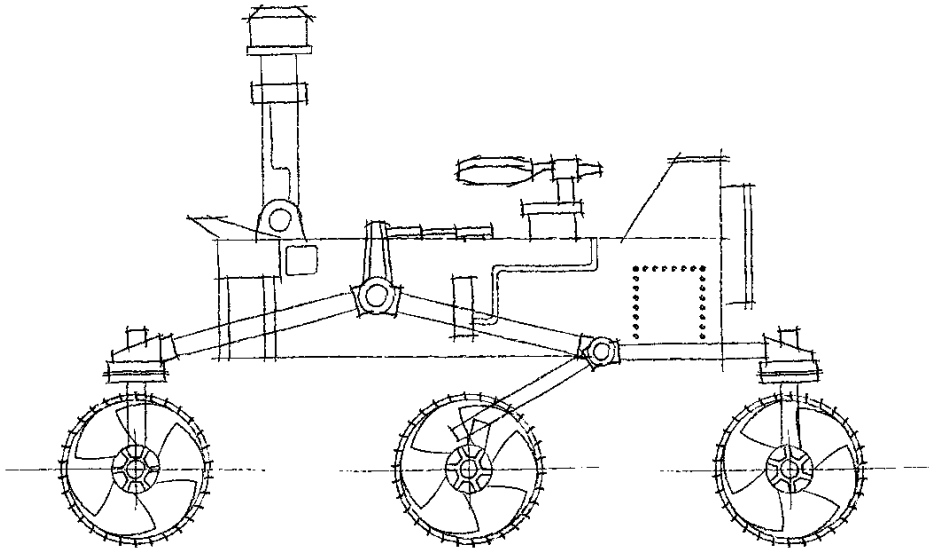
Paul Brugarolas, Jordi Casoliva, Allen Chen, Andrew Johnson, Swati Mohan

12th International Planetary Probe Workshop

Cologne, Germany

June 15th, 2015



Mars 2020 Project

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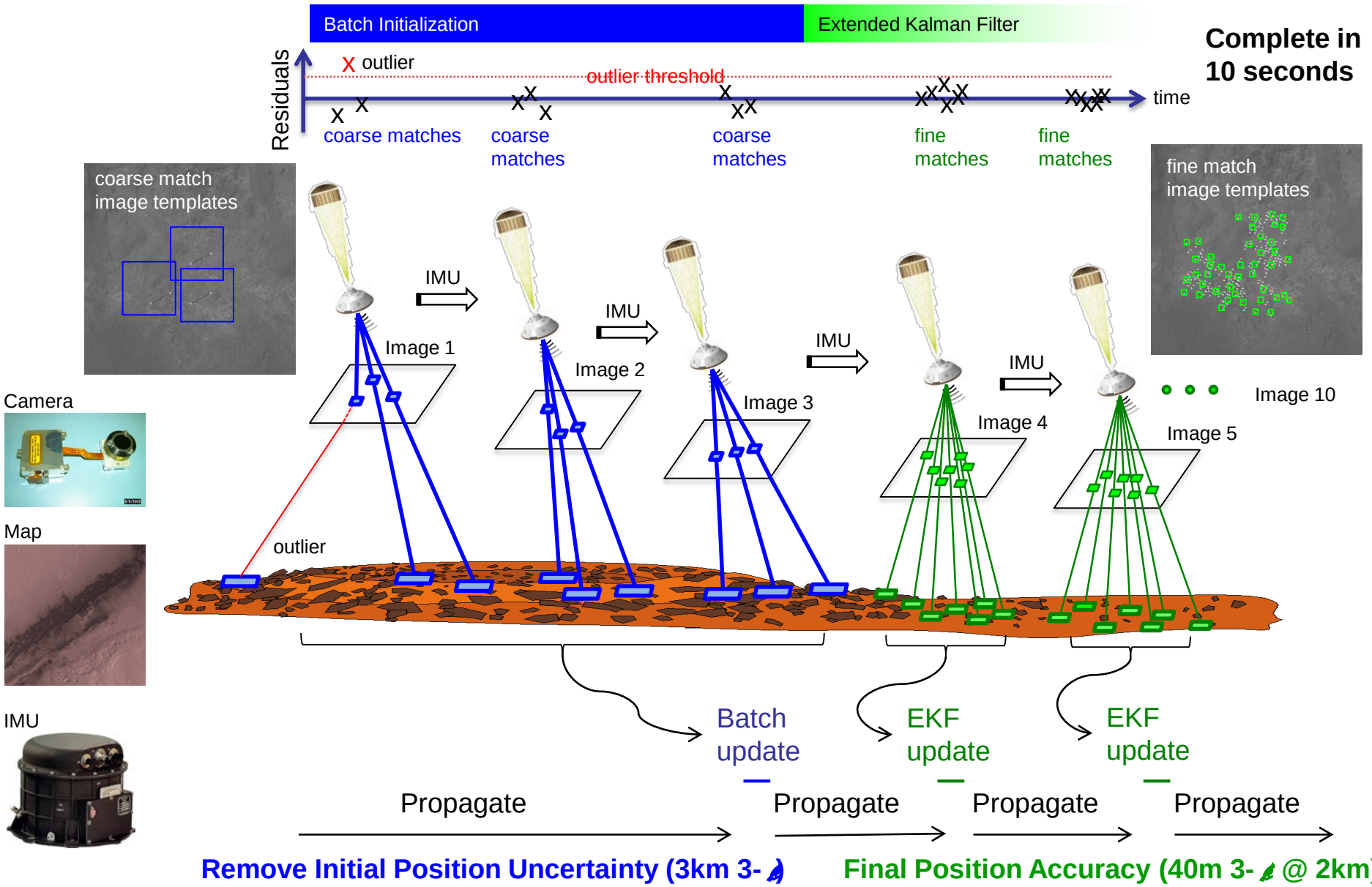
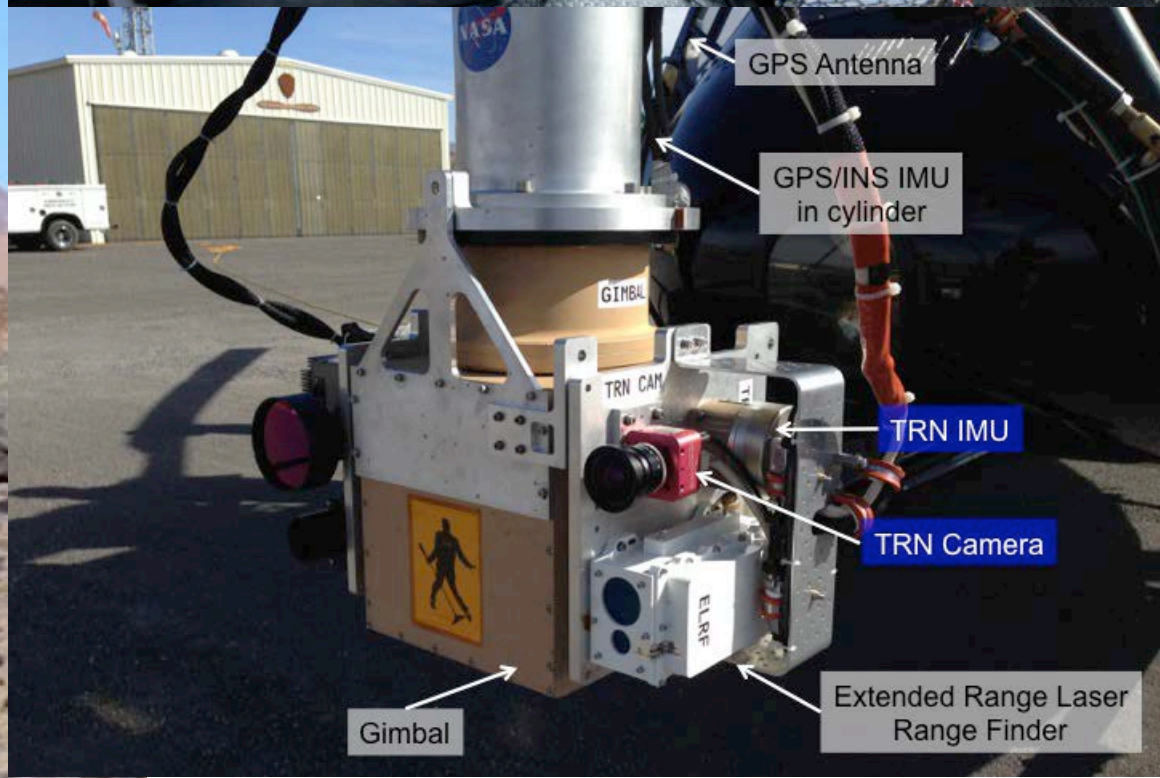
Map Relative Localization

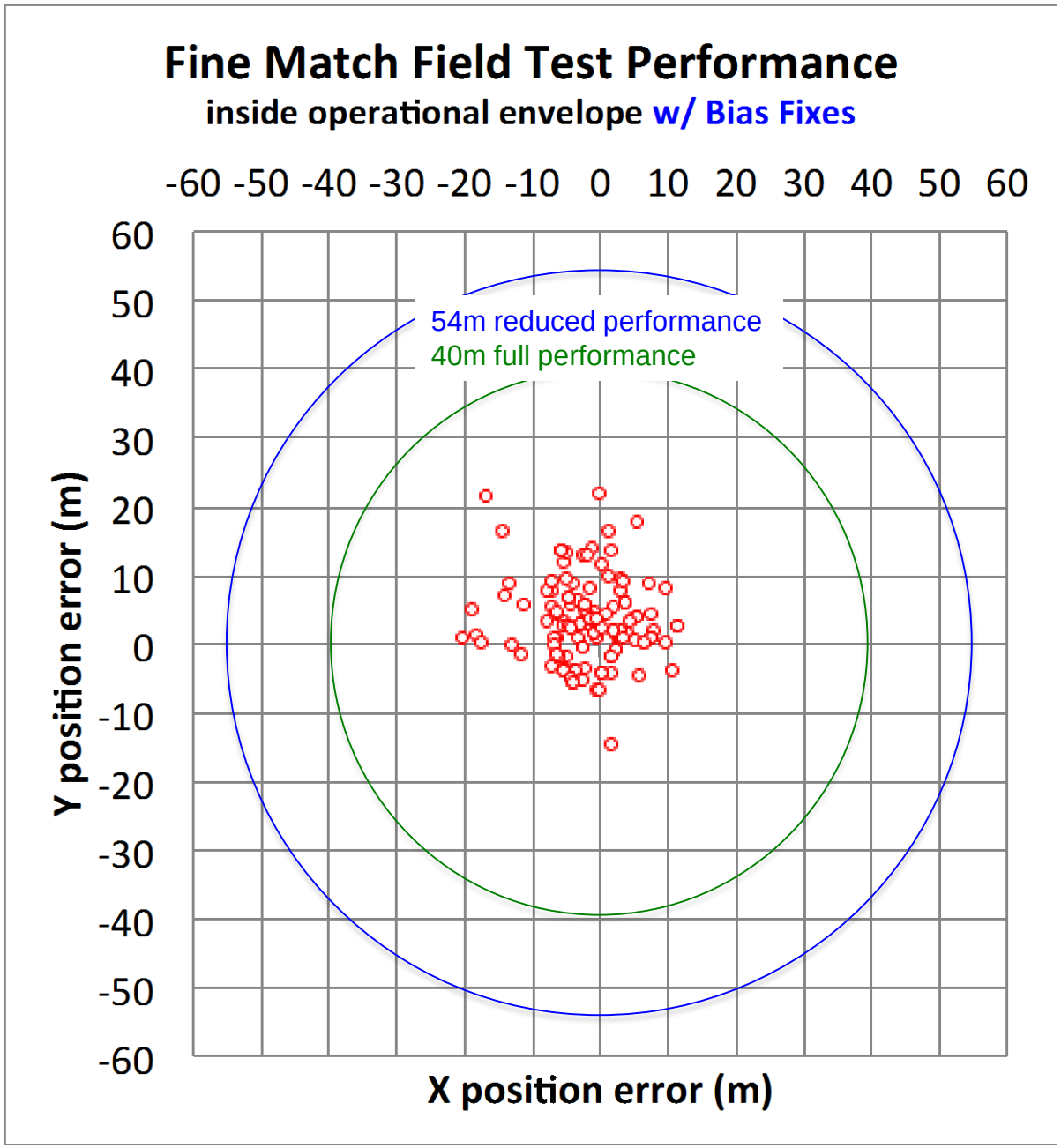


- LVS prototype tested over Mars-analog terrains in Feb/March 2014

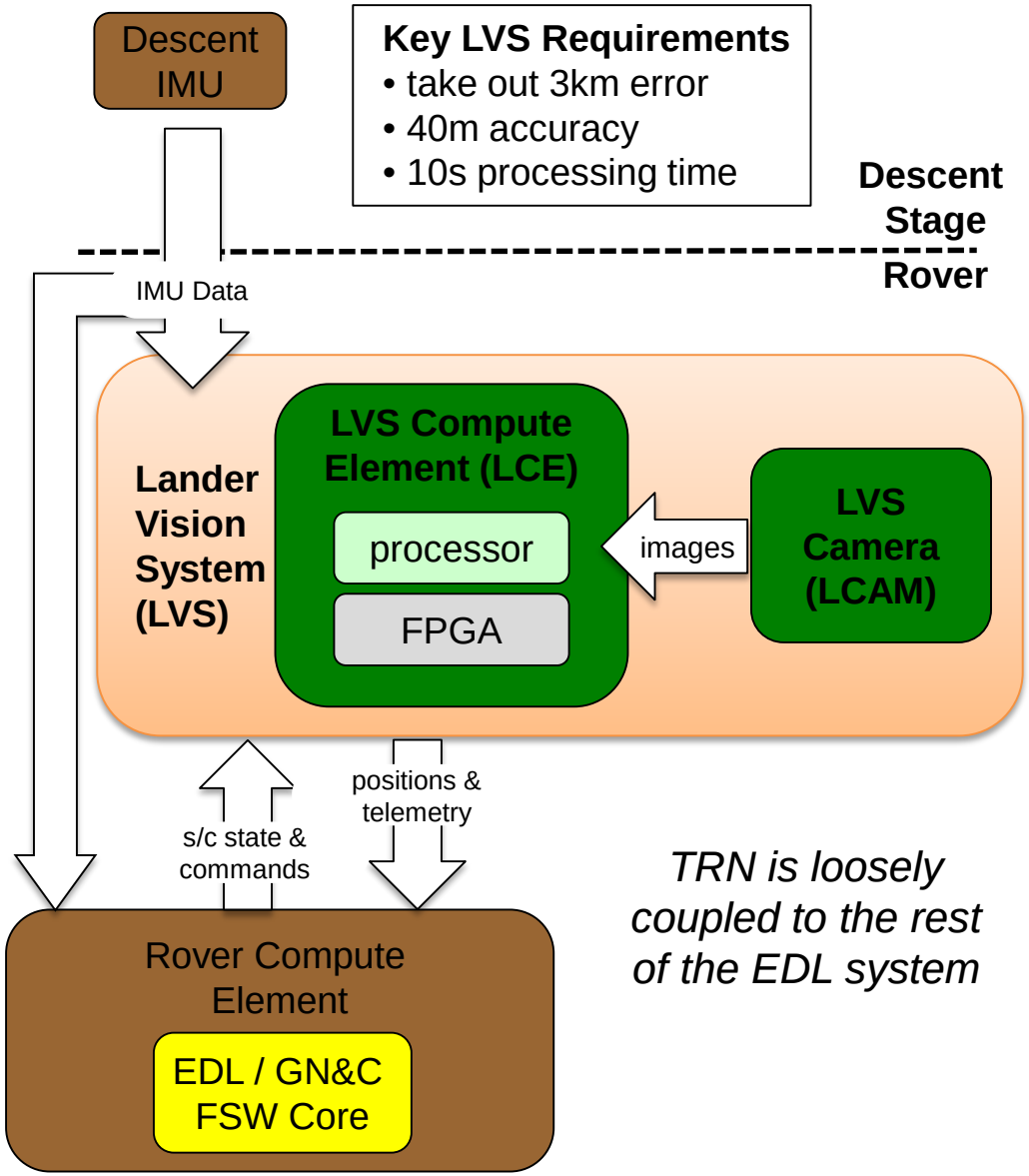
- Test collected data to validate technology over a wide operational envelope defined by expected M2020 conditions
- LVS meets position accuracy and robustness requirements
- Field test demonstrated maturity of the algorithms



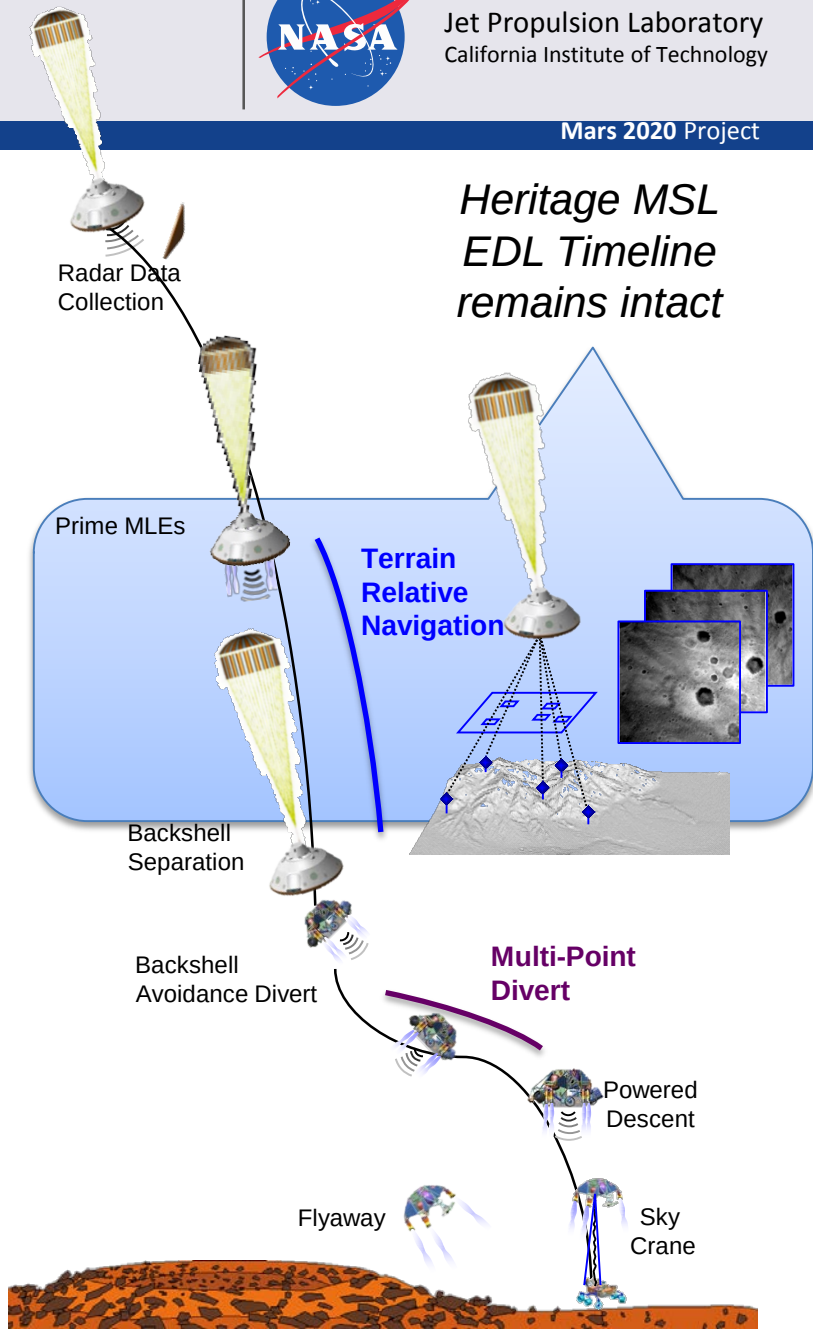
LVS Prototype Field Test Video


Fine Match Field Test Performance
inside operational envelope w/ Bias Fixes
-60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
54m reduced performance
40m full performance
Y position error (m)
X position error (m)

TRN Flight Implementation

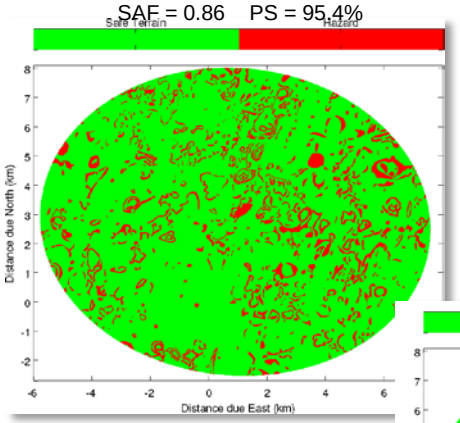


TRN is loosely coupled to the rest of the EDL system



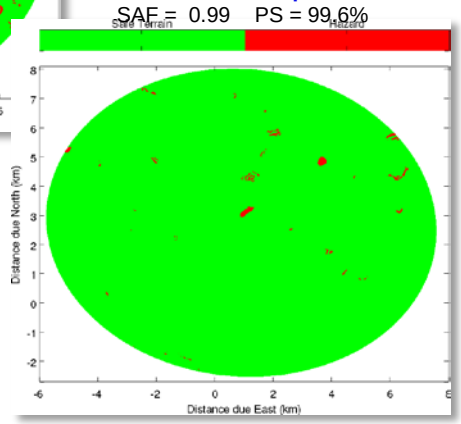
Landing Site Access & Traverse

Without TRN/Multi-point:
SAF = 0.86 PS = 95.4%



TRN can make more sites of scientific interest accessible

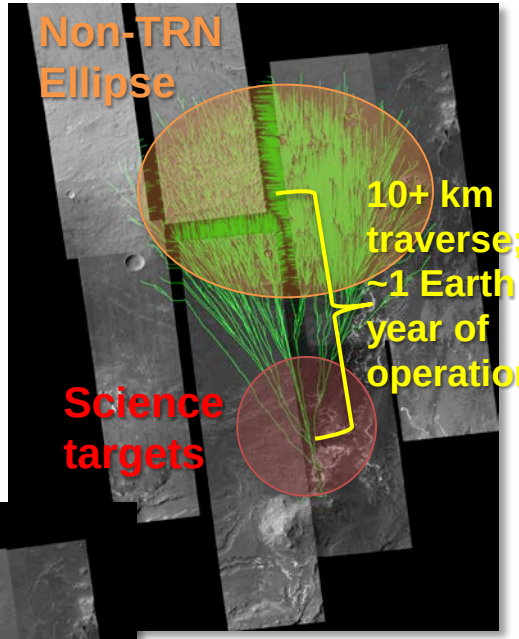
With TRN/Multi-point:
SAF = 0.99 PS = 99.6%

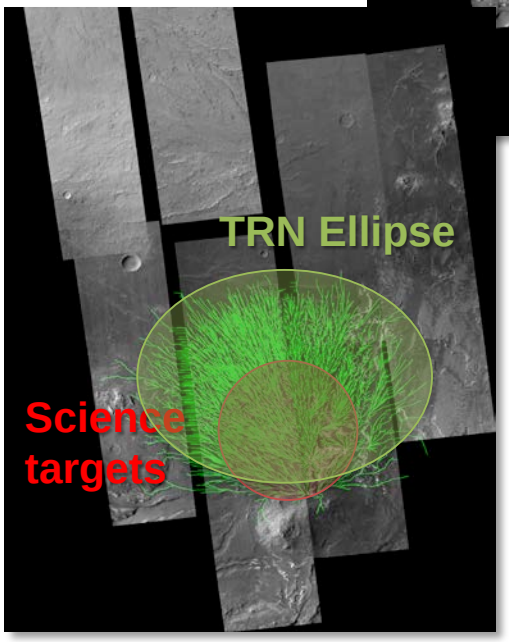


NE Syrtis
#1 Site (LSW1)

Landing Site	% Area Unsafe	
	Baseline	With TRN
NE Syrtis Major	14%	1%
Nili Fossae	5%	1%
E Margaritifer	17%	4%
Holden Crater (“land-on” target)	5%	1%

TRN can reduce traverse distance and improve surface productivity





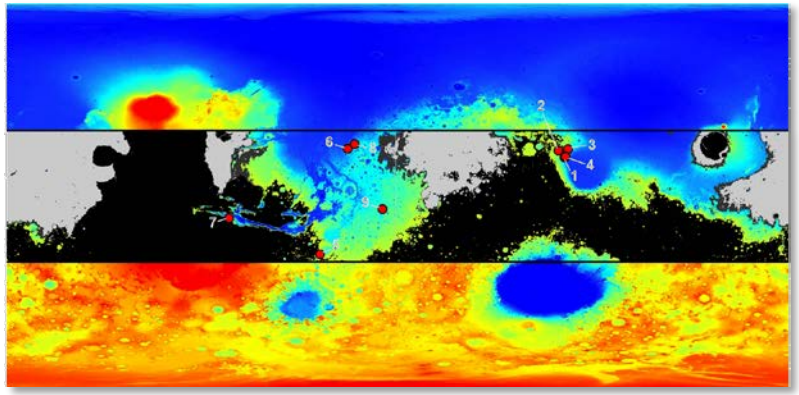
Holden Crater
#5 Site (LSW1)
MSL Finalist

The Road Ahead

Assess Landing Site Impacts

Landing Site Workshop II

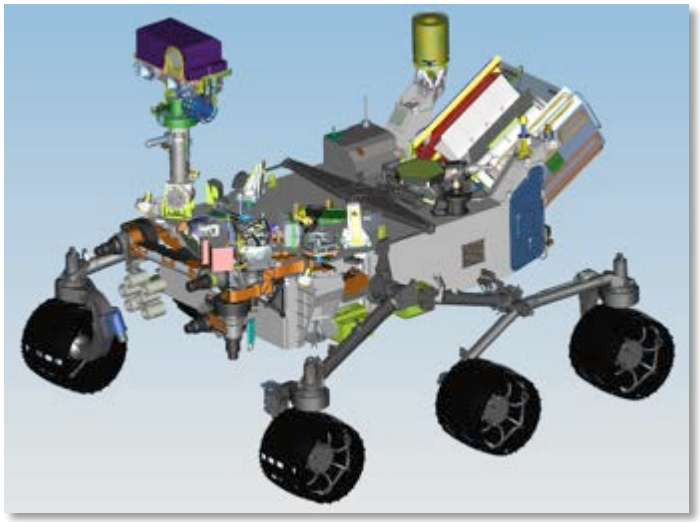
August 4th-6th, 2015



LVS Preliminary Flight Design

TRN PDR

November 10th-11th, 2015



Mars 2020 Baseline Decision

TBD

Backup

IPPW-12 Abstract

Previously approved for unlimited release under URS250528 (CL#15-1393)

The Future of Landing: Terrain Relative Navigation From Prototype to Mars 2020

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Abstract:

The Terrain Relative Guidance Target Selection (TRGTS) system is an enabling Entry, Descent, and Landing (EDL) technology proposed for inclusion in the Mars 2020 mission [1]. TRGTS provides real-time, terrain-relative position determination and generates a landing target based on a priori knowledge of hazards. TRGTS is composed of the Lander Vision System (LVS) and the Safe Target Selection (STS) algorithm. The LVS generates a map-relative localization solution by fusing measurements from a visible-wavelength camera and an inertial measurement unit using the Terrain Relative Navigation algorithm operating on a high-performance compute element. Updated state knowledge is provided to the spacecraft navigation filter, which uses the STS algorithm to direct a divert maneuver away from known hazards within an onboard map.

A prototype LVS was developed and demonstrated over relevant terrain using both a helicopter and a rocket-powered vertical takeoff and landing vehicle. This proof-of-concept and other analytical and simulation-based studies have paved the way for potentially including TRGTS as an essential EDL technology for Mars 2020. This paper discusses results from these studies and how they fed into requirements tailored for this mission. Finally, analyses are summarized that show how TRGTS enables access to new, scientifically compelling sites and allows landing ellipse placement for easier access to regions of interest at sites considered by previous missions.

Reference:

[1] Allen Chen. et al. (2014) Mars 2020 Entry, Descent, and Landing System Overview, IPPW11 Presentation #8015.

TRN Operations Concept

LVS powered on just after Cruise Stage Separation

Nav Filter (NF) converges with TDS measurements and begins providing NF estimates to LVS

time varies

LVS initialization

Baseline: 3.7 km AGL
(Between 3.0 km & 3.7 km AGL)

6 seconds

First LVS <u>reduced</u> performance solution available

4 seconds

Accuracy: [54] m, 99%-tile, per solution
Robustness: Provide solutions 95% of the time

First LVS <u>full</u> performance solution available

time varies

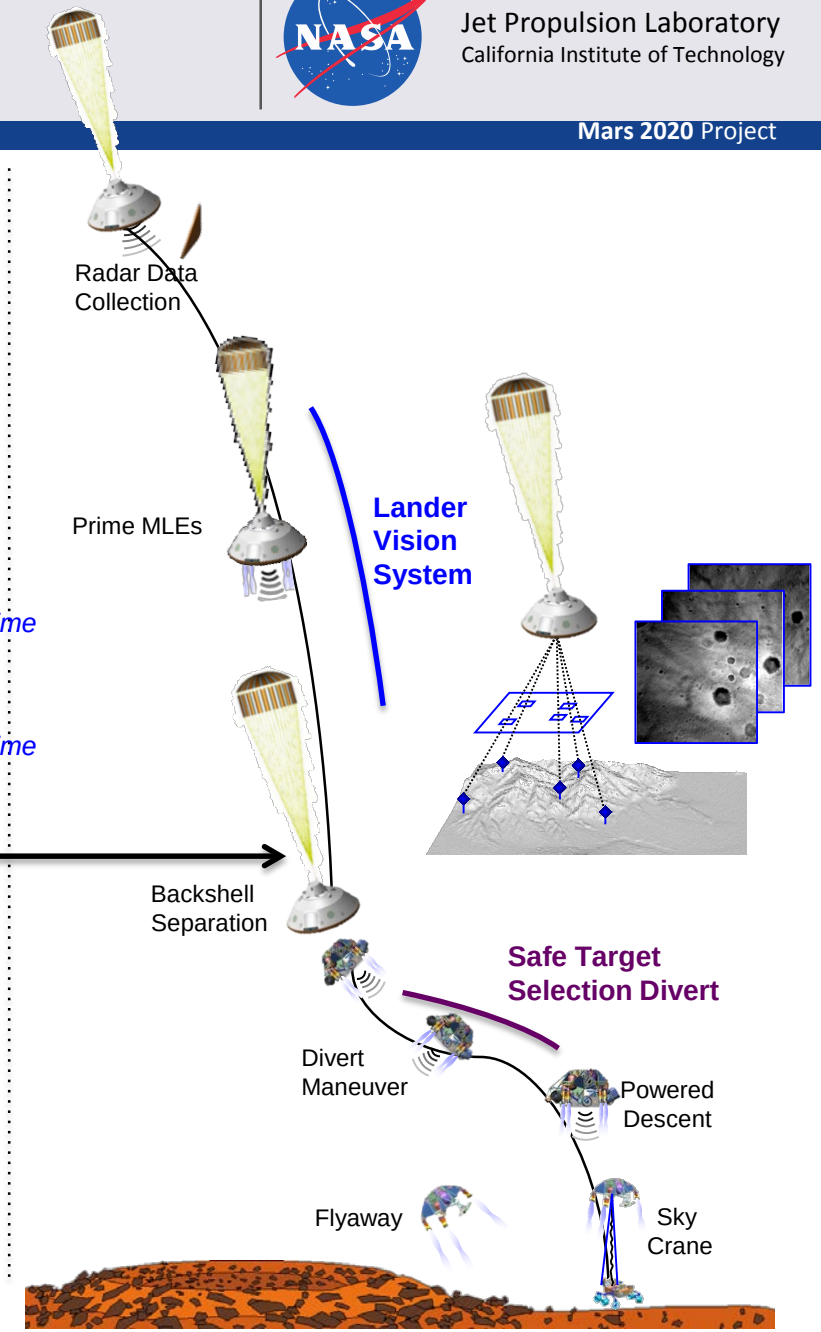
Accuracy: 40 m, 99%-tile, per solution
Robustness: Provide solutions 99% of the time
LVS continues to provide solutions
(as low as BSS or 2.0 km AGL)

Safe Target Selection begins

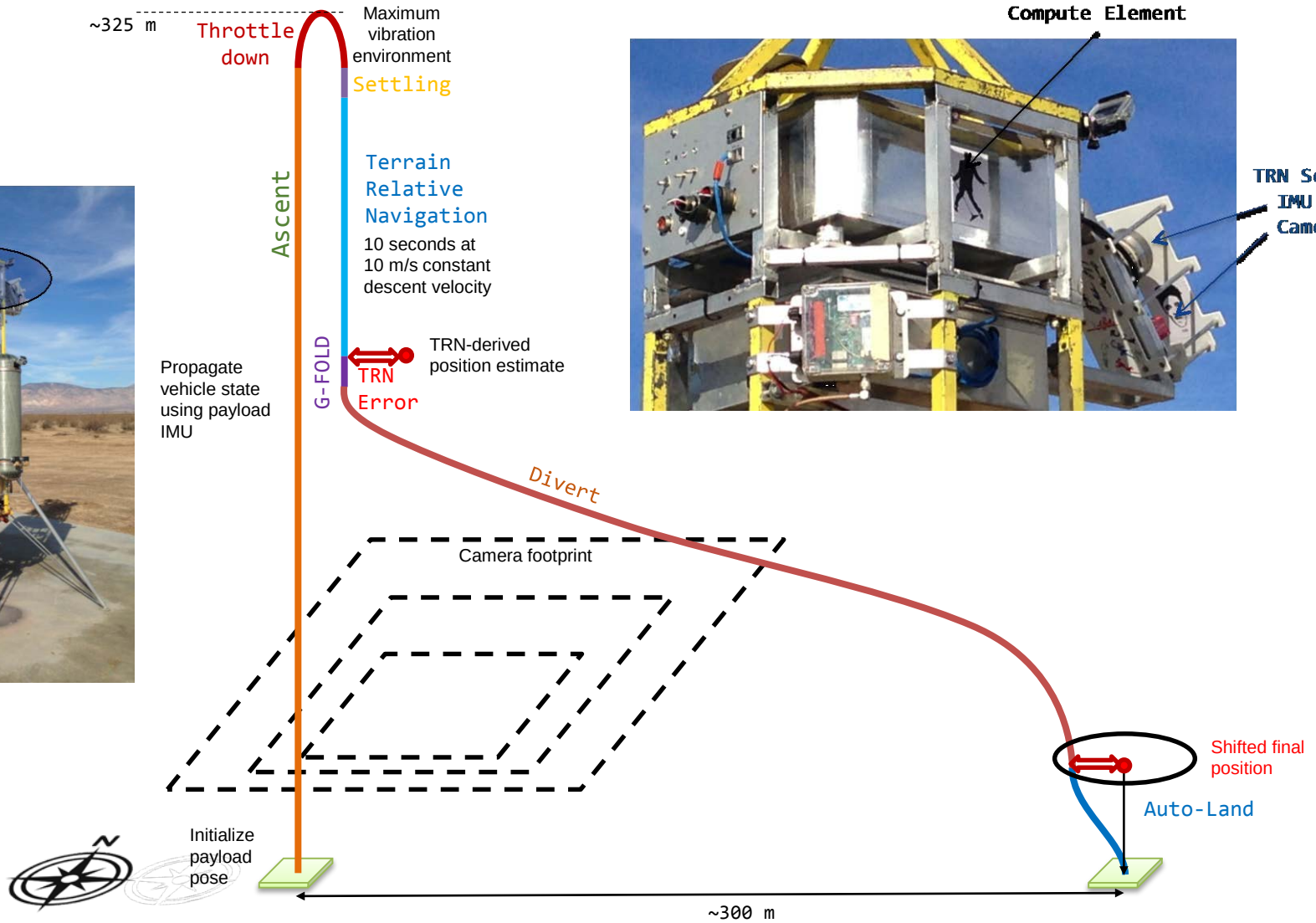
1 second

Baseline: 2.5 km AGL
(Between 2.0 km & 2.7km AGL)

Safe target selected and provided to MSL heritage powered approach, which executes the Safe Target Selection Divert Maneuver

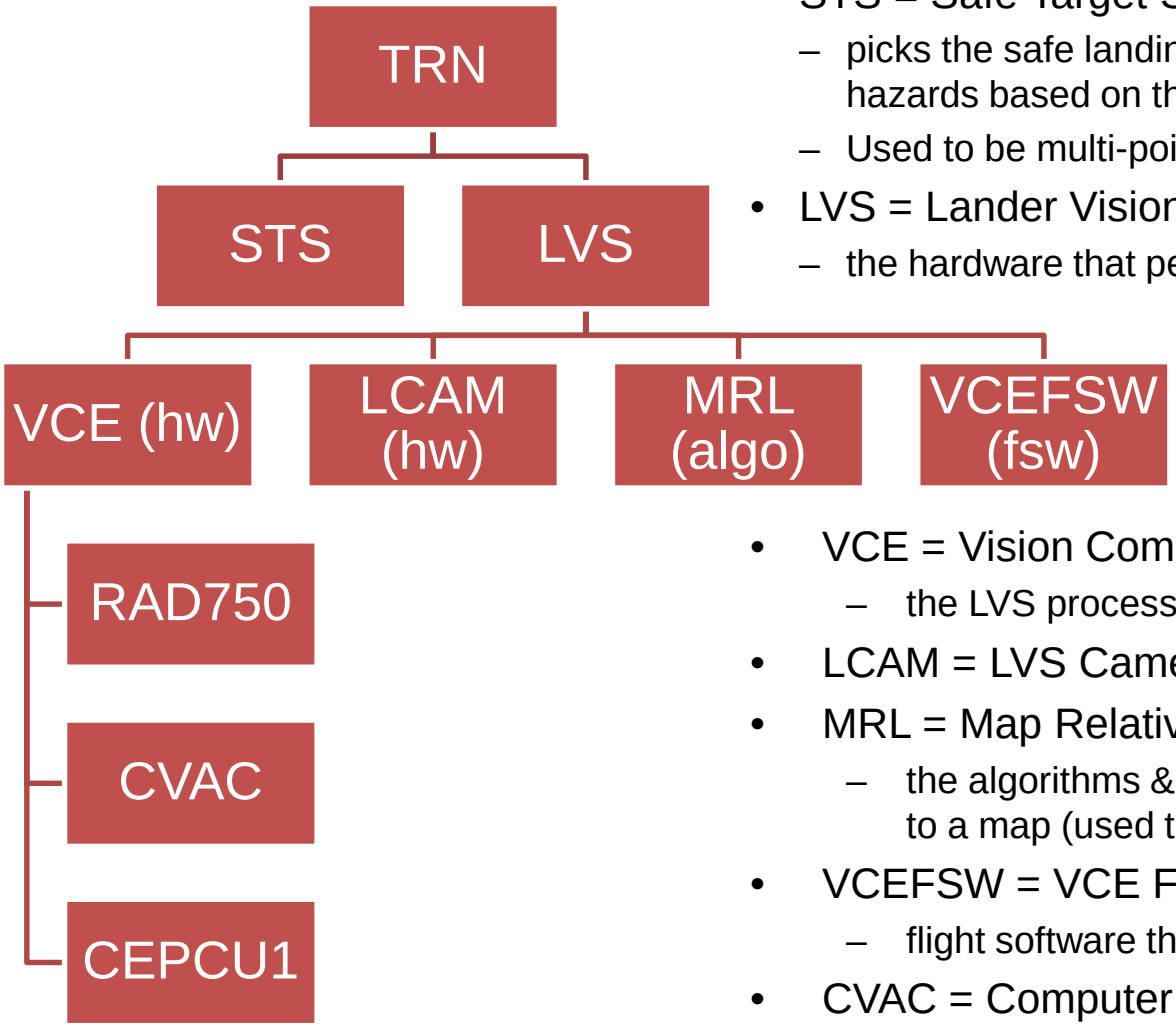


LVS Closed Loop Powered Flight Tests, December 2014



ADAPT Closed Loop Flight Test Movie

TRN Terminology



- TRN= Terrain Relative Navigation
  - all the new development to avoid hazards in the landing ellipse
- STS = Safe Target Selection
  - picks the safe landing site between a-priori hazards based on the position provided by LVS
  - Used to be multi-point or multi-X. Runs on the RCE
- LVS = Lander Vision System
  - the hardware that performs Map Relative Localization

- VCE = Vision Compute Element
  - the LVS processor (formerly VCE)
- LCAM = LVS Camera
- MRL = Map Relative Localization
  - the algorithms & code that compute position relative to a map (used to be called TRN!)
- VCEFSW = VCE Flight Software
  - flight software that runs on the Rad750 VCE
- CVAC = Computer Vision Accelerator Card
  - new Virtex5 co-processor card in the VCE

TRN Top Level Development Schedule

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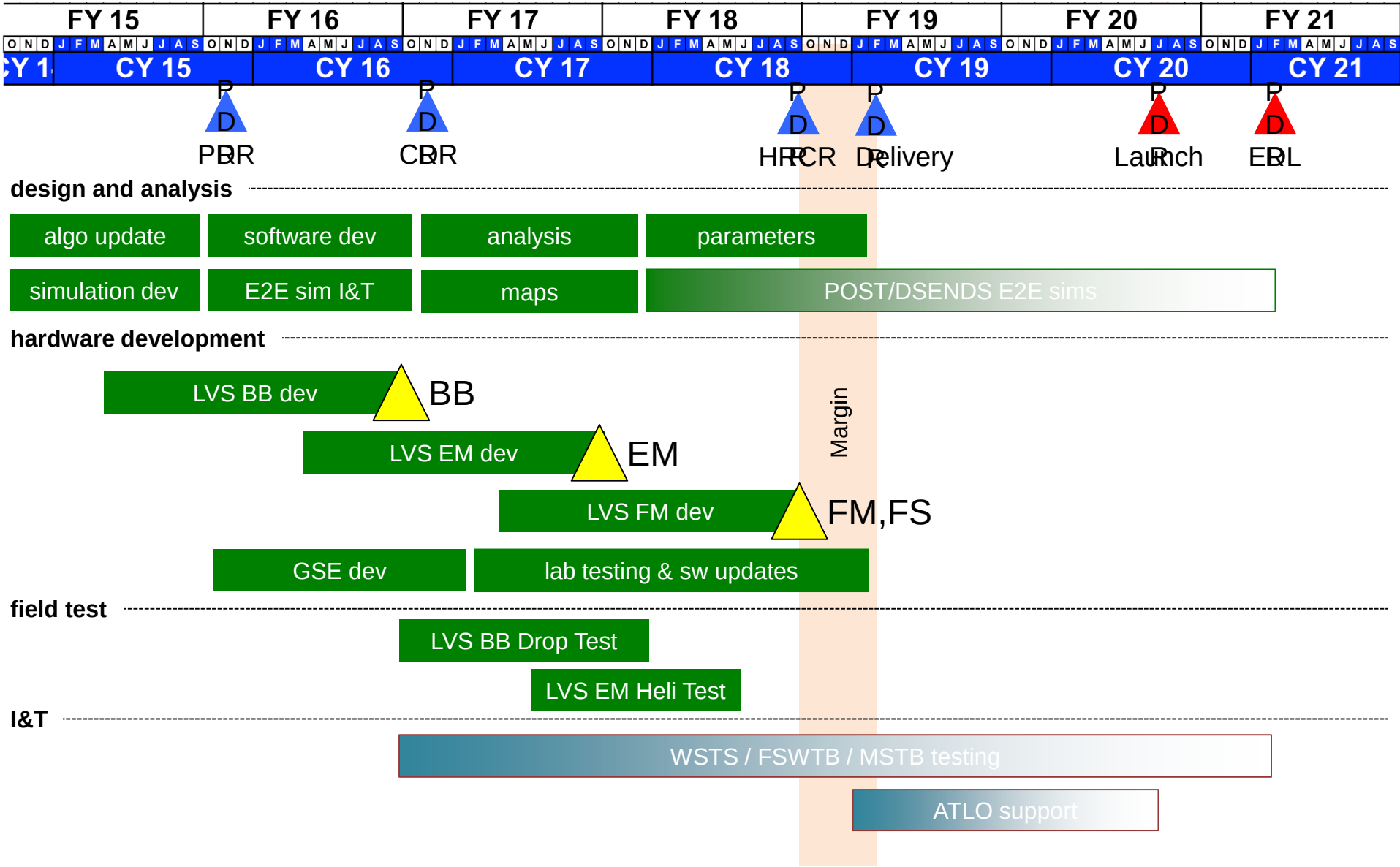
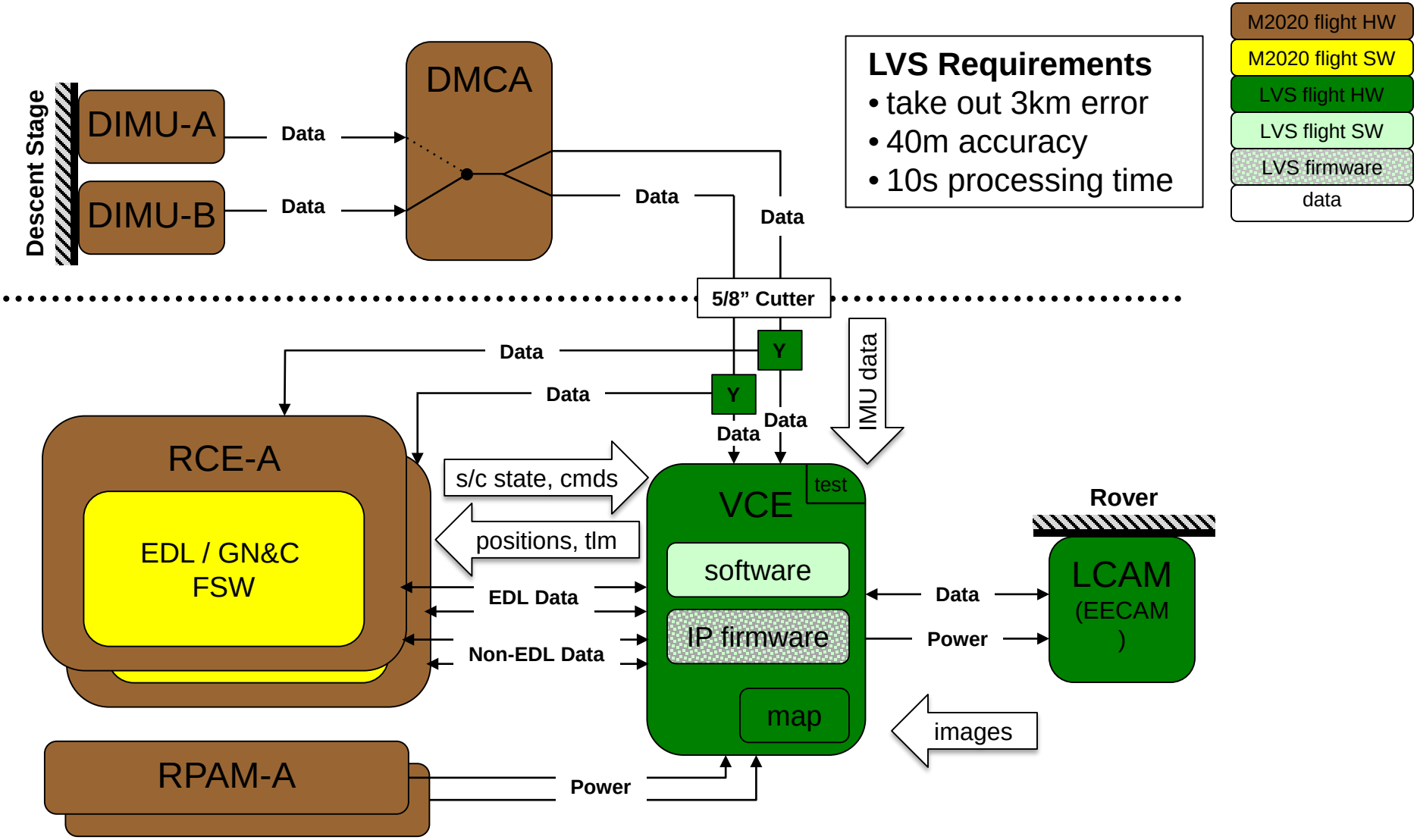
Lander Vision System Flight Configuration