

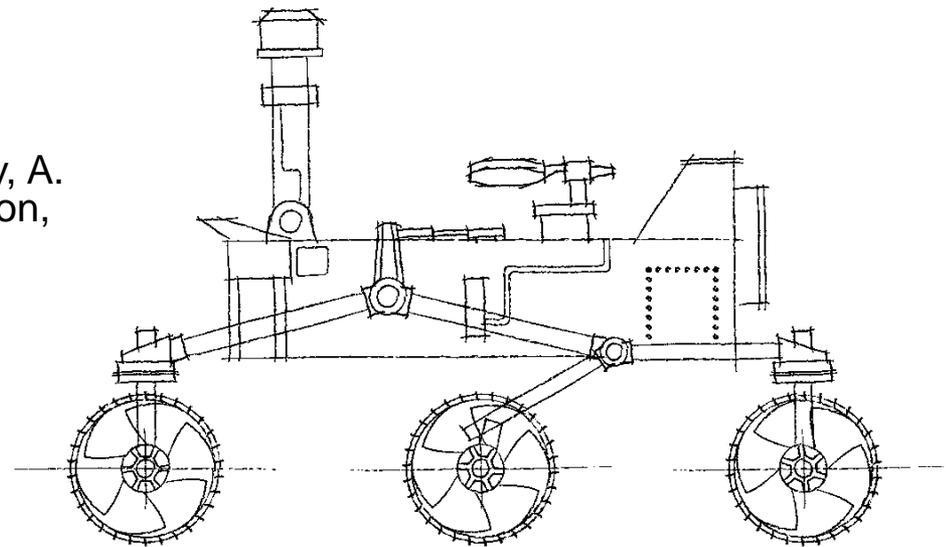


Mars 2020 Terrain Relative Navigation Performance During Landing

IPPW 2017

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Stehura, S. Dutta, J. Montgomery, A. Johnson,
S. Aaron, A. Chen

June 15, 2017



Mars 2020 Project

TRN EDL Operations Concept



Jet Propulsion Laboratory
California Institute of Technology

LVS is powered on shortly after Cruise Stage Separation

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

time varies

LVS initialization *Baseline: 4.2 km AGL
(Between 3.0 km & 4.2 km AGL)*

6 seconds

First LVS reduced performance solution available

4 seconds

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

First LVS nominal 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

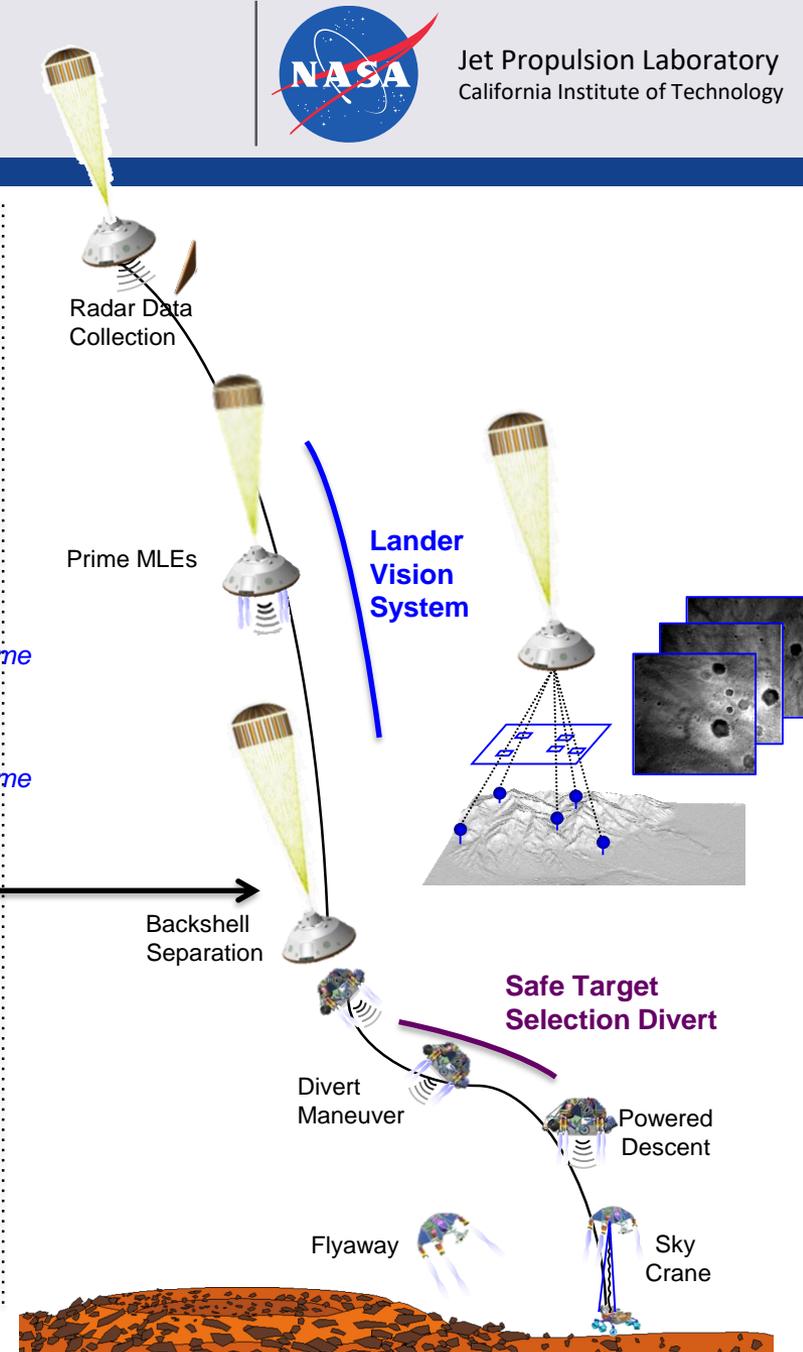
~2.6 seconds

*Baseline: 2.15 km AGL
(Between 1.6 km & 2.3 km AGL)*

Safe target selected and provided to MSL-heritage powered approach

Divert maneuver is executed

If TRN ceases to function at any point, we execute a MSL-heritage backshell avoidance divert by default





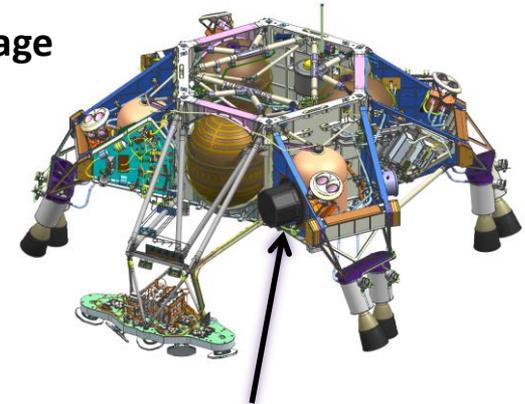
LVS Architecture



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LVS operates during parachute descent when the descent stage and rover are attached and inside backshell

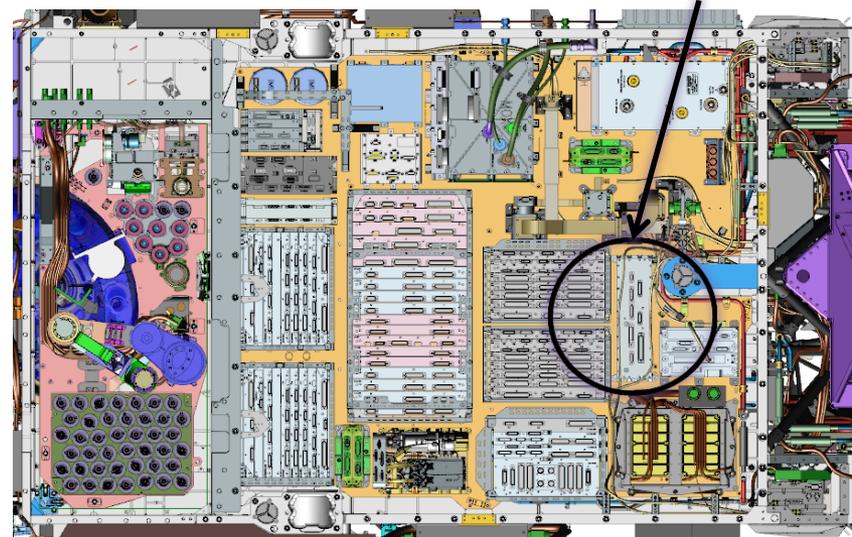
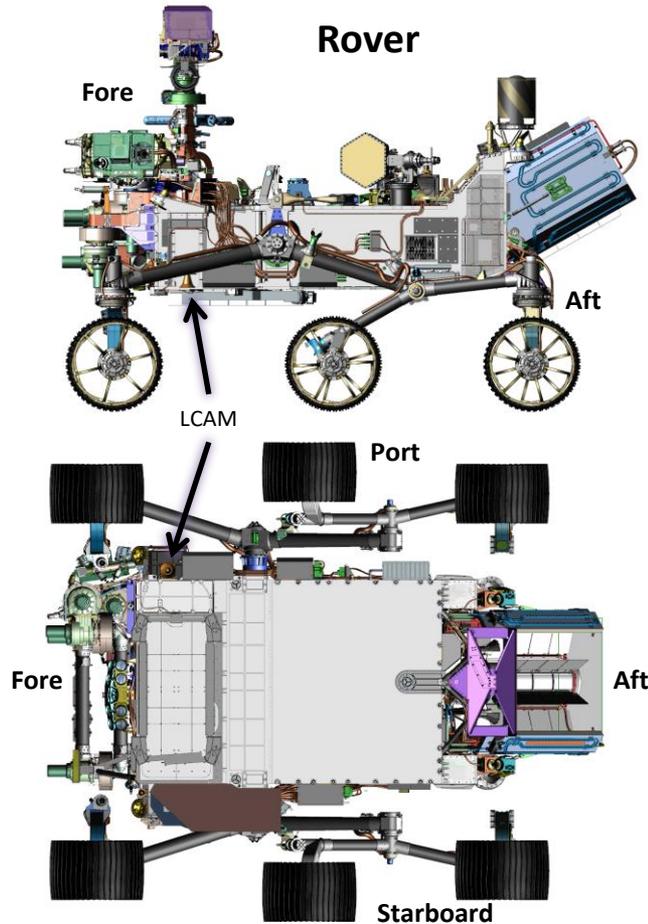
Descent Stage



The LCAM is mounted to the rover, downward-looking, 90° FOV

LVS uses the Descent IMU (DIMU) on the descent stage

The VCE is on the RAMP inside the rover

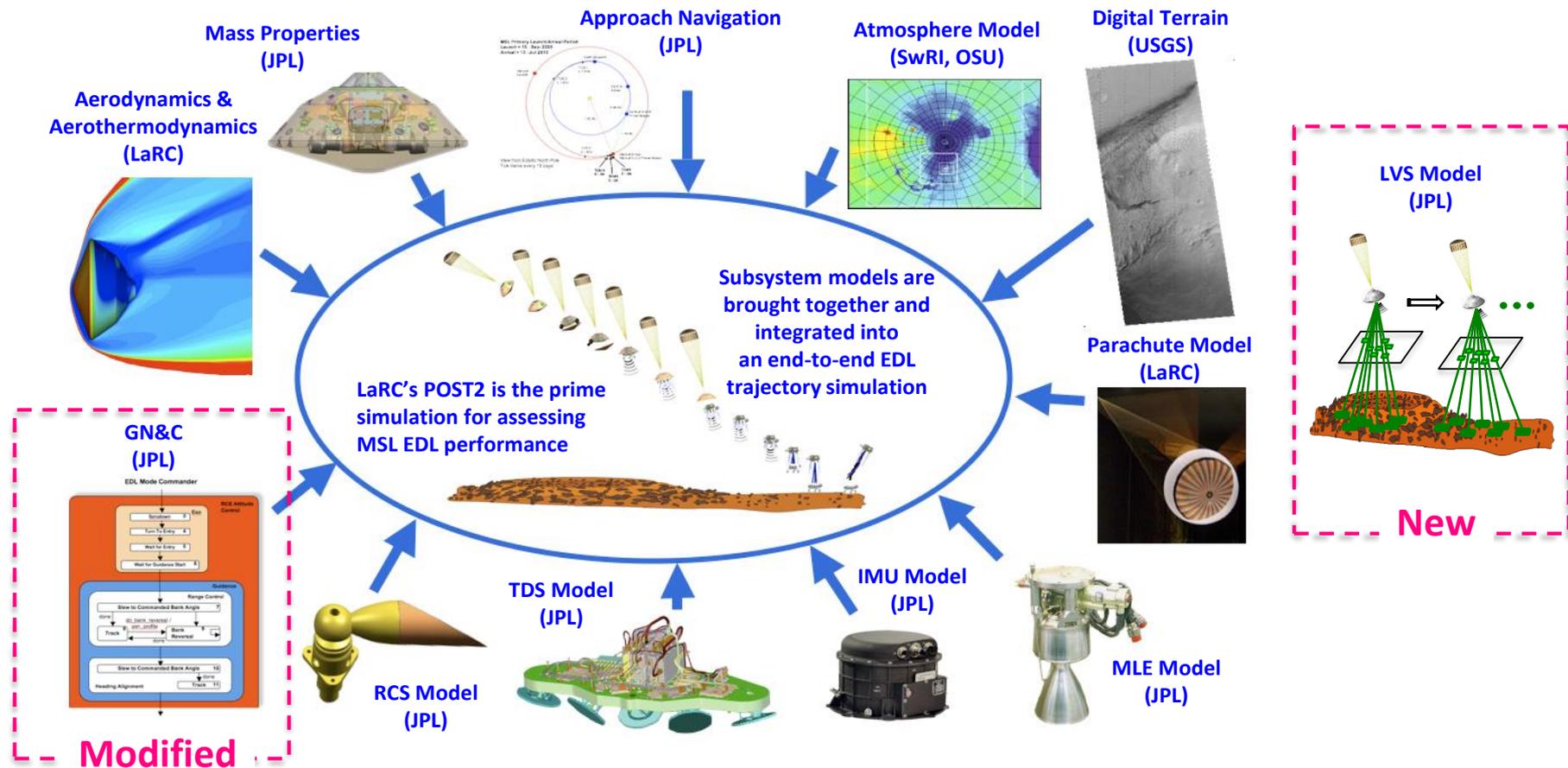


POST2: Mars 2020 Trajectory Simulation



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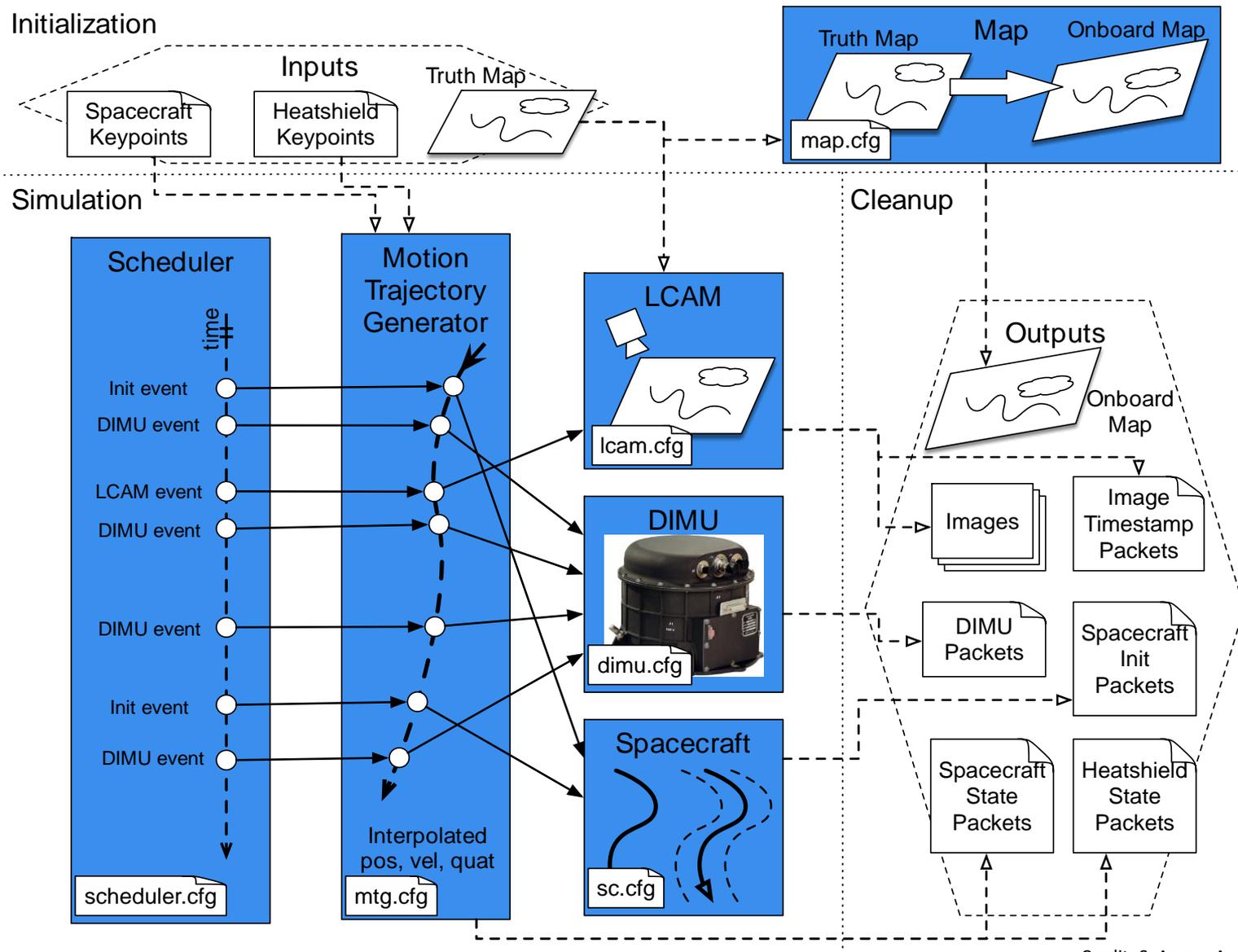
The Program to Optimize Simulated Trajectories (POST2) is a multi-body, 6-DoF trajectory simulation tool, initially developed for the Space Shuttle (circa 1973). POST2 has been tailored specifically for Mars 2020 to include project-specific models and GN&C flight software.



LVSS: Lander Vision System Simulation



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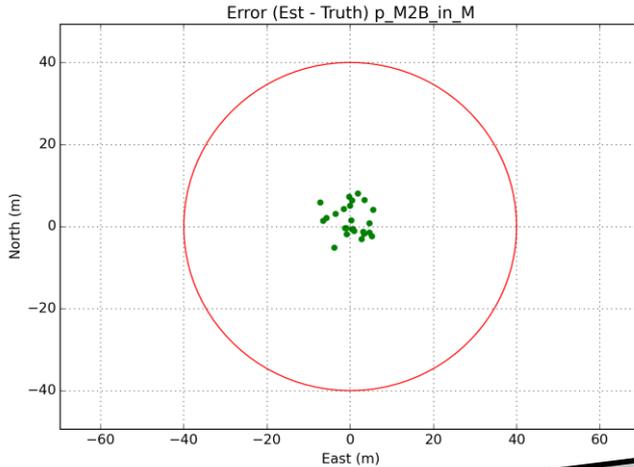


Targeting Error: LVS Localization



CBEs from LVSS

All errors included. Max over nominal performance envelope.



LVS Localization
Allocation: 40 m, 99%
CBE: 17.33 m, 99%

56% Margin

LVS Image-based Localization
Allocation: 28.23 m, 99%
CBE: 17.33 m, 99%

Position error due to algorithm effects
Allocation: 1 m, 99%
CBE: 0.6 m, 99%

Position error due to DIMU noise
Allocation: 1 m, 99%
CBE: 0.41 m, 99%

Position error due to local Map errors
Allocation: 12 m, 99%
CBE: 3.41 m, 99%

Position error due to LCAM/DIMU latency
Allocation: 1 m, 99%
CBE: 0.00242 m, 99%

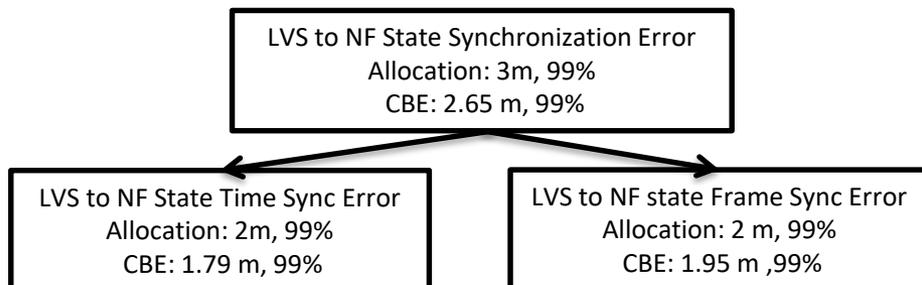
Position error due to LCAM noise
Allocation: 5 m, 99%
CBE: 1.06 m, 99%

Position error due to focal length errors
Allocation: 20 m, 99%
CBE: 16.91 m, 99%

Position error due to static misalignments
Allocation: 15 m, 99%
CBE: 1.14 m, 99%

Individual error contributions determined by simulating with only 1 error source on at a time.

Targeting Error: LVS & Nav Filter synchronization error

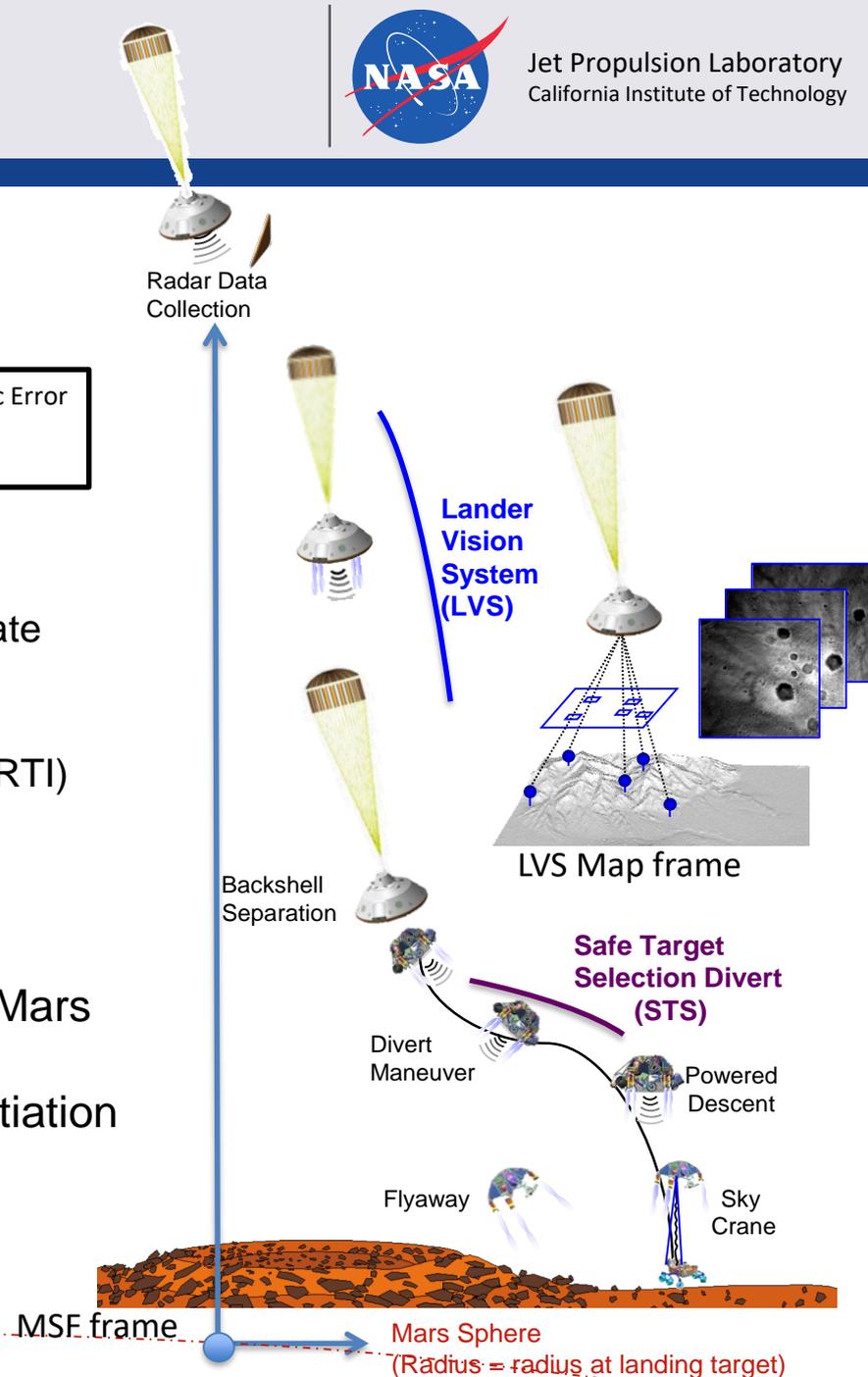


- Time synchronization

- T_{LVS} = LVS solution time
- T_{NF} = EDLGNC Navigation Filter estimated state closest in time to LVS solution
- Error = Max Velocity * Max Time = 1.79m
 - Max Time = $T_{NF} - T_{LVS} = 0.0156s$ (64 Hz RTI)
 - Max Velocity = 115 m/s

- Frame synchronization

- LVS solution is in LVS Map frame
- EDLGNC Navigation Filter solution is in Mars Surface Frame (MSF)
- Error from Nav Filter error at MSF instantiation = 1.95m
 - East/Up \rightarrow 3km Nav Filter position error
 - North \rightarrow Attitude error ~ 0.15 deg



Targeting Error: Map errors

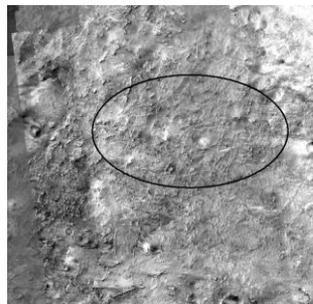


Map Errors with respect to Truth
Allocation: 16.89 m, 99%
CBE: 11.15 m, 99%

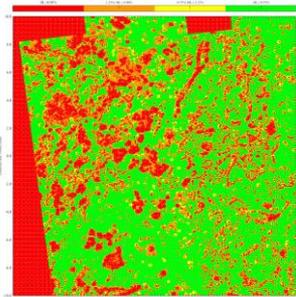
Co-registration error
b/w LVS & STS map
Allocation: 6 m, 99%
CBE: 6 m, 99%

Long Range Map
distortion w.r.t. Truth
Allocation: 12 m, 99%
CBE: 9.4 m, 99%

STS 1 mrad map
orientation error
Allocation: 10.2 m, 99%
CBE: 0.011 m, 99%

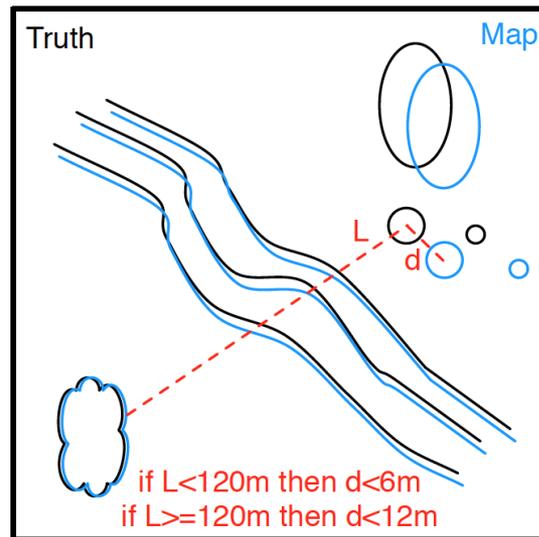


LVS Map
- CTX images
- 6m per pixel

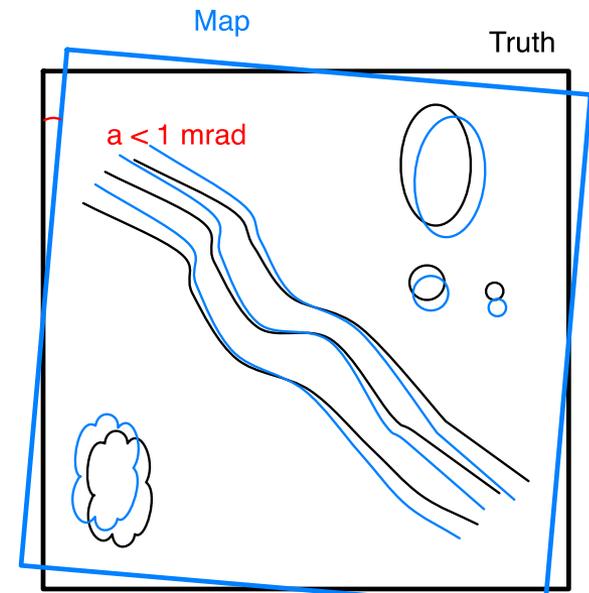


STS Map
- HiRise images
- 1m per pixel

Map Co-Registration Max
= 1 CTX Pixel



Map accuracy error caused by
distortion between Map and Truth



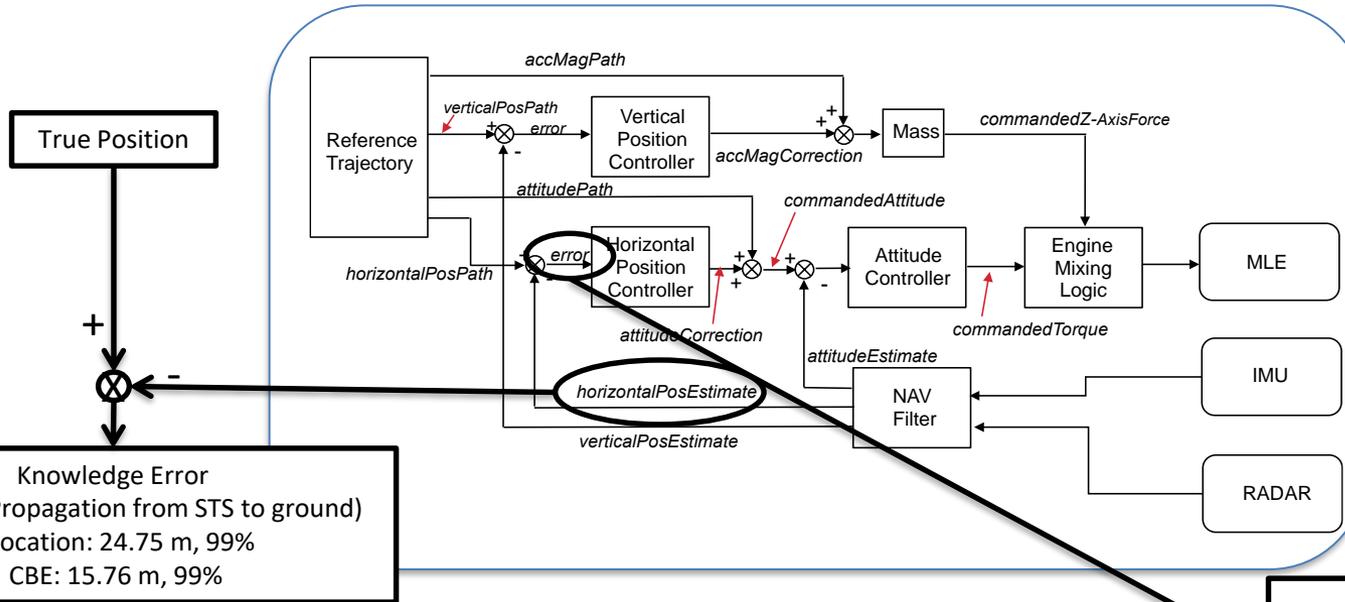
Map accuracy error caused by **rotation**
about the normal vector between Map
and Truth

Knowledge Error & Control Error



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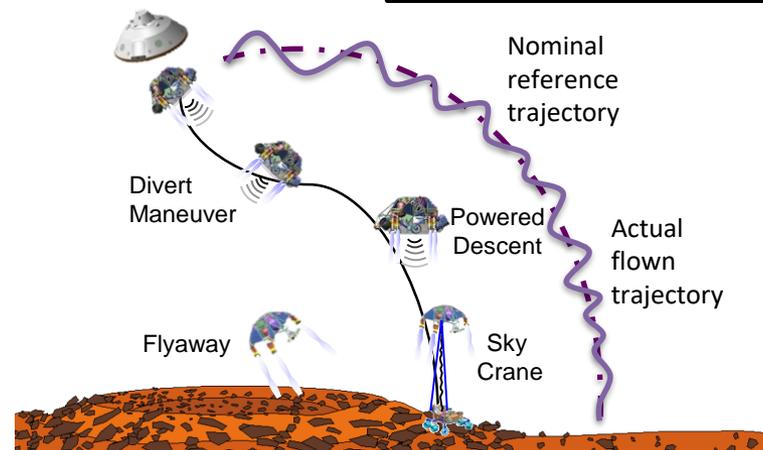
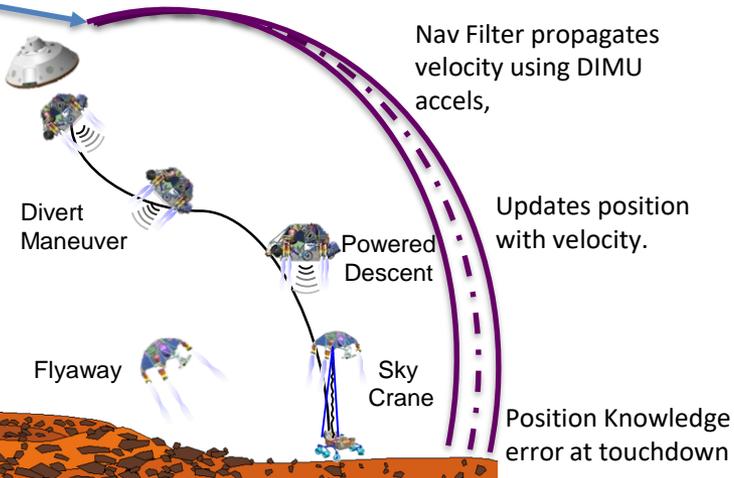
CBEs from POST2



Knowledge Error
(Nav Filter Propagation from STS to ground)
Allocation: 24.75 m, 99%
CBE: 15.76 m, 99%

Control Error
(Powered Descent Controller Error)
Allocation: 3 m, 99%
CBE: 0.48 m, 99%

Nav Filter & LVS
Measurement
Sync-ed



TRN Performance Summary

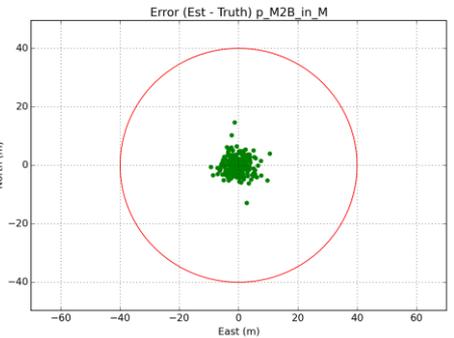
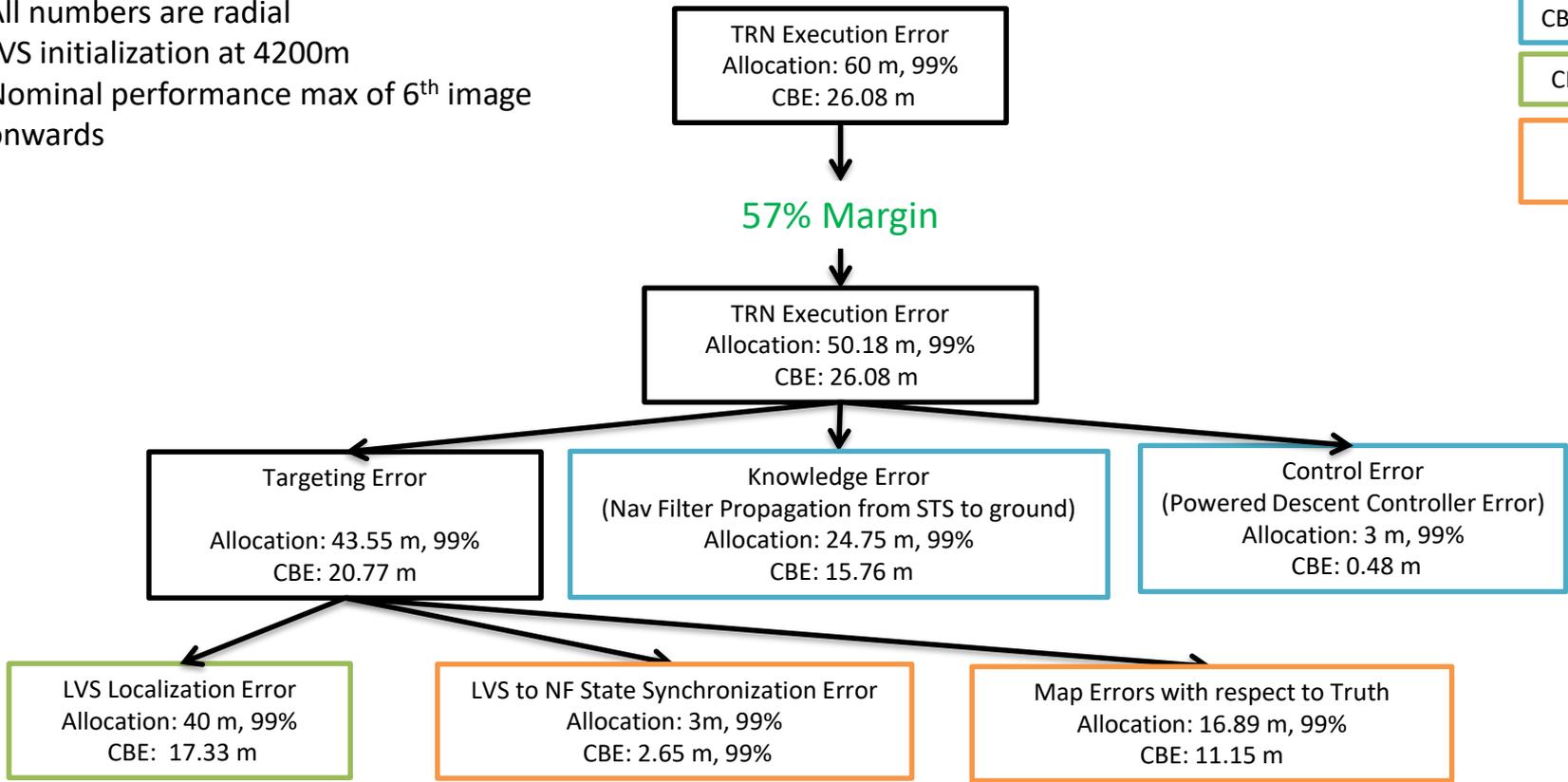


All numbers are radial
LVS initialization at 4200m
Nominal performance max of 6th image
onwards

CBEs from POST2

CBEs from LVSS

Stand alone
Analysis



- High fidelity modelling used to estimate TRN performance during landing
- System shows healthy margins to requirements!

BackUp



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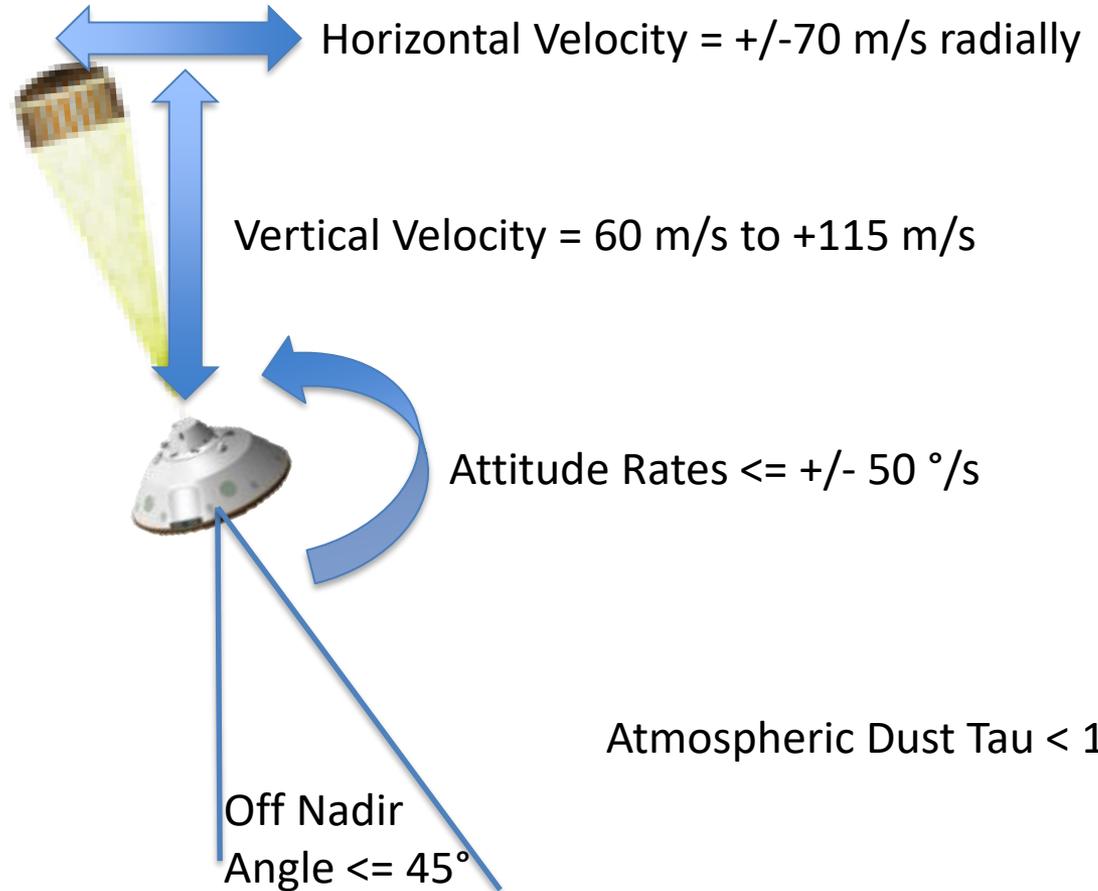
TRN Operational Envelope



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Sun elevation = 25deg to 55deg
Sun azimuth = 240 to 310 deg
(clockwise from N)
Sun distance ≤ 1.58 Au



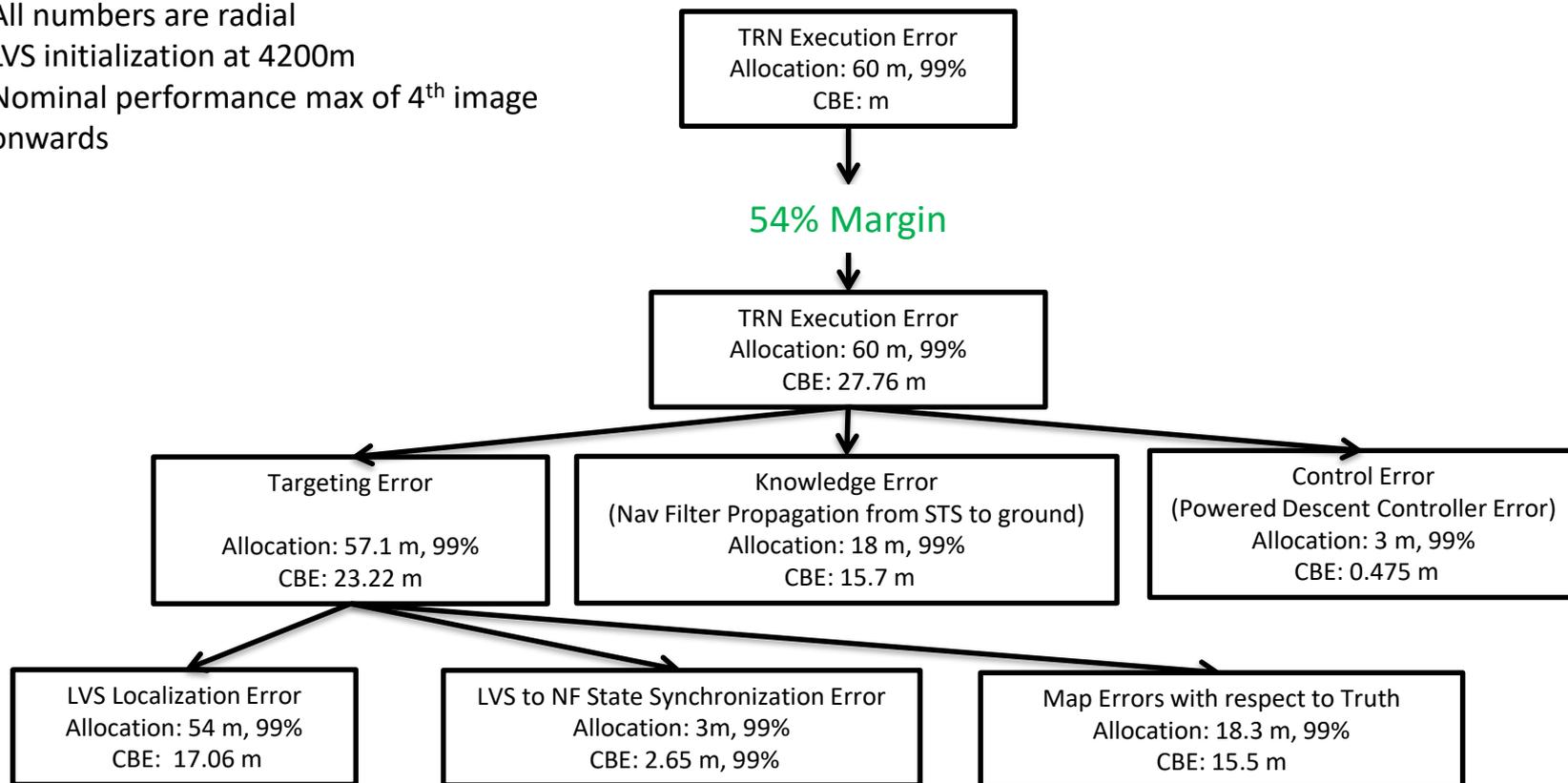
Terrain elevation changes < 150 m 99%-tile over a 1500m x 1500m patch
Terrain slopes < 15 deg (calculated as a plane fit to a 1500 m x1500m patch)



TRN Error Budget – Reduced CBE



All numbers are radial
LVS initialization at 4200m
Nominal performance max of 4th image
onwards



54% Margin

Error (Est - Truth) p_M2B_in_M

