



Application of Direct Force Control to Human-Scale Mars Entry, Descent, and Landing

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Introduction



- **NASA has been investigating various aspects of human-scale Mars landers**

- EDLAS: Architecture studies
- ESM: Entry systems
- DSS: Powered descent
- SPLICE: Sensors

Deorbit

Deploy Inflatable
Decelerator

Entry

Powered Descent

- **Current work looks at two vehicles:**

- Rigid Mid L/D
- Deployable Low L/D

- **Problem complexity is pushing limits of 3DOF approximations**

- Transitioned analysis to 6DOF
- More detailed models

Precise (<100 m) and safe landing of human scale (20 t) payloads at Mars with powered descent (PD)

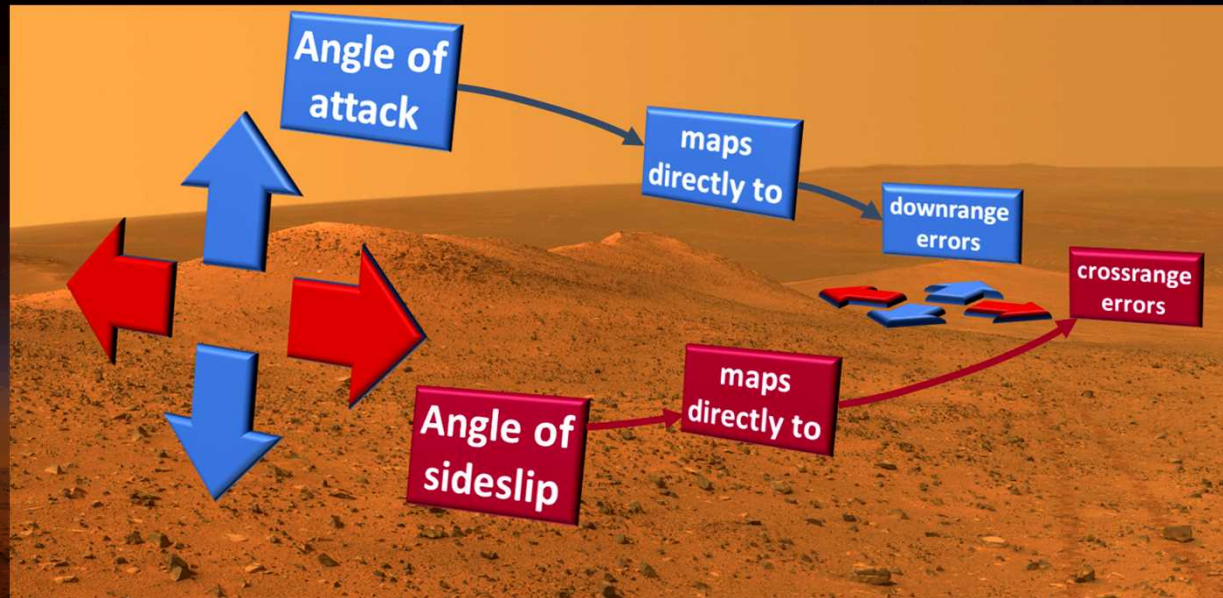
Emerging and advanced guidance, navigation, and control (GN&C) techniques with new algorithms and sensors can improve performance and landing accuracy

Enabling Technologies for Low L/D

Direct Force
Control

NPC
Guidance

Direct Force Control (DFC)



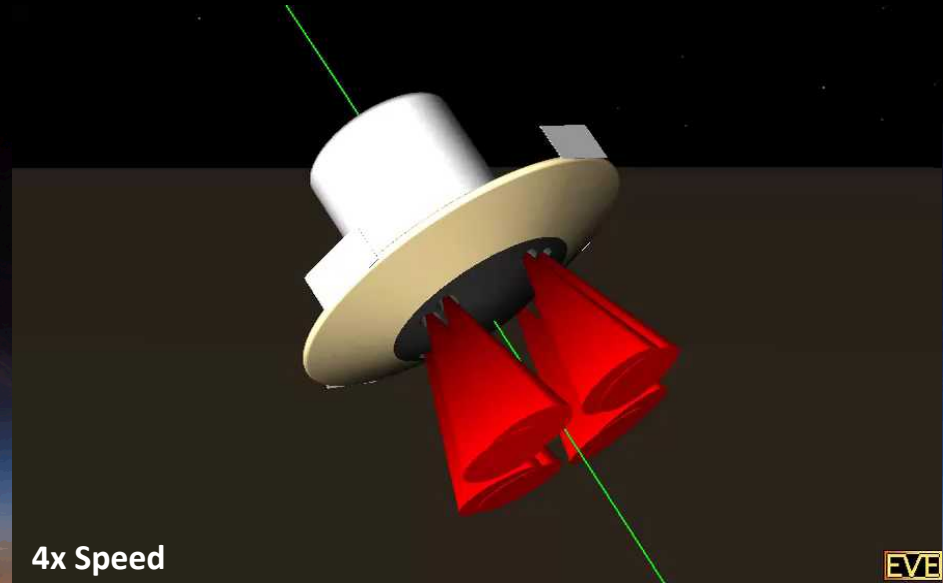
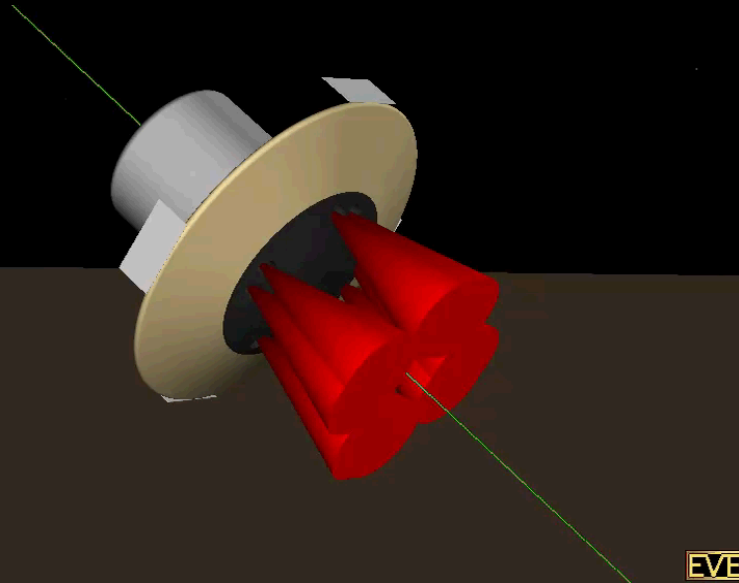
Numerical Predictor-Corrector (NPC) Waypoint Guidance



- Generation of commands that satisfy targets
- Targeting trajectories propagated internally using 3DOF equations of motion and simplified disturbance models
- **Has been applied to atmospheric EDL, aerocapture, powered descent**

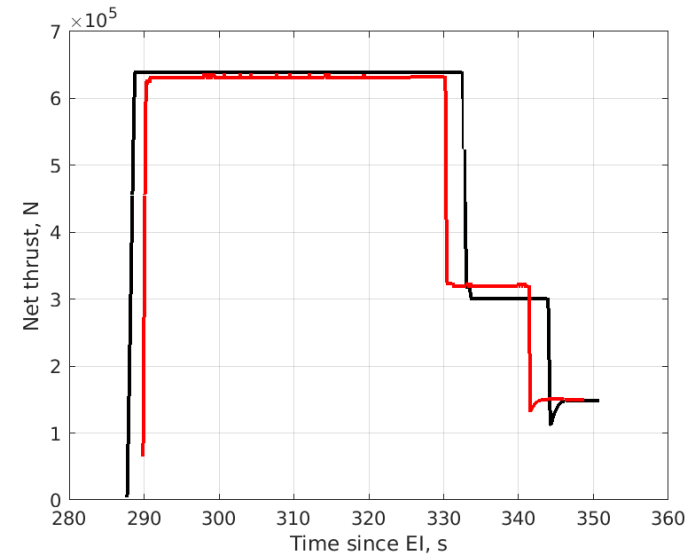
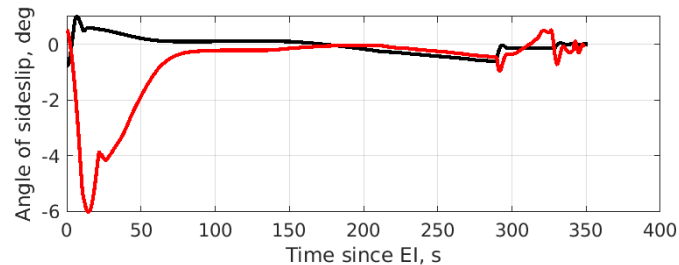
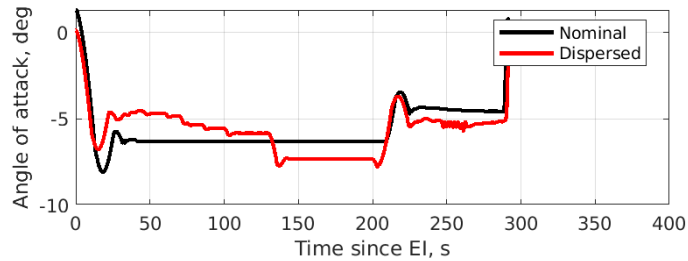
Segment	Commands	Targets
Entry	• Angle of attack • Angle of sideslip • Time of PDI	• Landing site location
Powered Descent	• Angle of attack • Angle of sideslip • Net engine thrust	• Landing site location
Landing	• Velocity at throttle down • Throttle setting at throttle down	• Pitch angle at terminal descent • Landing site radius

Engineering Visualization: 3DOF to 6DOF



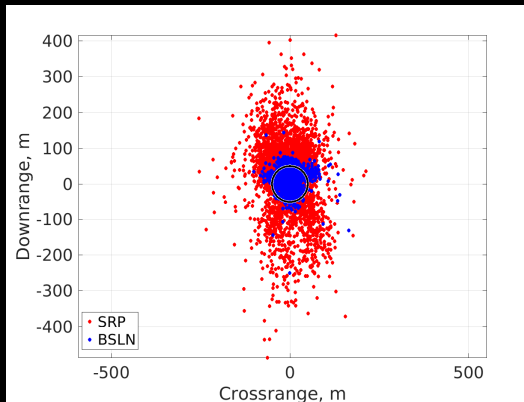
6DOF Results

NPC Guidance & Direct Force Control

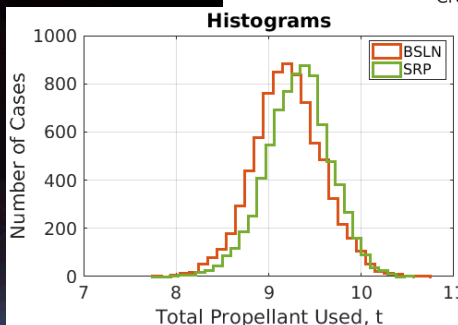


6DOF Results

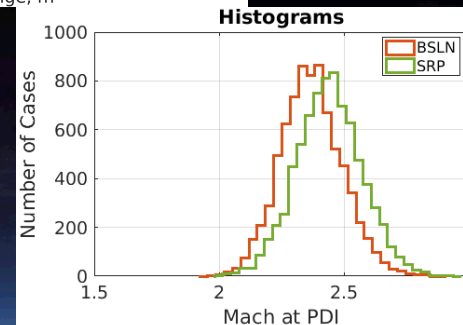
Supersonic Retropropulsion (SRP) Interference



- Addition of SRP interference model introduces large performance variations that G&C must correct



	BSLN	SRP
Mean	9.203	9.315
1-sigma	0.374	0.351
3-sigma	1.121	1.054
1.00 %-tile	8.304	8.413
99.00 %-tile	10.097	10.096
Max Value	10.72	10.547
Min Value	7.771	7.765
Percentage	97.7	98



	BSLN	SRP
Mean	2.369	2.439
1-sigma	0.124	0.131
3-sigma	0.373	0.394
1.00 %-tile	2.092	2.133
99.00 %-tile	2.679	2.752
Max Value	2.907	2.94
Min Value	1.95	1.984
Percentage	97.7	98

Summary and Forward Work



- **Near-term work**
 - Improve range errors at landing
 - Adding navigation errors through use of extended Kalman filter and various onboard sensors
 - Human-scale Lunar descent & landing