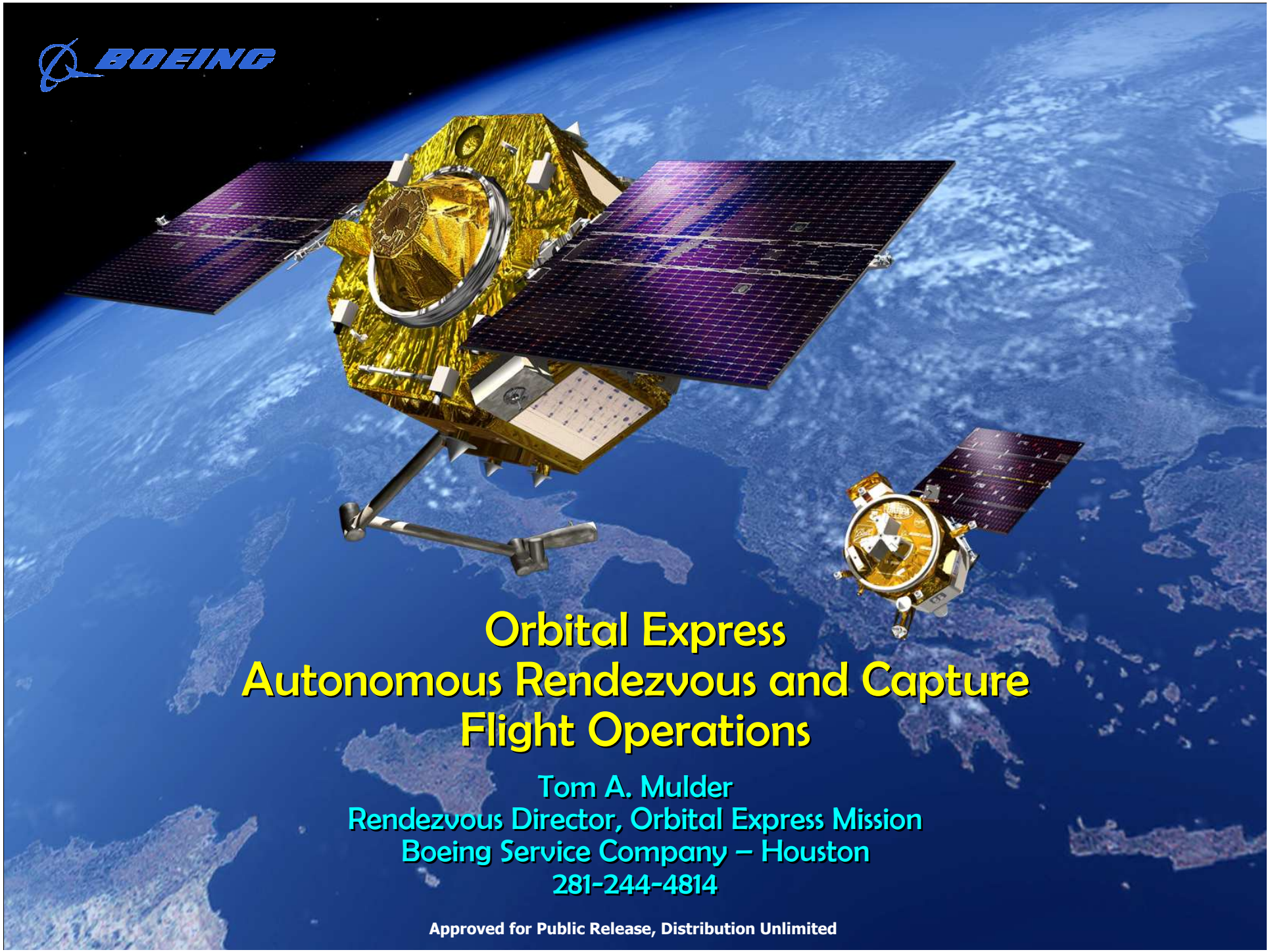


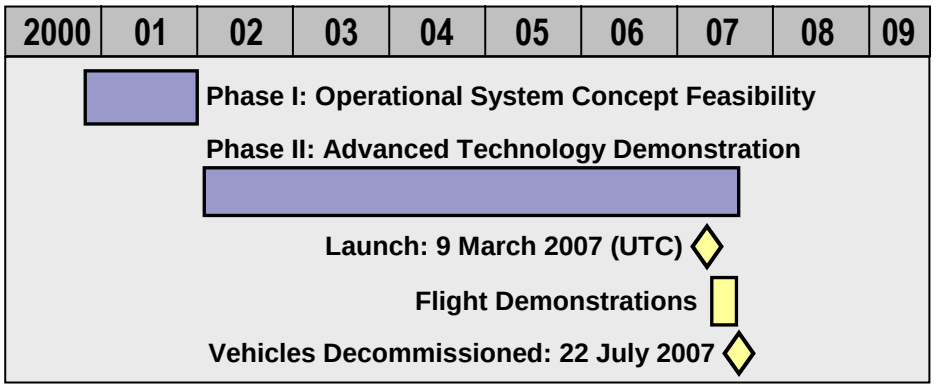
Orbital Express Autonomous Rendezvous and Capture Flight Operations

Tom A. Mulder
Rendezvous Director, Orbital Express Mission
Boeing Service Company – Houston
281-244-4814

Orbital Express (OE) Flight Demonstration

Program Objectives

- Design and develop 2 demonstration servicing satellites
  - ASTRO (Boeing)
  - NextSat (Ball)
- New levels of spacecraft autonomy
- Atlas V launch
- 492 x 492 km, 46° orbit
- 3-month demonstration period
- Post-demonstration application on operational spacecraft



Autonomous Technologies

- Long-range rendezvous & capture without ground assistance
- Onboard & ground-commanded abort and collision avoidance
- Soft direct capture
- Grapple & berth
- Hydrazine propellant transfer
- Robotic battery & computer transfer

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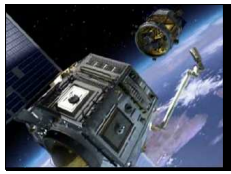

Mission Summary

- 7 AR&C exercises planned, 5 executed (plus end-of-life)
  - Second exercise satisfied 3 exercises
- Fuel expenditure on 4 exercises slightly lower than predicted
  - Prior to end-of-life exercise, ASTRO had 127 of 144 kg usable fuel remaining (88%)
  - After end-of-life exercise, but prior to decommissioning, ASTRO had 98 kg usable fuel remaining (68%)
  - After decommissioning, ASTRO had 0 kg fuel
- Mission had its share of problems
  - Some hardware, mostly software
  - Each resolved by OE ground team
  - Both vehicles healthy prior to decommissioning
- Several firsts in autonomous operations
- Numerous lessons learned from things that went right & things that went wrong
- Total mission success – all mated & unmated objectives met

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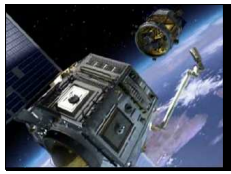
AR&C Exercise #1

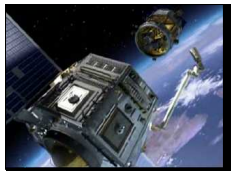
(Scenario 2-1)

6 May 2007 (UTC)



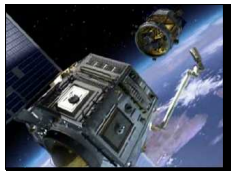
AR&C Exercise #1

Movie



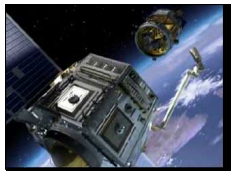
AR&C Exercise #1 Plan

- First U.S. demonstration of autonomous rendezvous & capture (AR&C)
  - World's first AR&C without target vehicle transmitting its navigation data
- Fully separate ASTRO from NextSat for the first time
- Max range = 12 m
- Unmated $1^{h}\ 53^{m}\ 29^{s}$ within $\pm 5^{m}$
  - Onboard-commanded countdown
  - Night demate over COOK AFSCN
  - Separation to 10 meter stationkeep
  - Approach
  - Night direct capture & mate over BOSS
  - Return to solar inertial attitude



AR&C Exercise #1 Plan

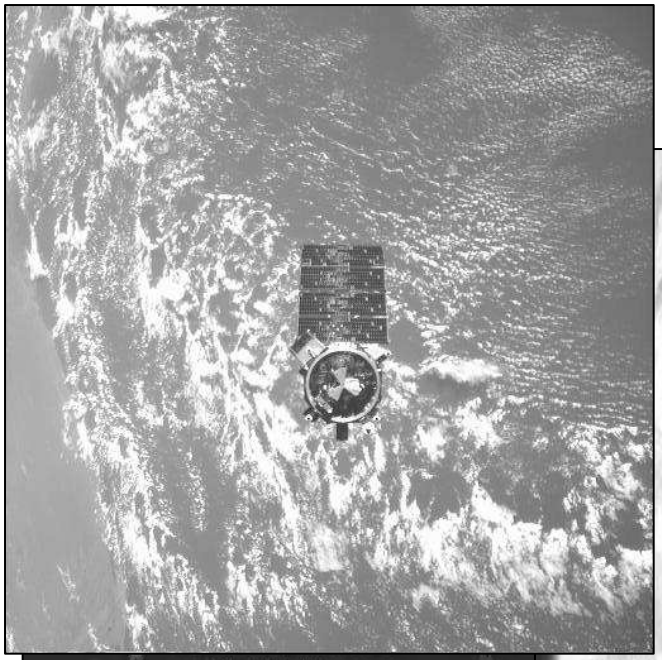
- Instructions preloaded at demate minus 4 hours
  - Ground hands-off until operation complete with vehicles mated & returned to solar inertial attitude
  - Onboard subsystem monitoring – and abort commanding, if needed
  - Ground subsystem monitoring – and backup abort commanding, if needed
- Redundant, dissimilar rendezvous sensors
  - Boeing passive camera-based tracking (Vis-STAR)
  - NASA-MSFC laser-based Advanced Video Guidance Sensor (AVGS)

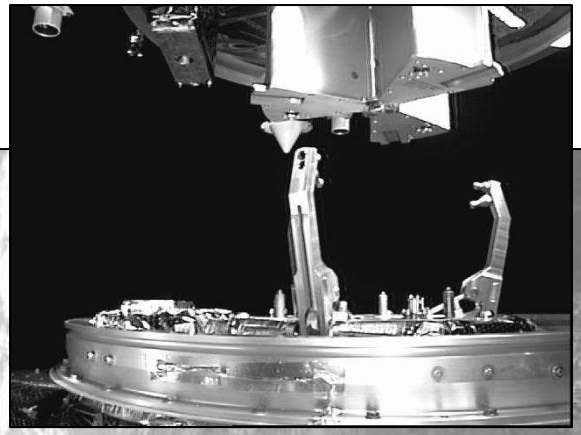


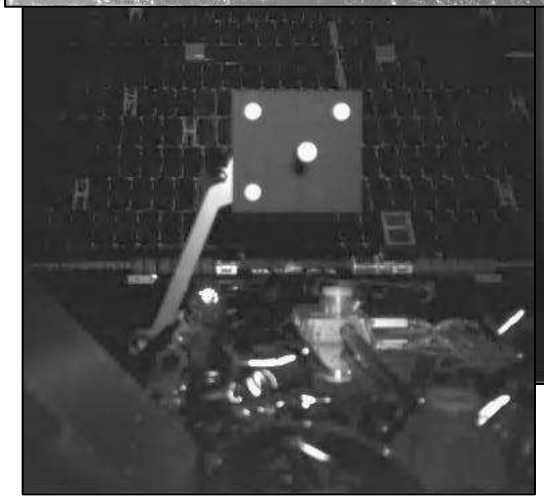
AR&C Exercise #1 Results

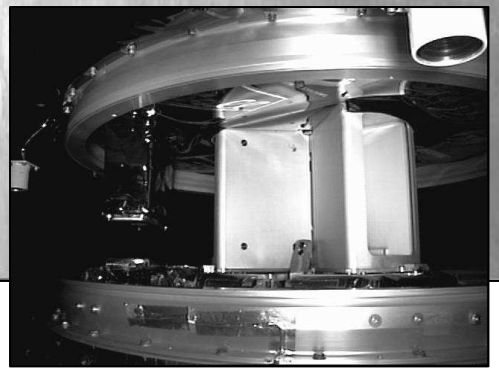
- 100% success
  - Fully autonomous, ground hands-off entire time
  - World's first AR&C without target vehicle assistance
- Max range = 12 m
- Unmated for $1^{h}\ 57^{m}\ 5^{s}$
  - Demate (UTC): May 6th at $5^{h}\ 22^{m}\ 36^{s}$
  - Capture initiation: May 6th at $7^{h}\ 17^{m}\ 51^{s}$
  - Mate: May 6th at $7^{h}\ 19^{m}\ 41^{s}$
- Mixed sensor performance
  - Wide FOV visible camera tracked inside 2 m & beyond 9 m (daylight), but not in between
  - IR camera provided good angle data but not attitude
  - AVGS continuous track entire time
- GN&C & propulsion behaved well
- Batteries remained charged
- NextSat maintained good-to-excellent solar inertial attitude
- Propellant use = 0.3 kg
  - Pre-exercise estimate = 0.4 kg

AR&C Exercise #1 Photos









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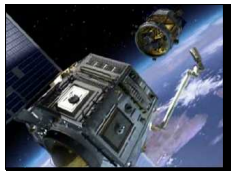
AR&C Exercise #2

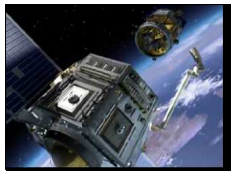
(Scenario 3-1)

12-20 May 2007 (UTC)



AR&C Exercise #2 Plan

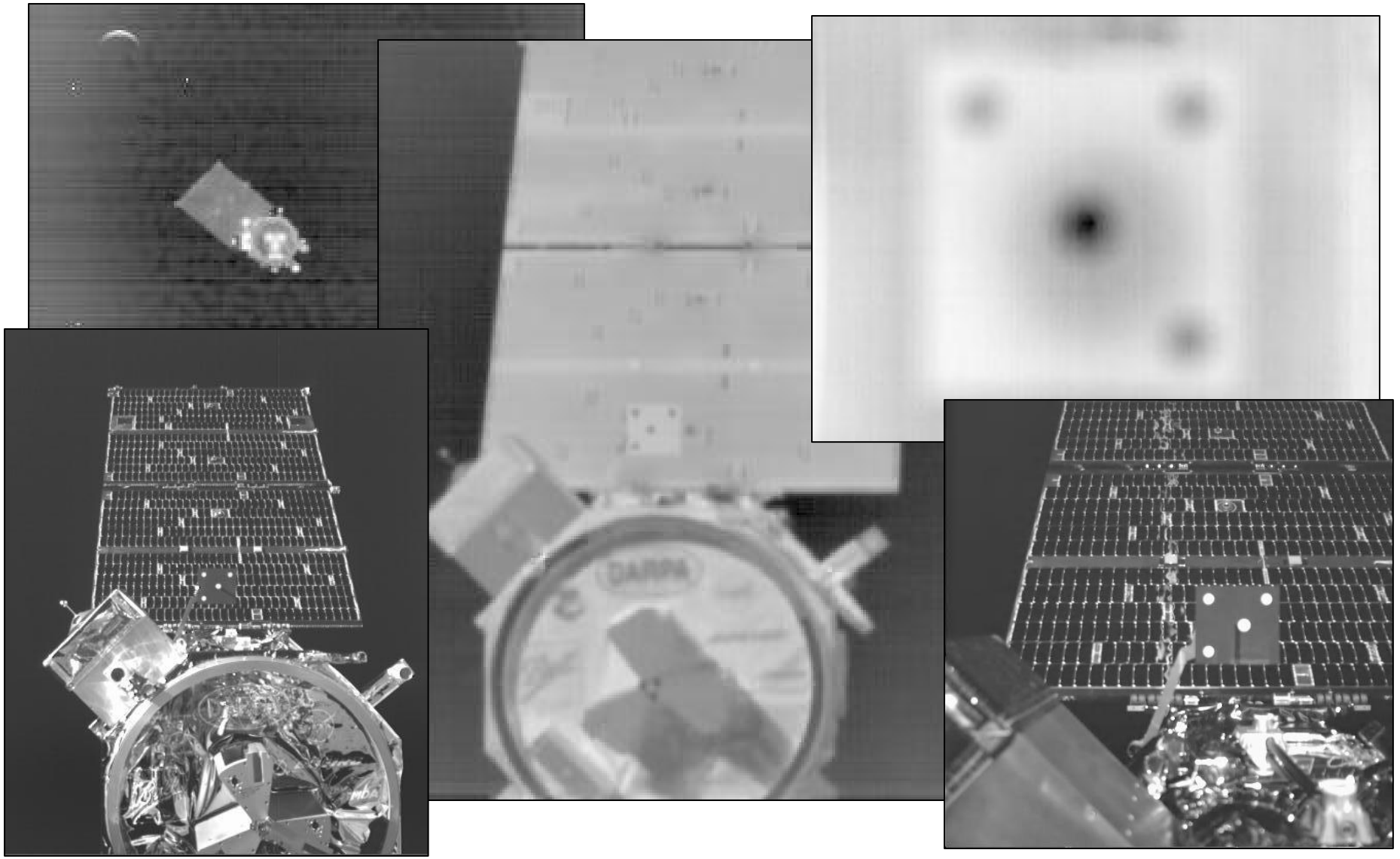
- Max range = 30 m
- Unmated for 2^{h} 8^{m} 16^{s} within $\pm 5^{m}$
  - Night demate over COOK
  - Separate to 30 m
  - Approach to 10 m stationkeep
  - Final approach
- First autonomous robotic grapple & berth
  - Night pass over BOSS
- Updated camera sensor inputs



AR&C Exercise #2 Results

- Max range = 6 km
- Unmated for 7^{d} 22^{h} 25^{m} 30^{s}
  - Demate (UTC): May 12th at 4^{h} 28^{m} 52^{s}
  - Capture initiation: May 20th at 2^{h} 52^{m} 30^{s}
  - Mate: May 20th at 2^{h} 54^{m} 22^{s}
- Flawless separation to 30 m, return to 10 m, initial stationkeep
  - Camera continuous track entire time
  - AVGS continuous track entire time
- Three problems ensued
  - Sensor computer processor failed during 10 m stationkeep
  - IR camera locked onto bright pixels during 120 m stationkeep
  - Ground "nudge" command resulted in large erroneous burn
- 2 hours turned into 8 days of relative navigation recovery
- Ended with +V-bar approach and direct capture
- Propellant use = 4.1 kg
  - Pre-exercise estimate = 0.8 kg

AR&C Exercise #2 Photos



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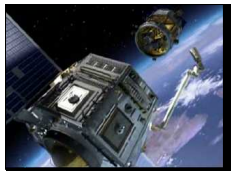
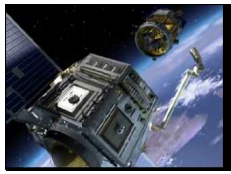
AR&C Exercise #3

(Scenario 5-1)
16 June 2007 (UTC)



AR&C Exercise #3 Plan

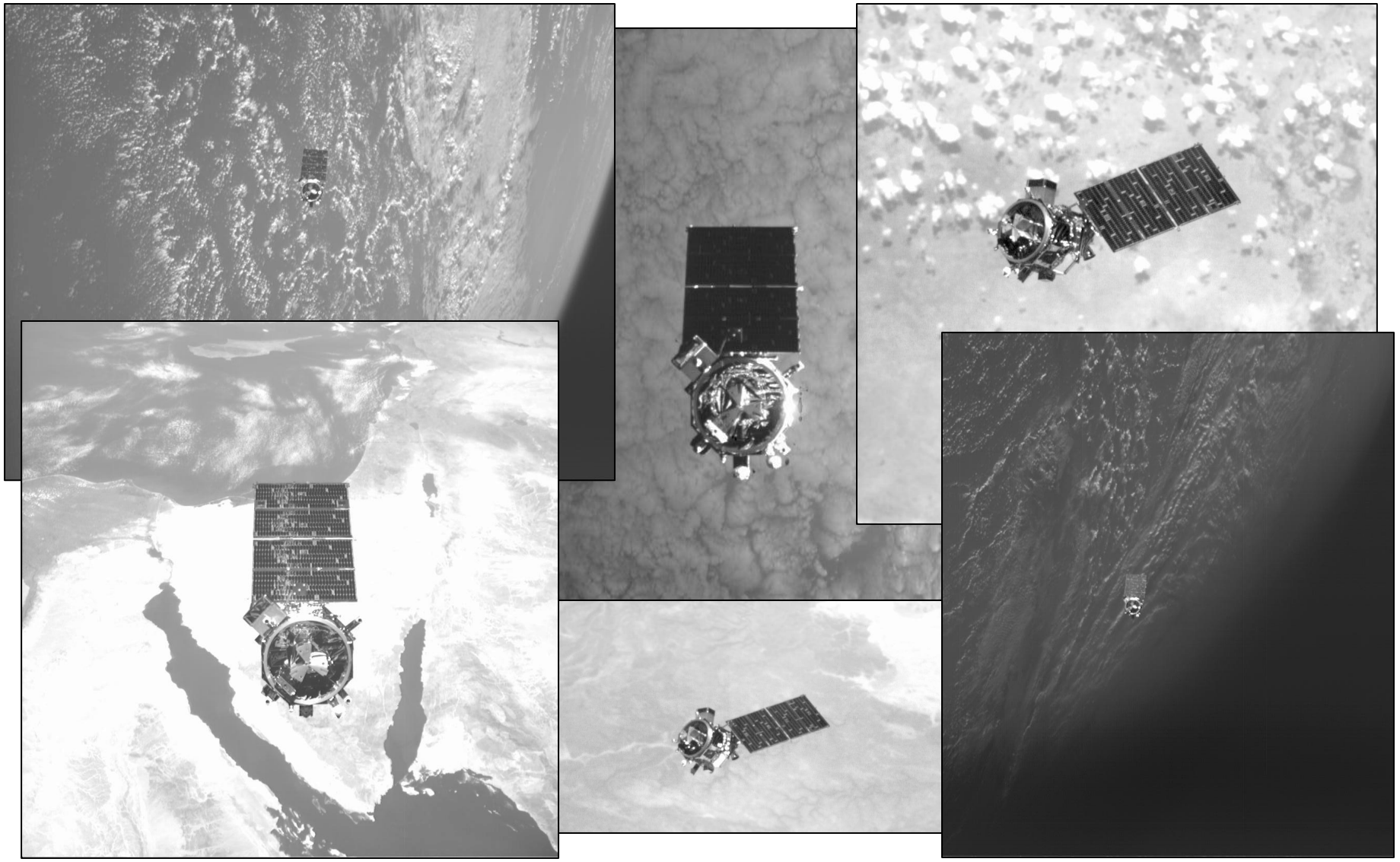
- Max range = 120 m
- Unmated for $4^h\,46^m\,54^s$ within $\pm 5^m$
  - Daylight demate over LION with sun β=–3.3°
  - Solar inertial separation to 70 m below/right of NextSat
  - Large 47 m crosstrack
  - ±120x60 m elliptical flyaround
    - Natural motion with correction burns as needed
    - Single-orbit rate
  - +120 m stationkeep
  - –R-bar approach
  - Daylight mate over TDRSS with β=–2.6°
- Sensor redundancy
  - Vis-STAR track entire time
  - AVGS track during corridor separation & approach
- Direct capture



AR&C Exercise #3 Results

- Max range = 120 m
- Unmated for $4^h\ 51^m\ 7^s$
  - Demate (UTC): June 16th at $9^h\ 47^m\ 2^s$
  - Capture initiation: June 16th at $14^h\ 36^m\ 22^s$
  - Mate: June 16th at $14^h\ 38^m\ 9^s$
- Fully autonomous, flawless execution
- Excellent sensor performance
  - Nearly-continuous Vis-STAR tracking during all phases & lighting conditions, including earth background
  - Laser rangefinder near-100% accurate returns while beyond 50 m
  - AVGS near-continuous track while within 27° alignment (98 m outbound)
- GN&C and thrusters behaved nominally (no overheating)
- Batteries remained mostly charged despite LVLH approach
- NextSat properly held solar inertial & LVLH attitudes
- Improved ground understanding of relative navigation settings
- Propellant use = 1.4 kg
  - Pre-exercise estimate = 2.2 kg

AR&C Exercise #3 Photos



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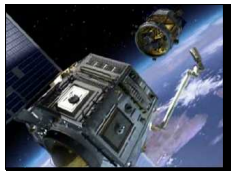
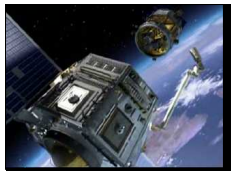
AR&C Exercise #4

(Scenario 7-1)
23 June 2007 (UTC)



AR&C Exercise #4 Plan

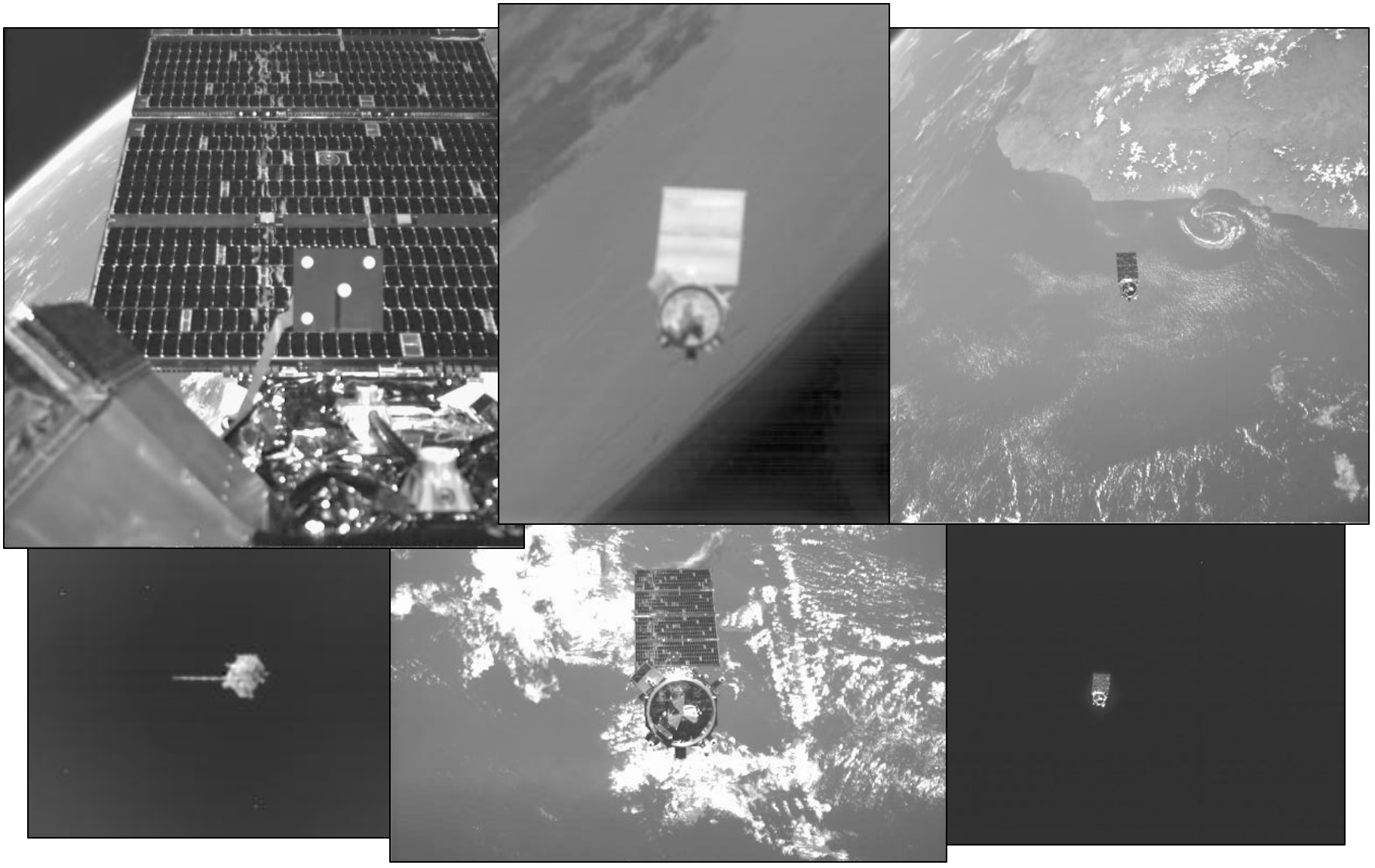
- Max range = 4 km
- Unmated for 16^h 45^m 59^s within $\pm 5^m$
  - Daylight demate over GUAM with sun β=24.6°
  - Solar inertial separation to 130 m above NextSat
  - Phasing to –4 km (behind NextSat)
  - Return to –120 m v-bar stationkeep
  - 100 m near-circular flyaround
    - Forced-motion, in-plane inspection
    - Single-orbit rate
  - +120 m v-bar stationkeep
  - Transfer to 60 m corridor
  - Solar inertial approach
- First autonomous robotic grapple & berth
  - Night pass over REEF or TDRSS with sun β=27.5°



AR&C Exercise #4 Results

- Max range = 4 km
- Unmated for $22^h\ 2^m\ 19^s$
  - Demate (UTC): June 23th at $0^h\ 55^m\ 42^s$
  - Grapple initiation: June 23th at $17^h\ 37^m\ 38^s$
  - Mate: June 23th at $22^h\ 58^m\ 1^s$
- Fully autonomous, flawless rendezvous & prox ops
- World's first autonomous grapple
- Autonomous berth stopped by onboard mission manager
  - Script error
  - Completed with ground assistance
- Improved ground understanding of relative navigation settings
- Propellant use = 3.7 kg
  - Pre-exercise simulation estimated 3.8 kg

AR&C Exercise #4 Photos



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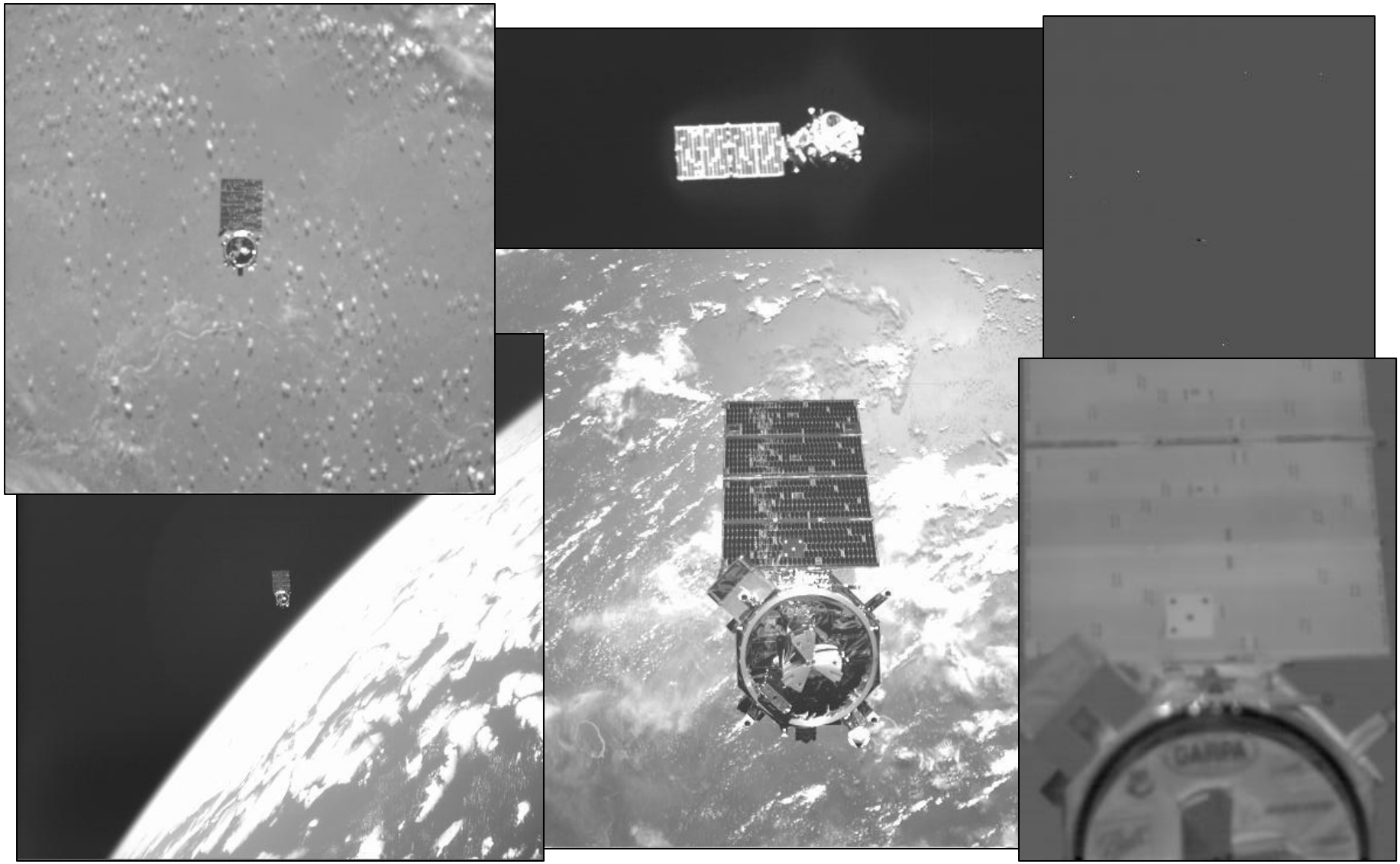
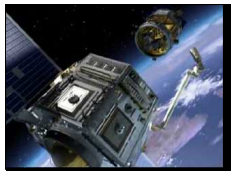
AR&C Exercise #4 Photos



AR&C Exercise #5

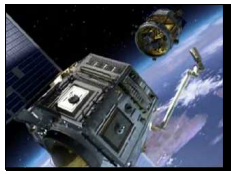
(Scenario 8-2)

27-29 June 2007 (UTC)



AR&C Exercise #5 Plan

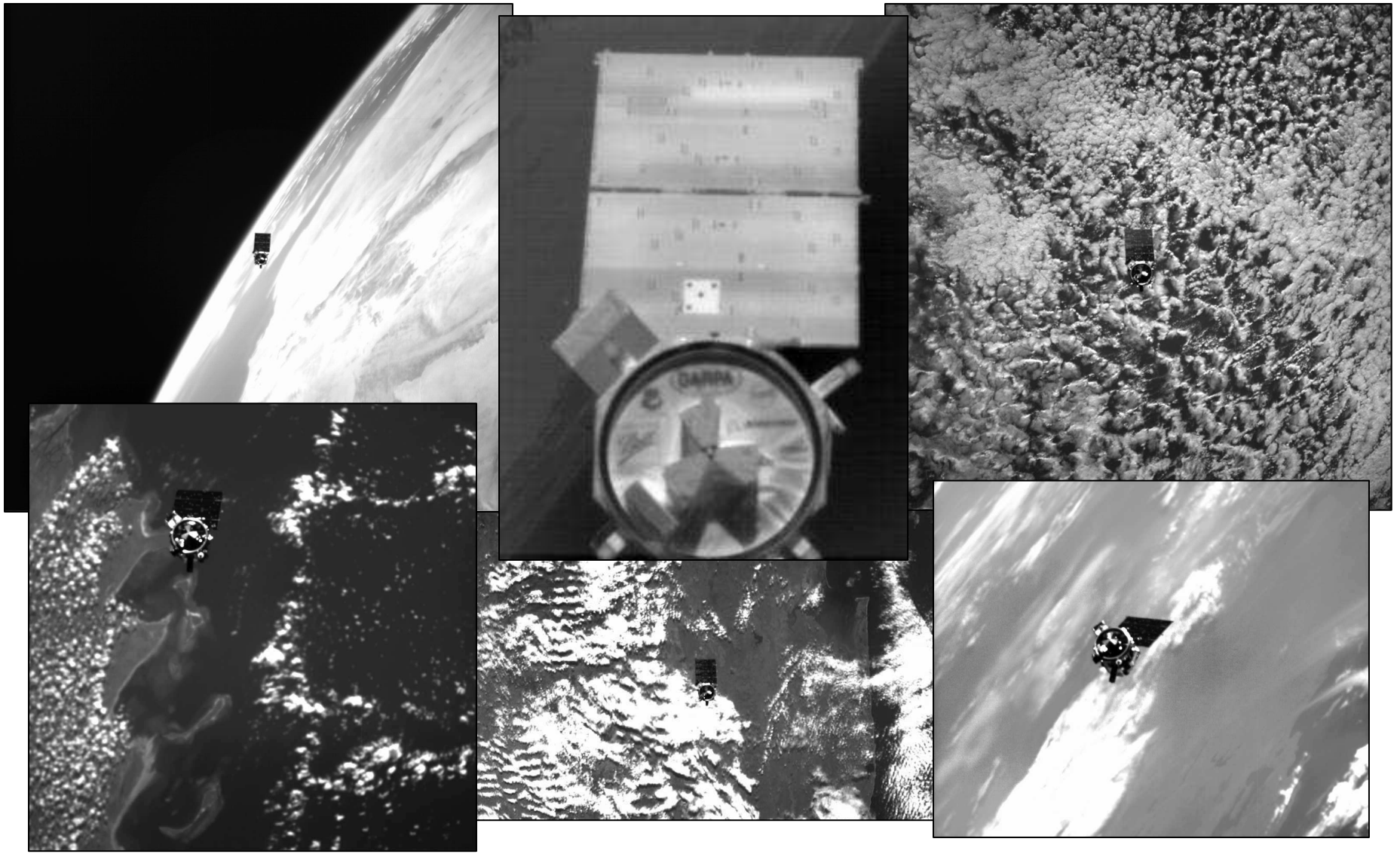
- Max range = 7 km
- Unmated for $1^{d}\ 1^{h}\ 25^{m}\ 45^{s}$ within $\pm 5^{m}$
  - Night demate with sun β=44.0°
  - Solar inertial separation to 78 m above and slightly left of NextSat
  - Phasing to –7 km (behind NextSat)
  - Return to –4 km followed by demonstration of standoff mode for ~$6^{h}43^{m}32^{s}$
  - Return to –120 m v-bar stationkeep to await good lighting
  - 100 m near-circular inspection flyaround at 3 times orbital rate
  - +120 m v-bar stationkeep
  - Transfer to 60 m corridor and solar inertial approach
  - Night grapple & berth over HULA within $\pm 5^{m}$ with β=48.6°
- Vis-STAR track entire time
- AVGS track during separation and approach



AR&C Exercise #5 Results

- Max range = 7 km
- Unmated for 1^{d} 21^{h} 54^{m} 19^{s}
  - Demate (UTC): June 27th at 8^{h} 9^{m} 13^{s}
  - Grapple initiation: June 28th at 9^{h} 31^{m} 55^{s}
  - Mate: June 29th at 6^{h} 3^{m} 32^{s}
- Fully autonomous, flawless rendezvous & prox ops
- Grapple anomaly
  - Late trigger of end effector "mousetrap"
  - Ground commanding required to berth NextSat
- Improved ground understanding of relative navigation settings
- Propellant use = 3.8 kg
  - Pre-exercise simulation estimated 4.0 kg

AR&C Exercise #5 Photos



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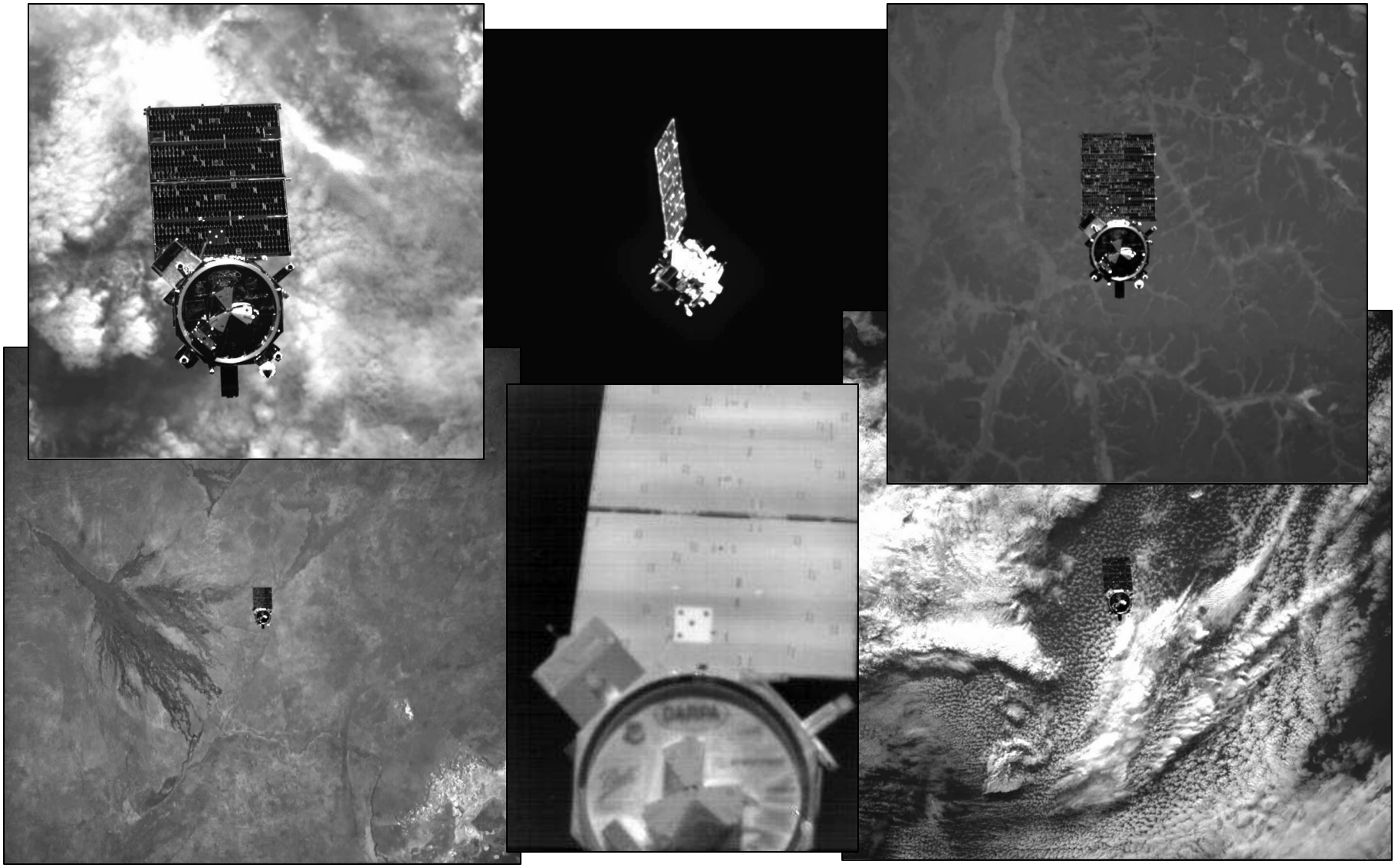
AR&C Exercise #5 Photos



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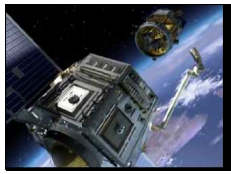
End-of-Life Exercise

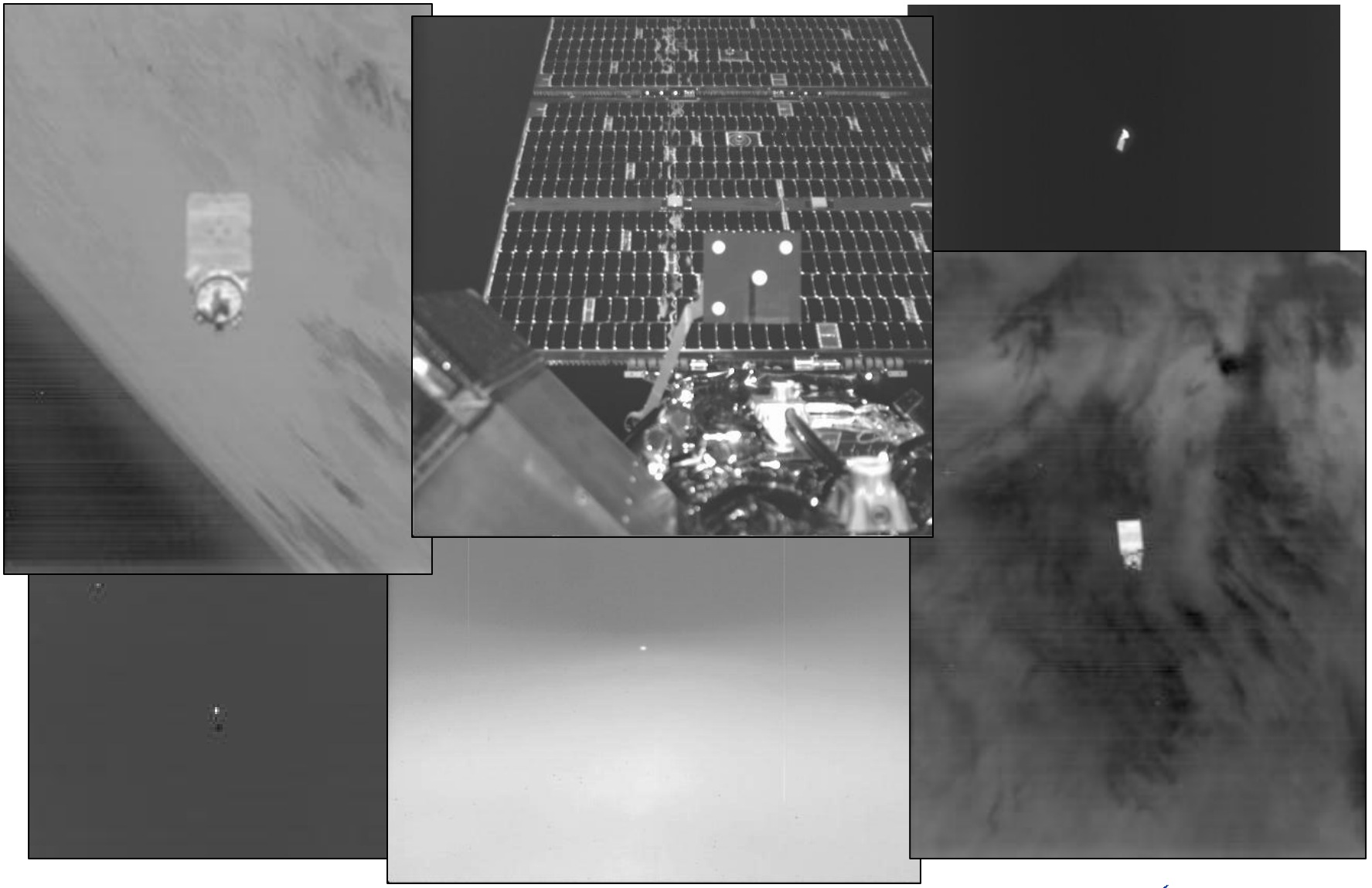
17-20 July 2007 (UTC)



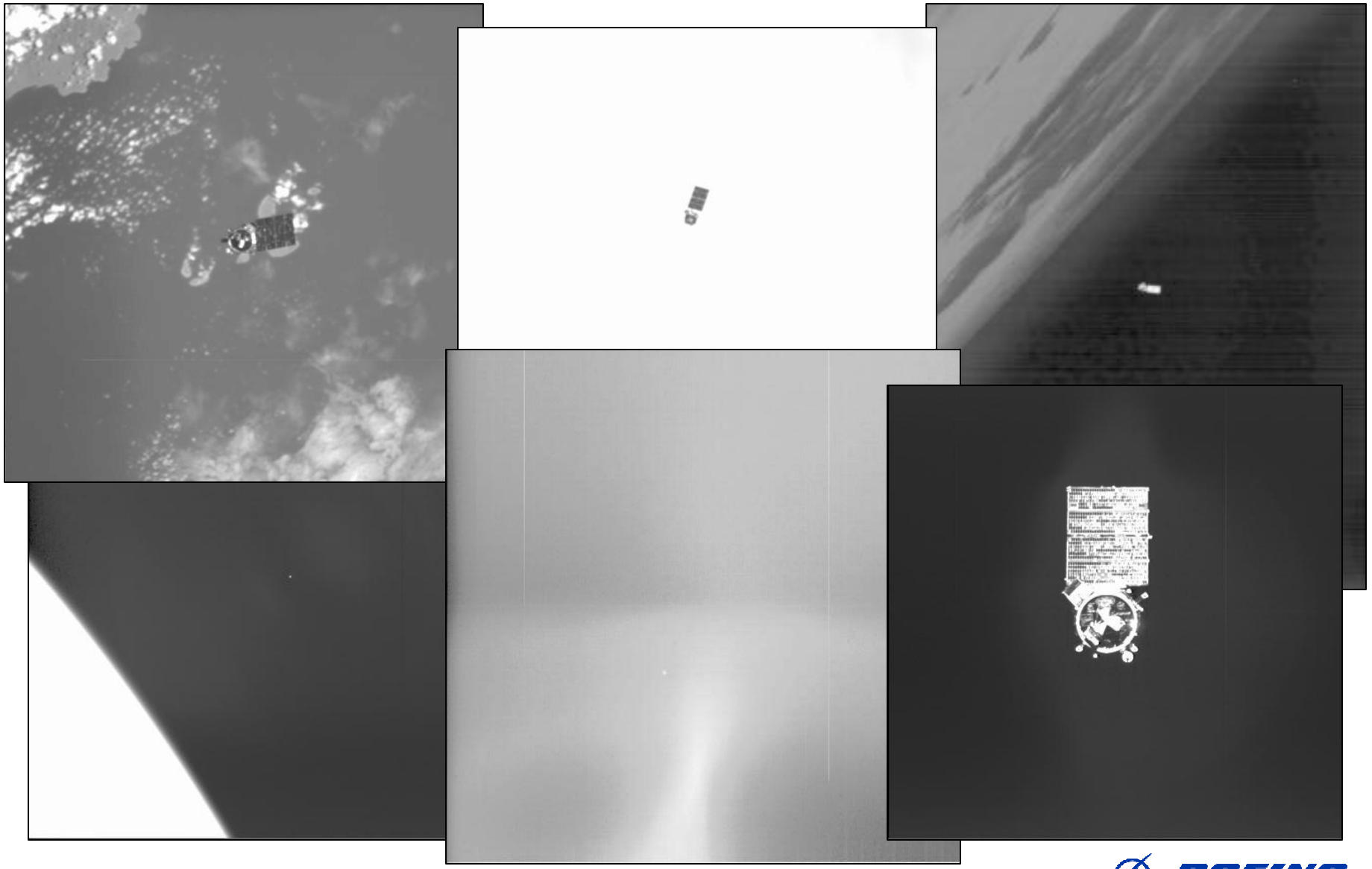
End-of-Life Exercise Results

- Unmated inside 1000 km for 3^{d} 4^{h} 26^{m} 0^{s}
  - Demate (UTC): July 17th at 3^{h} 41^{m} 0^{s}
  - –1000 km outbound: July 20th at 8^{h} 7^{m} 0^{s}
  - Propellant use: 29 kg
- Final tests of autonomous rndz
  - Transfer to –410 km, return to –1 km
  - Standoff between –1 km & –500 m (4 laps around "racetrack") for 1^{d} 5^{h} 44^{m} 27^{s}
    - Unrecoverable laser rangefinder failure
    - IR camera provided good angles data
  - Transfer to +500 m
    - Ended in erroneous football orbit behind NextSat with 1 km crosstrack
    - SIGI accumulated velocities again added to guidance solution
- Final state unmated, never to re-contact again (DARPA requested separation and unmated re-entry in accordance with USAF and USG policy)
  - Transfer to 15 km above NextSat, drifting behind
  - Additional safety with 1.25 km crosstrack
- Remaining fuel depleted prior to ASTRO permanent shutdown
  - Boosted ASTRO to 32 km above
- Both spacecraft to de-orbit within 25 yrs

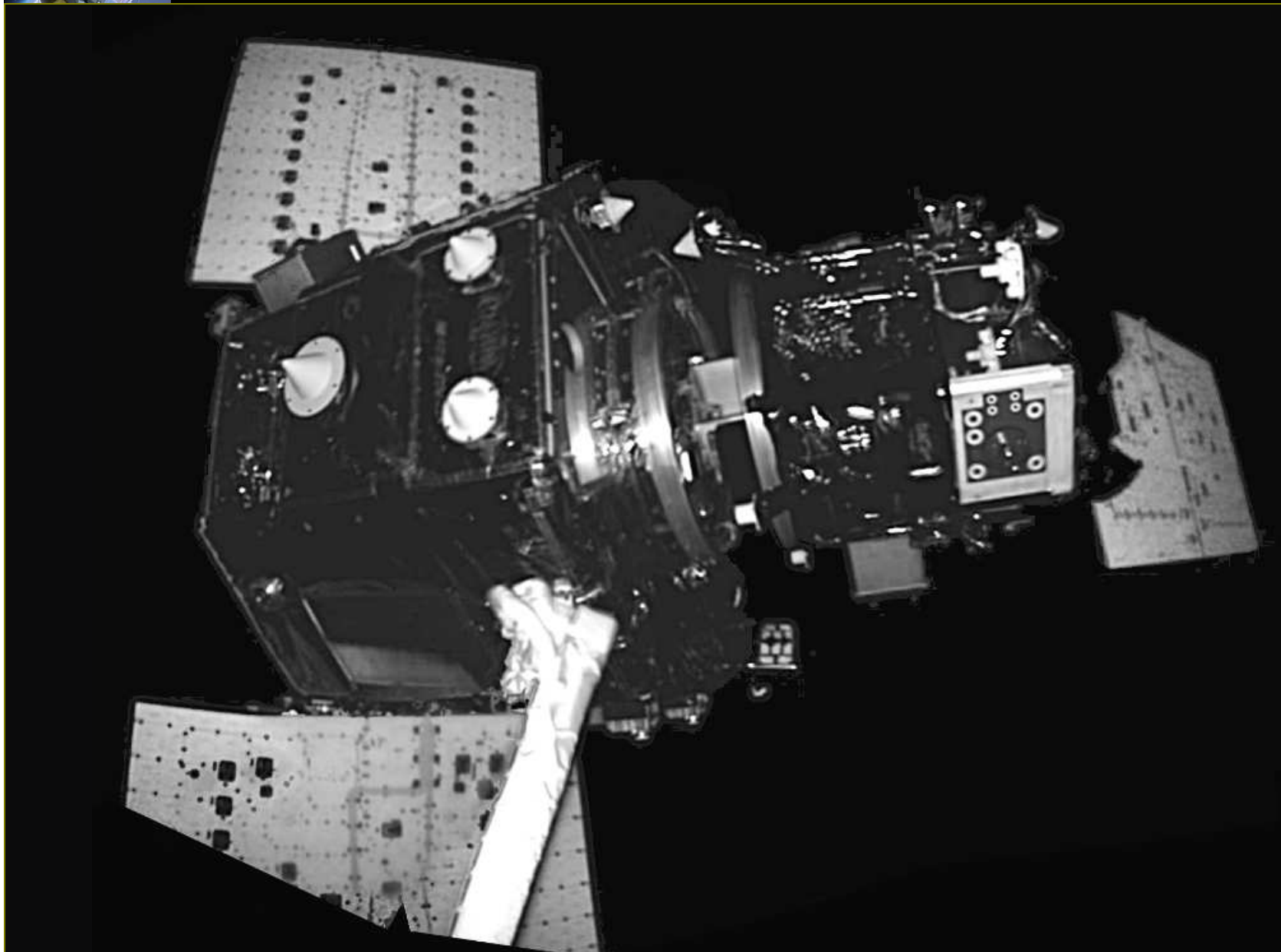
End-of-Life Exercise Photos



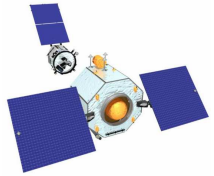
End-of-Life Exercise Photos

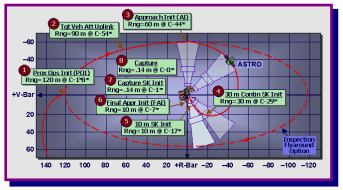


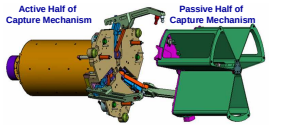
OE Self-Portrait

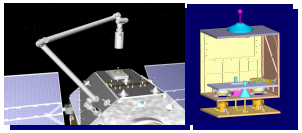


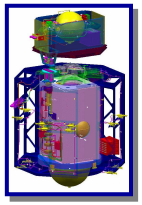
OE Firsts

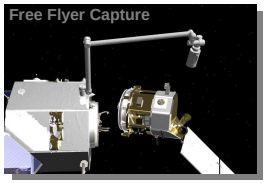












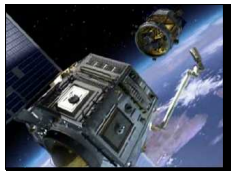
OE Exhibited a Number of Firsts in Space

Most Notable

- First autonomous rendezvous and capture from a range of 7 km
- First autonomous soft capture of a satellite (i.e., during close stationkeep)
- First autonomous capture of a satellite using a robotic arm
- First autonomous robotic transfer of a component from one spacecraft to another
- First autonomous propellant transfer from one spacecraft to another
- First on-orbit use of an embedded IEEE 1394 (Firewire) spacecraft network

BOEING

Backup Charts



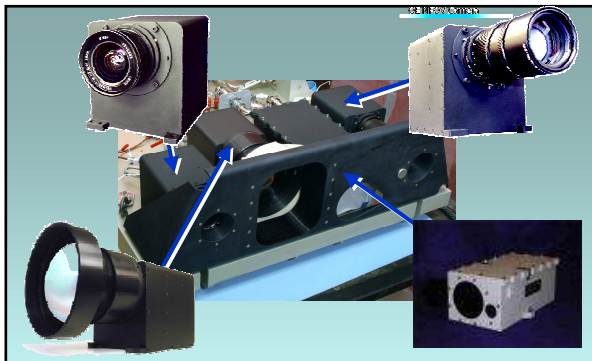
Big Blue Chart – Final Prelaunch Draft

OEDS Test Plan Summary (Rev N Beta 3 - Unofficial)

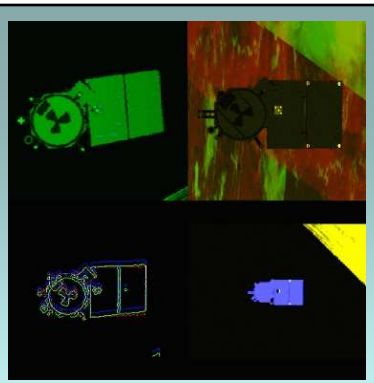
Test	Rendezvous		Prox Ops						Capture		Unmated				Mated				
Scen	Direction	Max Rng	Flyrnd	Max Rng	Apprch	Snsr	Contin Mnvr	Cmd	Type	Lite	hr	min	m/s	kg	Bat	AC3	Fluid	Days	kg
L&A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1.0	0.0
C/O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	14.0	0.5
0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	9	19.0	0.0
1	-	-	-	-	-	A/V	-	-	-	-	7	0	0.0	0.0	2	0	4	16.7	4.0
2	-	-	-	10 m	Sol Inrl	A+V	-	XL	Direct	D	1	52	0.8	0.7	0	0	2	5.9	0.0
3	-	-	-	30 m	Sol Inrl	A+V	-	XL	Fr-Flr	N	1	52	0.9	0.8	2	0	2	5.9	0.0
4	-	-	-	60 m	Sol Inrl	A	-	Grd	Direct	D	3	27	2.0	1.9	0	0	0	0.9	0.0
5	-	-	Flyrd 1x	120 x 60 m	-R-Bar	A+V	-	XL	Direct	D	6	26	3.1	3.0	0	0	0	3.7	0.3
6	Behind	1 km	Flyrd 1x	100 x 100 m	Sol Inrl	V	Prox Ab 20-30	XL	Fr-Flr	N	8	11	4.9	4.0	2	0	2	5.7	0.0
7	In Front	7 km	Direct	-	+V-Bar	A+V	-	XL	Direct	D	20	58	4.2	3.4	0	0	0	3.1	0.3
8	Behind	7 km	Flyrd 3x	100 x 100 m	Sol Inrl	A+V	4 km Standoff	XL	Fr-Flr	N	23	59	8.0	5.9	2	1	5	11.0	0.0
EOL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1.0	--
All	20% Uncertainties										-	-	4.8	3.9	-	-	-	-	1.0
Total Required:				91 Days		29.8 kg Fuel		21%		3	1	45	28.7	23.6	9	2	24	87.9	6.1
Total Propellant Available:						144 kg Fuel (FTAPS Usable)													

Note 1: ASTRO initial wet mass (excluding SSS and battery ORU) = 1040.32 kg (29 Sept 2006 Report)
Note 2: AC3 used for Scenario 8

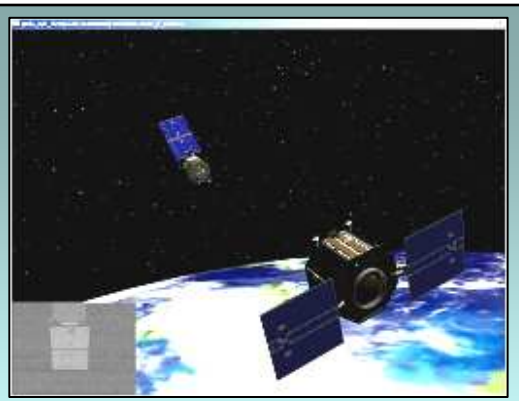
Boeing AR&C Technologies



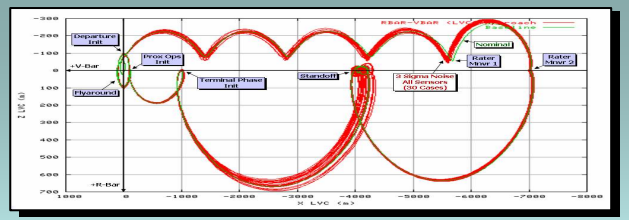
Space Qualified Rendezvous Sensors
- Enable Automated Rendezvous from 200 km to Dock



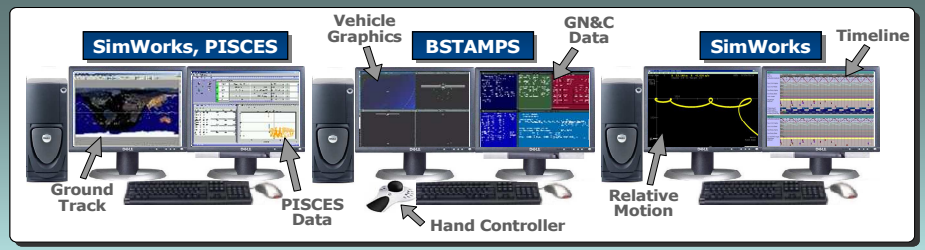
Vis-STAR
- Flight Sensor Software for Passive Client Attitude Determination



SensorSIM
- Realistic Scene Injection for Closed Loop Rendezvous Simulations



AutoGuide/AutoNav
- Guidance and Relative Navigation (G&RN) Software Enables Fully Automated Rendezvous and Capture



BSTAMPS+
- Mission Design
- GN&C Software Development
- Control Center Telemetry & Graphics

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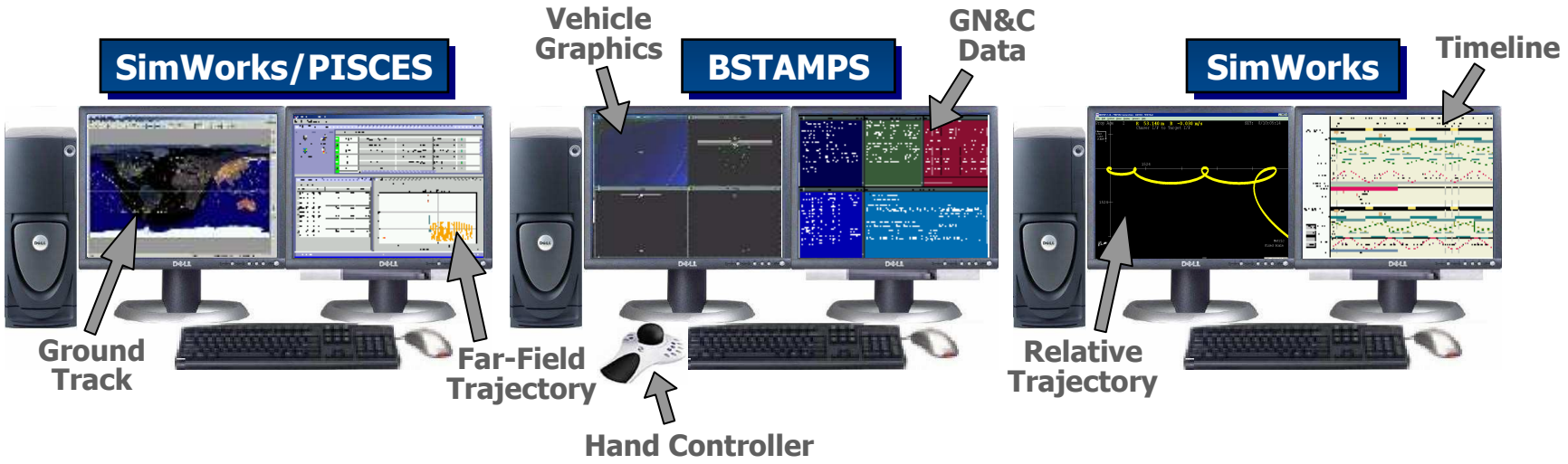
Translation Guidance Modes

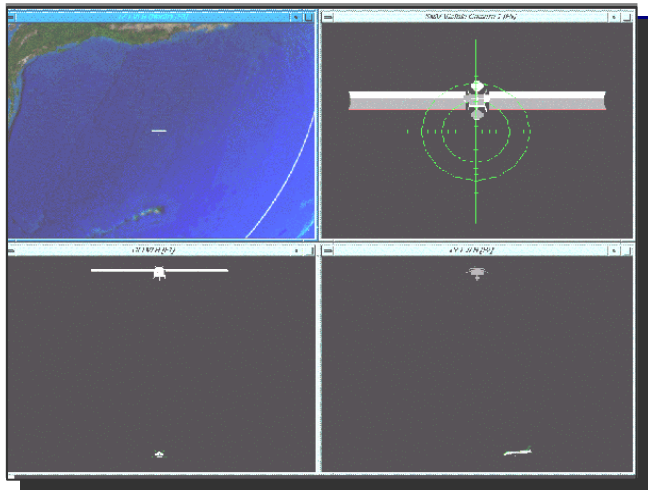
No.	Translation Mode	Description	Application
1.	Phasing (NC)	Phase angle adjustment by targeting a point downrange of target vehicle	♦ Catch-up during far-field rndz
2.	Height Adjust (NH)	Raises or lowers chaser altitude relative to target orbit	♦ Altitude adjustment during far-field rndz
3.	Coelliptic (NSR)	Generates equal separation distances between chaser & target at apogee & perigee; aligns lines-of-apsides	♦ Orbit matching during rndz ♦ Contingency hold initiation
4.	Rater (NR)	Computes mnvr ignition time, transfer time, & delta-v to achieve aimpoint position with zero radial velocity	♦ Near-field rndz phasing/tangential mnvr
5.	Lambert (NCC)	Gooding's Lambert targeting algorithm computes mnvrs required to achieve aimpoint position, using orbit perturbations. Includes optional algorithms for 1) spreading out-of-plane components, & 2) in-plane transfer components, only	♦ Prox ops flyaround
6.	Corridor	Constrains chaser position inside a cone while traversing an approach or separation vector within velocity limits relative to target LVLH or body coordinates	♦ Vectored approach & separation
7.	Stationkeep	Constrains chaser position & velocity inside a 3-dimensional rectangle, cylinder, or truncated cone relative to target LVLH or body coordinates	♦ Nominal & contingency holds in LVLH or body frame
8.	Standoff	Places chaser in a football-shaped orbit offset from the target using Gooding's Lambert targeting algorithm	♦ Contingency V-bar hold at ranges ≥1 km
9.	Prox Abort	Redirects proximity operations trajectory during separation or approach, to best of 2 computed v-bar aimpoints using Rater guidance. Prevents penetration of keepout sphere & executes backout or breakout algorithms, if required.	♦ Abort flyaround trajectory during prox ops ♦ Abort approach or separation trajectory near target in response to critical failure
10.	External Delta Velocity (EXDV)	Ground-computed external DV in either LVLH or chaser body coordinates	♦ Ground-targeted mnvr

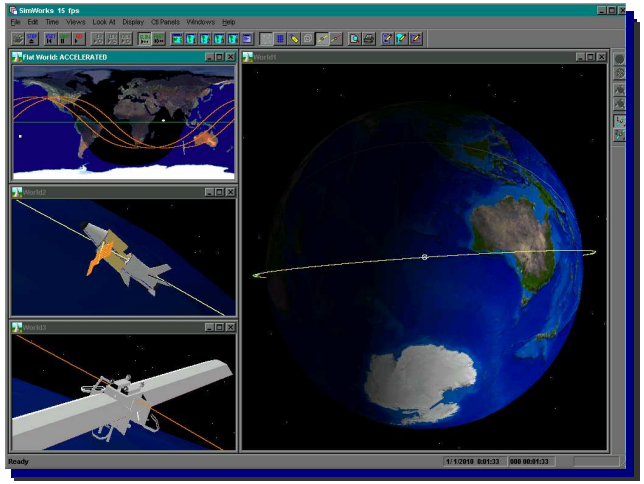
Pointing Guidance Modes

No.	Pointing Mode	Description	Application
1.	Stellar Inertial (STI)	Maintains body vector relative to the stars	♦ Sensor calibration
2.	Solar Inertial (SI)	Maintains body vector relative to the sun	♦ Contingency response to rotating solar array joint failure ♦ Docked operations
3.	Local Vertical Local Horizontal (LVLH)	Maintains body vector relative to the earth	♦ Ground-computed orbit adjustment
4.	Target Track (TT)	Computes fixed or rotating vector stemming from specified chaser point (e.g., sensor) to specified target point (e.g., centroid), while maintaining a clock angle about that vector (secondary pointing constraint – e.g., sun angle). TT executes in 1 of 3 submodes: 1) Target Point (TP, vector fixed on a point – used at short ranges & long ranges during LRF operation), 2) Target Circle (TC, vector rotates in a circle with specified radius & time per rev about target vector – used at long ranges during non-LRF operation), or 3) Target Search (TS, vector spirals outward about target vector & stops when target identified – contingency use, only)	♦ TP during corridor separation & departure prior to LRF power-off – except during TS ♦ TC during departure beyond LRF power-off & return prior to NR2 – except during large mnvrs or TS ♦ TP following NR2 until 8 m – except during large mnvrs or TS ♦ TS as contingency during loss of tracking by camera or LRF
5.	Target Align (TA)	Aligns chaser X, Y, & Z body axes with target axes	♦ Final approach alignment with grapple or docking mechanism
6.	Thrust Align (THA)	Points chaser axes along computed thrust vector to use fuel-efficient (e.g., aft) jets during large translation mnvrs	♦ Large orbit adjust mnvr ♦ Reboost
7.	Free Drift (FD)	Chaser unconstrained rotation	♦ Post-grapple to berth ♦ Docked operations ♦ Contingency response to certain GN&C & propulsive failures

BSTAMPS+ Computer Layout







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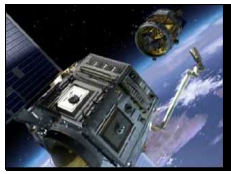

BSTAMPS+ Software Components

Chaser Telemetry Data

Target Ground Track States

Orbit Data

RGNM I-Loads

Boeing Spacecraft Trajectory Analysis and Mission Planning Simulation (BSTAMPS)

- Executed on PC running Red Hat Linux OS

- Pre-mission flight software: RGNM design, development, & test platform
- Pre-mission trajectory design: Simulates chaser & target orbital motion
- GN&C monitoring: Displays real-time data from telemetry & ground track
- Rndz planning: Generates real-time I-loads, flown out at accelerated rate

- Propagates vehicle states & attitudes
- Generates Monte Carlo dispersion data
- Accepts piloted hand controller (Spaceball) inputs
- Includes GN&C flight software, vehicle & sensor models, environment models

- Displays live graphics generated by Vega Prime & Globe View
- Displays live plots generated by Viper
- Displays GUI-driven GN&C data

Guidance, Navigation, Articulation Data

Initial States, Engine Properties

Far-Field Rndz Mnvr Solutions

SimWorks

- Executed on PC running Windows OS

- Predicts & displays ground tracks
- Predicts & displays globe tracks
- Predicts & displays relative trajectories
- Predicts & displays guidance trajectories
- Computes & displays timeline data
- Displays vehicle attitudes, shadows, jet firings, solar array positions, comm zones

Platform Independent Software Components for the Exploration of Space (PISCES)

- Executed on PC running Windows OS

- Pre-mission trajectory design: Computes 3-DOF rndz solutions
- Pre-mission dispersion analysis: Computes Monte Carlo trajectories
- Rndz planning: Computes ΔV inputs to far-field rndz translation sequence

- Displays final solution data & plots

Orbital Express Control Center
Kirtland AFB – Albuquerque, New Mexico

◄ ASTRO Mission Control Team

NextSat Mission Control Team ►

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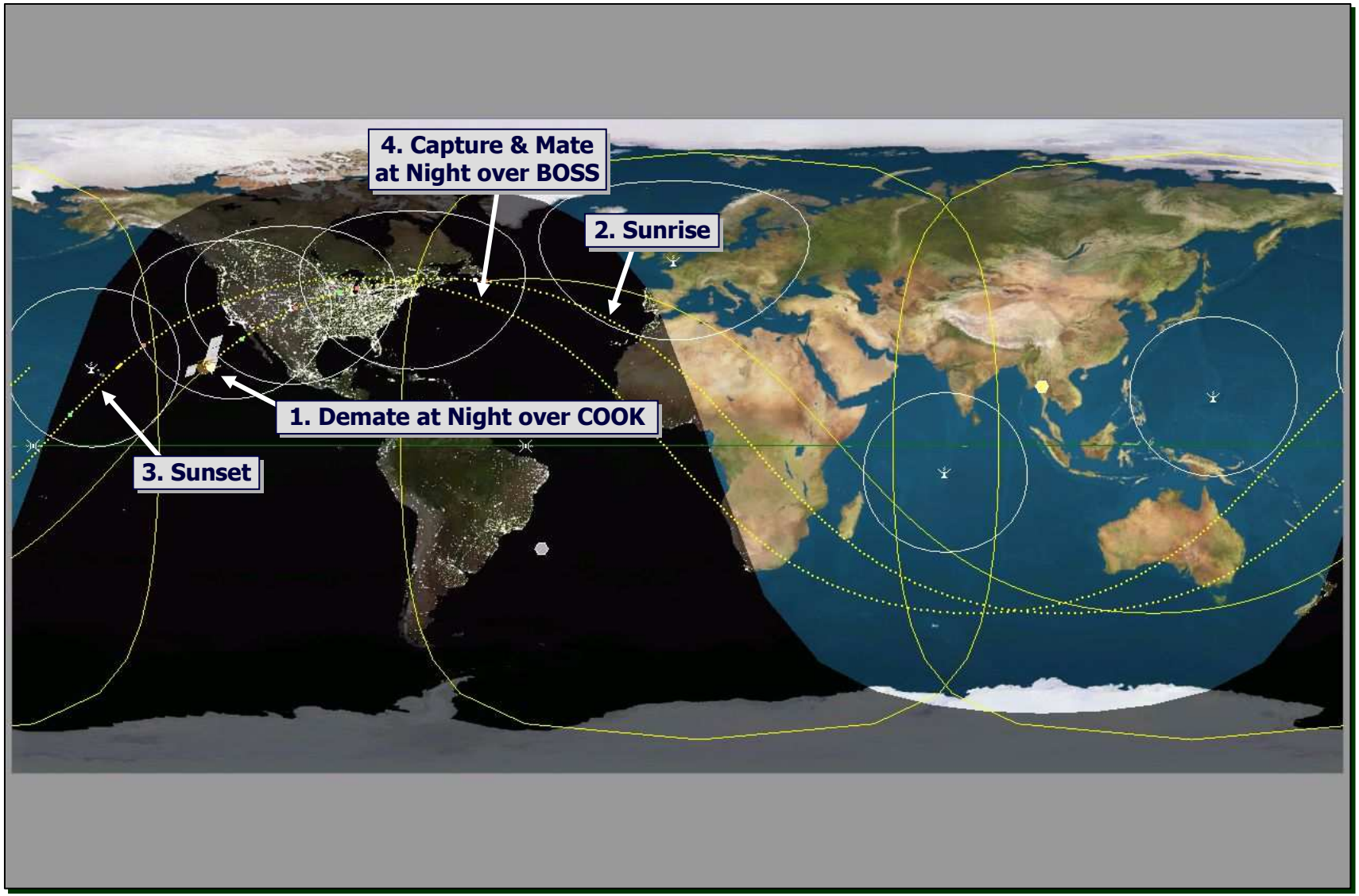
AR&C Exercise #1 (Scenario 2-1)
Planned/Simulated Groundtrack



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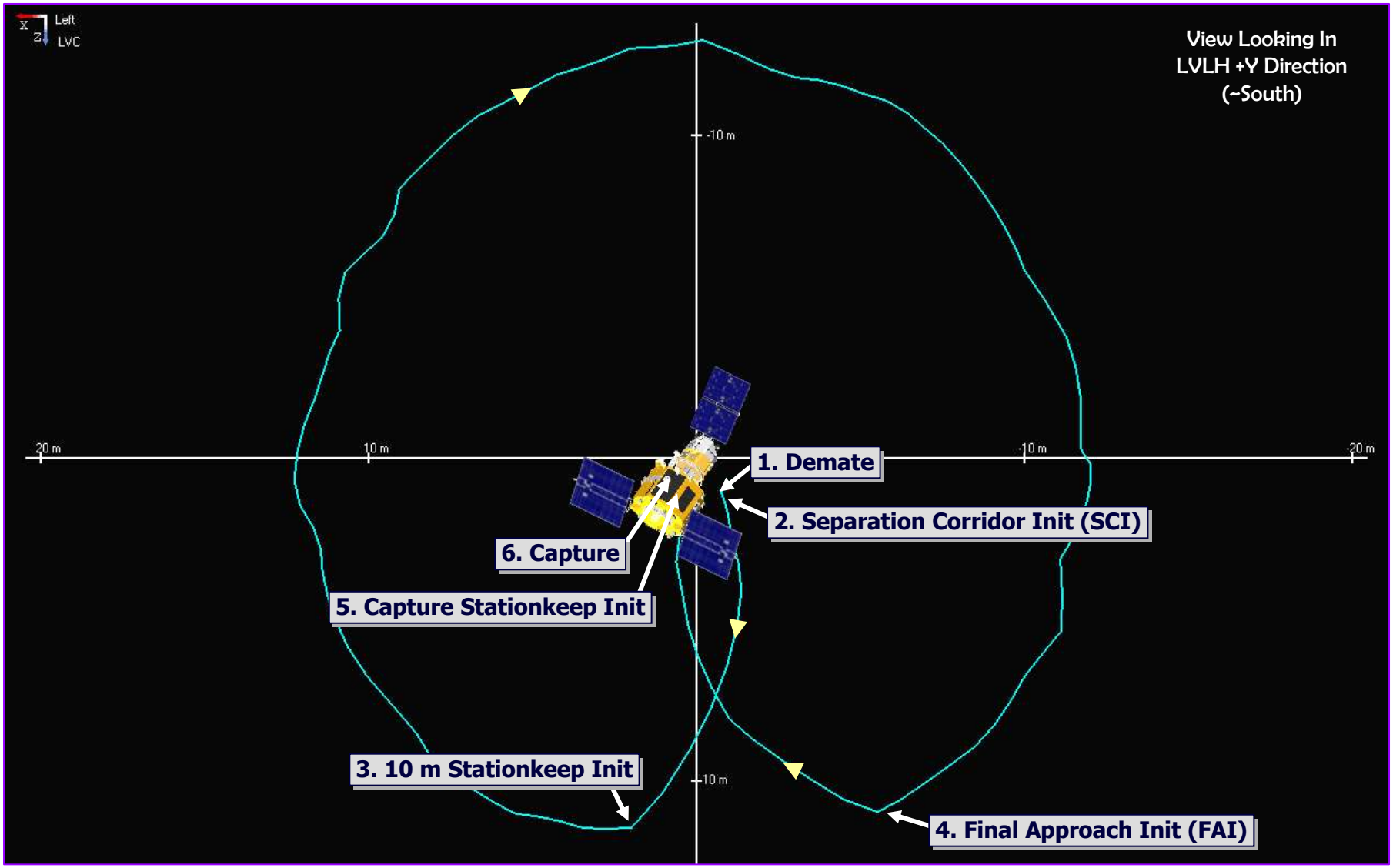
AR&C Exercise #1
Planned/Simulated In-Plane Trajectory



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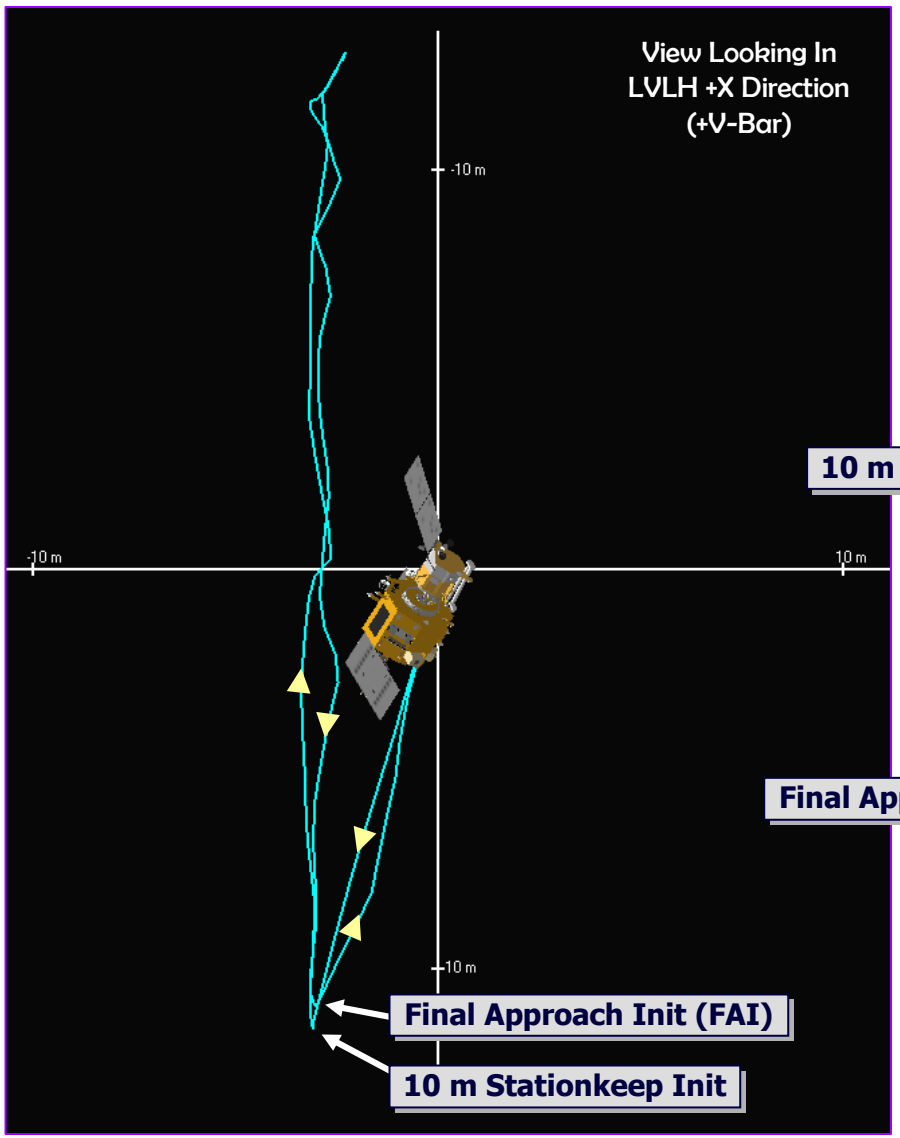
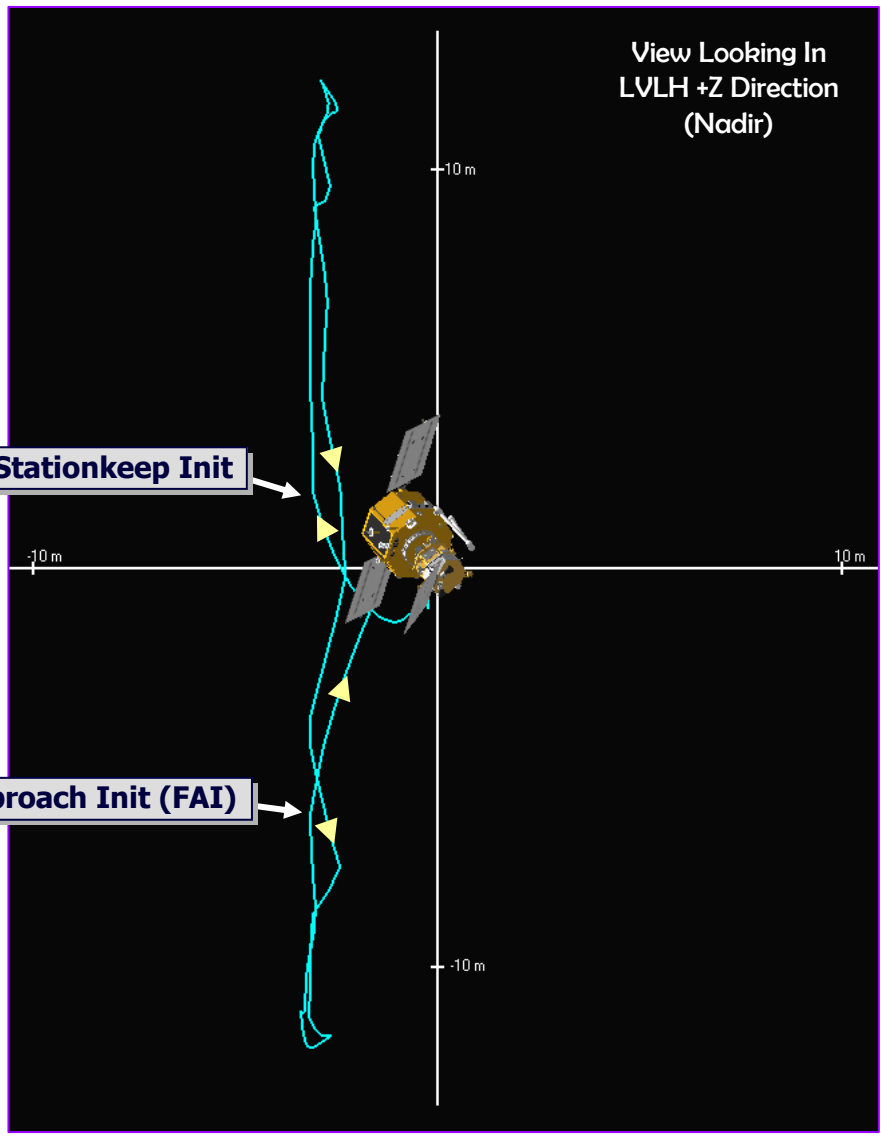
AR&C Exercise #1
Planned/Simulated Out-of-Plane Trajectory





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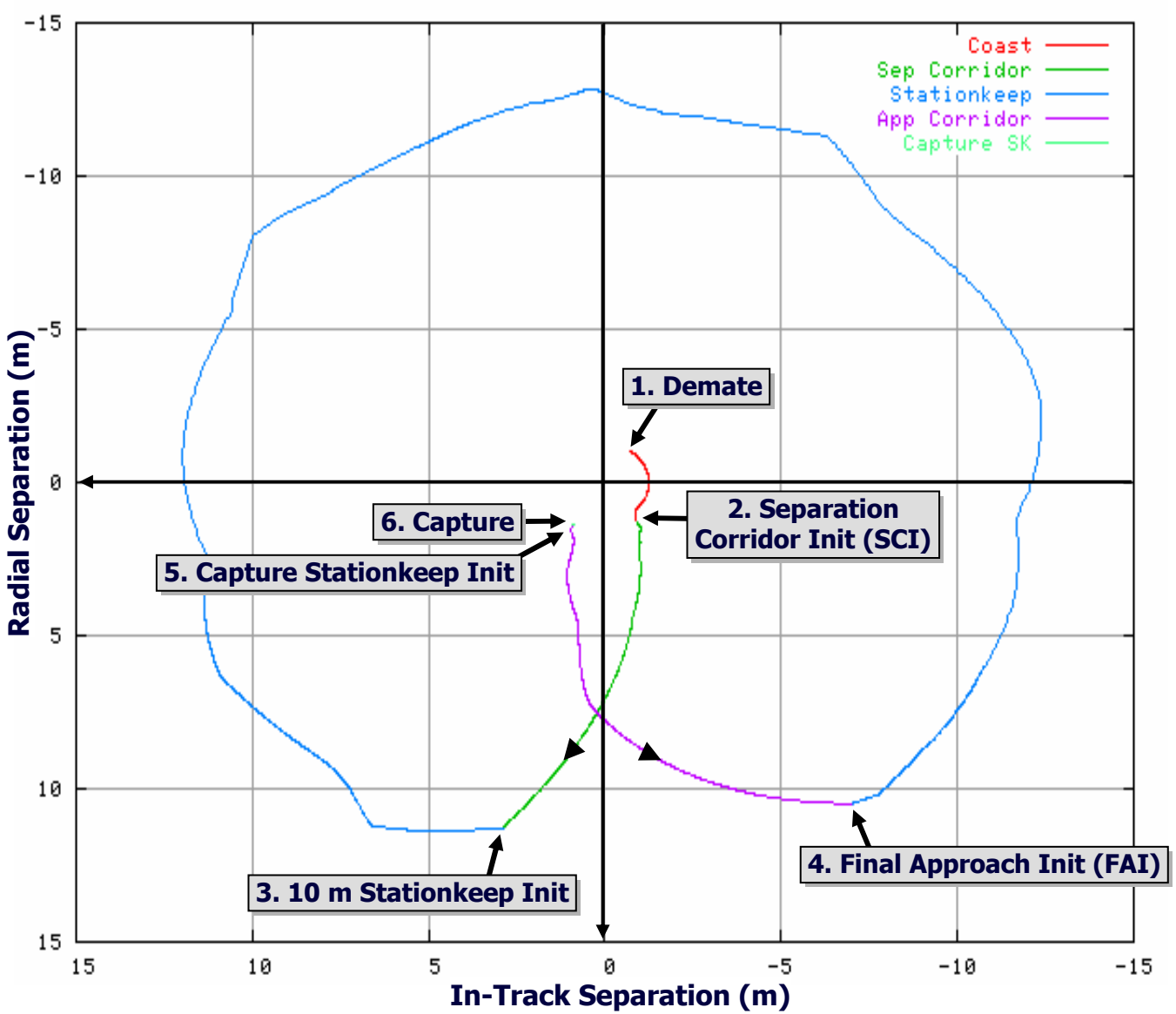
AR&C Exercise #1
Actual/Onboard In-Plane Trajectory



Note 1
This and Subsequent Actual Plots Show ASTRO's Onboard State Relative to NextSat

Note 2
Trajectory Changes Color at Each Translation Guidance Transition

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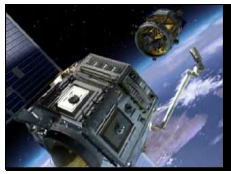
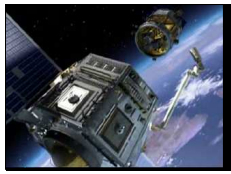


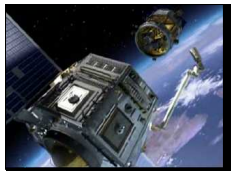
AR&C Exercise #2 (Scenario 3-1)
Detailed Results

- Sensor computer processor failed during 10 m stationkeep
  - Mission manager correctly commanded abort
  - Guidance executed flawless collision avoidance separation to 35 m, transfer to –120 m on NextSat v-bar (behind NextSat), stationkeep
  - As expected, AVGS continued track until short distance outside corridor
- During transfer, ground unable to recover sensor computer, ground booted backup computer, recovered camera tracking
- During –120 m stationkeep, Kalman filter rejected IR camera data
- Without sensor inputs, ground commanded guidance to coast & observed safe opening rate behind NextSat
- ASTRO coasted overnight to –2.4 km while Air Force tracked NextSat using PRN ranging
- Ground commanded single-pulse retrograde "nudge" burn to null opening rate, Δv = –.01, 0, 0 m/s
  - Resulted in large erroneous burn, Δv = –.06, .14, .37 m/s
  - Problem later traced to SIGI accumulated velocities added to guidance solution (diagnosed, fixed, & flight-tested prior to next exercise)
- Ground eventually determined ASTRO given fast closing rate
  - PRN ranging
  - NextSat appeared as disk in narrow FOV visible camera



AR&C Exercise #2
Detailed Results

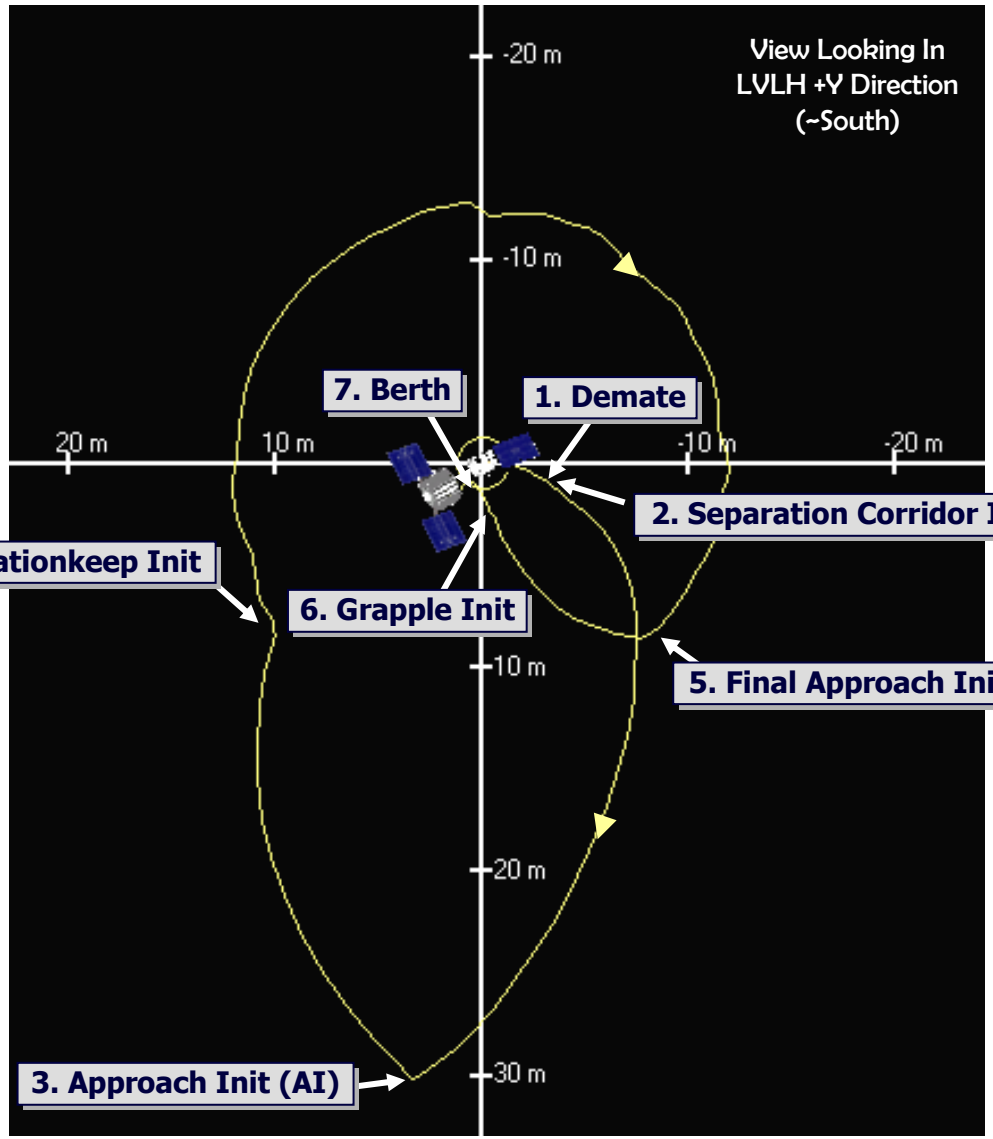
- Exact orbit dimensions unknown, so ground allowed ASTRO to coast ahead of NextSat
  - No sensor tracking
  - Apogee above, perigee below, some out-of-plane
- ASTRO coasted to approx. +6 km, then ground commanded posigrade correction burn to null opening rate
- Over several days, ground iterated on sensor & Kalman filter inputs
  - Learned a great deal, given true imaging environment
  - Bad data incorporated into nav filter not a problem, since ASTRO coasting
  - Occasional ground updates of NextSat state vector reset nav filter
- Ground commanded burns to close on NextSat
- IR Camera tracking & laser track established



AR&C Exercise #2
Detailed Results

- Ground loaded new guidance inputs ending in successful AR&C (direct capture)
  - IR Camera track entire time
  - LRF track inside 2.5 km
  - AVGS track inside 150 m
- Improved ground understanding of relative navigation settings

AR&C Exercise #2
Planned/Simulated In-Plane Trajectory



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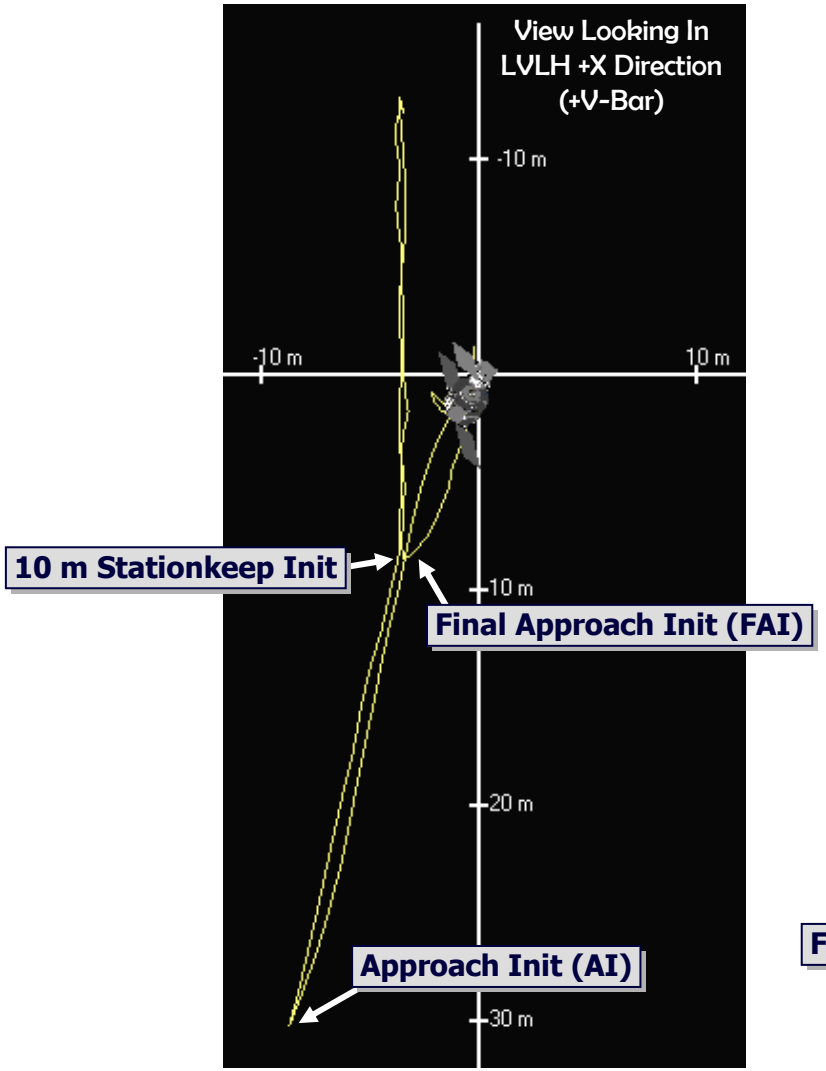
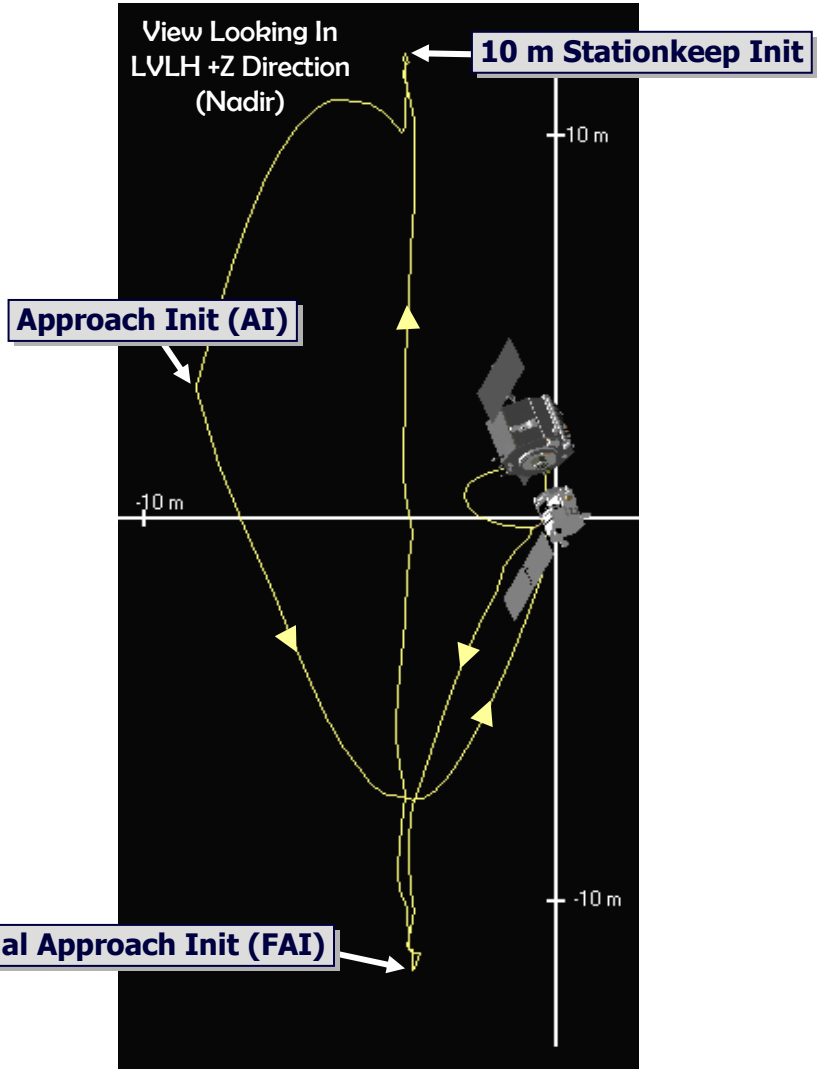
AR&C Exercise #2
Planned/Simulated Out-of-Plane Trajectory





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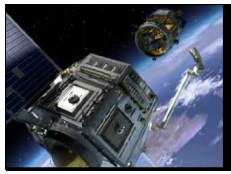
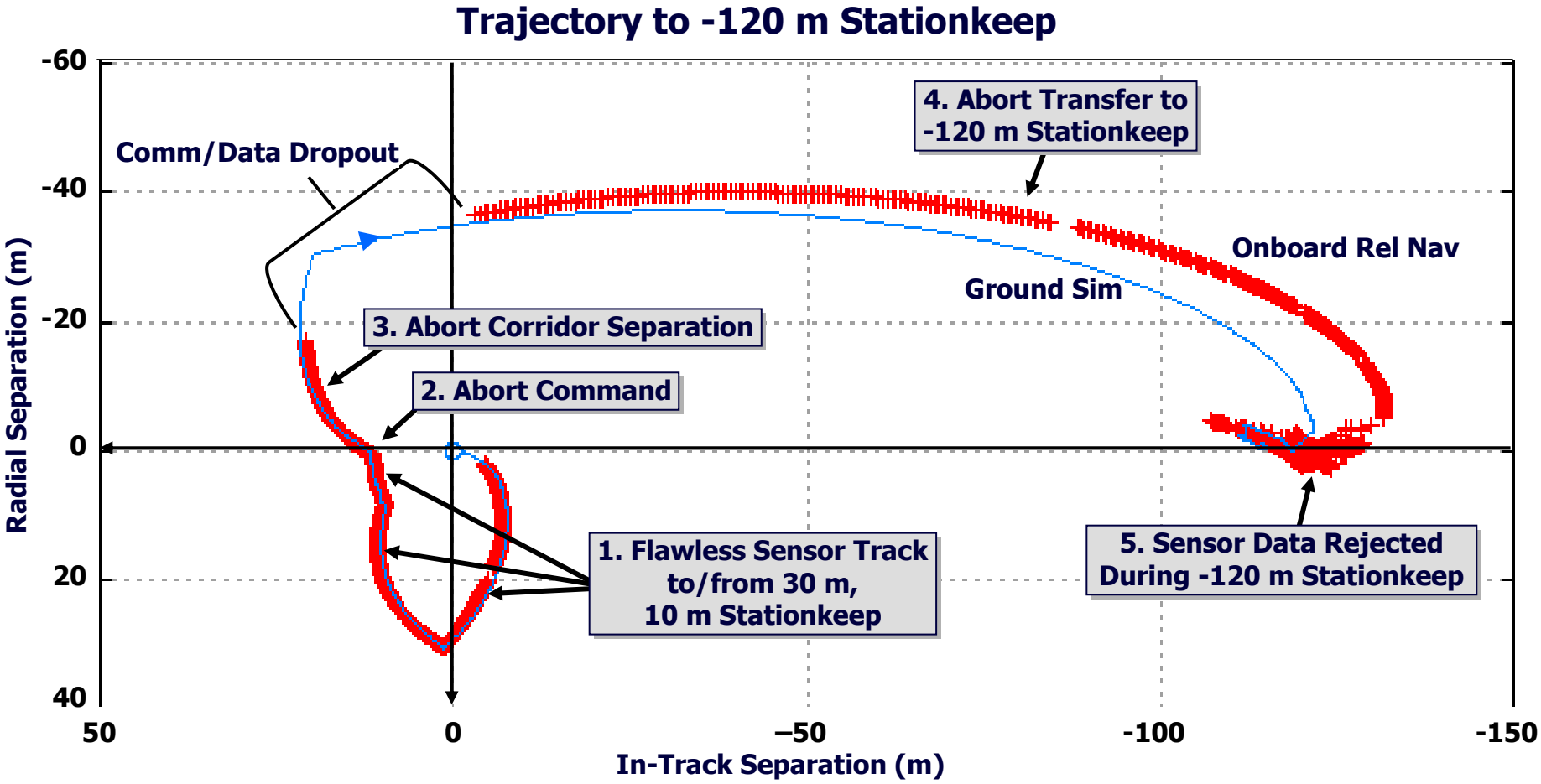
AR&C Exercise #2
Planned/Nominal & Actual/Abort Trajectories





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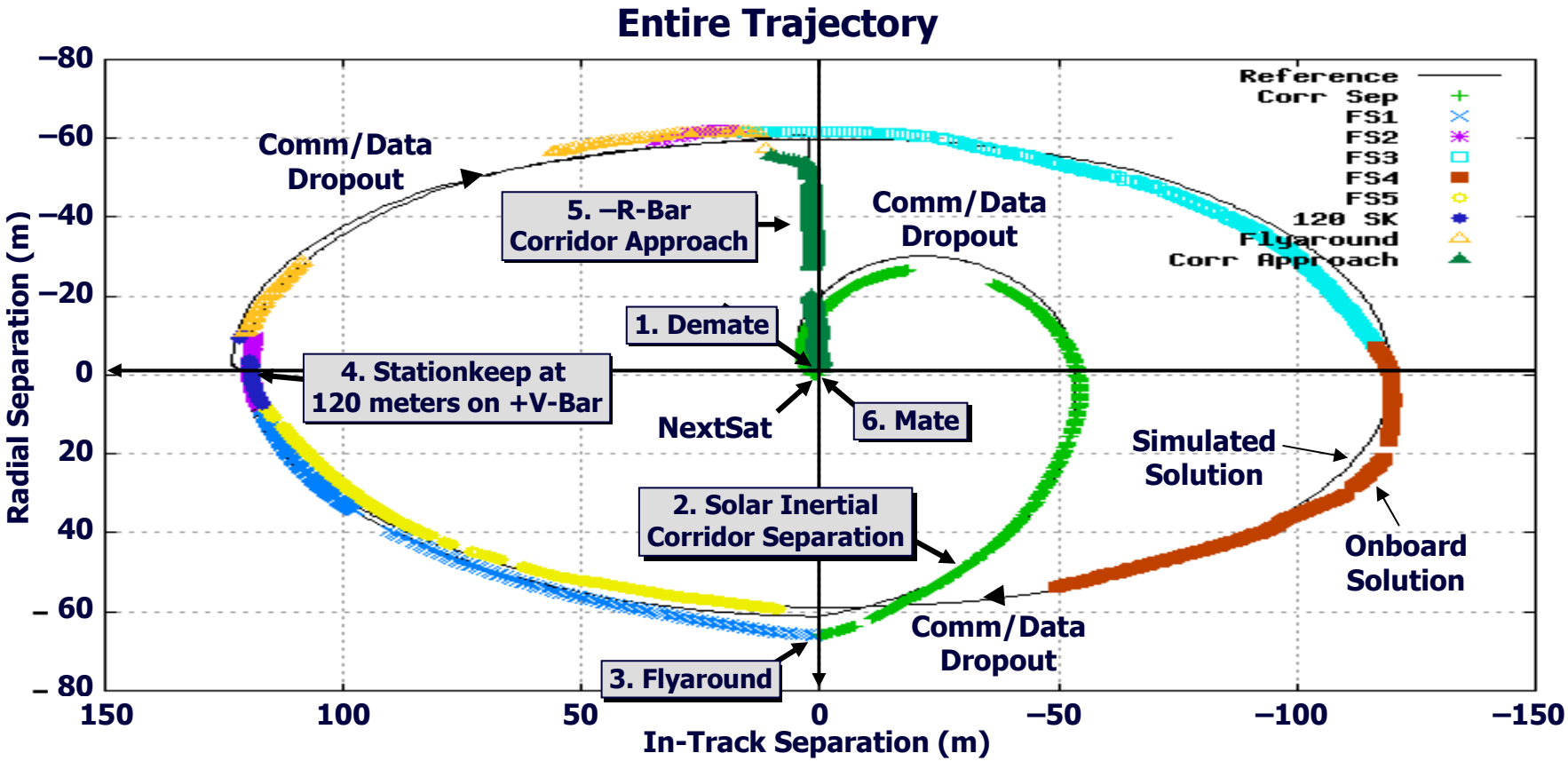
AR&C Exercise #3 (Scenario 5-1)
Planned & Actual In-Plane Trajectories



Exercise #3 Onboard-Computed Trajectory Closely Matched Ground Simulation

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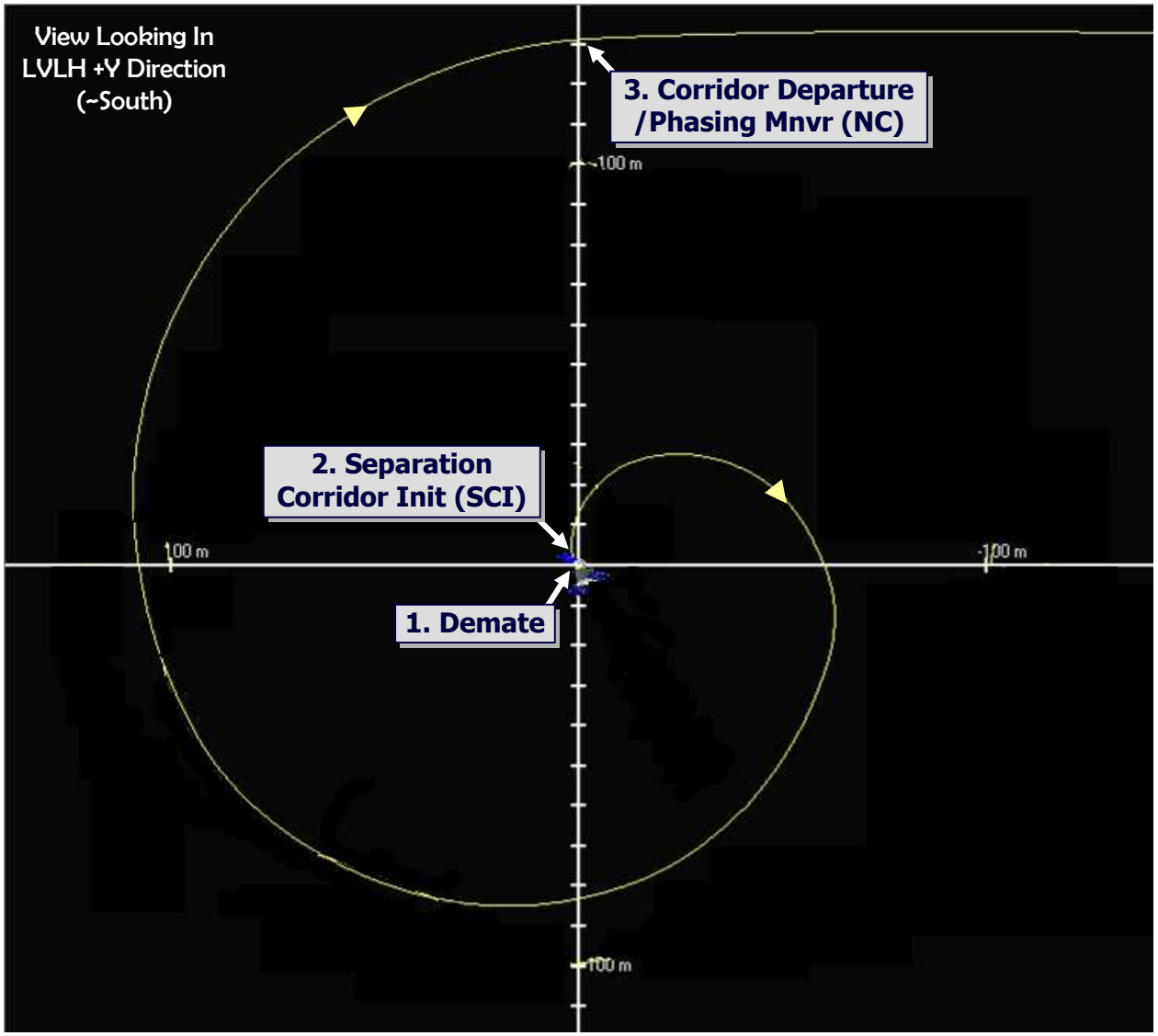
AR&C Exercise #4 (Scenario 7-1)
Planned/Simulated In-Plane Corridor Separation



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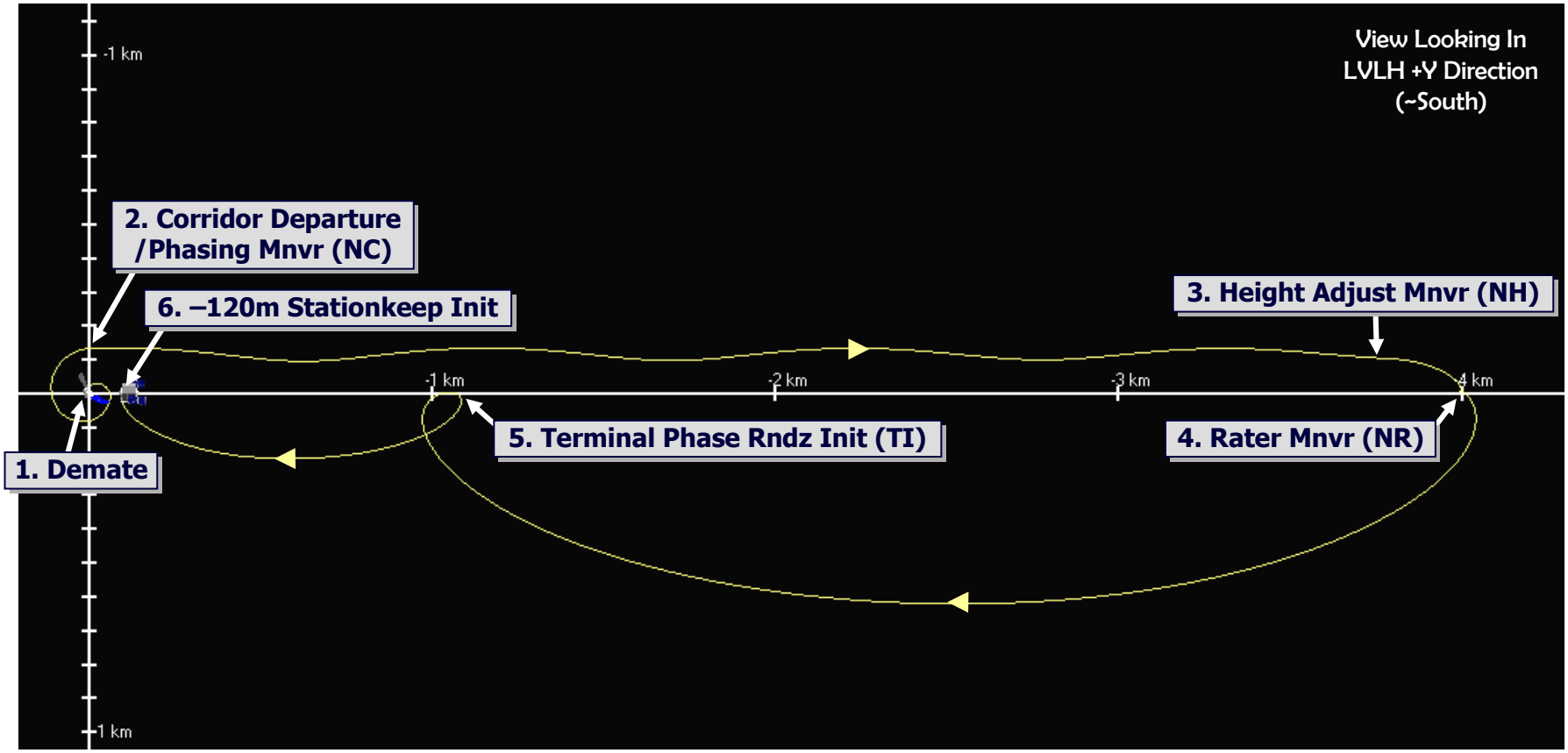
AR&C Exercise #4
Planned/Simulated In-Plane Rendezvous Trajectory



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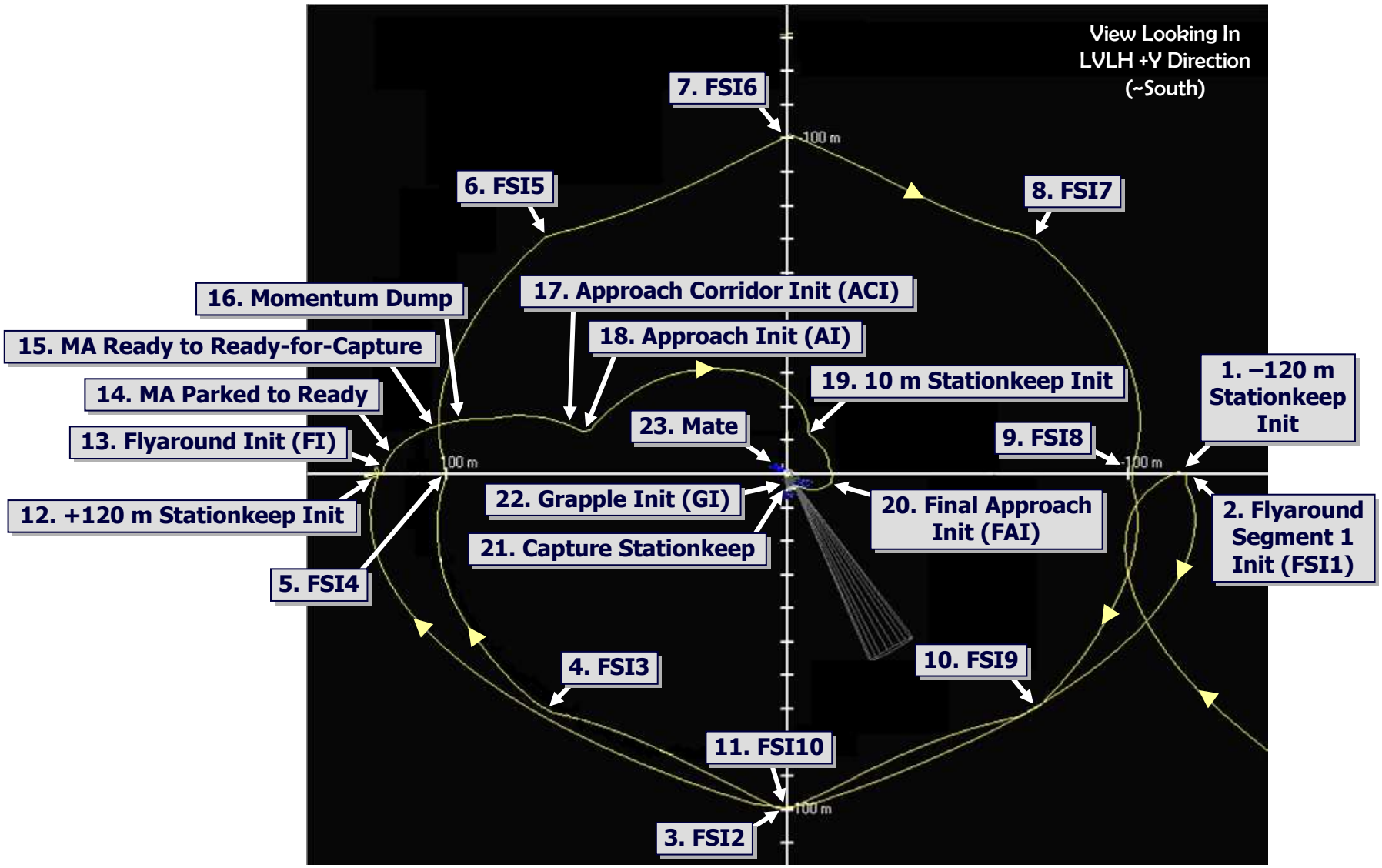
AR&C Exercise #4
Planned/Simulated In-Plane Prox Ops Trajectory



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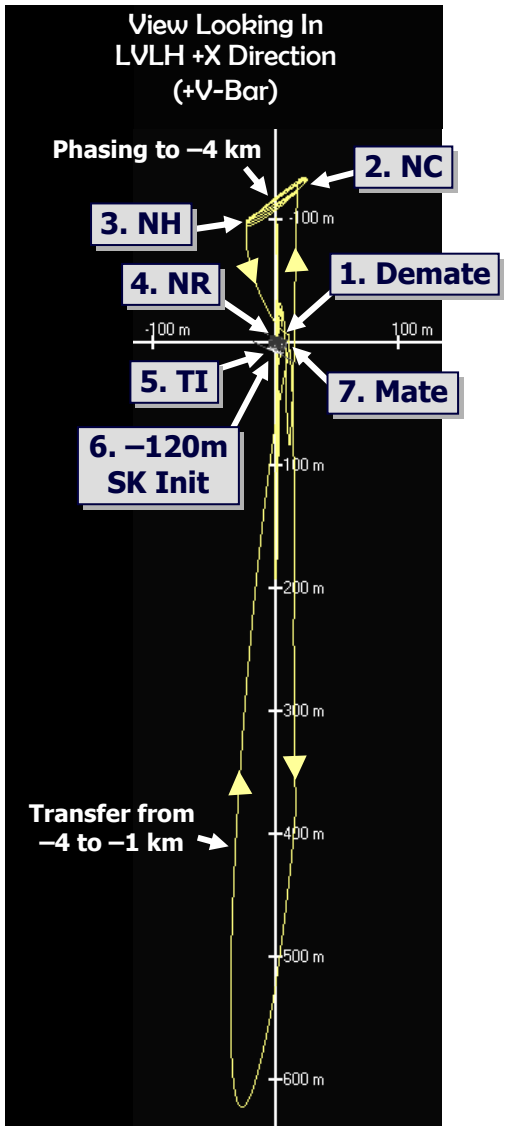
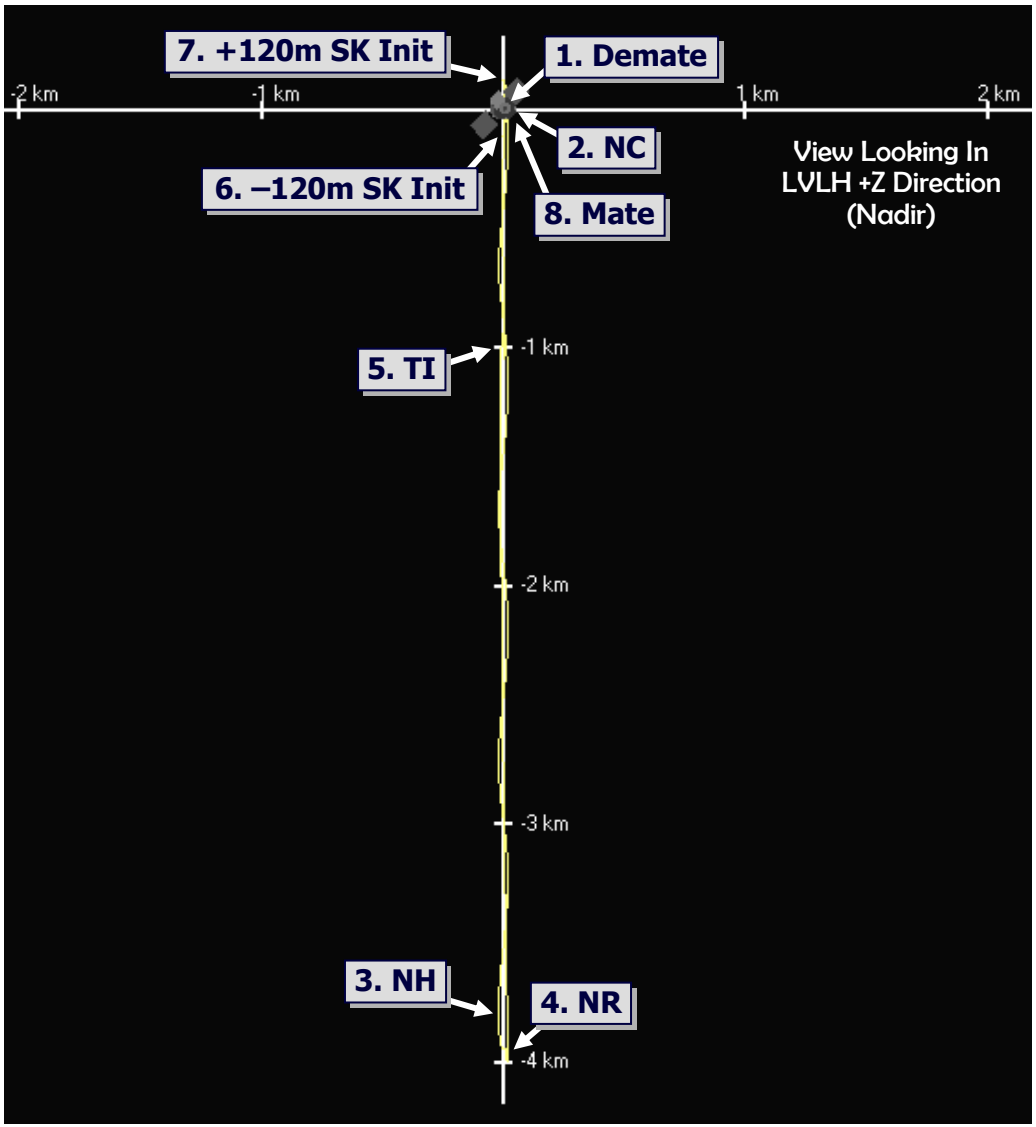
AR&C Exercise #4
Planned/Simulated Out-of-Plane Trajectory





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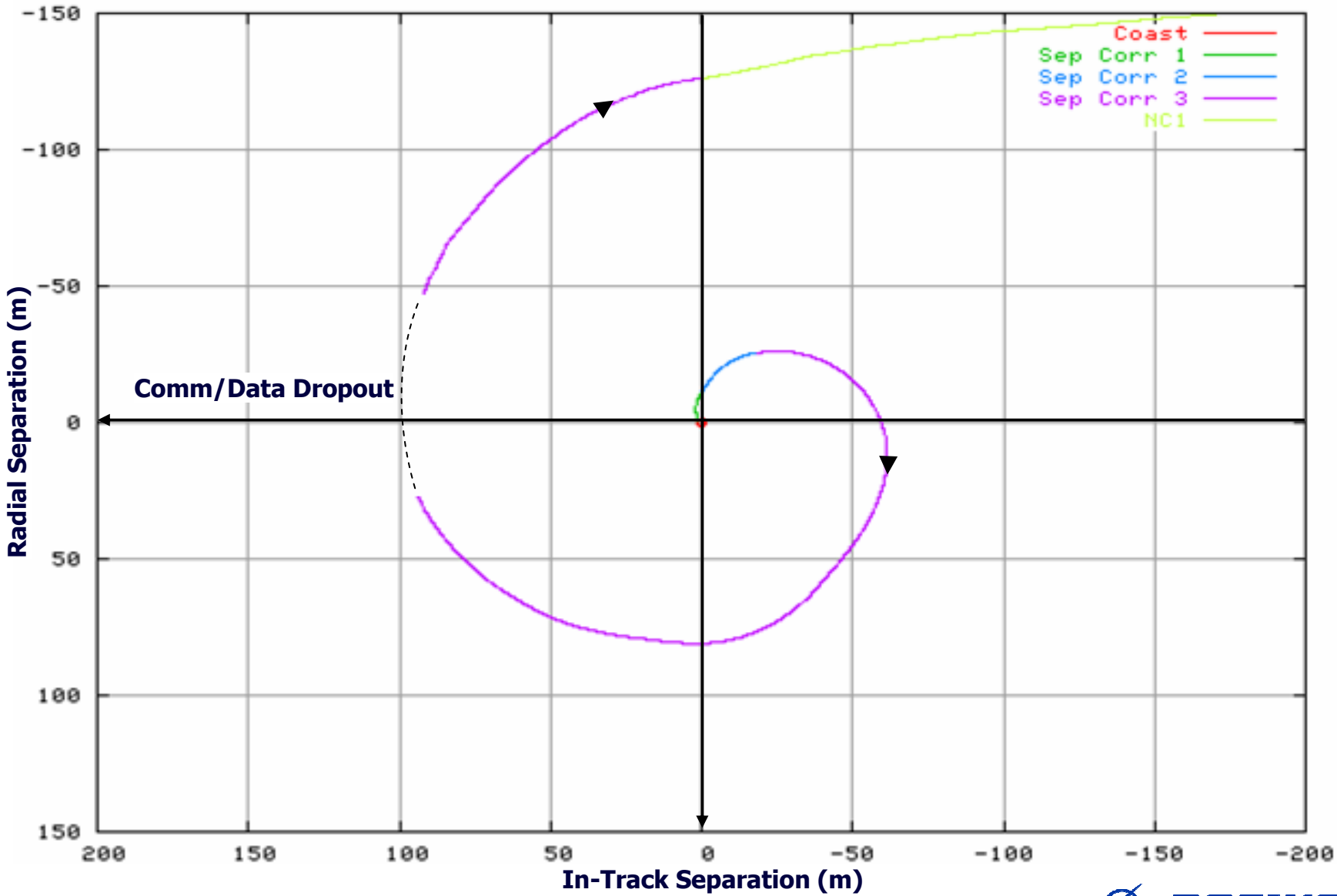
AR&C Exercise #4
Actual/Onboard In-Plane Corridor Separation



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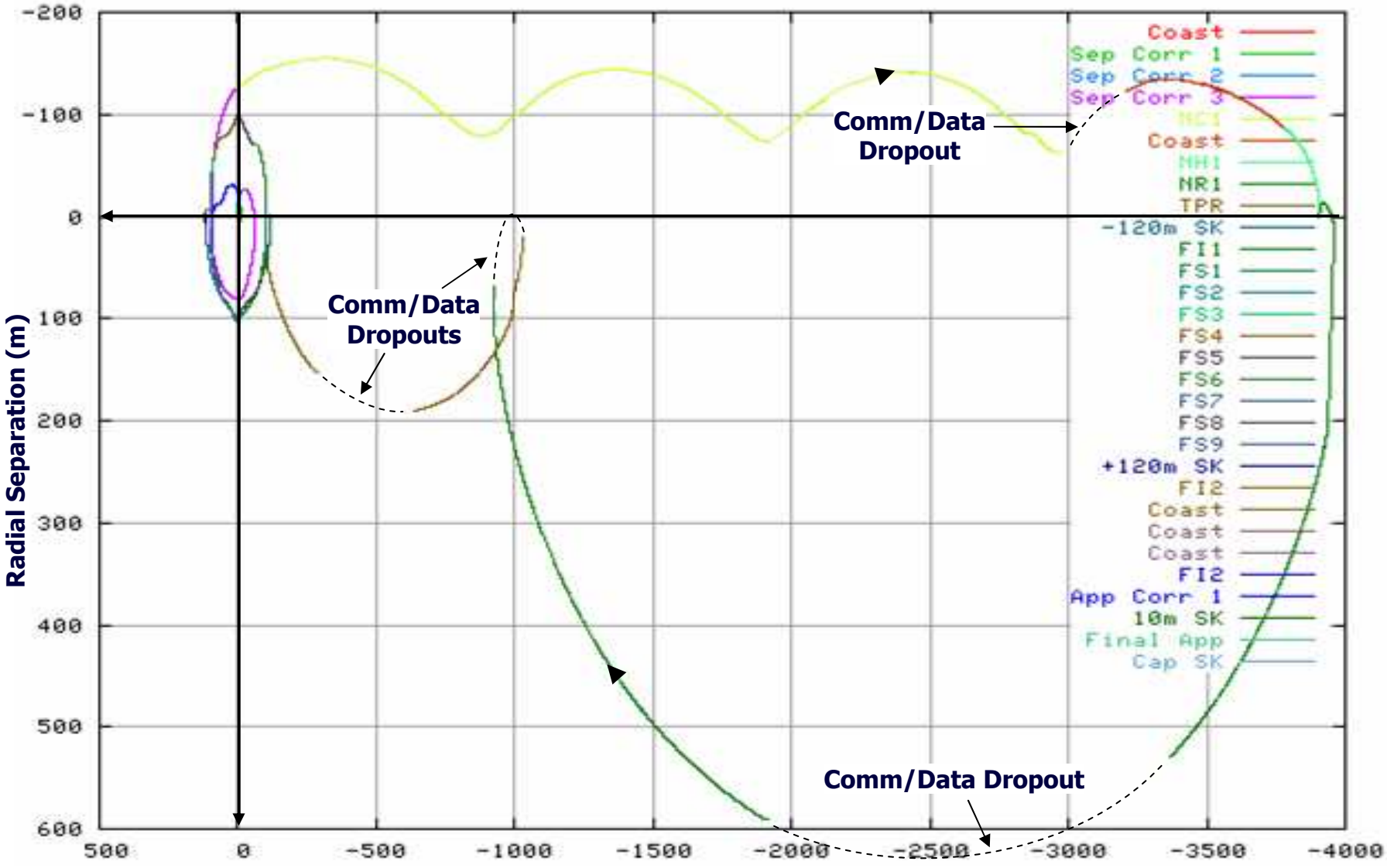
AR&C Exercise #4
Actual/Onboard In-Plane Rendezvous Trajectory



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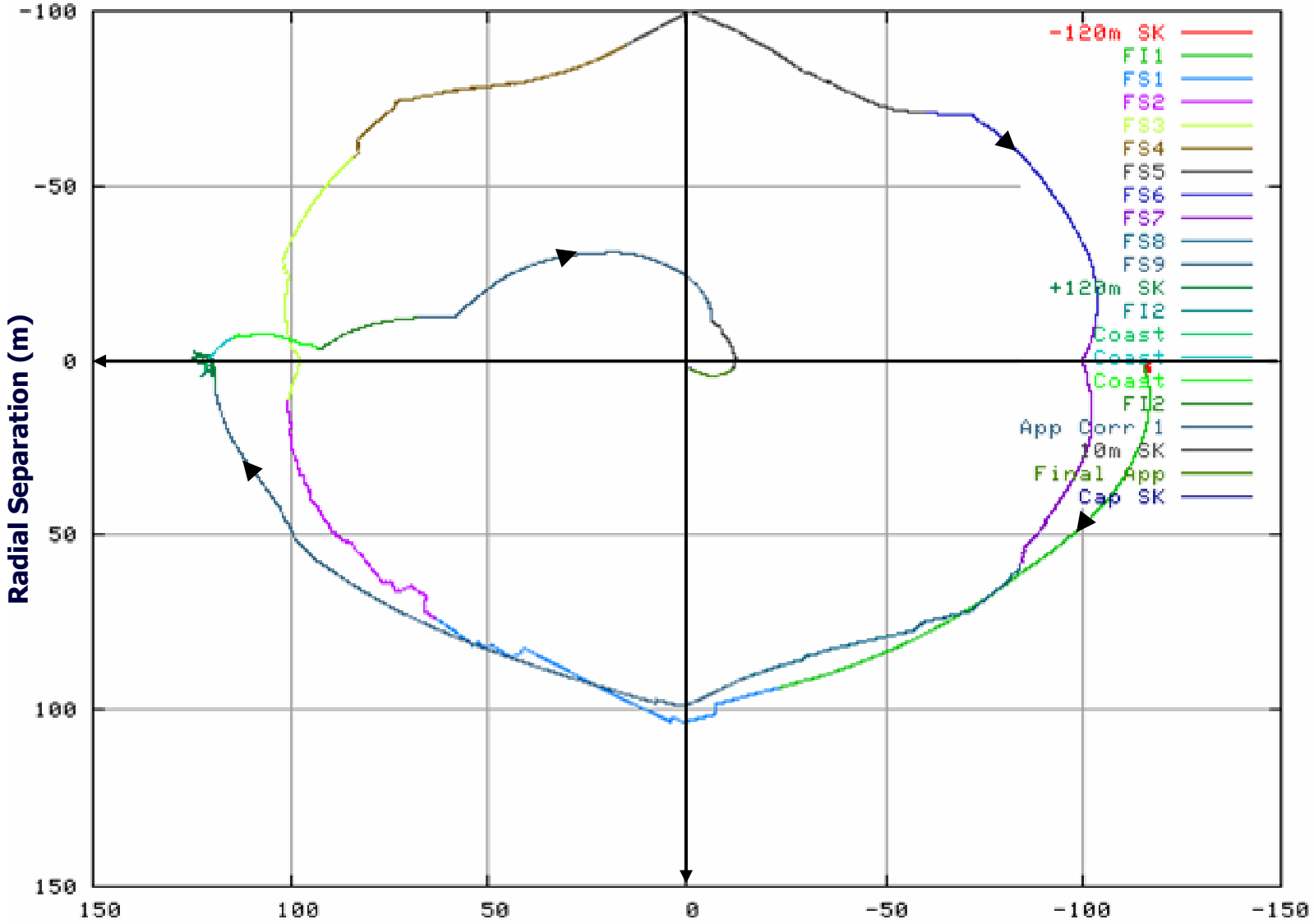
AR&C Exercise #4
Actual/Onboard In-Plane Flyaround & Approach



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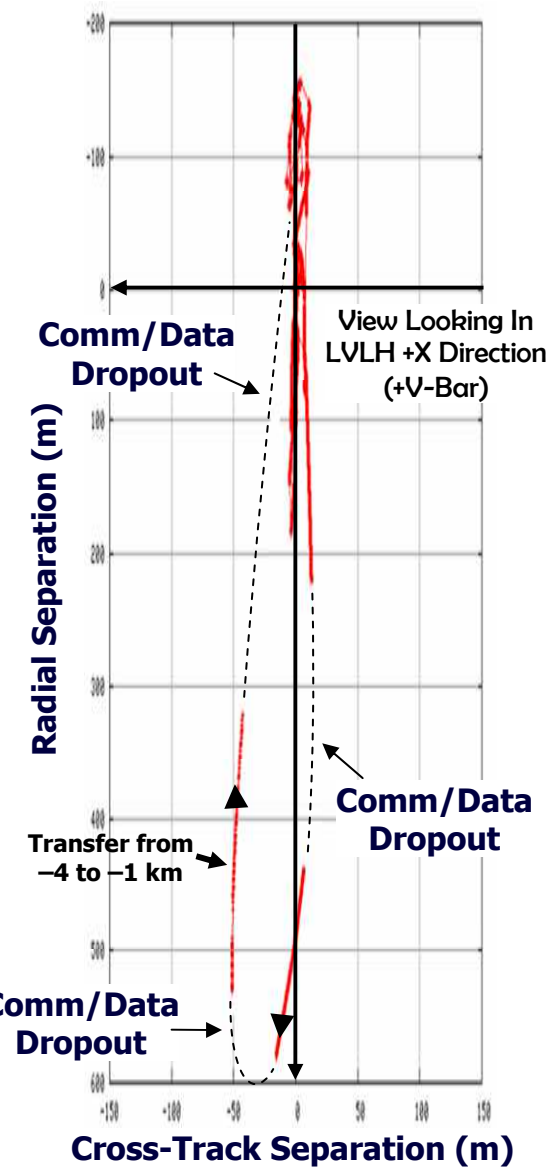
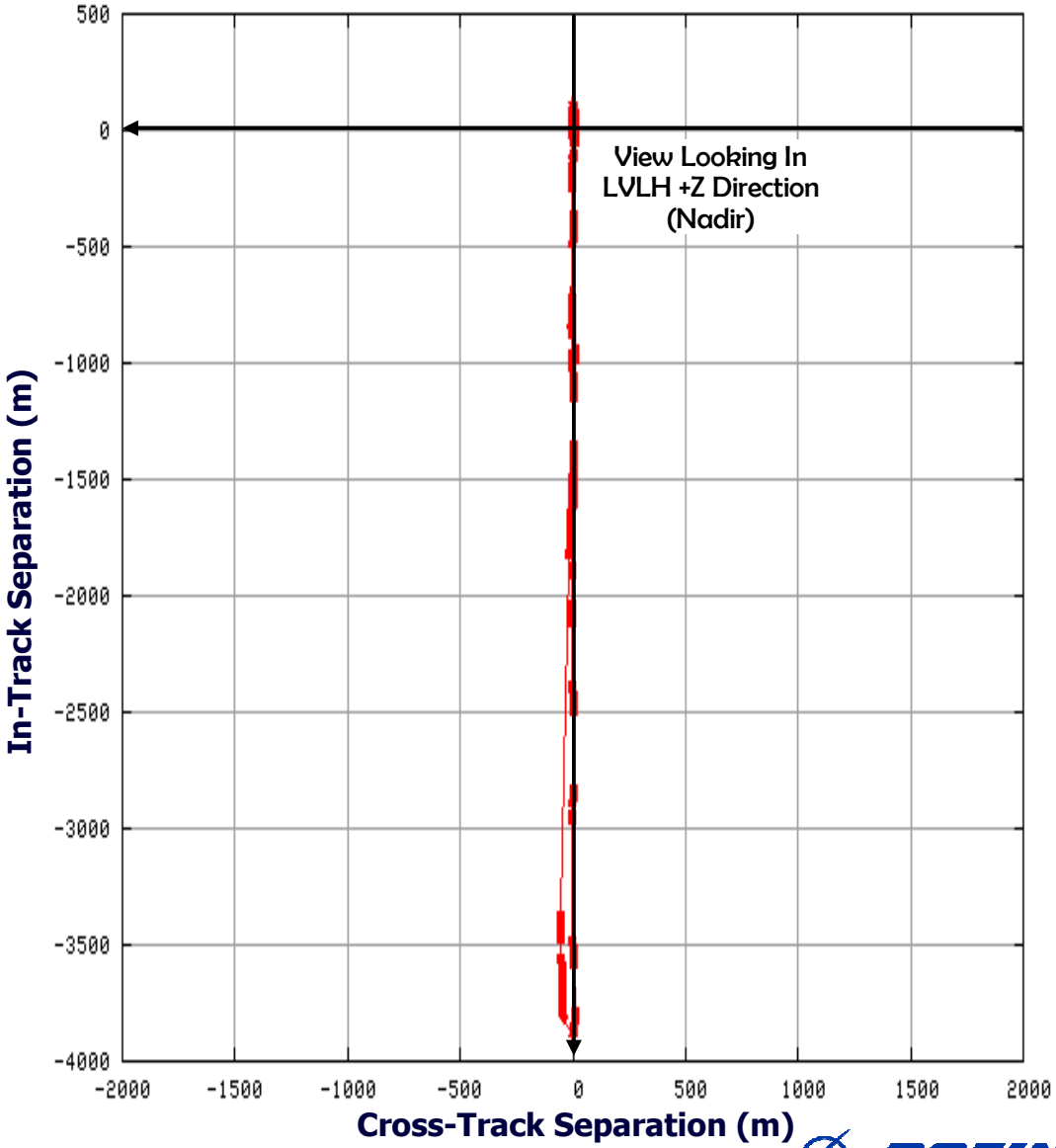
AR&C Exercise #4
Actual/Onboard Out-of-Plane Trajectory





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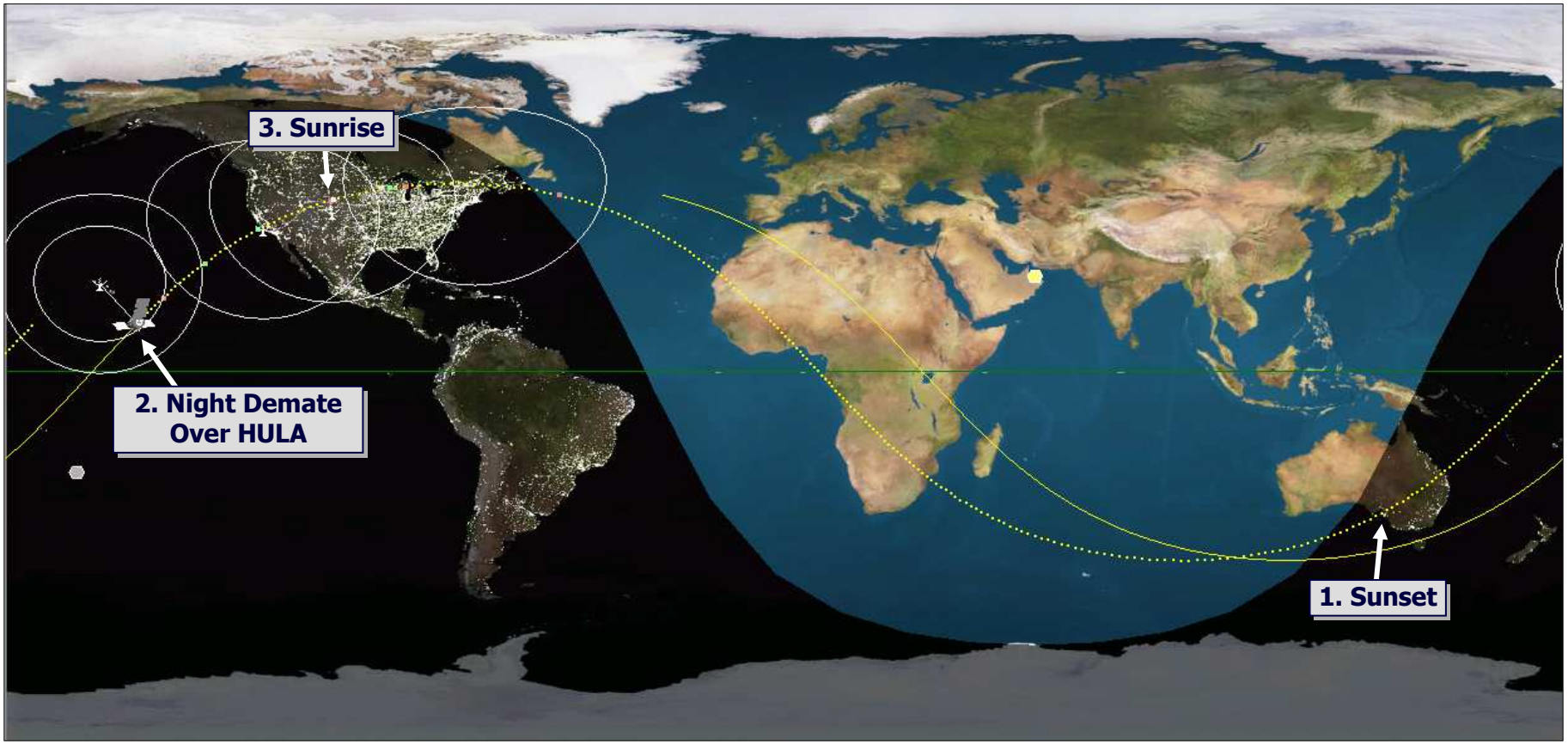
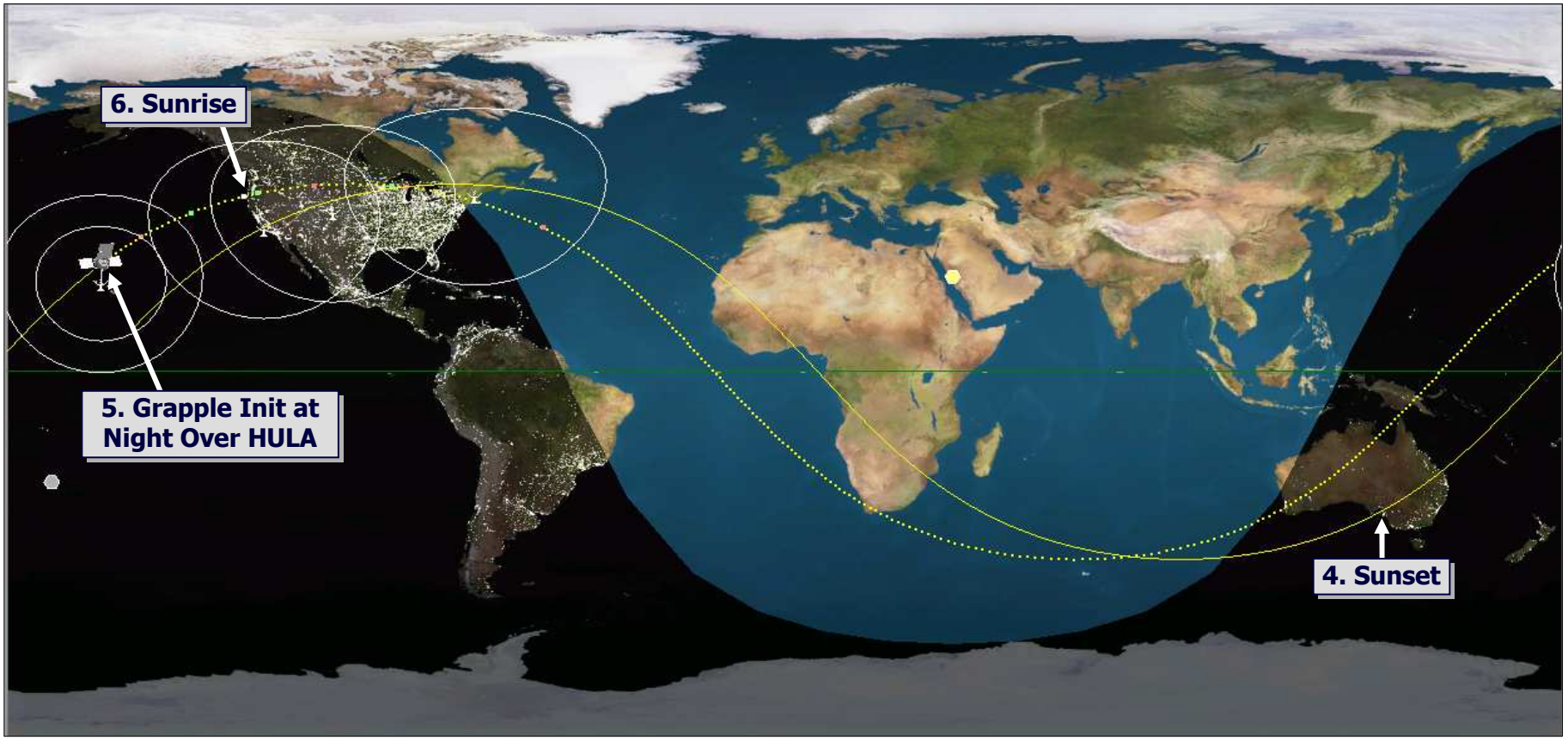
AR&C Exercise #5 (Scenario 8-2)
Planned/Simulated Groundtrack at Demate



BOEING

AR&C Exercise #5
Planned/Simulated Groundtrack at Grapple Initiation



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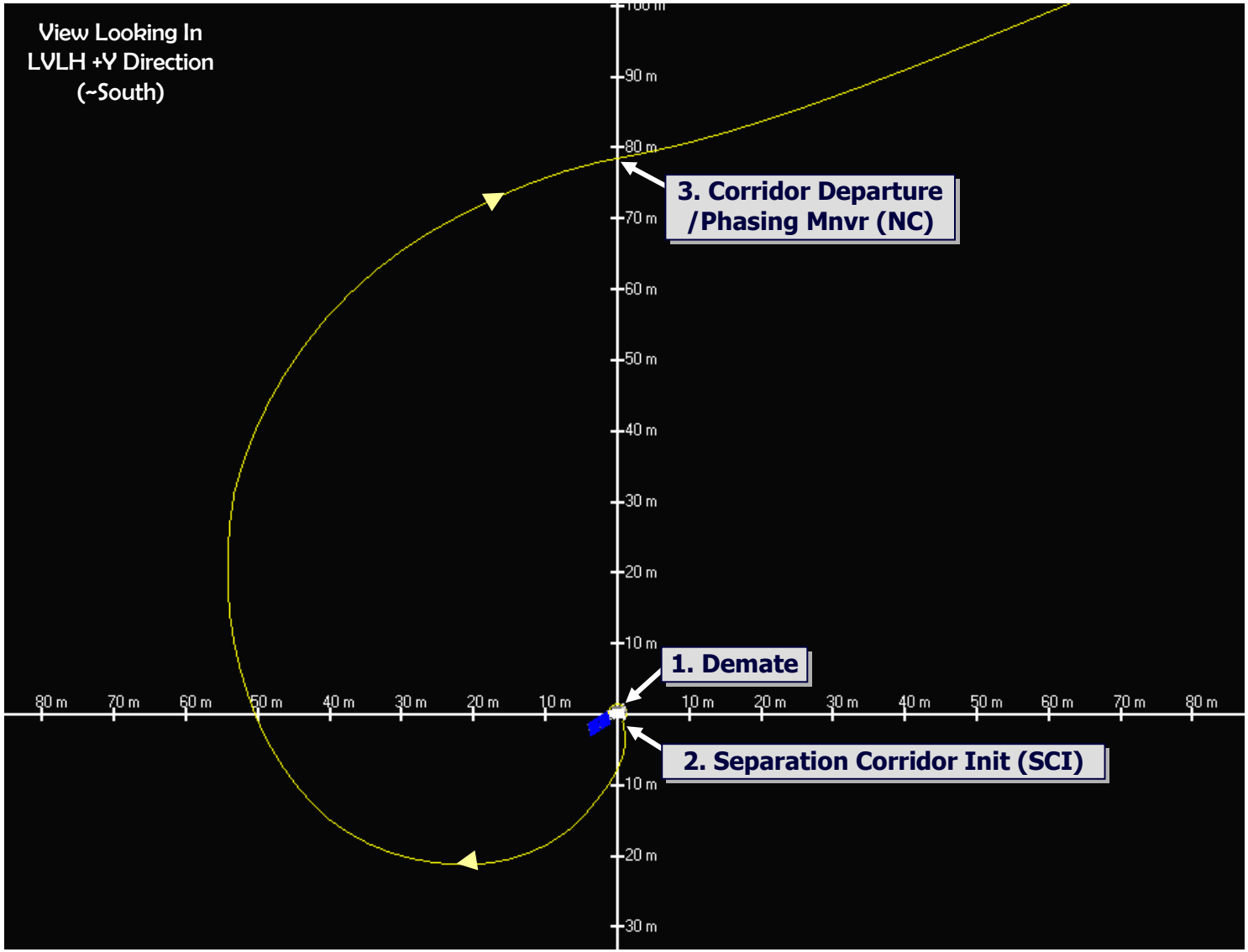
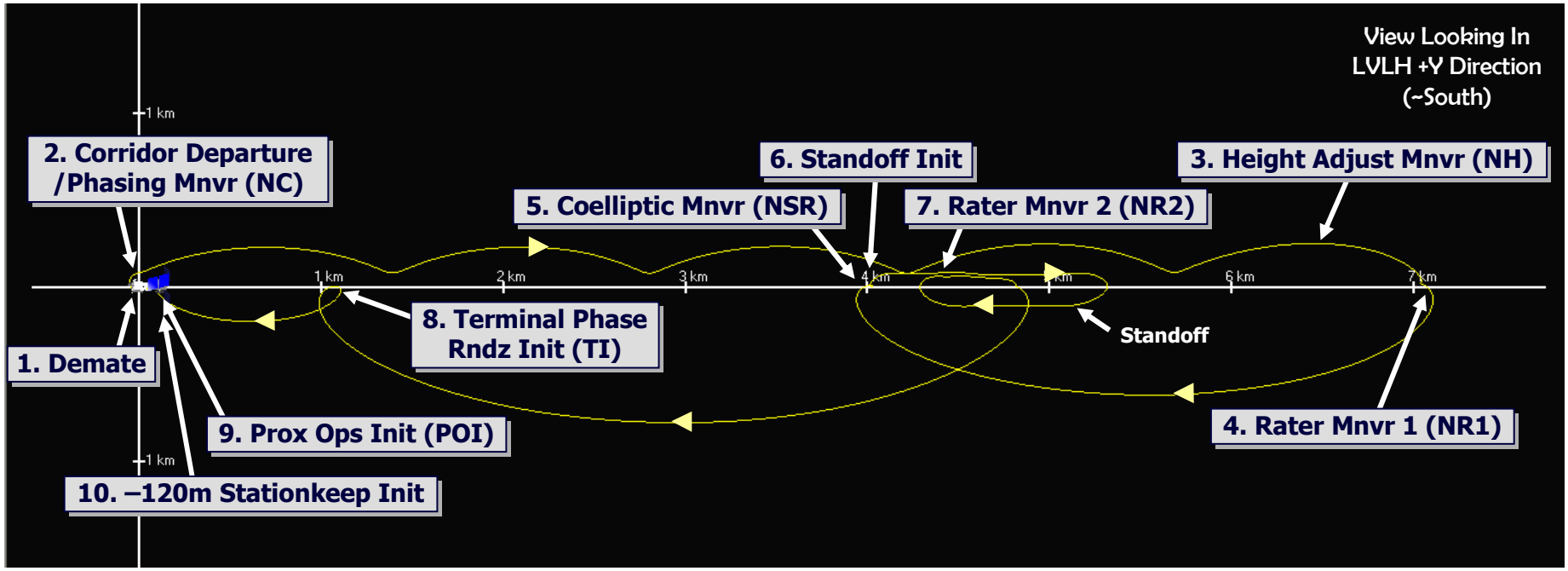
AR&C Exercise #5
Planned/Simulated In-Plane Corridor Separation



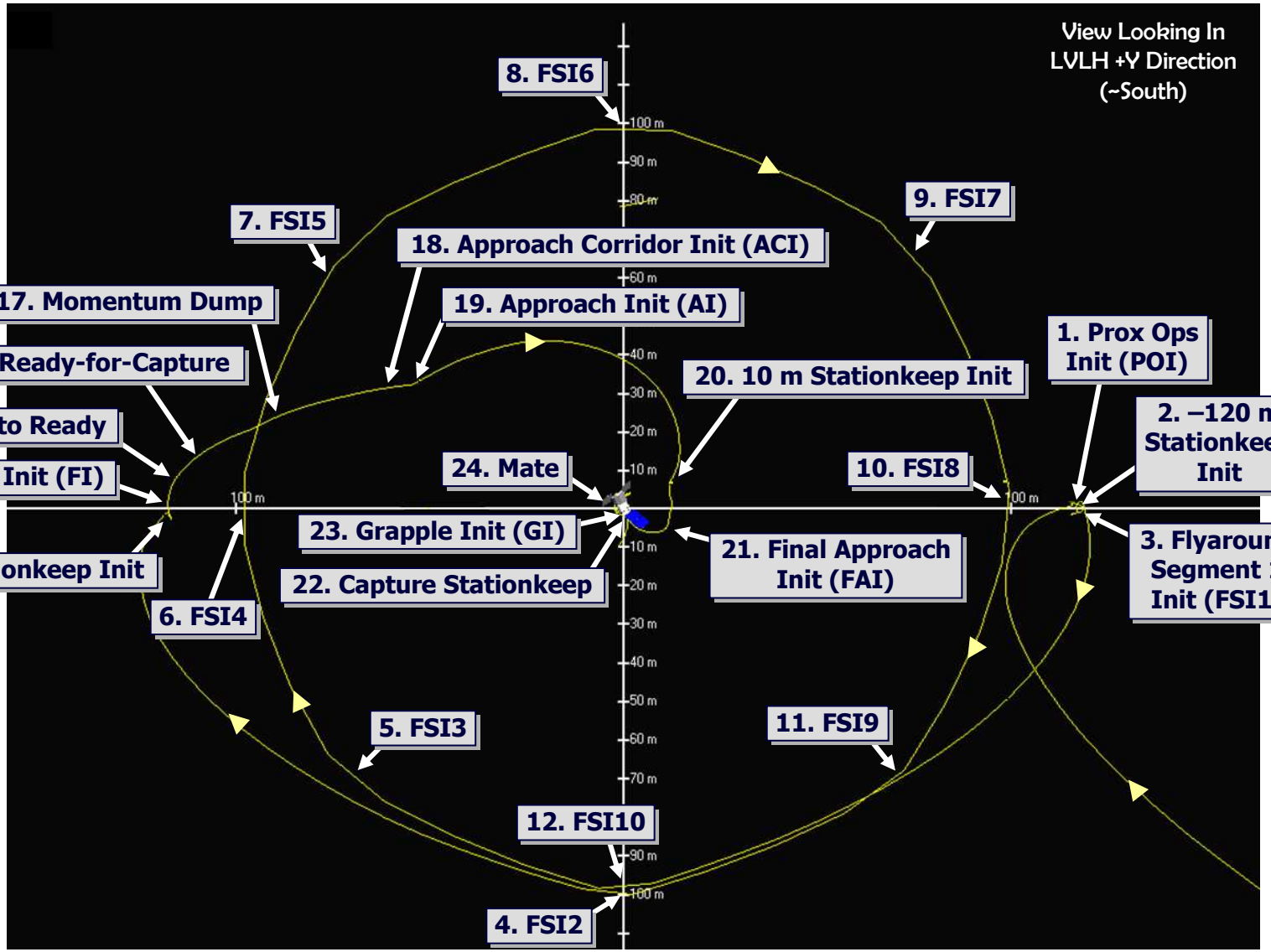
BOEING

AR&C Exercise #5
Planned/Simulated In-Plane Rendezvous Trajectory



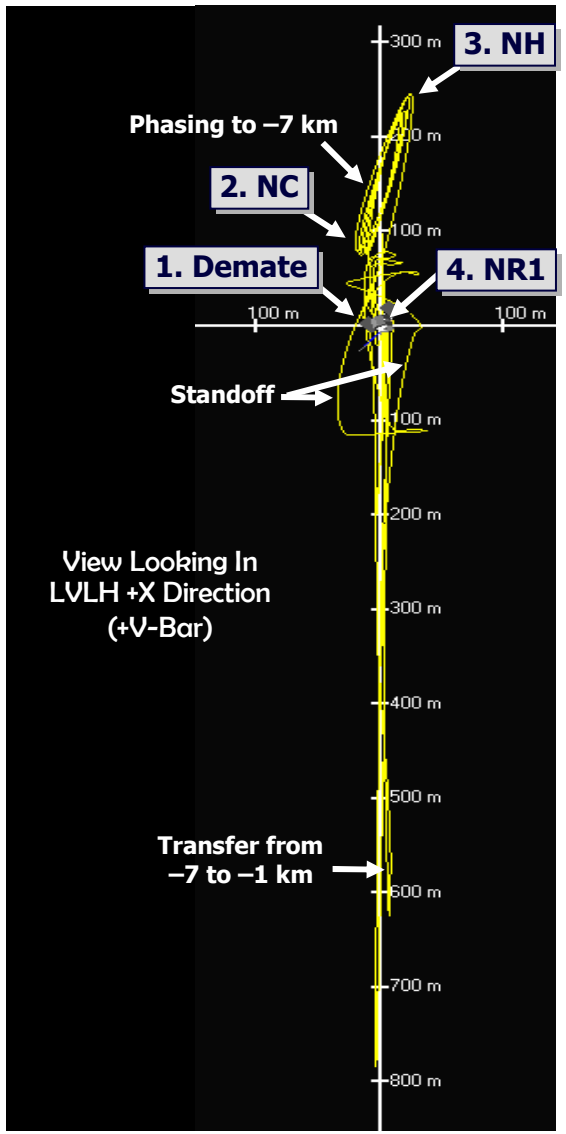
BOEING

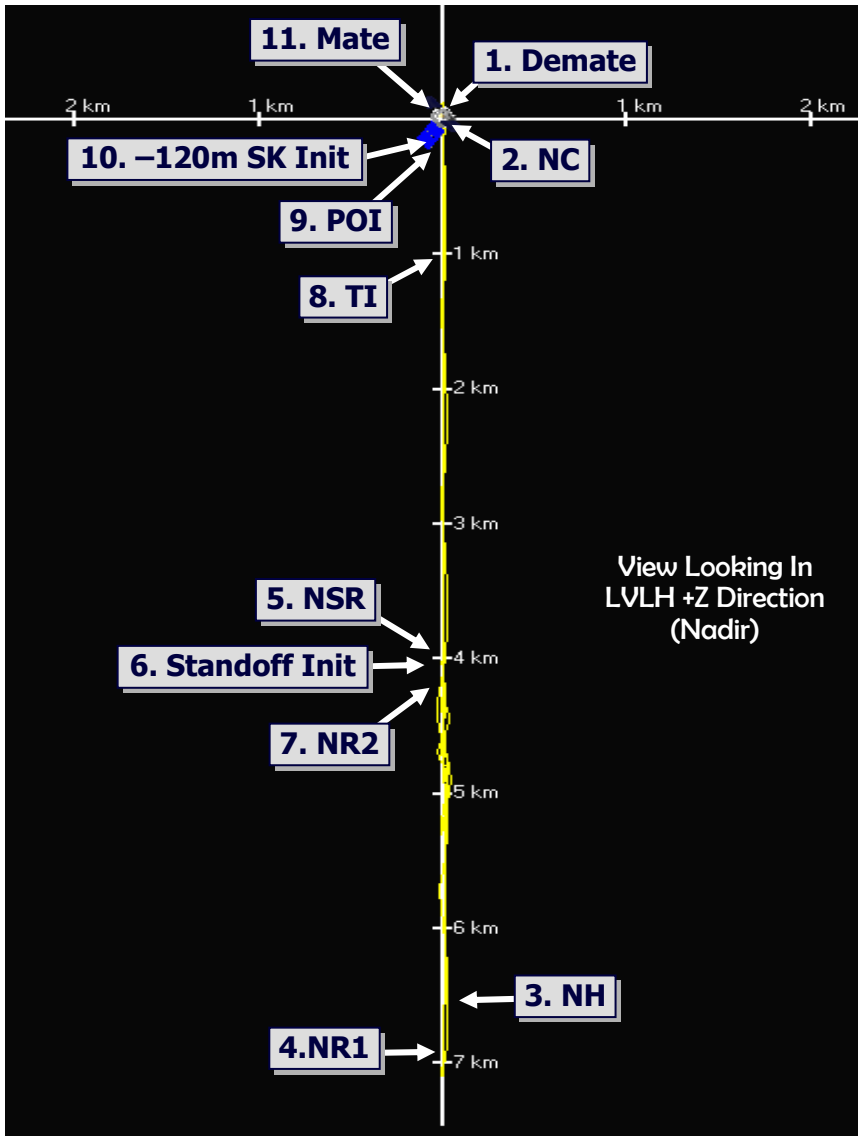
AR&C Exercise #5
Planned/Simulated In-Plane Prox Ops Trajectory



BOEING

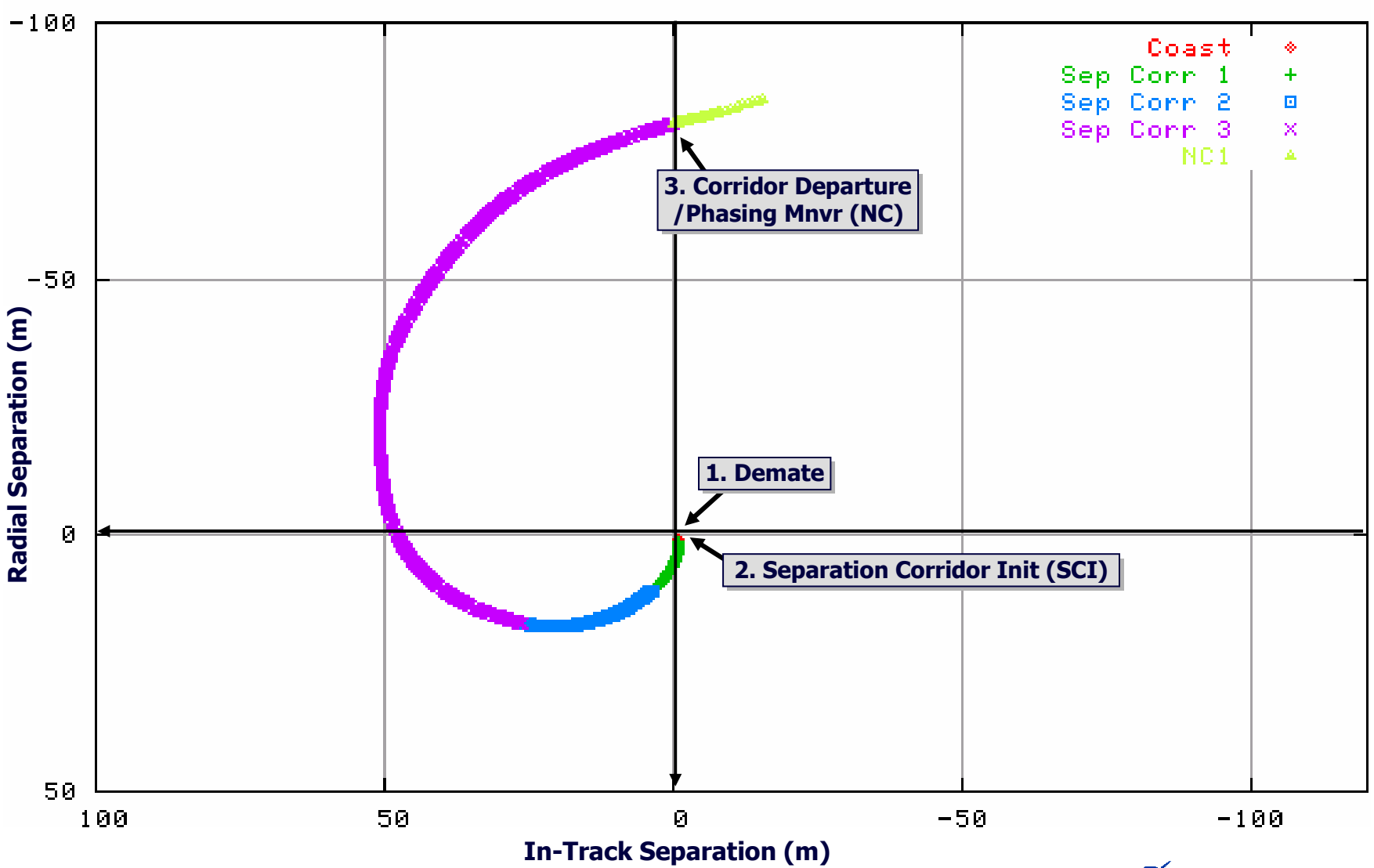
AR&C Exercise #5
Planned/Simulated Out-of-Plane Trajectory





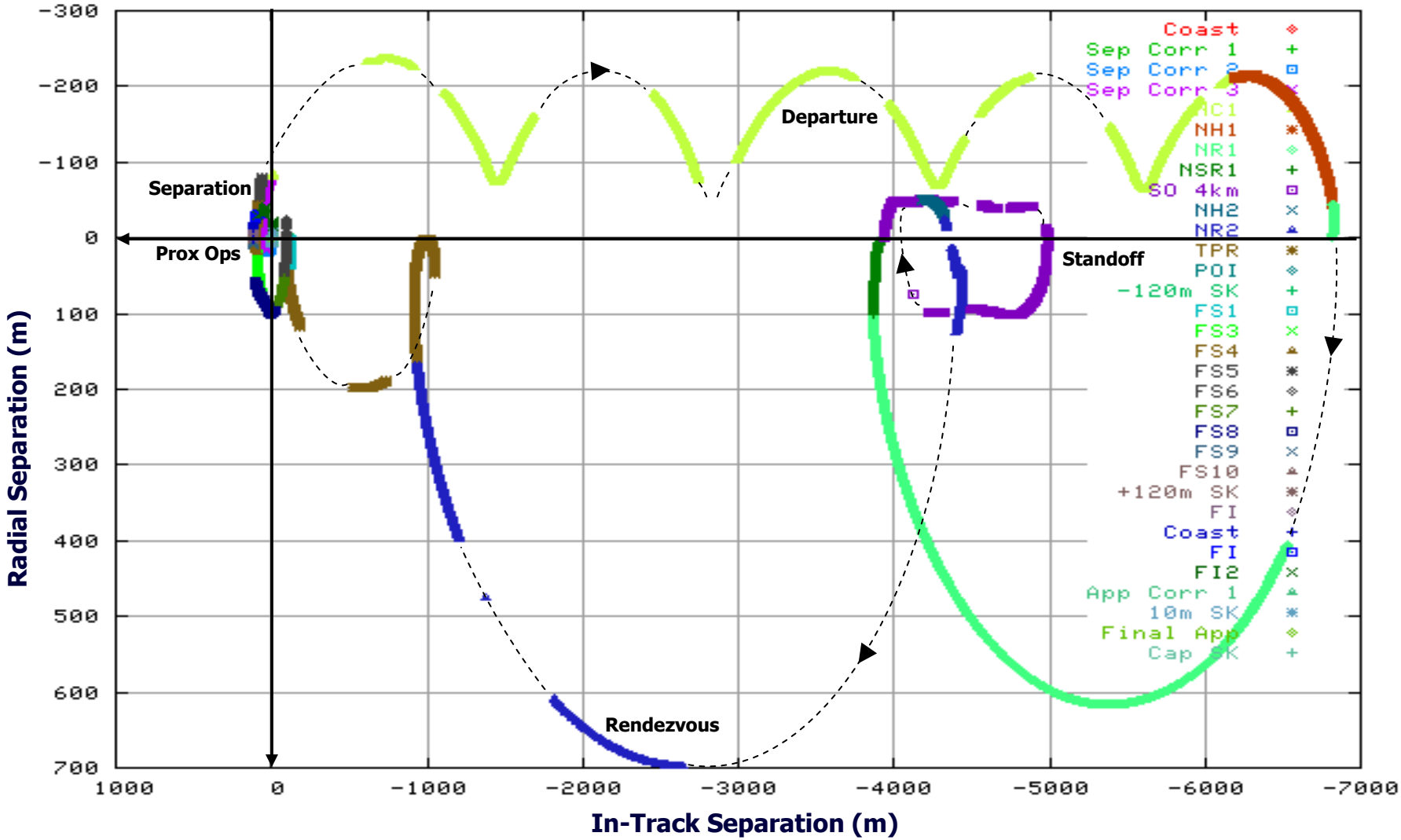
BOEING

AR&C Exercise #5
Actual/Onboard In-Plane Corridor Separation



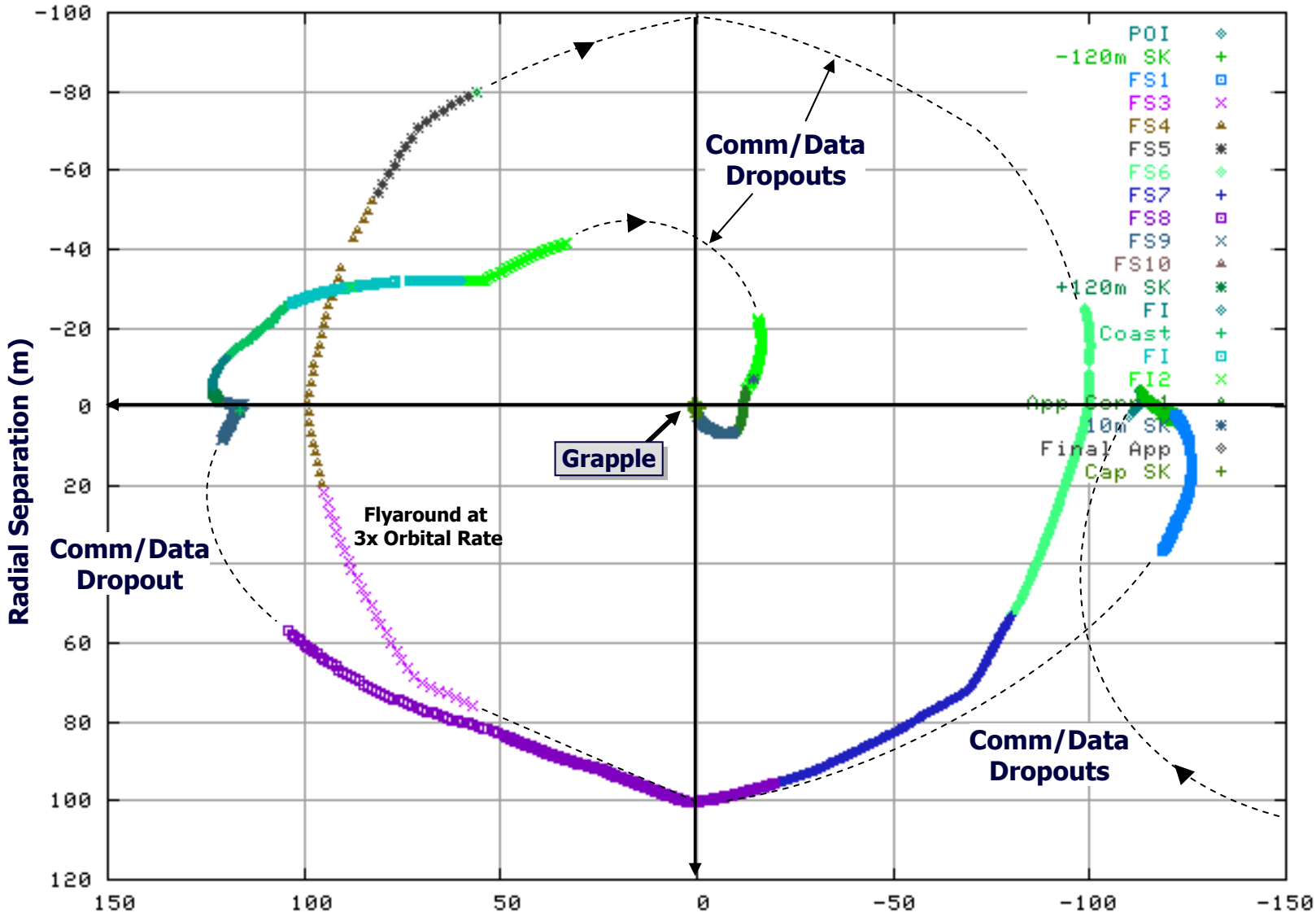
BOEING

AR&C Exercise #5
Actual/Onboard In-Plane Rendezvous Trajectory



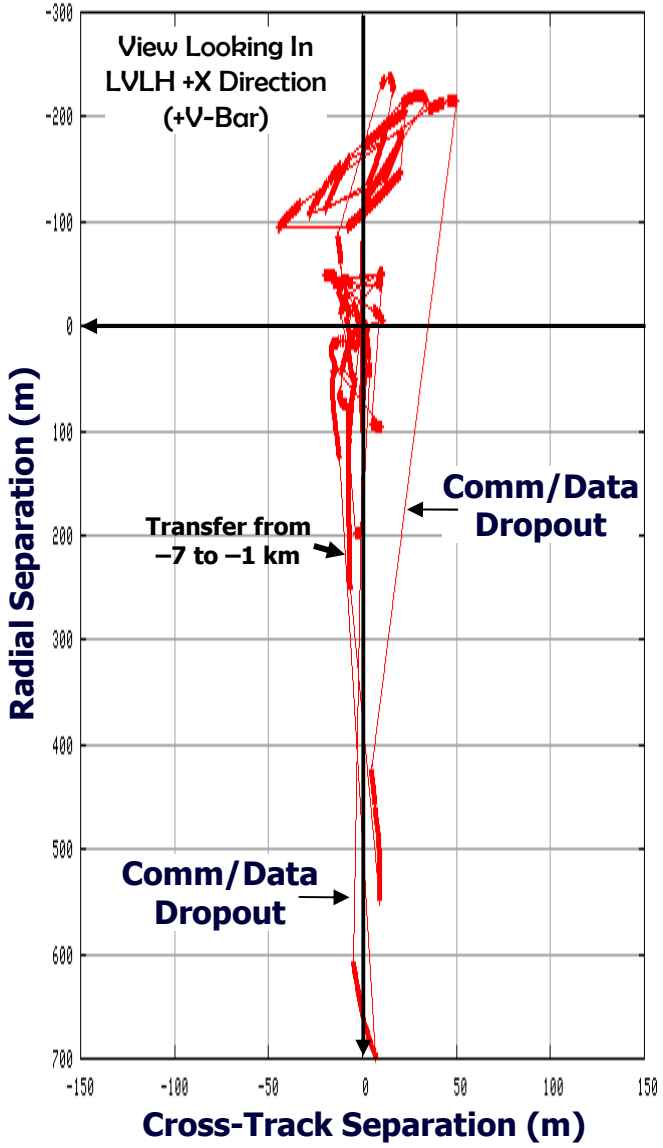
BOEING

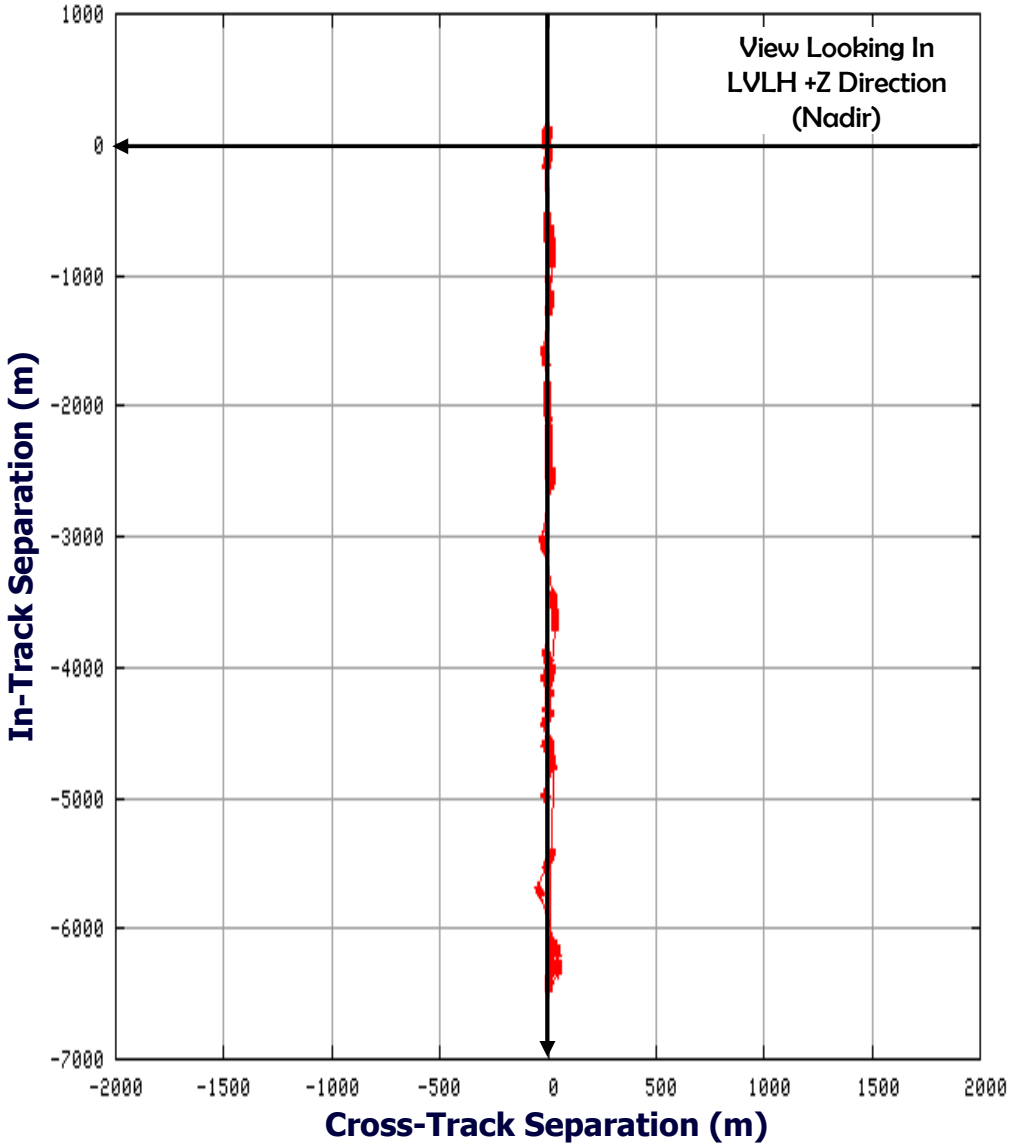
AR&C Exercise #5
Actual/Onboard In-Plane Prox Ops Trajectory



BOEING

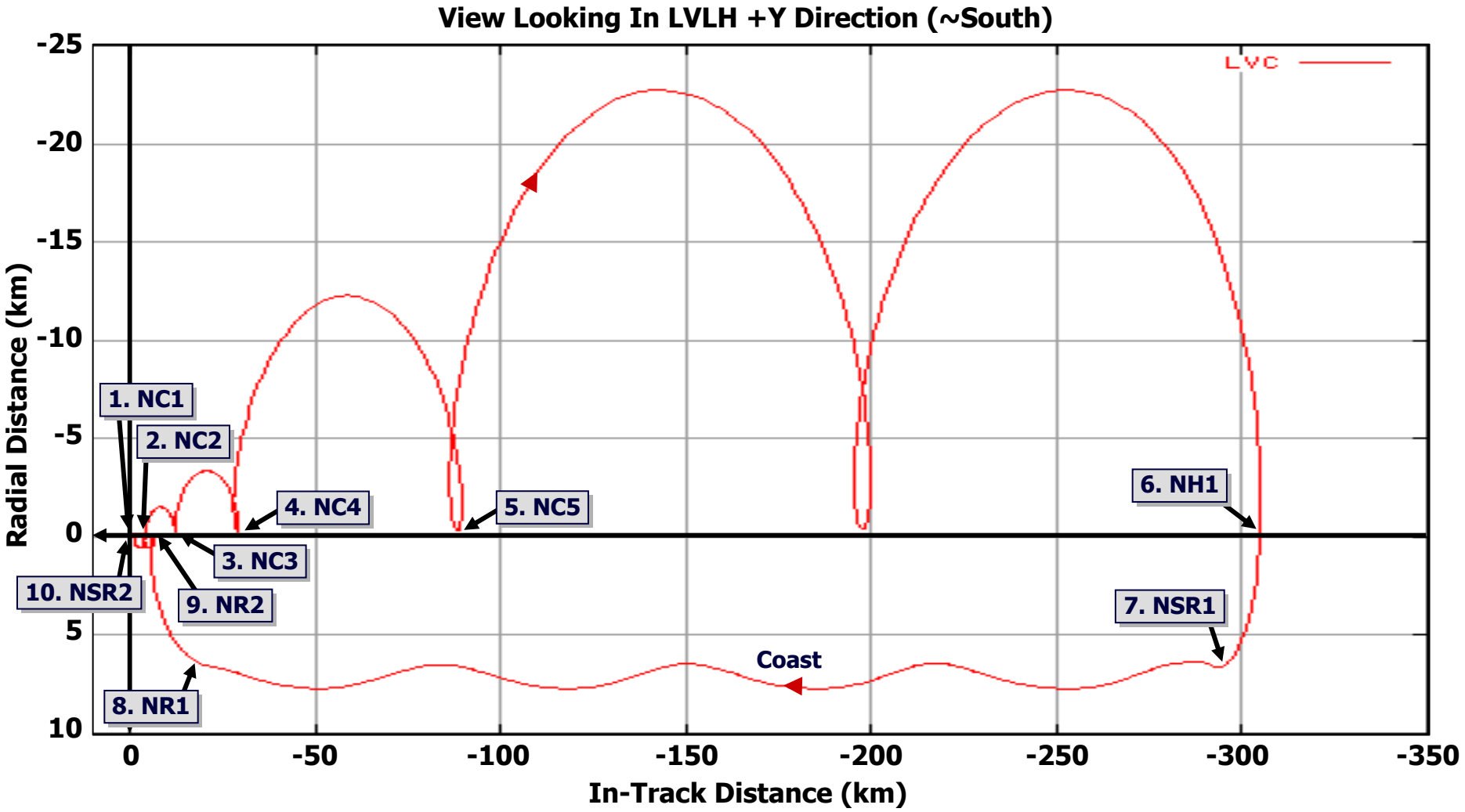
AR&C Exercise #5
Actual/Onboard Out-of-Plane Trajectory





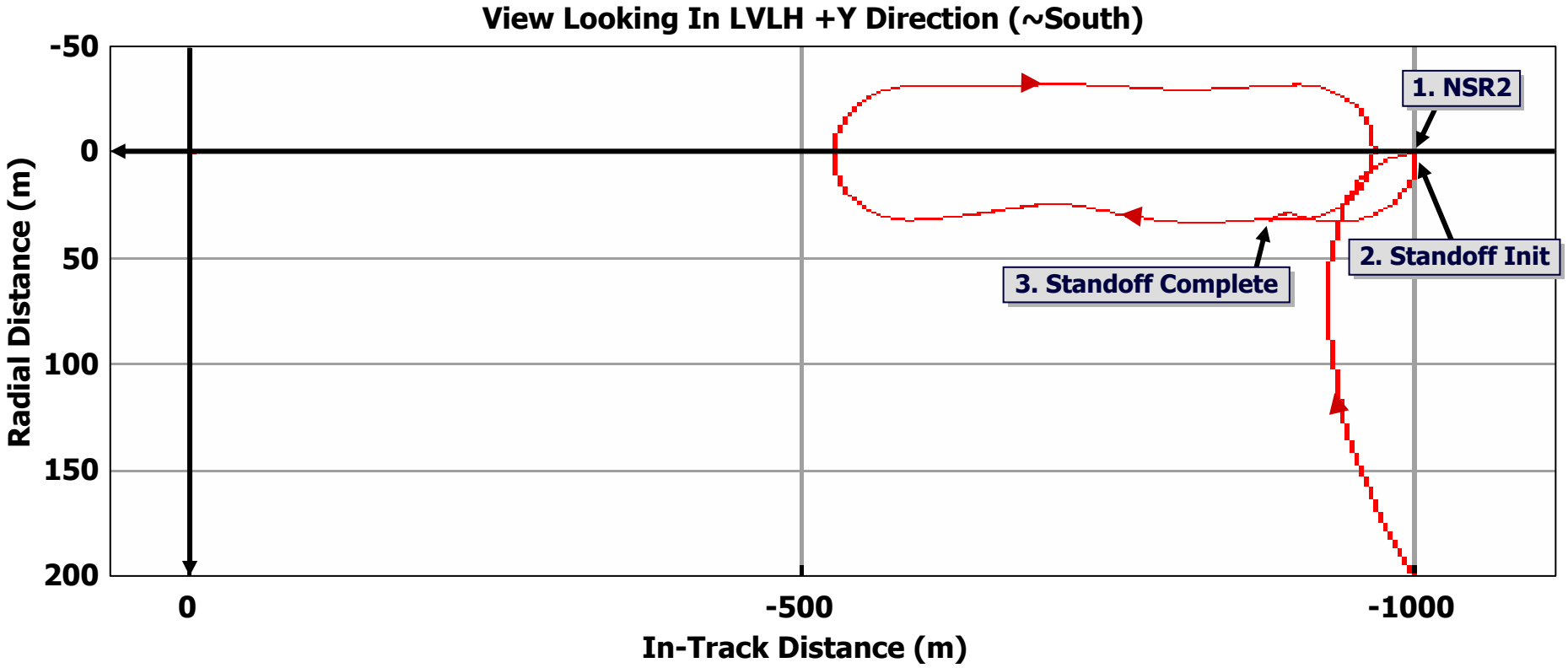
BOEING

End-of-Life Exercise Part 1
Planned/Simulated In-Plane Outbound & Rendezvous



BOEING

End-of-Life Exercise Part 1
Planned/Simulated In-Plane Standoff Trajectory



ASTRO Spent 4 to 6 hrs per Lap Around the Standoff Racetrack

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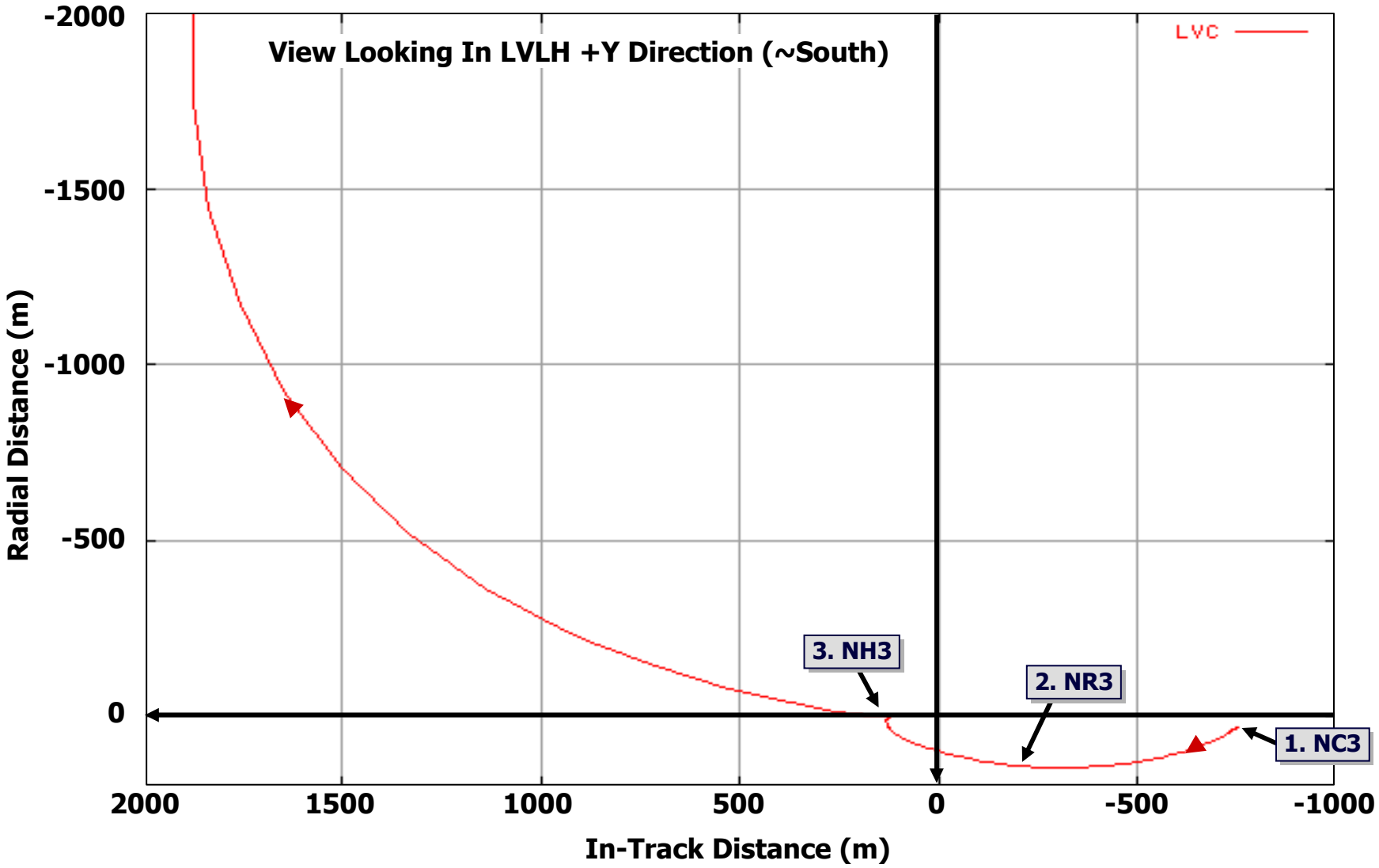
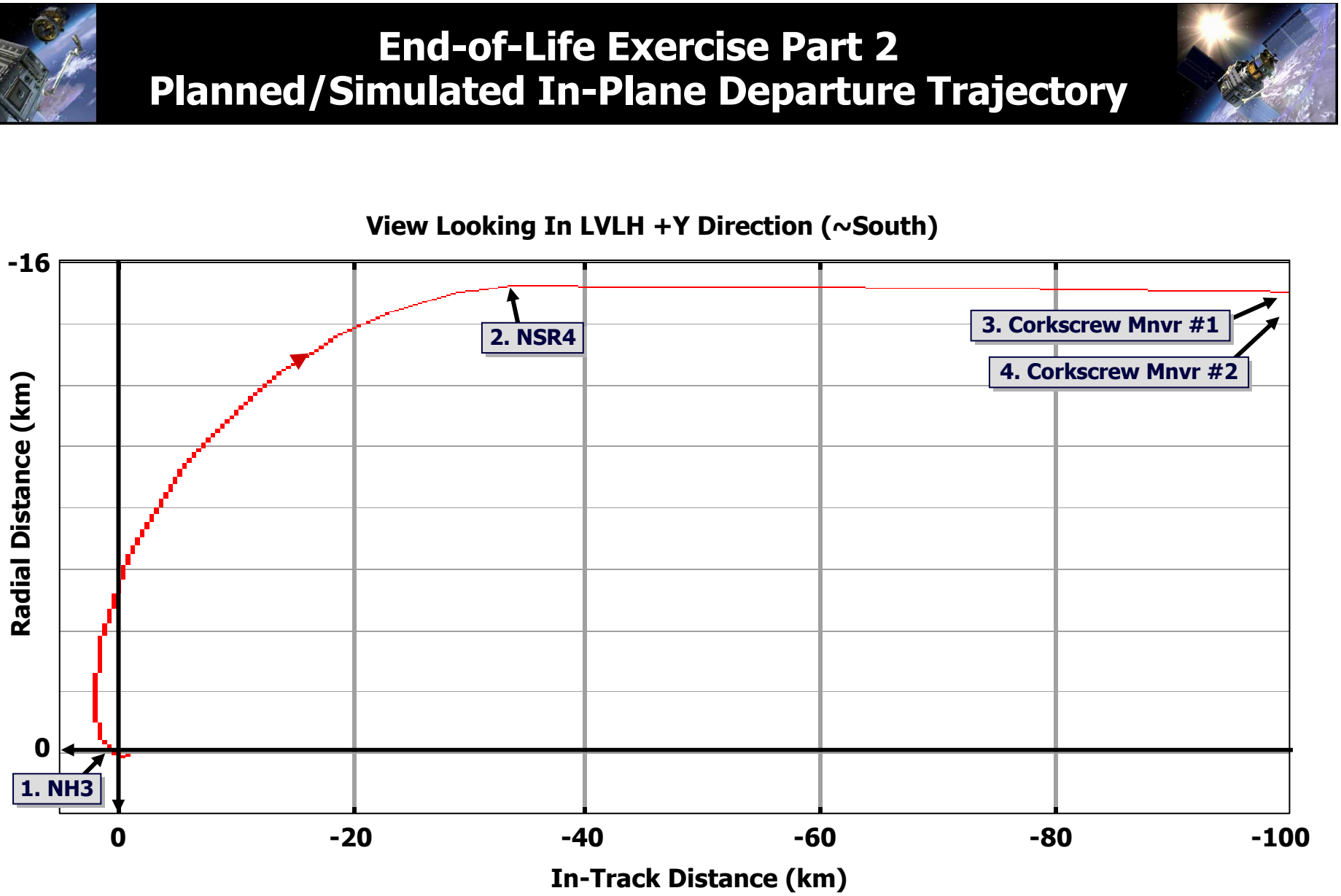
End-of-Life Exercise Part 2
Planned/Simulated In-Plane Transfer & Early Departure



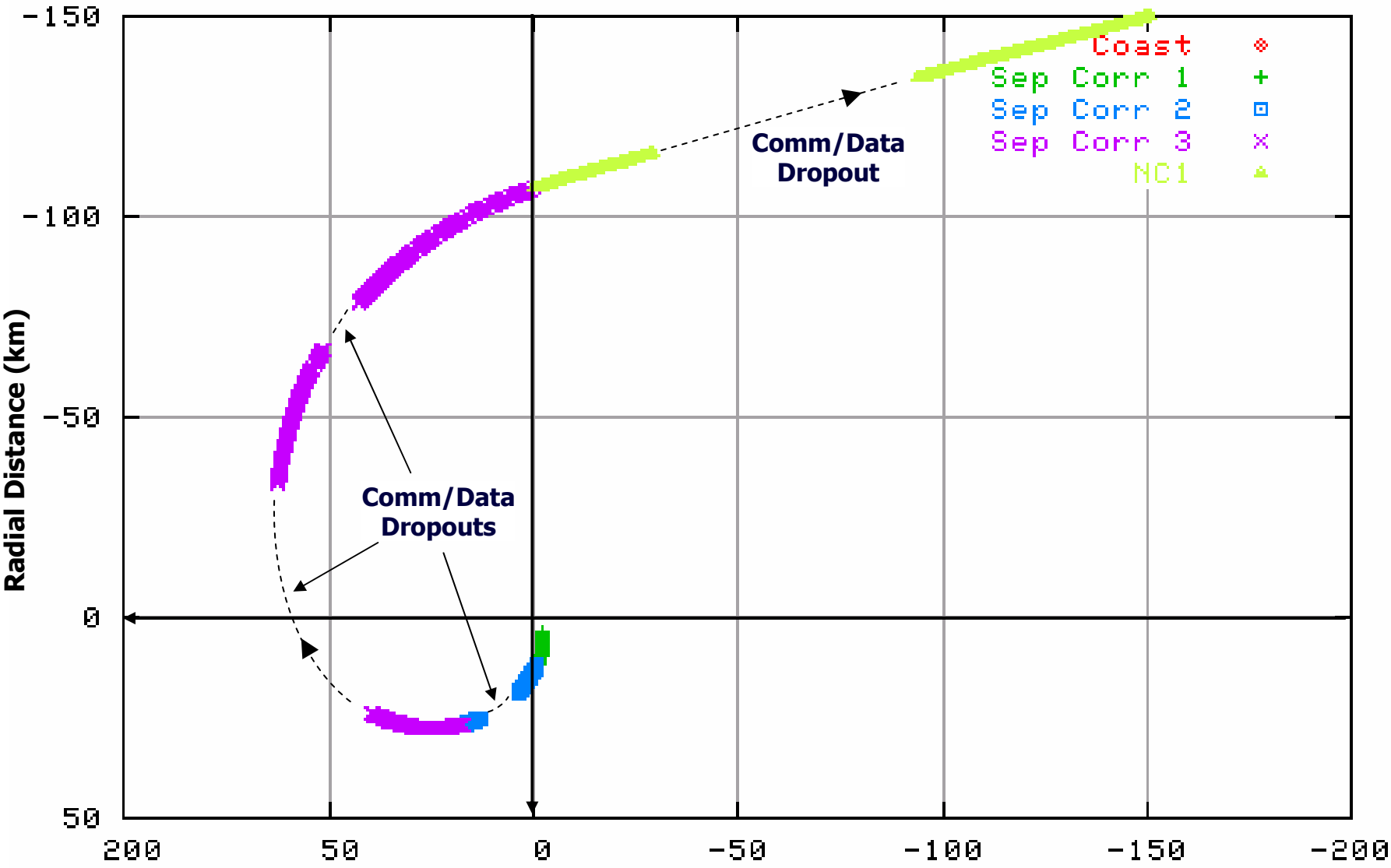
BOEING

End-of-Life Exercise Part 2
Planned/Simulated In-Plane Departure Trajectory



BOEING

End-of-Life Exercise Part 1
Actual/Onboard In-Plane Corridor Separation



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