

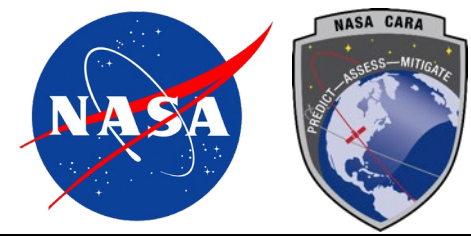


# Conjunction Assessment Risk Analysis

## OSIRIS-REX Conjunction Screenings: Earth Gravity Assist & Earth Return Analysis & Results

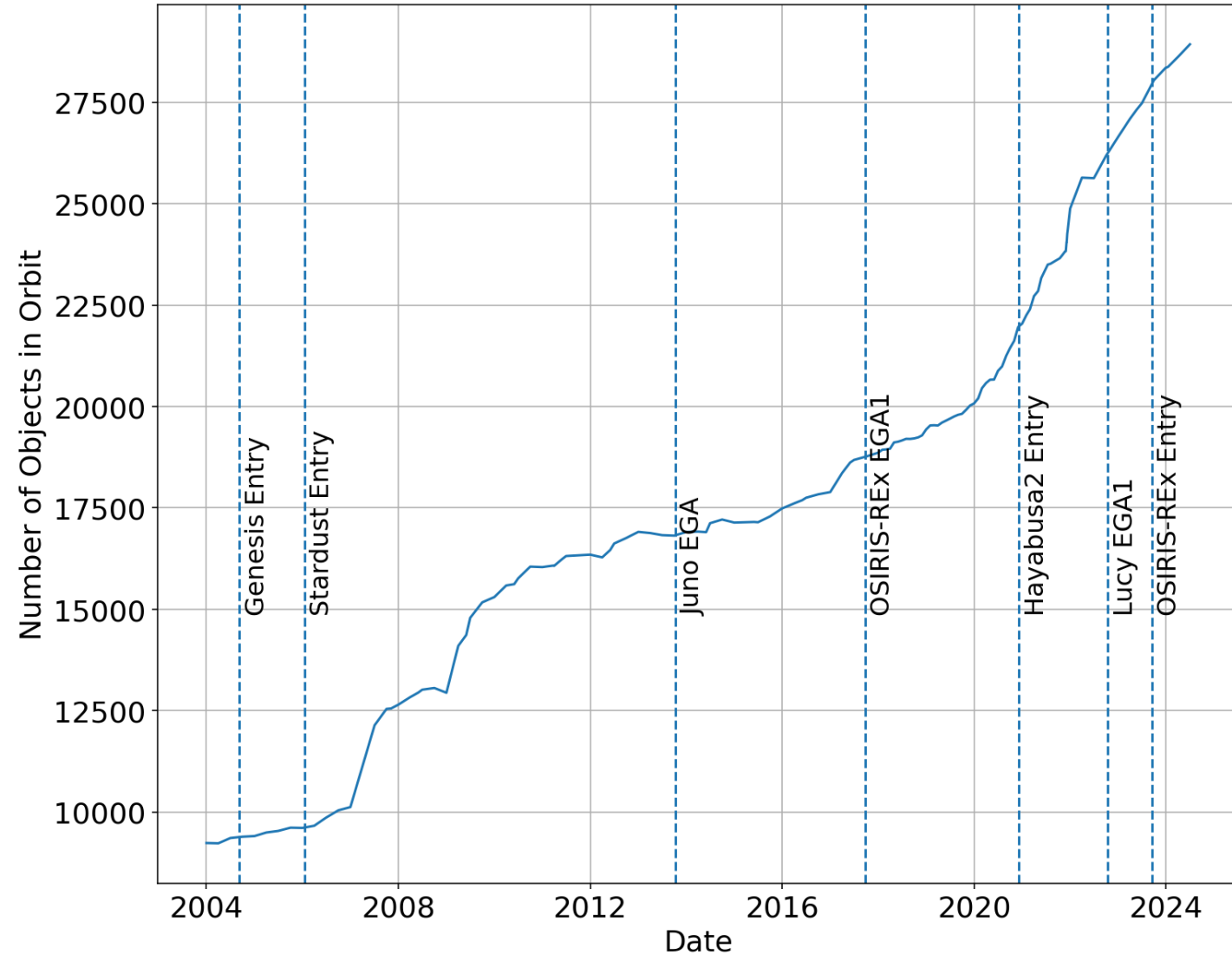
Dolan Highsmith, Roger Thompson  
The Aerospace Corporation

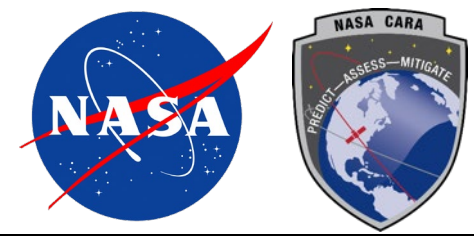
August 14, 2024



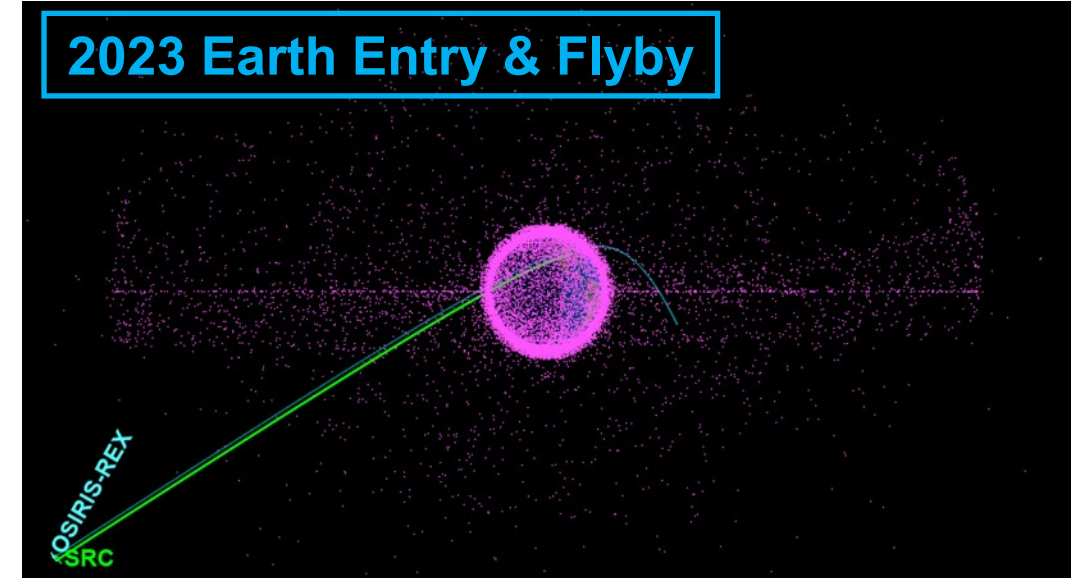
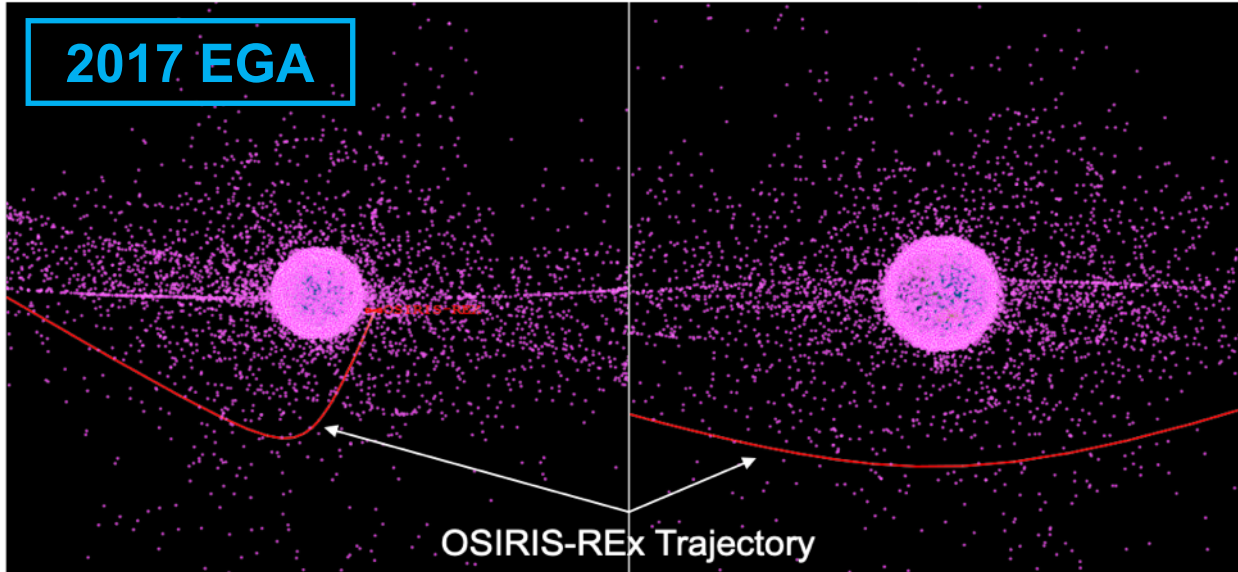
# Motivation

- **Earth flyby and entry missions face increased collision risk due to significant increase in resident space object (RSO) population in recent years**
  - CARA began screening Earth flyby/entry missions with Juno in 2013
- **Document OSIRIS-REx screening experience to highlight knowledge gained and lessons learned by CARA**
  - Rare mission profile, but frequent enough to normalize support





# 2017 & 2023 Trajectories



- **Perigee ~17,200 km altitude over South Pole**
- **Orbit crossing forecasting analysis indicated few objects would pose significant risk**
  - Trajectory passed through ~660 orbit *planes* of objects with apogee > OREX perigee
- **1 CAM option:**
  - Change TCA by +2 sec

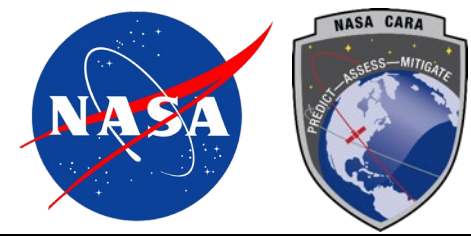
- **Bus perigee ~780 km altitude**
- **SRC landing in Utah**
- **3 CAM options:**
  - Change TCA by -0.5, -1.0, -2.0 sec
- **CAM @ EI-13h, SRC Release @ EI-4h**
  - CAM affects both objects

CAM = Conjunction Avoidance Maneuver

TCA = Time of Closest Approach

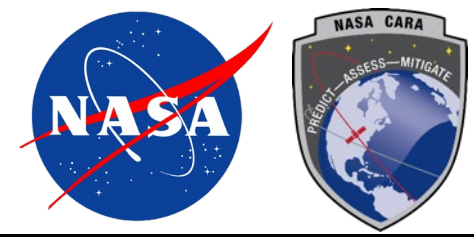
SRC = Sample Return Capsule

EI = Entry Interface



# CARA Support for 2023 Earth Return

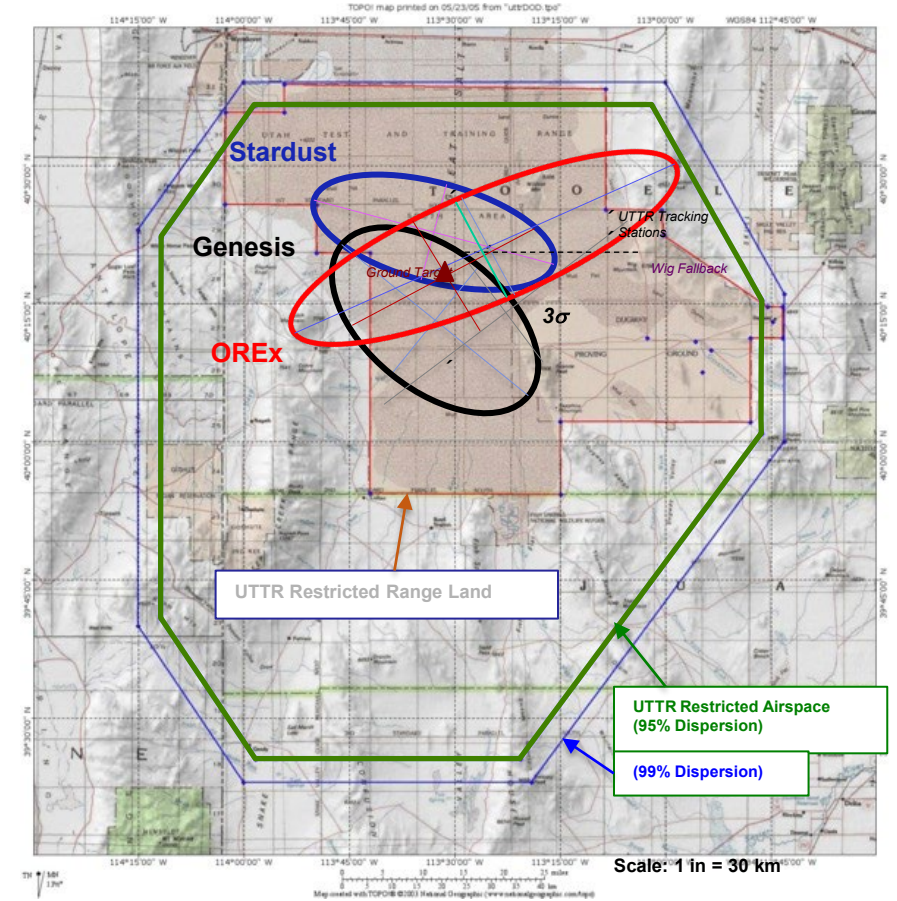
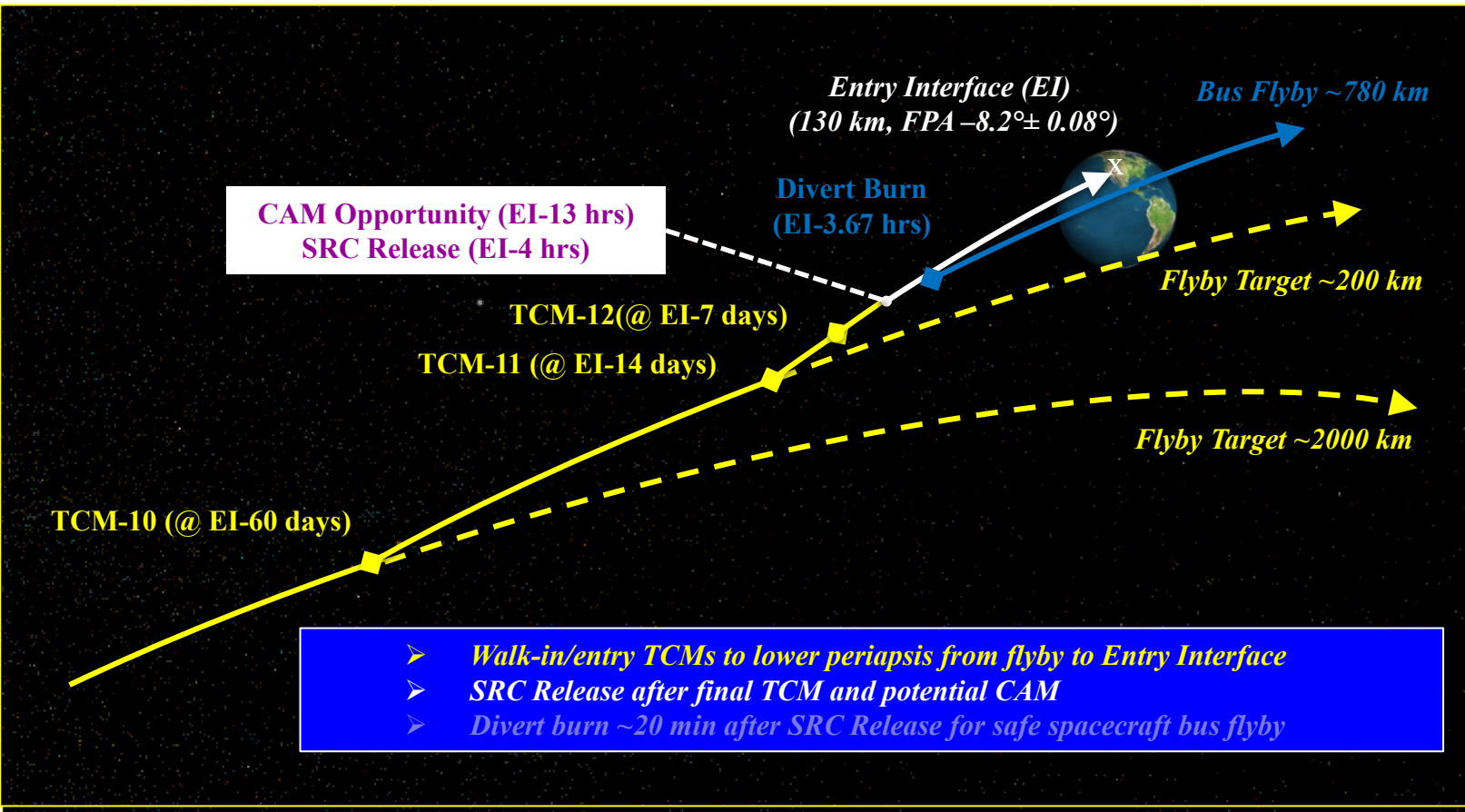
- **Development and execution of Conjunction Assessment Operations Implementation Agreement (CAOIA) Document**
  - Coordination between CARA and mission on details of support
- **Orbit crossing forecasting analysis > 10 days out**
  - Identify objects with small relative node separation distances and time from node
  - Similar to JPL MADCAP conjunction metrics for non-Earth environments
- **Participation in pre-arrival testing/simulations**
  - Created conjunction scenarios for table-top discussions and mission operational readiness tests
- **Operational screenings**
  - Relied on mission ephemerides since no passive ephemeris would be available



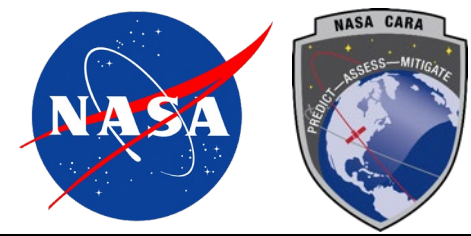
# Baseline Earth Return Concept of Operations

## Entry Targeting Maneuver Sequence

## Landing Ellipse Comparison



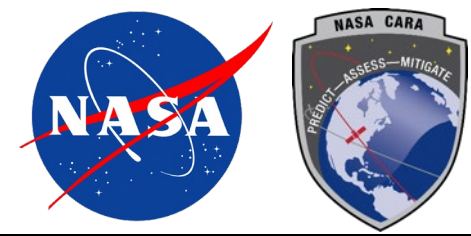
EI = Entry Interface    SRC = Sample Return Capsule    TCM = Trajectory Correction Maneuver    CAM = Collision Avoidance Maneuver



# Earth Return: Conjunction Screening Timeline

- **OREX Flight Dynamics to deliver CCSDS Orbital Ephemeris Message (OEM)-formatted ephemerides to CARA for both bus & SRC**
  - Start daily deliveries at E-12 days with preliminary TCM-12 modeled at E-7 days
  - Deliver nominal post-TCM-12 ephemeris starting at E-6 days
  - Deliver nominal plus CAM ephemerides starting at E-3 days (total of 8 ephemerides)
- **Timeline for final OD delivery:**

Event	Hours to Entry	Hours to CAM	Date (UTC)	Date (EDT)	Date (MDT)	Comment
OD Data Cutoff	47.7	34.7	9/22/23 14:00	9/22/23 10:00	9/22/23 08:00	Final OD for screening
Deliver 8 OEMs to CARA	38.7	25.7	9/22/23 23:00	9/22/23 19:00	9/22/23 17:00	2 no-burn & 6 CAM ephems
Receive CARA Report	~35.7	~22.7	9/23/23 02:00	9/22/23 22:00	9/22/23 20:00	Updates at 1000 & ~1600 UTC
CAM Go/No-Go	20.7	7.7	9/23/23 17:00	9/23/23 13:00	9/23/23 11:00	
Start of CAM Go U/L Window Deliver SPK, ESF	20	7	9/23/23 18:41	9/23/23 14:41	9/23/23 12:41	Passes at Canberra, Madrid
CAM Execution	13	0	9/24/23 01:41	9/23/23 21:41	9/23/23 19:41	If needed

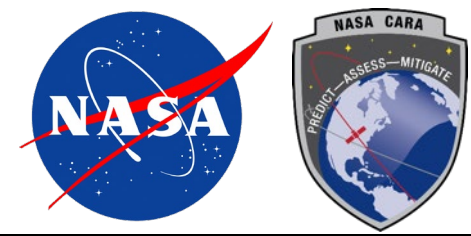


# Earth Return: Pre-Arrival Testing Scenario

- Screening results summary presented at *test* CAM Go/No-go meeting →

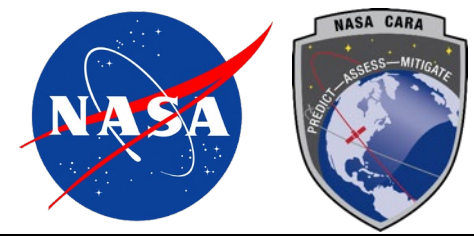
Ephemeris	Pc		Combined Pc	CARA Recommendation	Notes
	SRC	Bus	$1 - (1 - Pc_1)(1 - Pc_2)$		
No CAM	3.40E-04	1.54E-04	4.94E-04		Both secondaries are well tracked with consistent updates. R/B for SRC; FY1C debris for Bus.
-0.5 sec	4.21E-09	3.70E-04	3.70E-04		Bus secondary is moderately tracked HAMR debris object with large covariance but small miss distance with significant reduction (1.5 sig radial) in most recent OD due to space weather
-1.0 sec	1.23E-04	6.40E-10	1.23E-04	<---	SRC secondary is a well tracked inactive payload with consistent updates. Overall lowest combined Pc.
-2.0 sec	7.85E-05	2.23E-04	3.01E-04		Both secondaries are well tracked with consistent updates. Starlink for SRC; CZ-6A debris for Bus. Starlink will move away from SRC.
<b>Key</b>					
	Pc >= 1E-4		Maneuver required by SRC/Bus or active secondary payload		
	1E-7 <= Pc < 1E-4		Watch		
	Pc < 1E-7		No concern		

- No clear option – exercise decision process and discuss relative risk tolerance
- Difficult to devise credible “failure” scenarios



# Earth Return: Pre-Arrival Testing Summary

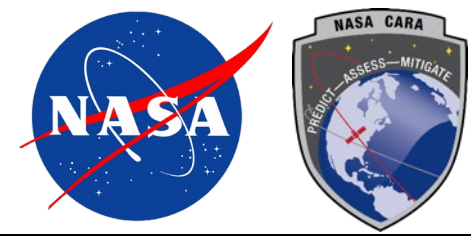
Date	Days to Entry	Activity	Description	Lessons
4/25/23	152	OREX Operational Proficiency Exercise 7a	Tests of varying sophistication (tabletop to full simulation) for which CARA provided support by defining conjunction scenarios to exercise CAM decision.	Detailed expectations of CARA support should be defined well ahead of time, e.g., during CAOIA development.
5/1/23	146	OREX Operational Readiness Test 8		
6/12/23	104	OREX Operational Readiness Test 9		
8/2/23	53	OREX Operational Proficiency Exercise 7a'		
8/15/23	40	OREX Operational Proficiency Exercise 7b		
8/23/23	32	Discussion on screening volume size options	Due to hyperbolic velocities with large radial component, is there a volume available bigger than HEO (40 x 77 x 107 km RIC)? Chose 250 km sphere used for LEOP.	Need to analyze proper volume for hyperbolic/ impact trajectories. JSC uses 50 km cube for Artemis.
8/30/23	25	CARA Screening Test	Performed screening of bus and SRC trajectories against current catalog by simulating entry on Aug 30. Discussed CARA products and timeline with OREX Flight Dynamics.	Certain missions would benefit from more sophisticated CARA simulation capabilities. Engage early with flight dynamics teams of missions without routine CARA support.
9/7/23	17	CARA Discussion with Mission Flight Dynamics		



# Earth Return: Operational Screening Results

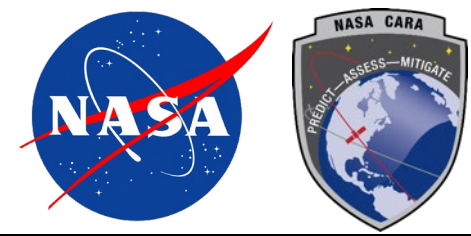
PRIMARY	SECONDARY NAME	SECONDARY ID	TCA (UTC)	MISS DISTANCE (KM)	Pc	ALTITUDE (KM)	RELATIVE SPEED (KM/S)	APPROACH ANGLE (DEG)
OREX	SL-16 DEB	22551	2023-09-24T14:42:13.774	43.844	7.47E-18	927.919	14.462	96.293
OREX	DELTA 1 DEB	37658	2023-09-24T14:47:41.881	46.430	6.13E-48	969.998	15.621	106.624
OREX	ONEWEB-0658	55819	2023-09-24T14:48:54.420	54.972	1.35E-24	1162.152	14.496	97.531
OREX	ONEWEB-0658	55819	2023-09-24T14:48:54.428	55.049	4.27E-25	1162.175	14.496	97.532
OREX	CZ-6A DEB	54960	2023-09-24T14:42:30.538	60.183	1.56E-70	896.379	17.599	130.208
OREX	FENGYUN 1C DEB	30244	2023-09-24T14:44:58.859	65.161	3.19E-44	773.884	14.204	91.261
OREX	COSMOS 1275 DEB	42181	2023-09-24T14:45:56.362	83.571	4.60E-111	804.029	12.163	74.373
OREX	UNKNOWN	54572	2023-09-24T14:44:20.635	93.014	2.07E-119	777.970	17.208	122.188
OREX	COSMOS 1823 DEB	29360	2023-09-24T14:50:40.750	93.404	1.44E-100	1545.686	13.169	88.193
SRC	COSMOS 1375 DEB	17107	2023-09-24T14:37:52.306	66.534	0.00E+00	955.245	7.410	36.713
SRC	STARLINK-6223	57057	2023-09-24T14:39:24.552	99.243	0.00E+00	554.973	11.742	69.960
SRC	STARLINK-6223	57057	2023-09-24T14:39:24.752	108.966	0.00E+00	554.206	11.745	69.982

- None of these objects are a concern
- Maneuver trajectories change miss distances by a few km, so also not a concern



# Earth Return: Operational Screening Summary

Date	Days to Entry	Activity	Description	Lessons
9/8/23	16	First OREX operational ephemeris delivery	Discovered propagation time > 10 days too long for entire catalog	No need for screenings beyond 10 days out.
9/14/23	10	Successful screening on nominal trajectories (Bus & SRC) using nominal 10-day propagations for GEO/HEO run	250 km volume not part of baseline, so Bus & SRC had to be screened separately	Determine appropriate reasonable screening volume and include in baseline
9/15/23	9	CDMs posted to SpaceTrack	No reportable conjunctions, but interest in seeing objects within screening volume	For missions with transitory encounters with Earth, provide additional context of objects within screening volume to go along with (typically) empty CARA report
9/16/23	8	Continued MSA on Bus & SRC, successful process achieved	Continued MSA on Bus & SRC, successful process achieved	
9/21/23	3	Begin delivering/screening 8 trajectories	1 nominal + 3 burn options for both primary objects	
9/22/23	2	Decisional Screenings for CAM	To support Go/No-Go at E-20h on 9/23/2023	Work with mission to define clear criteria for remediation decision and, if needed, adjudication of conflicting recommendations
9/24/23	0	Entry/Flyby	Continued screening past Go/No-Go for situational awareness	

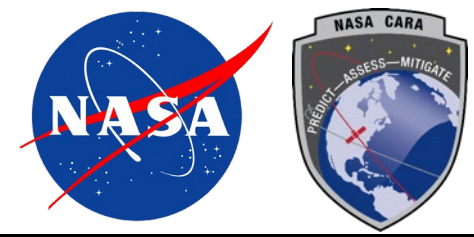


## • Overall Lessons:

- Develop a baseline for support of flyby & entry missions
  - Including appropriate screening volume and expanded reporting of results
- Clearly define simulation/testing and operations support for non-routine missions well ahead of time
  - Understand any special requests and their implications to the CARA system and process
- Understand that orbit crossing forecasting analysis defines the conjunction environment in broad strokes and the results are subject to the limitations of long propagations

## • Next up:

- Lucy flyby on Dec 12, 2024
- OSIRIS-ApEx on Sep 23, 2025



**QUESTIONS?**

