ICSSA 2024

Enhancing Space Situational Awareness To Mitigate Risk:

A Case Study In The Misidentification Of A Starlink Satellite Train As UAP In Commercial Aviation

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Presented by: Nick Snell

Agenda

- Show: photographic evidence from our case study of an Unidentified Aerospace Phenomenon (UAP*) report from two commercial flights
- Show: results of orbit modeling used to confirm this was in fact deploying Starlinks
- Describe: modeling done in a University of Utah engineering course
- Suggest: making this a standard approach easily available to pilots and ground controllers in support aviation safety

* UAP uses Aerospace, Aerial or Anomalous almost interchangeably

MUFON* Case # 124190

- What makes this case study interesting to study and use?
  - Multiple eyewitnesses:
    - 3 pilots on one flight and 2 pilots on the other flight
  - Aircraft flight data provides latitude, longitude & altitude with time:
    - AC536 flying from Maui to Vancouver B.C.
    - AC34 flying from Sydney Australia to Vancouver B.C.
  - Photographic evidence (iPhone 12) from one of the AC536 pilots:
    - Photo 1: 2022-08-10T11:39:08UTC
    - Photo 2: 2022-08-10T11:39:24UTC
      - UTC is Coordinated Universal Time
    - An approximately16 sec movie taken between the first and second photos

* Mutual UFO Network (MUFON)

MUFON Case # 124190

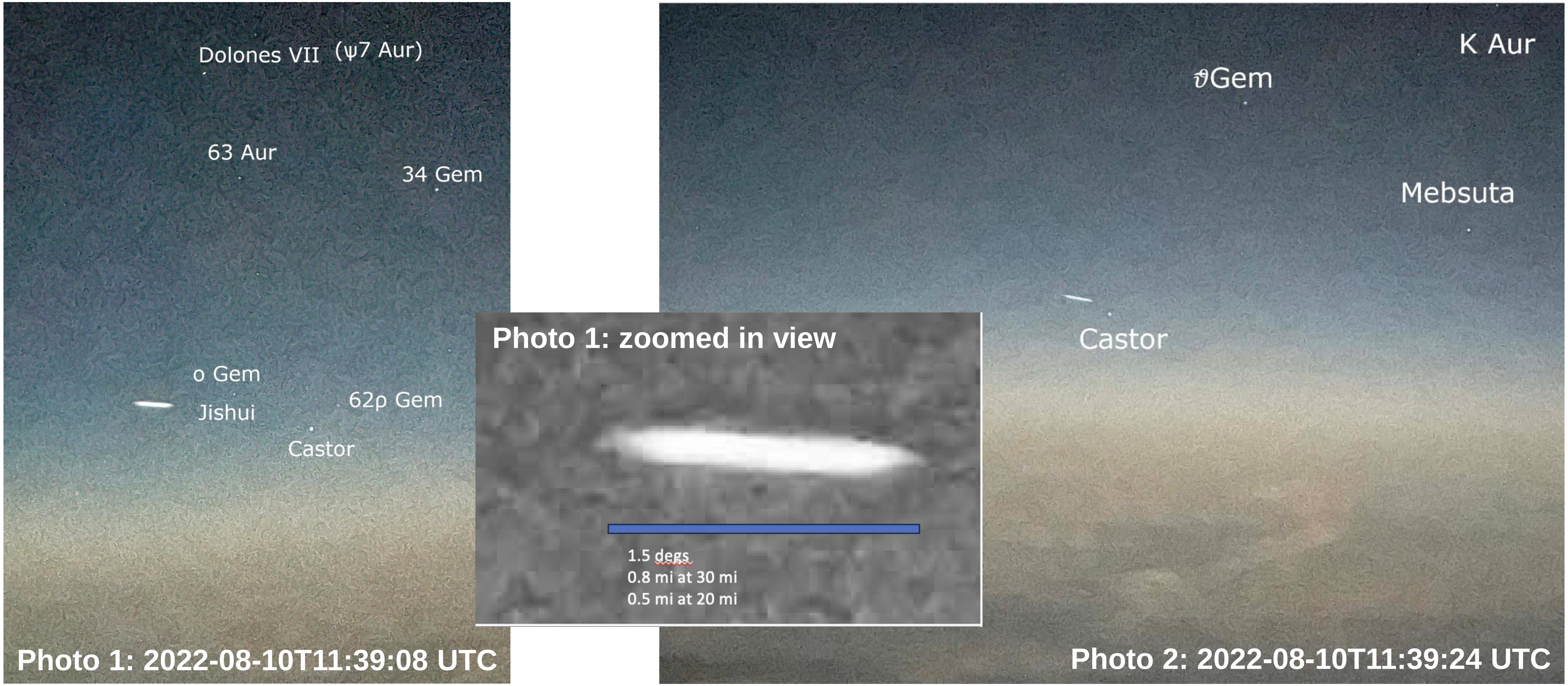


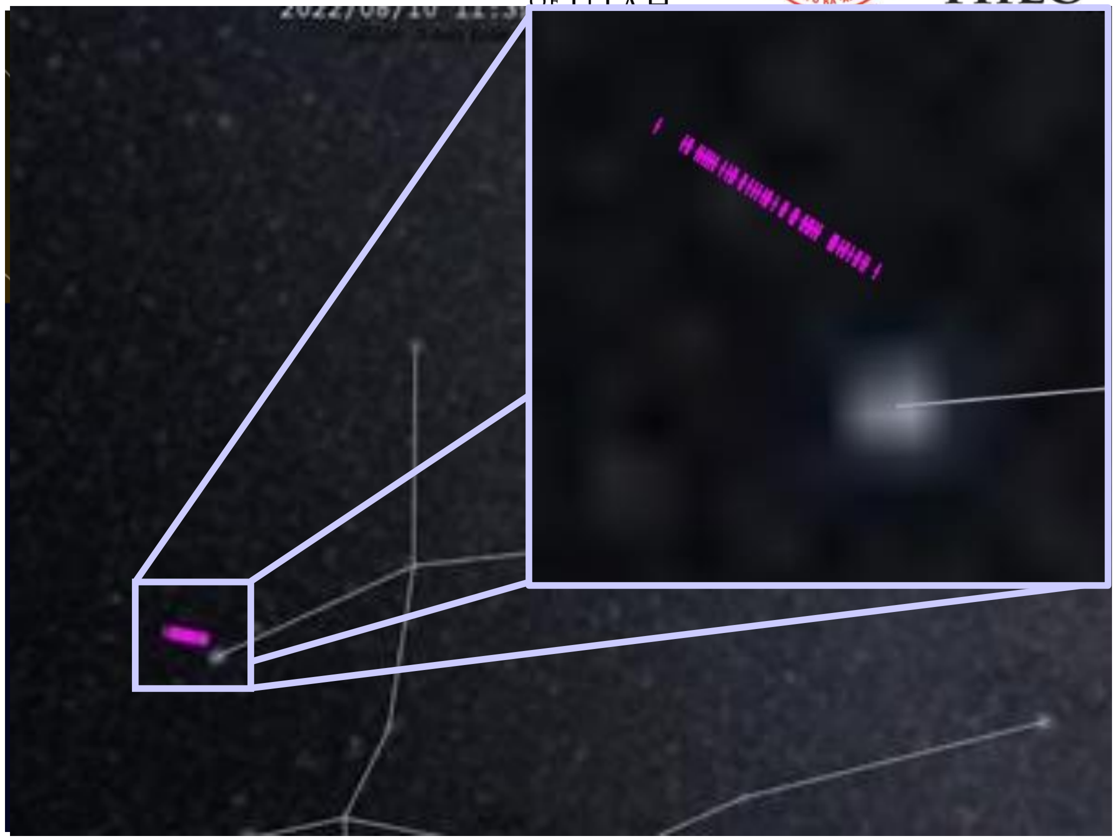
Photo 1: 2022-08-10T11:39:08 UTC

Photo 2: 2022-08-10T11:39:24 UTC

Photos courtesy of an anomalous pilot on AC536

MUFON Case # 124190

- Initially analyzed by Dr. Richard Griffiths at the University of Hawaii
  - Misidentified as a UAP, believing that the Starlinks were not in view of the aircraft
- Subsequent modeling results by Dr. Doug Buettner at the University of Utah using The Aerospace Corporation’s Satellite Orbital Analysis Program (SOAP) demonstrated these were the Starlinks launched earlier that day



Logo provided for informational purposes.

MUFON Case # 124190

- Since SOAP is only available to Aerospace employees and their government customers, Dr. Buettner wanted the modeling redone using publicly available tools
- He offered the following as a project to students in his Space Mission Engineering course at the University of Utah
  - Task 1: Model the SpaceX launch and Starlink locations using Ansys/AGI's System Toolkit (STK) after identifying other potential modeling tools
  - Task 2: Identify tools for (and do) physics-based visualization (rendering) to provide a photo-realistic cockpit view
    - OpenSpace, which is a professional rendering software for the space industry, was recommended but we chose not to use it due to its complexity

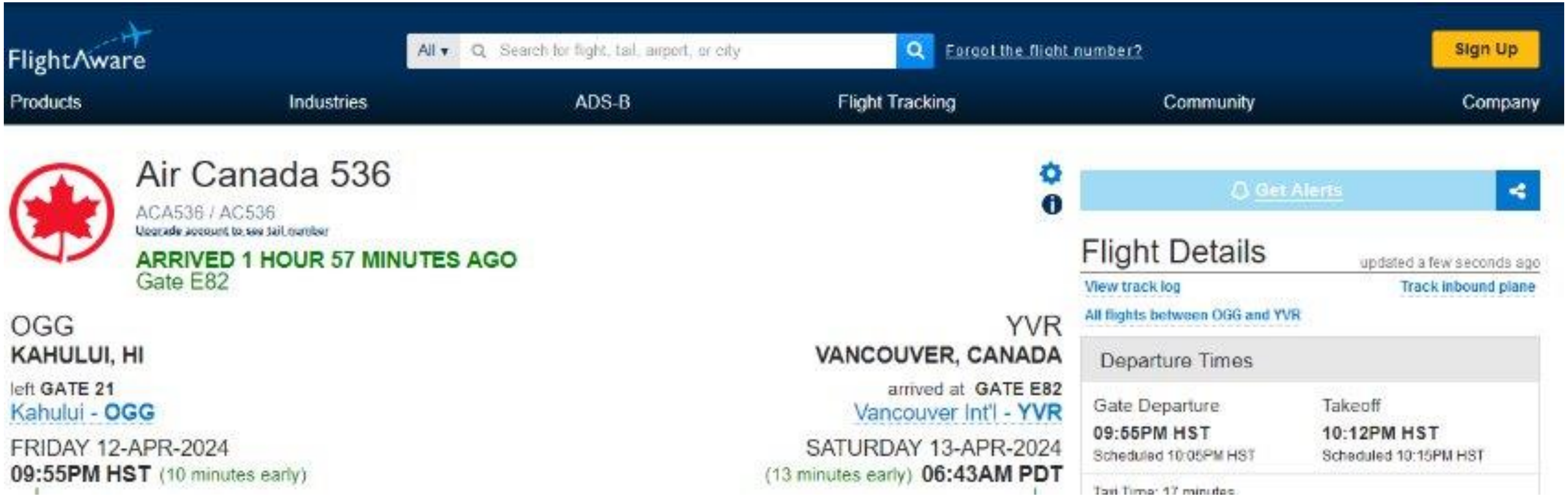
Task 1: Ansys STK Modeling

- Necessary modeling info can be obtained from:
  - AC536’s Automatic Dependent Surveillance–Broadcast (ADS-B) flight data: FlightAware.com
  - SpaceX/Starlink launch information: Space Launch Now
  - SpaceX debris and Starlink satellite Two-Line Elements (TLEs): Celestrak®
  - Falcon 9 launch information (to add fidelity): SpaceX

Logos provided for informational purposes.

Task 1: Obtaining AC536 ADS-B data

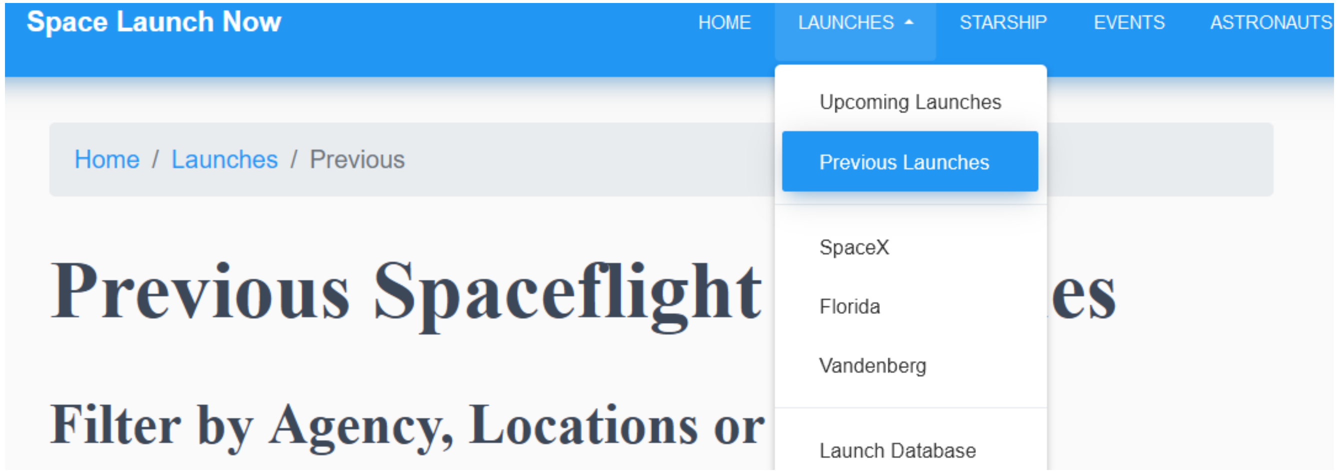
- To obtain the required ADS-B data of your flight, we used FlightAware.com to search for our flight number
  - https://www.flightaware.com/live/flight/ADSB/history
  - In our case, this is AC536



Task 1: Space Launch Now data

Reactive mode:

- Needed launch information
  - Space Launch Now used here
  - NASA Space Flight is another potential site
  - And there are others…



Task 1: TLEs from Celestrak

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Logo provided for informational purposes.

- Celestrak provided Two-Line Elements (TLEs) for the Starlinks for STK
- Initially, Dr. Kelso, the owner of Celestrak, changed his query format for us.
- This has recently changed, and our paper is already out of date!
  - The 7XXXX format as documented in the paper no longer works!
  - Now simply use Celestrak's supplemental data query dialogue, the NORAD-ID, with a request for 7 to 10 days of data after the launch date

Task 1: Falcon 9 Rocket data

- Falcon 9 Launch Specs:
  - https://www.spacex.com/vehicles/falcon-9/
- Day of launch information for Space Launch Now and others as previously mentioned
  - https://www.spacelaunchnow.com/aslkdfj

FALCON 9

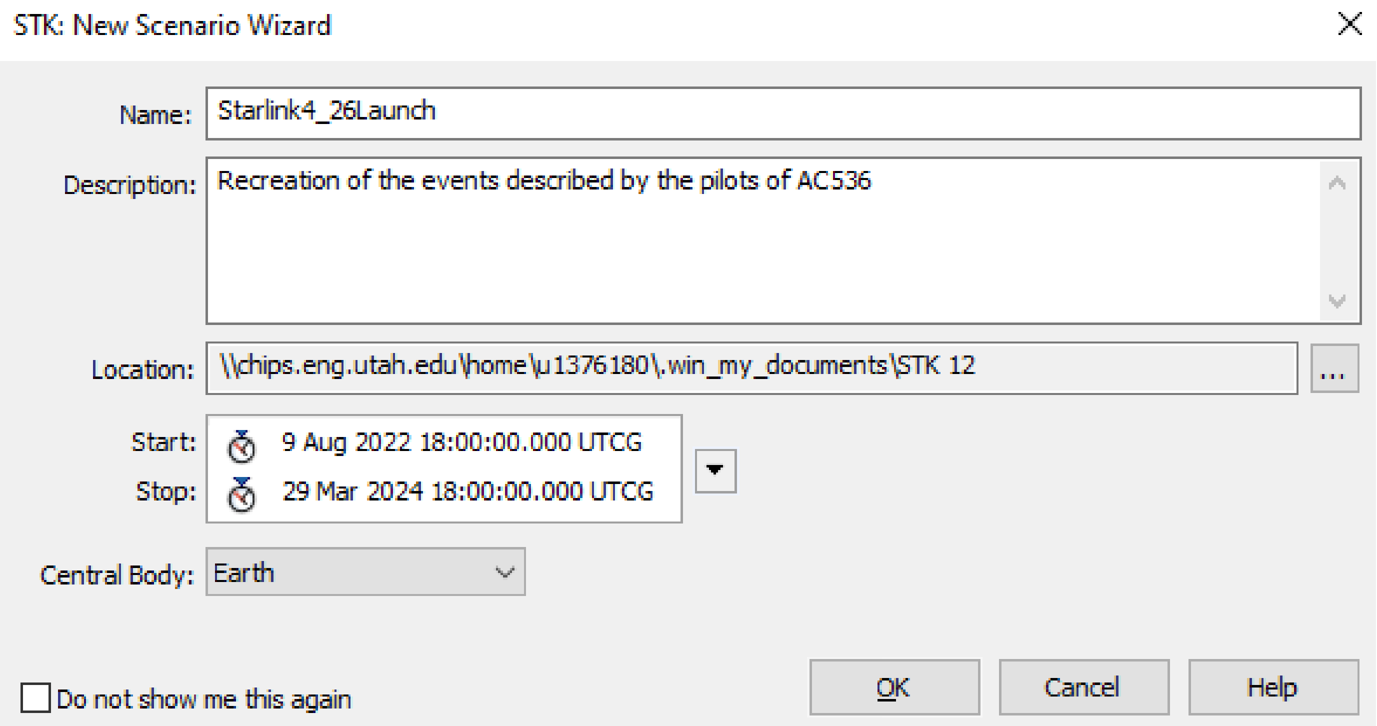
OVERVIEW

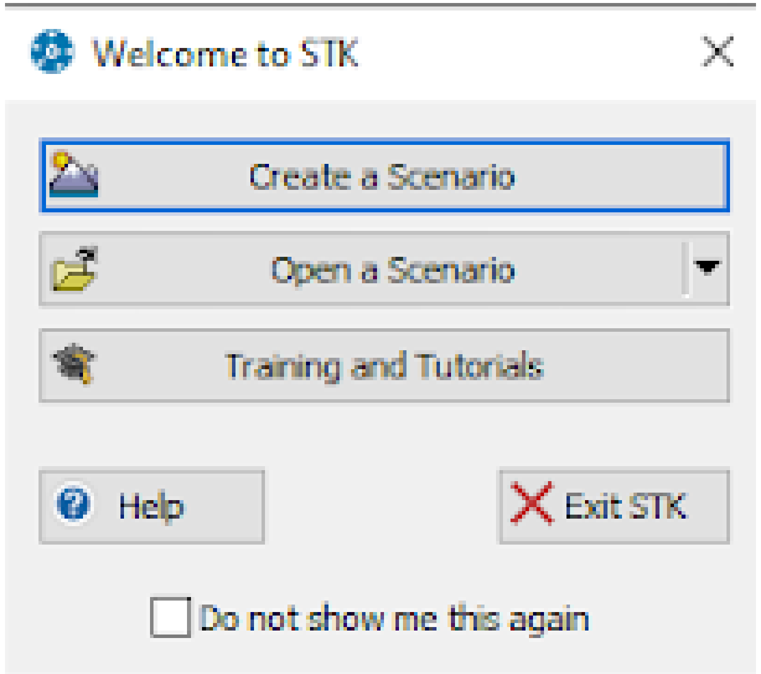
HEIGHT	**70 m** / 229.6 ft
DIAMETER	**3.7 m** / 12 ft
MASS	**549,054 kg** / 1,207,920 lb
PAYLOAD TO LEO	**22,800 kg** / 50,265 lb
PAYLOAD TO GTO	**8,300 kg** / 18,300 lb
PAYLOAD TO MARS	**4,020 kg** / 8,860 lb

Falcon 9 Information and photo courtesy of SpaceX

Task 1: Ansys STK Modeling

- STK's starting dialogue box
  - Selecting Create a Scenario starts the New Scenario Wizard
- The required information is shown below

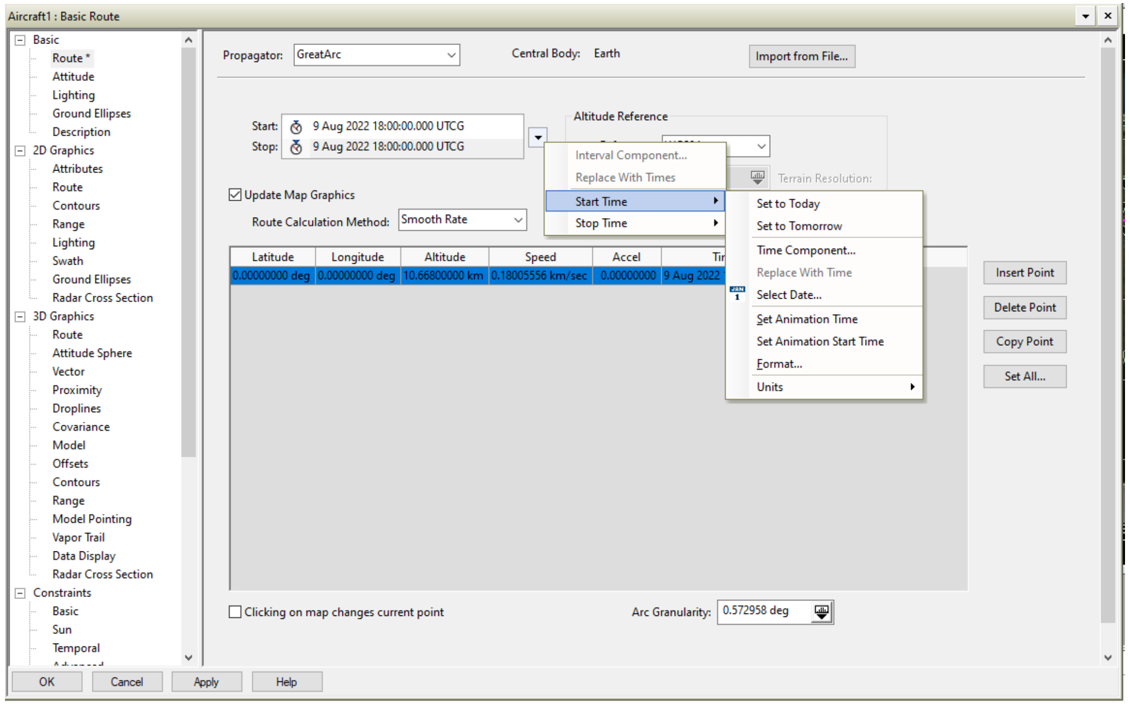




Logo provided for informational purposes.

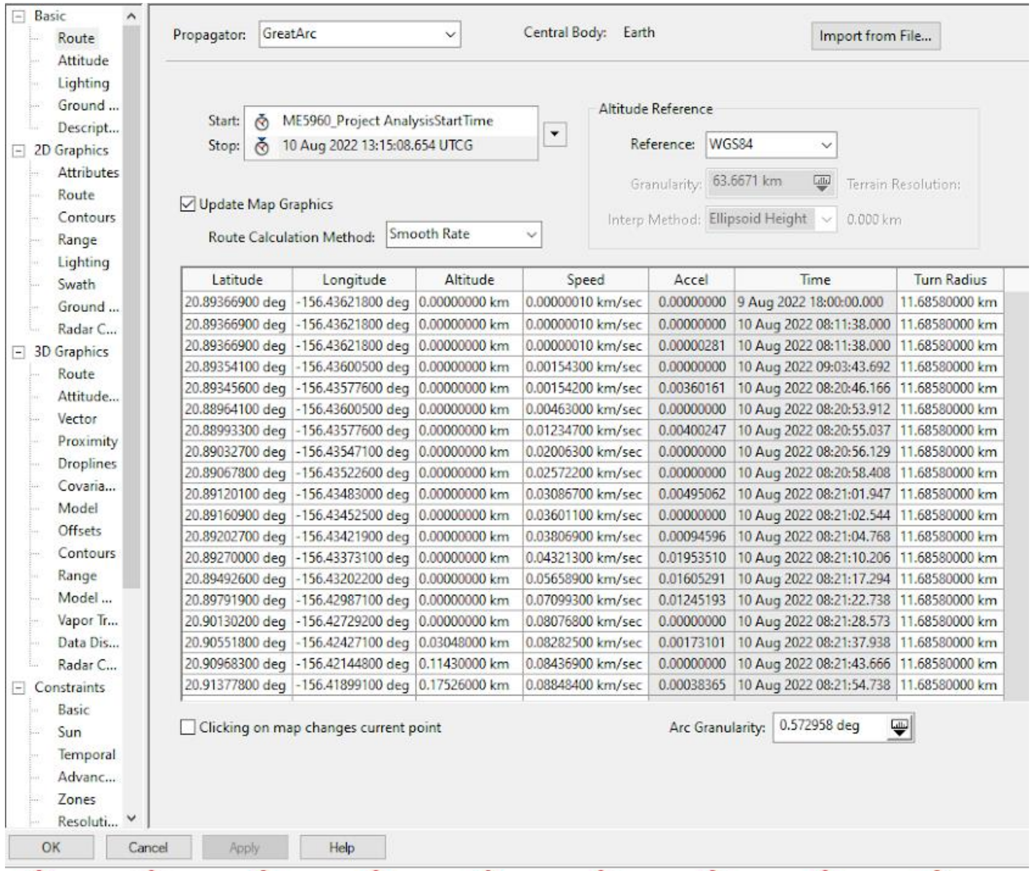
Task 1: STK Aircraft Flight Path Modeling

- To insert an aircraft, click insert and select “Aircraft” then “Define Properties”
  - A pop up will open and make sure propagator is set to “GreatArc”
  - From there, you need to change your “Start Time” to be the UTC time of the first ADS-B point available
  - Next you want to click insert a point and fill out the latitude, longitude, altitude, and speed columns.
    - Repeat until all ADS-B points have been entered

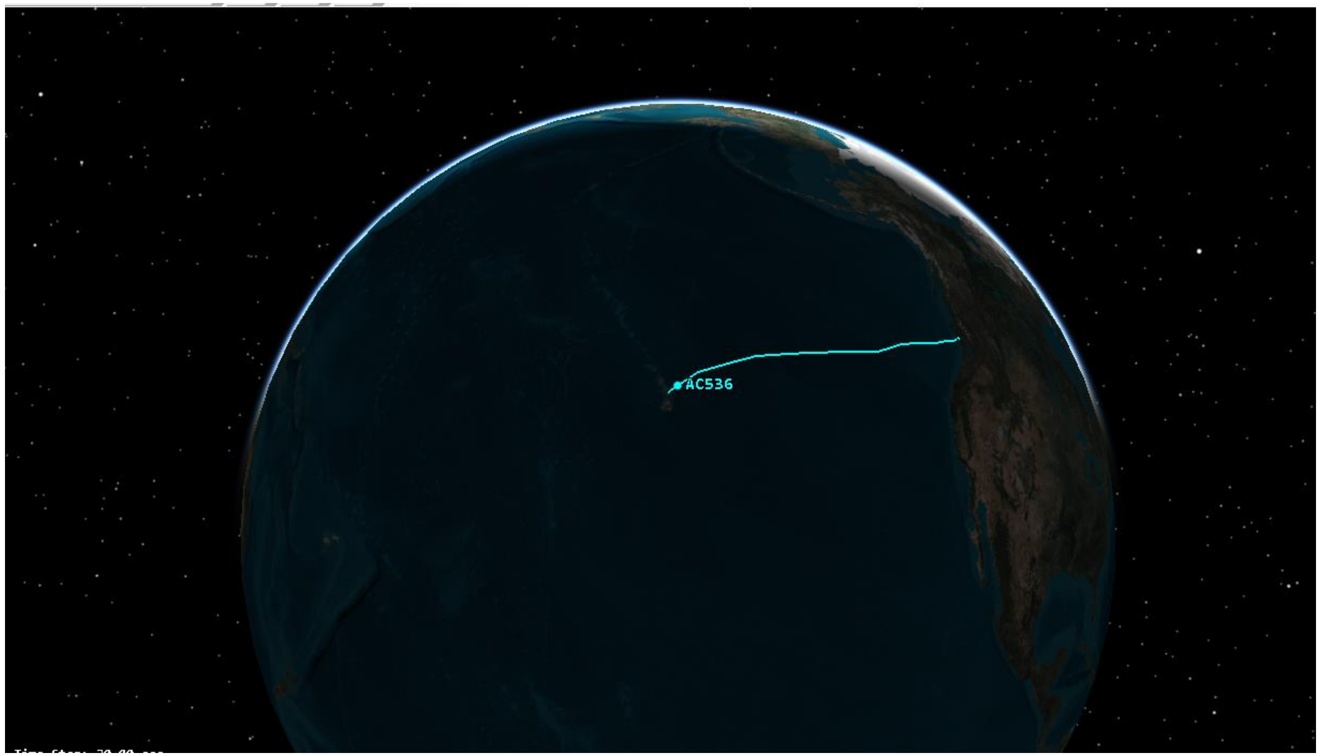


Task 1: STK Aircraft Flight Path Modeling

- If done correctly, your aircraft pop up window and 3D viewer should look like the following



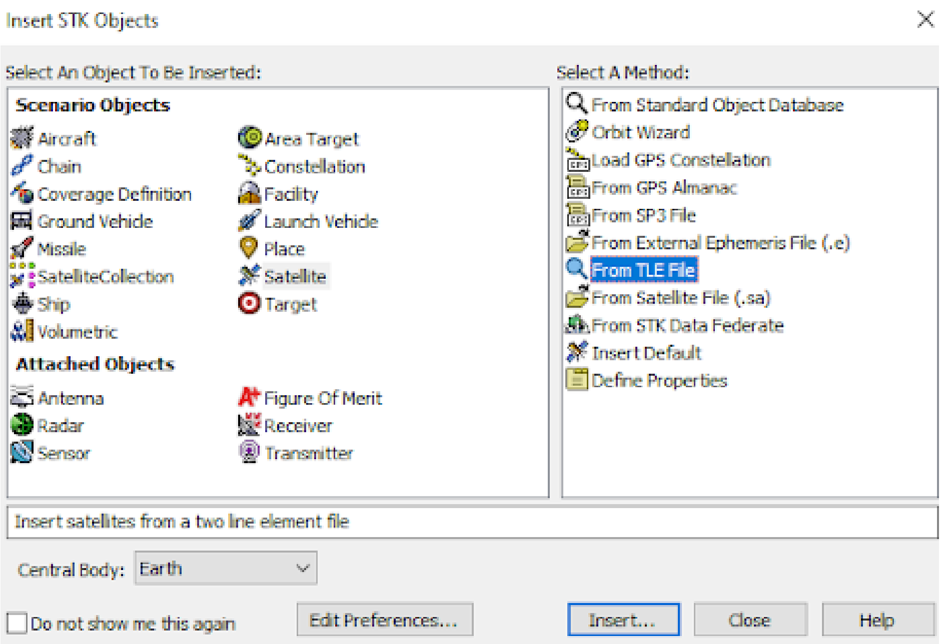
Latitude	Longitude	Altitude	Speed	Accel	Time	Turn Radius
20.89366900 deg	-156.43621800 deg	0.00000000 km	0.00000010 km/sec	0.00000000	9 Aug 2022 18:00:00.000	11.68580000 km
20.89366900 deg	-156.43621800 deg	0.00000000 km	0.00000010 km/sec	0.00000000	10 Aug 2022 08:11:38.000	11.68580000 km
20.89366900 deg	-156.43621800 deg	0.00000000 km	0.00000010 km/sec	0.00000281	10 Aug 2022 08:11:38.000	11.68580000 km
20.89354100 deg	-156.43600500 deg	0.00000000 km	0.00154300 km/sec	0.00000000	10 Aug 2022 09:03:43.692	11.68580000 km
20.89345600 deg	-156.43577600 deg	0.00000000 km	0.00154200 km/sec	0.00360161	10 Aug 2022 08:20:46.166	11.68580000 km
20.88964100 deg	-156.43600500 deg	0.00000000 km	0.00463000 km/sec	0.00000000	10 Aug 2022 08:20:53.912	11.68580000 km
20.88993300 deg	-156.43577600 deg	0.00000000 km	0.01234700 km/sec	0.00400247	10 Aug 2022 08:20:55.037	11.68580000 km
20.89032700 deg	-156.43547100 deg	0.00000000 km	0.02006300 km/sec	0.00000000	10 Aug 2022 08:20:56.129	11.68580000 km
20.89067800 deg	-156.43522600 deg	0.00000000 km	0.02572200 km/sec	0.00000000	10 Aug 2022 08:20:58.408	11.68580000 km
20.89120100 deg	-156.43483000 deg	0.00000000 km	0.03086700 km/sec	0.00495062	10 Aug 2022 08:21:01.947	11.68580000 km
20.89160900 deg	-156.43452500 deg	0.00000000 km	0.03601100 km/sec	0.00000000	10 Aug 2022 08:21:02.544	11.68580000 km
20.89202700 deg	-156.43421900 deg	0.00000000 km	0.03806900 km/sec	0.00094596	10 Aug 2022 08:21:04.768	11.68580000 km
20.89270000 deg	-156.43373100 deg	0.00000000 km	0.04321300 km/sec	0.01953510	10 Aug 2022 08:21:10.206	11.68580000 km
20.89492600 deg	-156.43202200 deg	0.00000000 km	0.05658900 km/sec	0.01605291	10 Aug 2022 08:21:17.294	11.68580000 km
20.89791900 deg	-156.42987100 deg	0.00000000 km	0.07099300 km/sec	0.01245193	10 Aug 2022 08:21:22.738	11.68580000 km
20.90130200 deg	-156.42729200 deg	0.00000000 km	0.08076800 km/sec	0.00000000	10 Aug 2022 08:21:28.573	11.68580000 km
20.90551800 deg	-156.42427100 deg	0.03048000 km	0.08282500 km/sec	0.00173101	10 Aug 2022 08:21:37.938	11.68580000 km
20.90968300 deg	-156.42144800 deg	0.11430000 km	0.08436900 km/sec	0.00000000	10 Aug 2022 08:21:43.666	11.68580000 km
20.91377800 deg	-156.41899100 deg	0.17526000 km	0.08848400 km/sec	0.00038365	10 Aug 2022 08:21:54.738	11.68580000 km

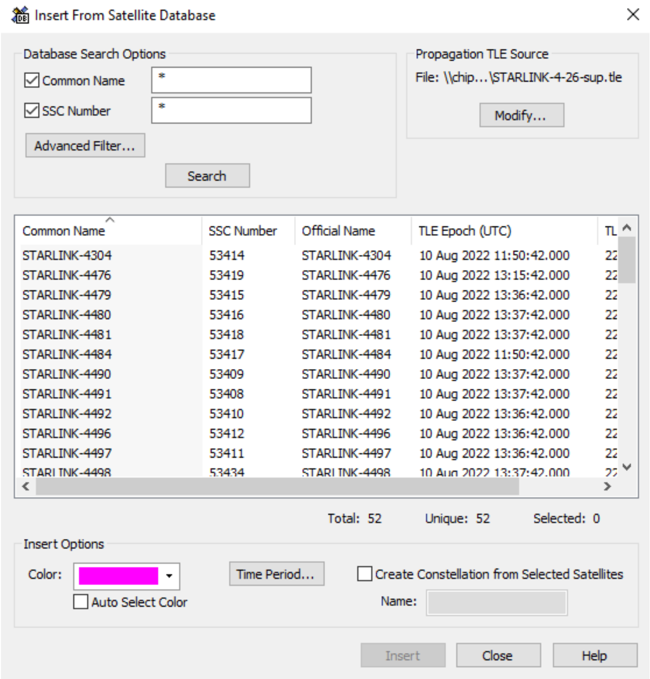


Flight path creation results from STK.

Task 1: Starlink Modeling

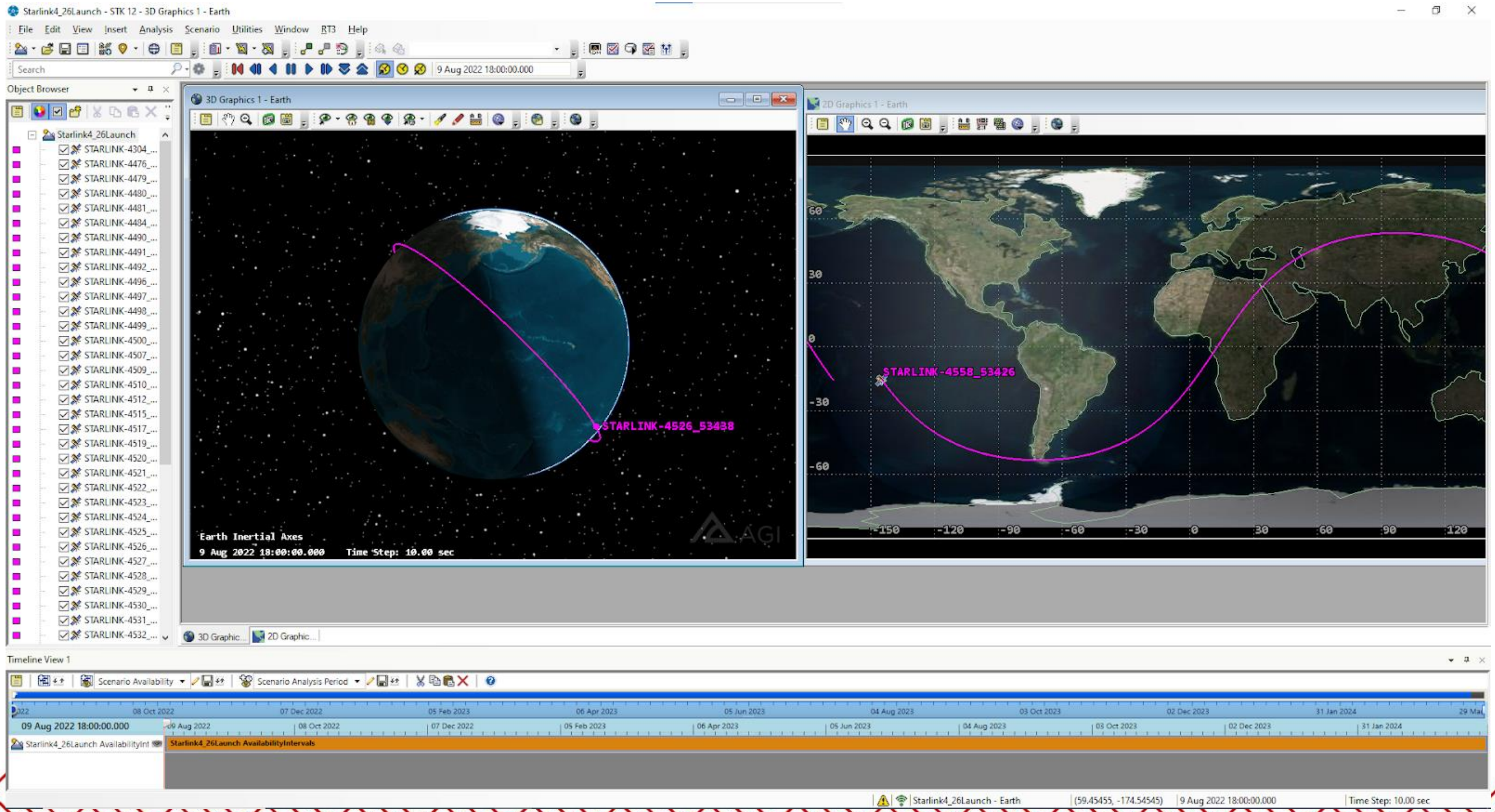
- Using the TLE's from Celestrak, to add them into the STK scenario
  - Select insert then select "Satellite" and "From TLE file"
  - After selecting "Insert", you will be prompted to select a TLE file
    - Another window will pop up prompting you to select the Satellite to add. For this scenario, you will select all of them





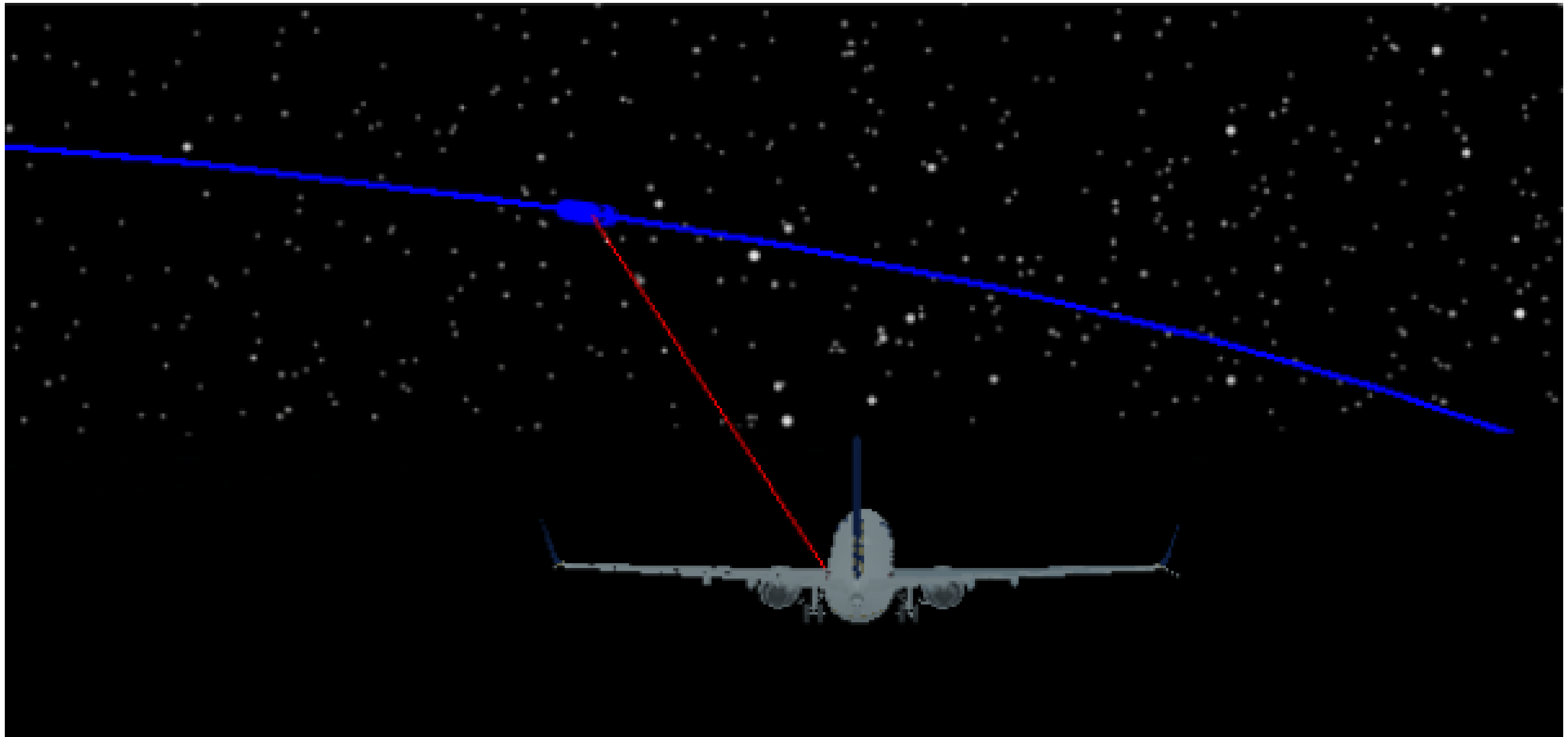
Task 1: Starlink Modeling

- Done correctly, your 3D and 2D windows will look like these ones



Task 1: Starlink Modeling Results

- Upon completion, the STK scenario is basically done
  - A “zoom to” the aircraft and you will see the Starlink train in basically the same part of the sky as seen in the case study photos



Our final modeling results from Ansys STK.

Task 2: Physics-Based Visualization

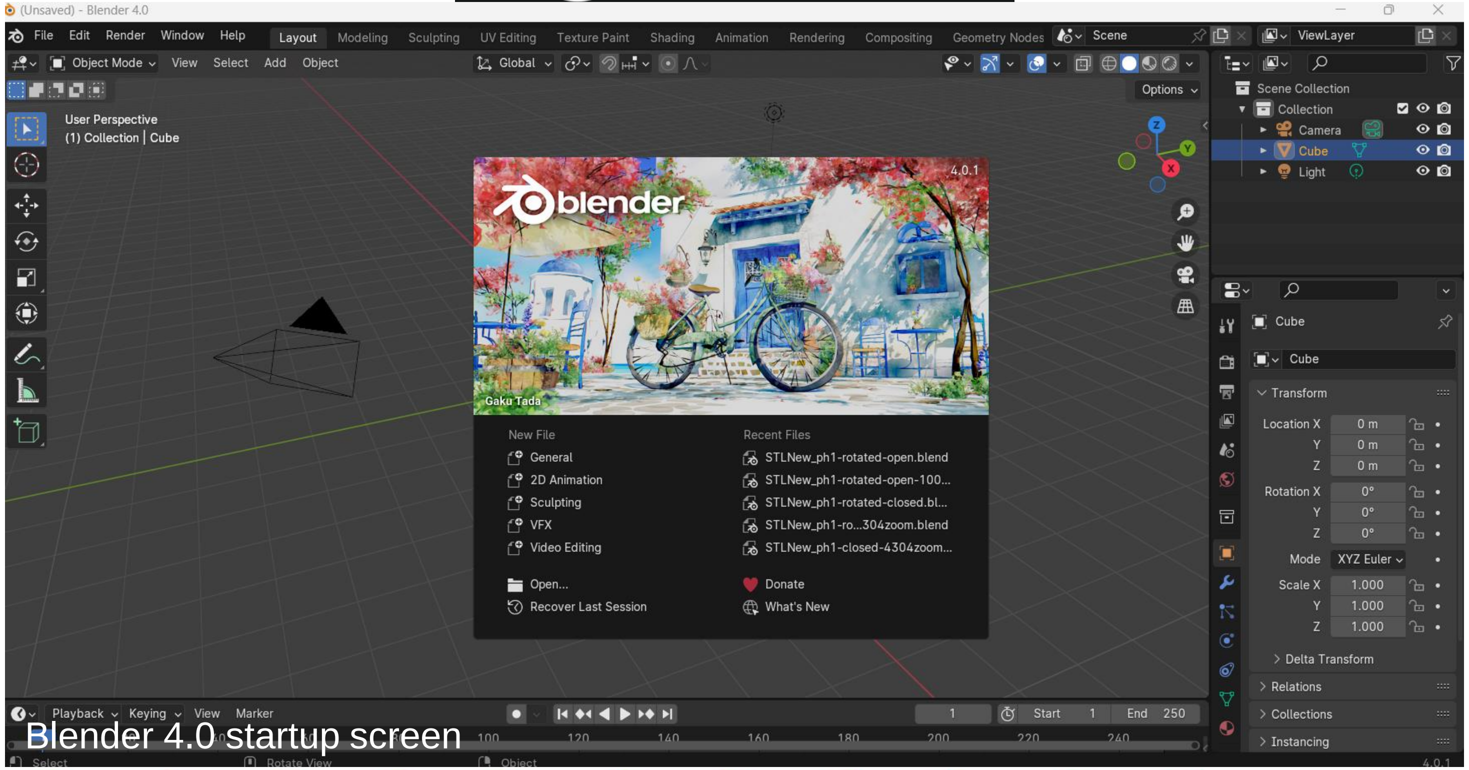
- Originally tasked to identify PROS & CONS of available rendering tools capable of physics-based modeling we reviewed OpenSpace, Autodesk 3ds Max, and Blender
  - Ultimately selecting Blender 4.0 due to its price (free) and the broad user community available online in addition to our original perception that physics-based modeling should be straightforward

Logos provided for informational purposes.

Task 2: Blender Visualization Modeling

- The final step is to create a blender model to better visualize what the pilots saw
- The following steps are needed:
  - Add an aircraft model
  - Add the earth
  - Add lighting
  - Add Starlinks

Logos provided for informational purposes.



Blender 4.0 startup screen

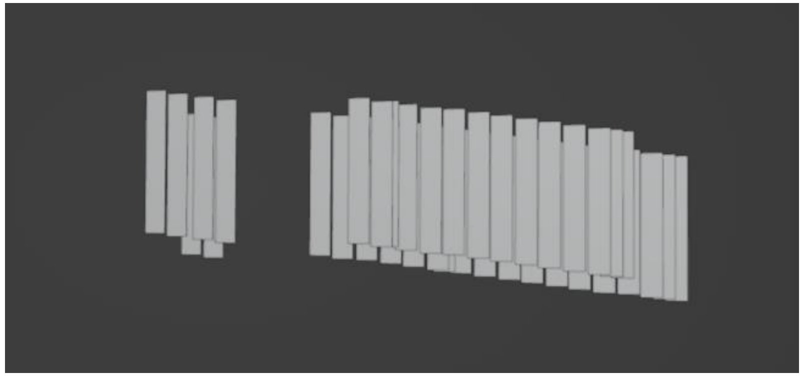
Task 2: Blender Visualization Modeling

- Use a free airplane model online (our paper documents which one)
  - Blender will not accept all CAD files, may need to convert the CAD file
- Import the plane model, this will be set at the center of the scene
  - This makes orientation and adding additional elements much simpler
- Scale the plane to the correct size.
  - All units will be in km, a Boeing 737 is 30 meters long.
- Add a spherical representation of the Earth using a “UV Sphere” *
  - In the Item tab, change the Dimensions to 12,742 m (diameter), and the z location to -6,371 m plus the airplane’s altitude
  - Right click the sphere and select shade smooth
- Add Earth satellite imagery
  - In shading, create a new node
  - Attach an image texture node with the satellite imagery of your choice
- Change the background color to black
- Rotate the Earth to approximately align with the position and heading of aircraft

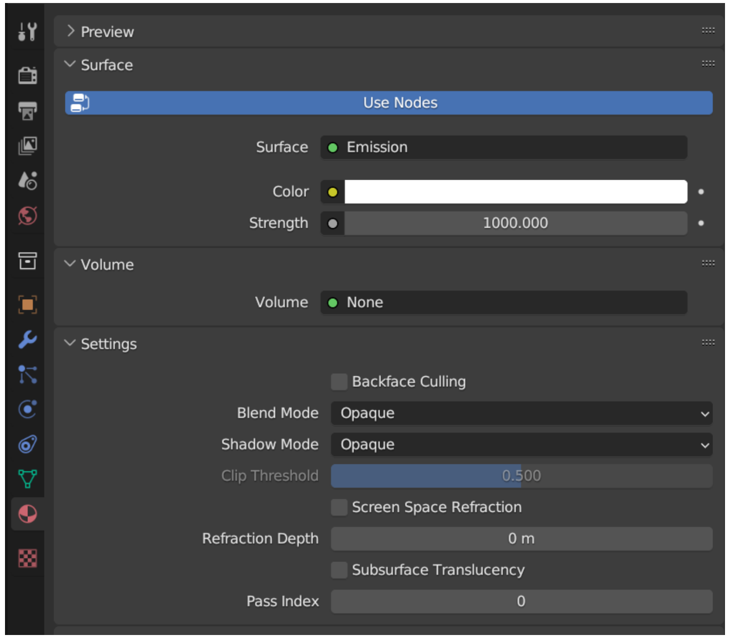
*Sphere is modeled with UV coordinates, which are blender Cartesian coordinates

Task 2: Initial Blender Modeling

- Add a Blender Cube (to simulate a Starlink satellite)
  - Modified the dimensions so it's as tall as the airplane is long, and as wide as it's fuselage. Exact scale was hard to achieve!
- Change the surface material properties of the cube
  - We used emission to simulate the rectangle reflecting light, surface was glass Bidirectional Scattering Distribution Function (BSDF)
- Change the location to a relative location using STK coordinates
  - Azimuth-Elevation-Range (AER) (initially obtained from STK) to XYZ coordinate conversion
  - If the reflection angle was calculated, that can also be added here
- Copy/paste new rectangles, change their relative location for each satellite



Starlink train modeled with STK data (not to scale)

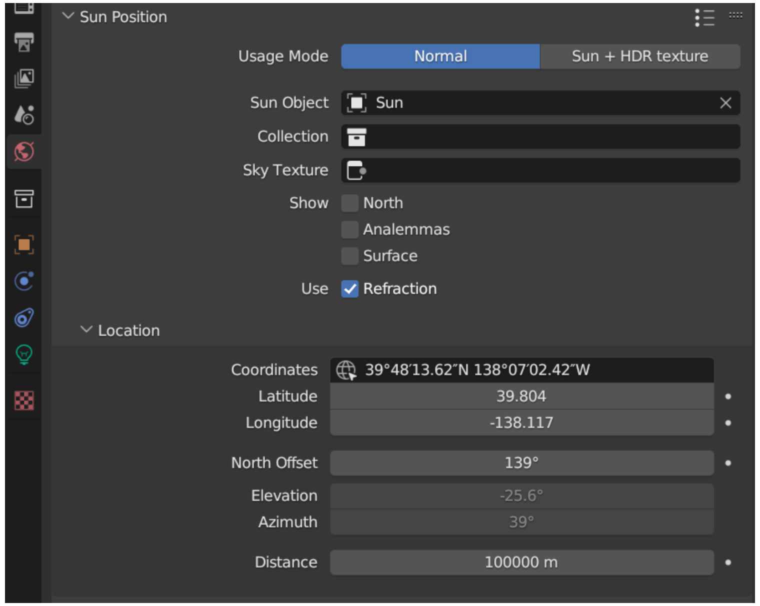


Material properties tab

Task 2: Initial Blender Modeling

- Add a sun object
  - Size didn't affect luminosity
- Position the sun accurately
  - Attach new sun object to "Sun Position" in "World Properties" (may need to enable "Sun Position" in "Preferences")
  - Adjust the date, time, and "North Offset" to the time of the photograph and the model airplane heading
  - Set the distance to a very far away value
- Set the "Strength" in "Data Properties"
- Added a small amount of light in the cockpit so the windows are visible

Shaded Earth Model

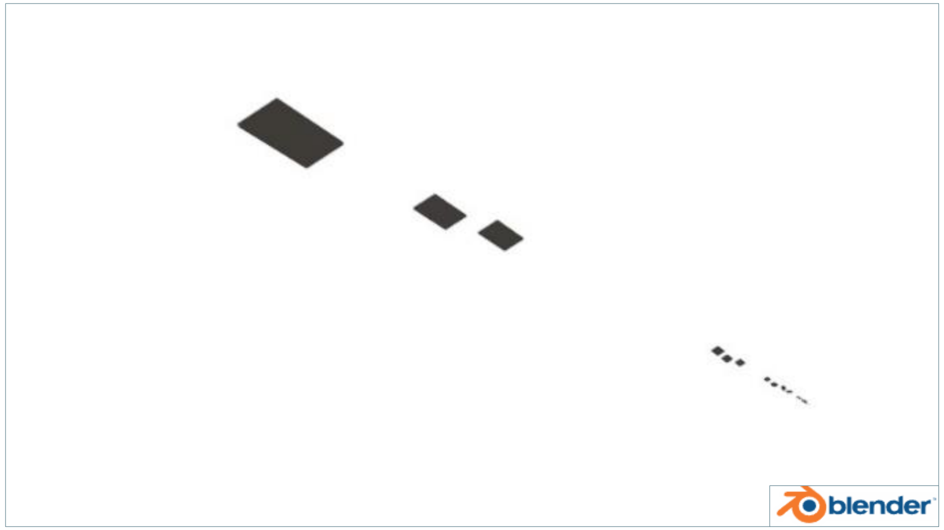


Material Properties Model

Task 2: Initial Blender Results

- Initially, we had to move the distance of the satellites much closer to the aircraft to ensure we could see them after rendering!
- After the term was over, Dr. Buettner modified our models to run visualization experiments
  - He moved the satellites out to their correct relative distances from AC536
  - And wanted to see if they were visible with and without the solar arrays being deployed

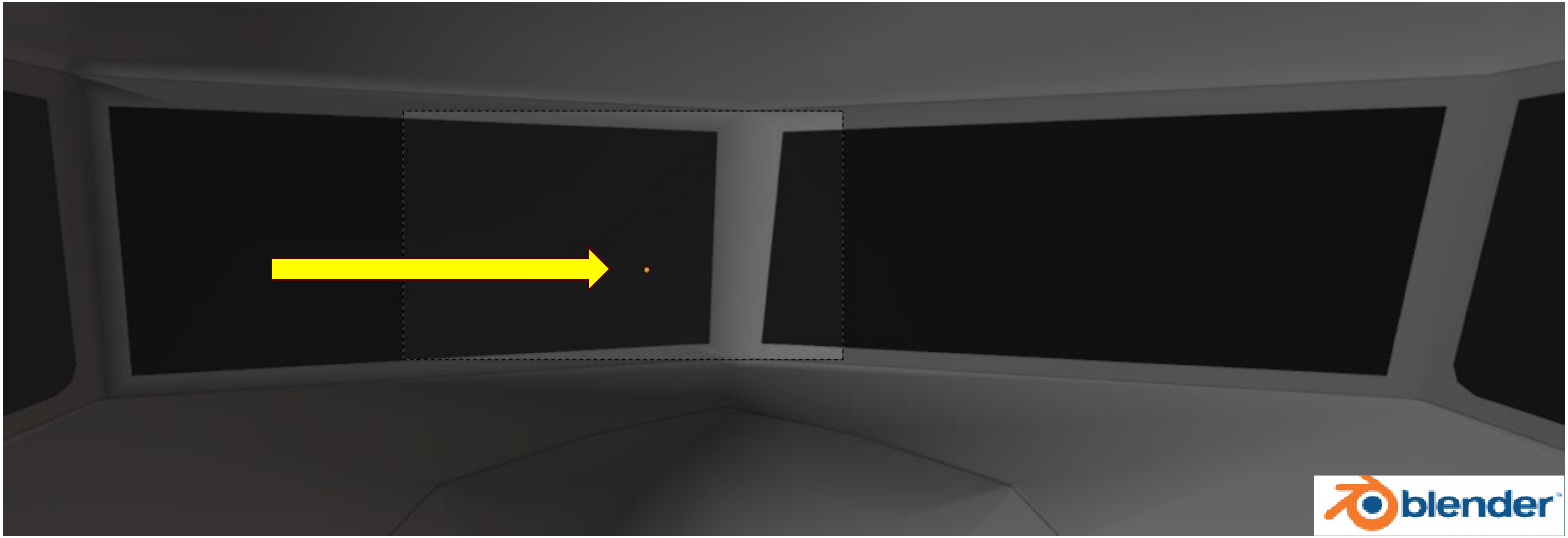
Solar arrays not deployed



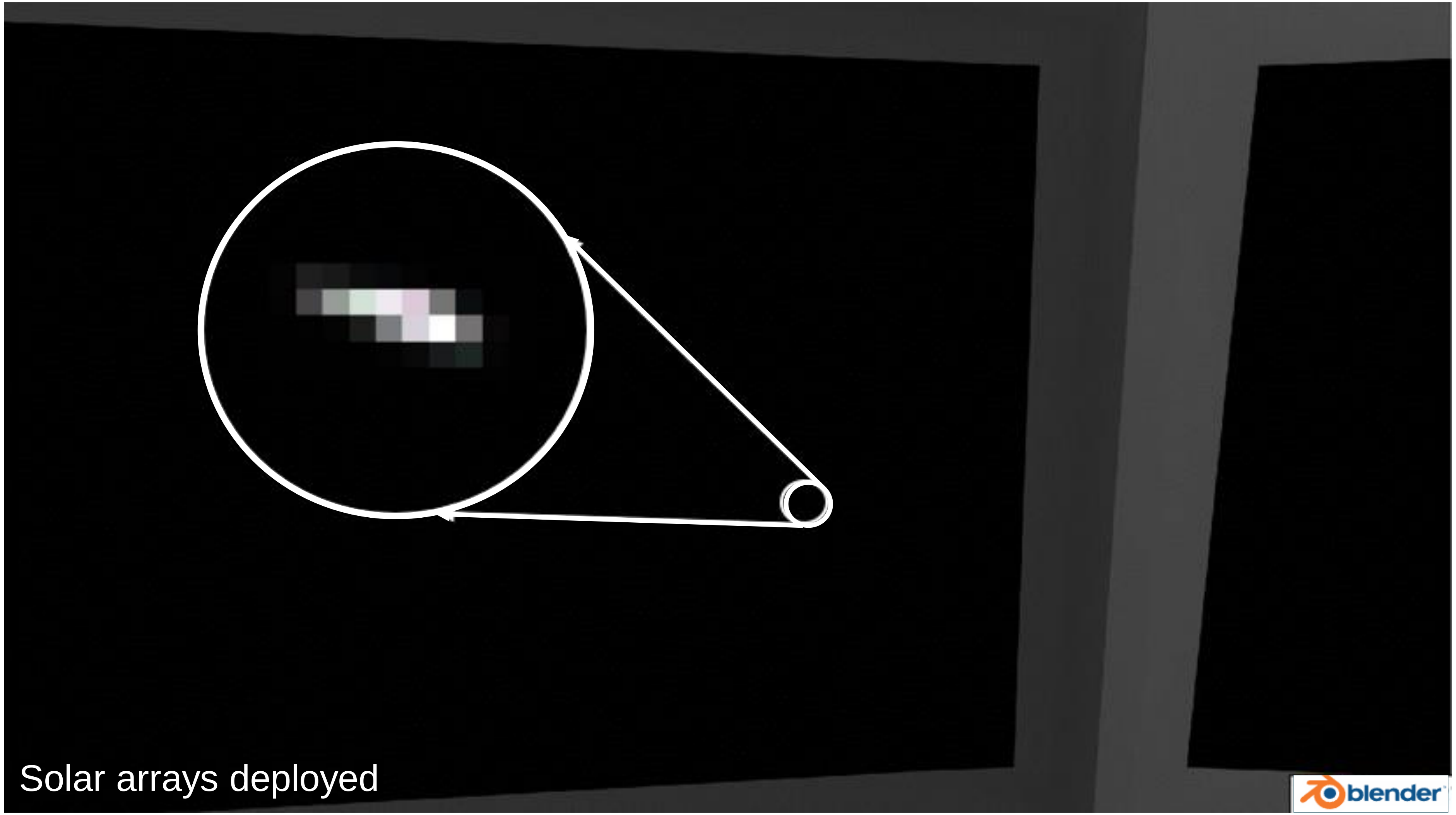
Solar arrays deployed

- After running “lots” of rendering experiments some of results are provided on the next few pages

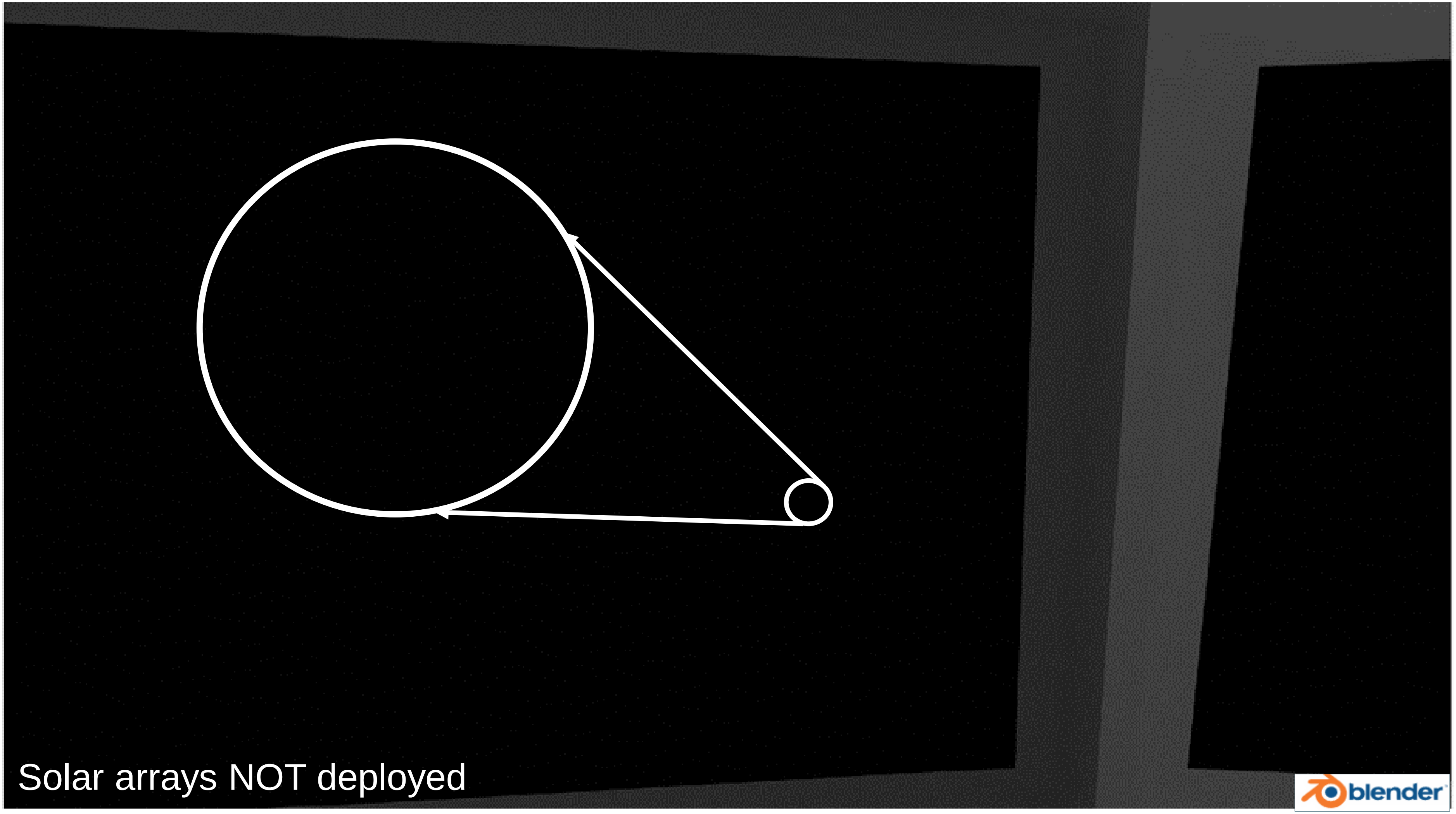
Task 2: Final Blender Results



Task 2: Final Blender Results



Task 2: Final Blender Results



Task 1 & 2: Challenges

- We ran into a lot of challenges while creating these models
  - Inserting ADS-B data into STK was a quite difficult
  - STK was unable to model Starlink deployment from Falcon 9 upper stage (as near as we could tell)
  - Blender's fidelity with the satellites at the correct distance did not allow us to replicate the photos
  - No accurate Starlink CAD models to use
  - And many others
- SpaceX doesn't provide much information about Starlink deployment
  - How are satellites released from second stage? When do solar arrays deploy? When do ion engines fire? SpaceX transparency could be improved to facilitate modeling.

Conclusions and Recommendations

- We accurately modeled the SpaceX/Starlink satellite train using both Aerospace's SOAP and Ansys' STK to demonstrate that this was likely the source of the UAP report
  - Starlink train was in the right place at the right time and able to duplicate the gap structure viewed in the movie
- Documented an approach in our paper that provides a viable method to provide a priori information to pilots and ground controllers about the visibility of deploying Starlink satellites
  - Information provided to us during multiple reviews indicate that some pilots consider this as a safety risk
  - Numerous recommendations were made regarding what would be needed to adopt this approach

For More Details

- Dr. Buettner and I will be providing a one-hour long talk at the hybrid SCU 2024 Conference on UAPs, May 31 to June 2

- Register @ https://scu.regfox.com/2024-scu-aapc-?t=AAPC2024

Acknowledgements

- This work would not have been possible without the excellent support from the following individuals and organizations:
  - Dr. Todd Easton, Univ of Utah Dept of Mech. Eng.'s Systems Eng. Program lead for funding Nick's trip to 4th IAA SSA Conf.
  - The anonymous pilot of ACA536, for taking the photographs and the movie required to do this case study analysis and for reporting the incident to MUFON
  - Mr. Mick West and his associates at metabunk.org, for identifying the correct culprit behind the sighting
  - Dr. Sarah Little, SCU's Science Advisor for data and thorough reviews for readability have been beyond extraordinary
  - Robert Powell, SCU's Executive Director for providing the FAA FOIA data used in our revised paper
  - Dr. T.S. Kelso, Celestrak.org, for adding changes to his website that facilitate pulling supplemental TLEs
  - Dr. Jonathan McDowell for providing relevant supplemental TLEs
  - Dr. Philip Antón, SERC/AIRC Chief Scientist for his support with my "hobby"
  - Dr. Dinesh Verna, SERC/AIRC Executive Director for his support with my "hobby"
  - Ben Hansen, for his insights into flight safety issues facing the aviation community and their lack of official feedback about their sightings
  - Tony Mallama and Richard Cole, for discussions about their unpublished/corroborating data and insights that suggested additional clarifications that we should include
  - AND FINALLY, the anonymous reviewers that were highly critical of our initial paper, that resulted in our adding several clarifications to our revision which greatly improved it

Questions?

Backup Slides

Orbit modeling: What's in a TLE???

- Technically, this is a 3LE, the first line is the name of the 'thing' in orbit.
  - On the previous page, this was a list of two 3LEs. Orbit modeling software can typically ingest the entire list of 3LEs.
- Here, this is STARLINK-G4-26 STACK.
  - Stack indicates it's the payload "stack" … eventually the "stack" spreads out…
  - Single indicates it's the 2nd stage rocket body

```
STARLINK-G4-26 STACK
1 72000C 22097A   22222.10427778  .00079168  00000+0  13040-3 0    09
2 72000  53.2190 249.4977 0077526  44.7868  32.1202 15.96675264    19
```

This is the Two-Line Element Portion

- How to read TLEs →

Orbit modeling: What’s in a TLE???

```
STARLINK-G4-26 STACK
1 72000C 22097A  22222.10427778  .00079168  00000+0  13040-3 0    09
```

01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1		2	5	5	4	4	U		9	8	0	6	7	A				0	8	2	6	4	.	5	1	7	8	2	5	2	8		-	.
1		2					3		4		5			6				7		8													9	

36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69
0	0	0	0	2	1	8	2			0	0	0	0	0	-	0		-	1	1	6	0	6	-	4		0			2	9	2	7
									10									11									12		13				14

Field	Columns	Content	Example
1	01	Line number	1
2	03–07	Satellite catalog number	25544
3	08	Classification (U: unclassified, C: classified, S: secret) [12]	U
4	10–11	International Designator (last two digits of launch year)	98
5	12–14	International Designator (launch number of the year)	067
6	15–17	International Designator (piece of the launch)	A
7	19–20	Epoch year (last two digits of year)	08
8	21–32	Epoch (day of the year and fractional portion of the day)	264.51782528
9	34–43	First derivative of mean motion; the ballistic coefficient [13]	-.00002182
10	45–52	Second derivative of mean motion (decimal point assumed) [13]	00000-0
11	54–61	*B**, the drag term, or radiation pressure coefficient (decimal point assumed) [13]	-11606-4
12	63–63	Ephemeris type (always zero; only used in undistributed TLE data) [14]	0
13	65–68	Element set number. Incremented when a new TLE is generated for this object.[13]	292
14	69	Checksum (modulo 10)	7

Prior to launch, this is the anticipated launch year and UTC day number fraction. If the launch is scrubbed… (yah, this happens… A LOT!) Then this will be updated!

https://en.wikipedia.org/wiki/Two-line_element_set

Case Study: MUFON case #124190

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Flight Track Log - Related Links

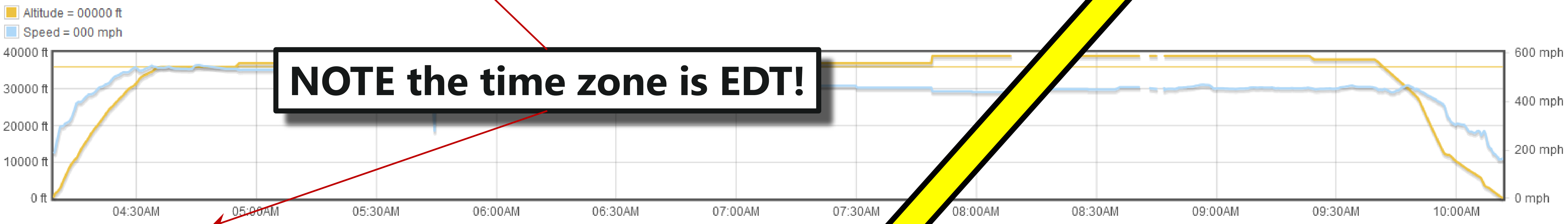
- Live Flight Tracker (ACA536)
- Flight ✈ ACA536 29-Mar-2024 (OGG / PHOG-CYVR)

Google EARTH

Data can now be copied into an Excel Spreadsheet

Times and Time Zones

All times are in EDT time to prevent confusion due to time zone crossing. See the ACA536 flight status page for this flight to view local times or setup timezone preferences in your user account.



NOTE the time zone is EDT!

Time (EDT)	Latitude	Longitude	Course	kts	mph	feet	Rate	Reporting Facility
Sat 04:09:17 AM **Departure (OGG) @ Friday 10:09:17 PM HST**								FlightAware ADS-B (OGG / PHOG)
Sat 04:09:17 AM	20.9080	-156.4226	↗ 34°	162	186	250		FlightAware ADS-B (OGG / PHOG)
Sat 04:09:33 AM	20.9182	-156.4164	↑ 21°	163	188	1,075	2,206 ↑	FlightAware ADS-B (OGG / PHOG)
Sat 04:09:51 AM	20.9340	-156.4134	↑ 6°	185	213	1,500	1,191 ↑	FlightAware ADS-B (OGG / PHOG)
Sat 04:10:07 AM	20.9483	-156.4123	↑ 4°	204	235	1,750	1,031 ↑	FlightAware ADS-B (OGG / PHOG)

Case Study: MUFON case #124190

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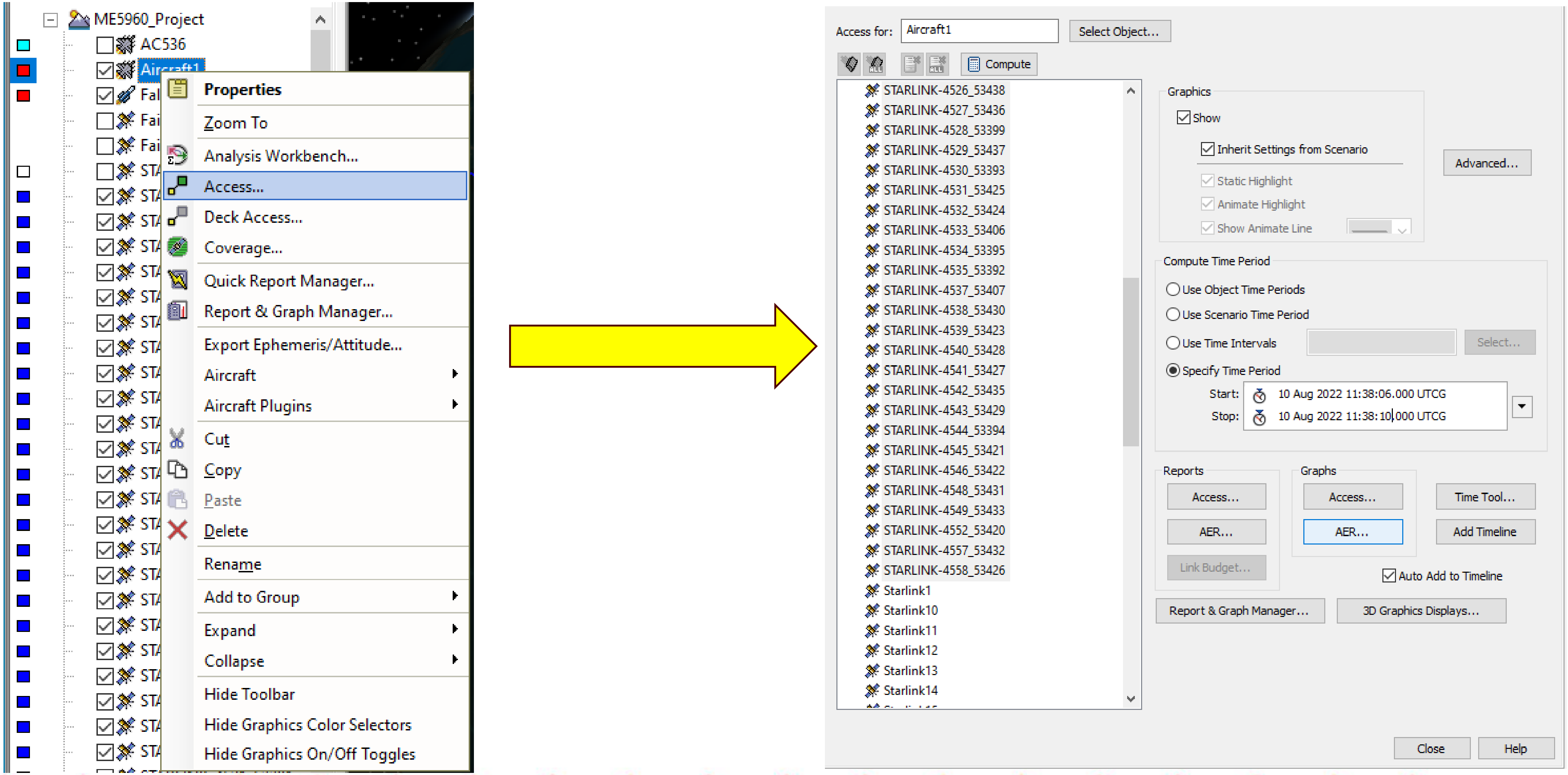
- ADS-B data provided by SCU's Science Advisor, Dr. Sarah Little
  - Dr. Little used a FlightRadar24 Gold account, that provides 1yr of historical data
  - Note that the data is in UTC
  - While scrolling down, and expanding the "Position" column

	A	B	C	D	E	F	G	H	I
136	1.66E+09	2022-08-10T10:35:02Z	ACA536	34.03508,-146.503952	37000	11.2776	499	0.256707556	46
137	**1.66E+09**	**2022-08-10T10:44:22Z**	**ACA536**	**34.94759,-145.31012**	**37000**	**11.2776**	**511**	**0.262880884**	**46**
138	1.66E+09	2022-08-10T10:44:59Z	ACA536	35.004589,-145.240067	37000	11.2776	476	0.244875344	39
139	1.66E+09	2022-08-10T10:54:07Z	ACA536	35.824635,-144.129379	37000	11.2776	468	0.240759792	47
140	1.66E+09	2022-08-10T11:03:40Z	ACA536	36.655186,-142.951508	37000	11.2776	467	0.240245348	48
141	1.66E+09	2022-08-10T11:13:16Z	ACA536	37.485031,-141.738785	37000	11.2776	466	0.239730904	48
142	1.66E+09	2022-08-10T11:41:53Z	ACA536	39.803783,-138.11734	37000	11.2776	449	0.230985356	49
143	1.66E+09	2022-08-10T11:42:13Z	ACA536	39.825115,-138.085541	37000	11.2776	449	0.230985356	37
144	1.66E+09	2022-08-10T11:51:39Z	ACA536	40.77491,-137.149582	37000	11.2776	450	0.2314998	35
145	1.66E+09	2022-08-10T12:01:04Z	ACA536	41.758778,-136.242462	37000	11.2776	447	0.229956468	35
146	1.66E+09	2022-08-10T12:10:48Z	ACA536	42.73772,-135.283798	37000	11.2776	448	0.230470912	36

AC536_2d008340 _alice_rg | geoid_height_2023-08-09 | AC536 | Photo UTCs

Obtaining AER Data From STK



Obtaining AER Data From STK