Memorandum

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To: Dr. A

From: Martin Kamme, Drew Phillippi

Date: October 22, 2019

Subject: AERO 452 GEO Object Rendezvous

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## The Object

After researching various objects, the satellite chosen to rendezvous with and service is Spaceway 3, a communications satellite that was launched in August of 2007. It was chosen because of its almost perfectly circular orbit in GEO, with an eccentricity of 0.0000182°.

## Starting Location & Orbit Descriptions

| **Initial Information for Spaceway 3 (A):** | |
|---|---|
| Eccentricity | 0.0000182° |
| Inclination | 0.0080° |
| RAAN | 115.4157° (2.0144 rad) |
| Argument of Perigee | 75.9974° (1.3264 rad) |
| True Anomaly | 190.4478° (3.3239 rad) |
| Period | 23.94 hrs (86184 s) |
| Initial R Vector | [3.9138, 1.5702, 0] $e^4$ km |

| **Initial Information for Chaser (B):** | |
|---|---|
| Eccentricity | 0.0° |
| Inclination | 0.0° |
| RAAN | 115.4157° (2.0144 rad) |
| Argument of Perigee | 75.9974° (1.3264 rad) |
| True Anomaly | 190.5829° (3.3263 rad) |
| Period | 23.94 hrs (86184 s) |
| Initial R Vector | [3.9101, 1.5795, 0] $e^4$ km |

**Table 1. Initial Conditions**

## Assumptions

Eccentricity of Spaceway 3 = 0
Inclination of Spaceway 3= 0
We have the ability to rendezvous
No perturbations

## Approach Profile

The approach profile consists of four total holds and various hops in between to arrive in the desired locations. All Vbar hold are held at 1.0025 periods to satisfy the requirement of staying in each hold for at least a day. The period of the chosen Target is 23.94 hrs, meaning that holding for one Target period would not satisfy the hold time requirement. Each hold and maneuver will be explained in more detail throughout this report. Refer to Table 1 for an overview of all the maneuvers and holds with their respective $\Delta$Vs and times.

| Maneuvers & Holds | Wait and Hop Time | $\Delta$V Necessary |
|---|---|---|
| 1. Burn in and out of Hop 100 → 40 km | 1 period (23.94 hrs) | 0.464124 m/s |
| 2. Burn into Football Orbit 20-40 km | Instantaneous | 1.4581 m/s |
| 3. Hold Football Orbit 20-40km | 1.5 Periods (35.91 hrs) | 0 m/s |
| 4. Burn out of Football Orbit 20-40 km | Instantaneous | 1.4581 m/s |
| 5. Burn in and out of Hop to $V_{bar}$ hold at 1 km | .5 Periods (11.97 hrs) | 1.4216 m/s |
| 6. Hold $V_{bar}$ at 1 km | 1.0025 Periods (24 hrs) | 0 m/s |
| 7. Burn in and out of Hop to $V_{bar}$ hold at 300 m | .5 Periods (11.97 hrs) | .0255 m/s |
| 8. Hold $V_{bar}$ at 300 m | 1.0025 Periods (24 hrs) | 0 m/s |
| 9. Hop in and out of $R_{bar}$ hold at 20 m | .05 Periods (1.197) hrs | .1418 m/s |
| 10. Hold $R_{bar}$ at 20 m | 1.0025 Periods (24 hrs) | .0276 m/s |
| 11. Hop to Rendezvous | 8.0233 hrs | .0054 m/s |
| 12. Hold Rendezvous | 24 hrs | 0 m/s |
| **TOTAL** | **7.8754 days** | **4.9741 m/s** |

**Table 2. Time and $\Delta$V of all maneuvers and holds**

The chaser begins at a relative distance from the target of 100 km on the $V_{bar}$. The chaser's first maneuver is a hop from 100 km to 40 km. This hop is shown in the CW frame in Figure 1 and in ECI in Figure 2. A zoomed in version is also included in Figure 2 to show the ECI position before and after the hop. The initial and final position of the Target is the same for this hop because the hop is conducted over one period of the Target orbit.

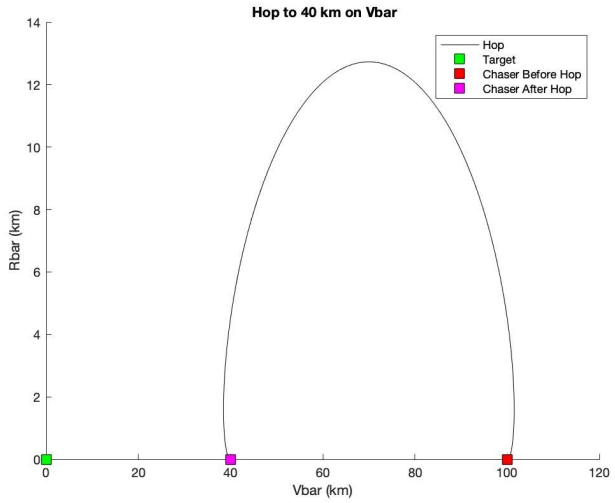


**Figure 1. Hop to 40 km on $V_{bar}$ in CW**

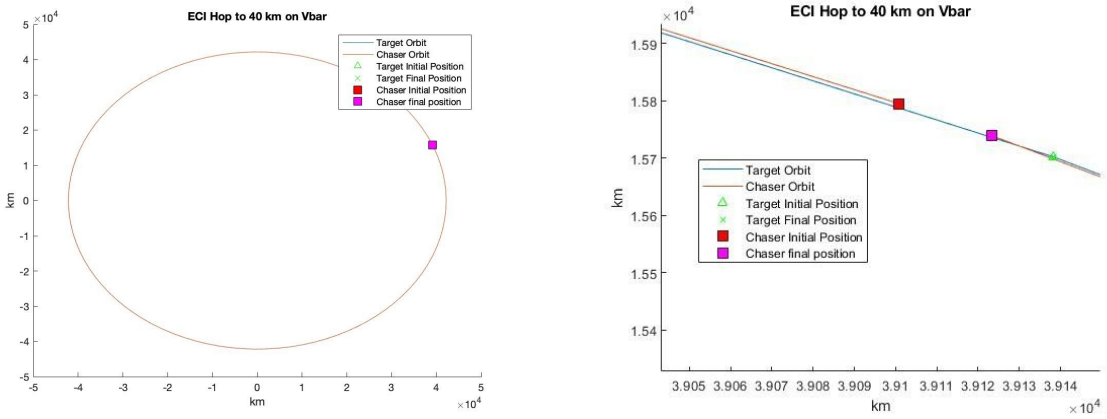


**Figure 2. Hop to 40 km on $V_{bar}$ in ECI**

After hopping to 40 km on the Vbar, the chaser now burns into a football orbit, with a semi-major axis of 40 km and a semi-minor axis of 20 km around Spaceway 3. The chaser orbits around Spaceway 3 for one and a half periods to satisfy the requirement of staying in a hold for at least 24 hours. This means that after the football hold, the Chaser ends up behind the target on the downrange. The football orbit hold is depicted in the CW and ECI frames in Figure 3. It is clear from the ECI plot that the 1.5 period hold means that the Target and Chaser end up on the opposite side of the orbit from where they were before the hold. Figure 4 shows that before the football hold the Chaser is ahead downrange and that after the hold the Chaser is behind the Target on the downrange.

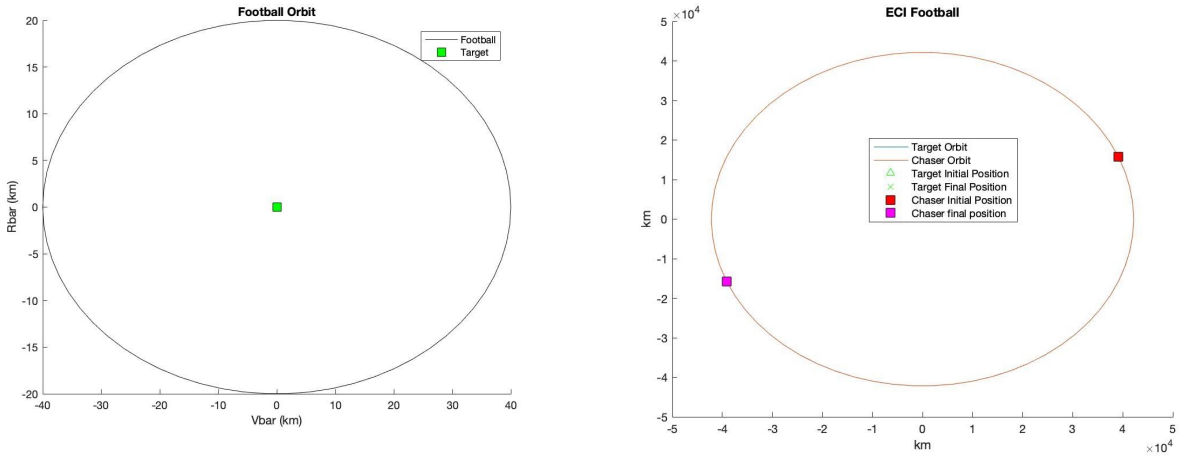


**Figure 3. Football Orbit Hold in CW and ECI**

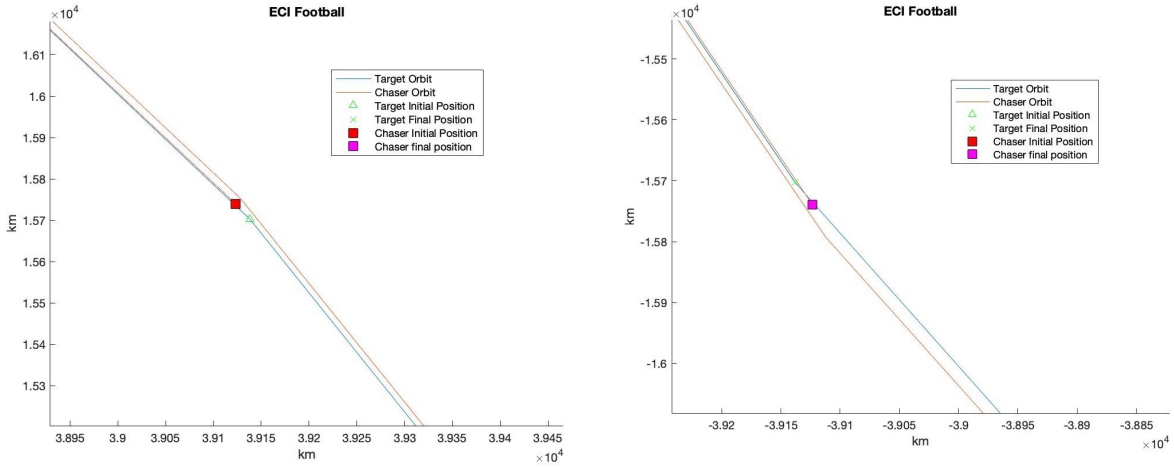


**Figure 4. Football Orbit Hold in ECI zoomed**

The chaser then performs a hop onto a $V_{bar}$ hold at 1 km. Figure 5 shows this hop in CW and ECI. The orbit is not completed in the ECI frame because the hop is completed in half a period. The chaser will then remain in the $V_{bar}$ hold for 1.0025 periods of the target orbit, equating to exactly 24 hours.

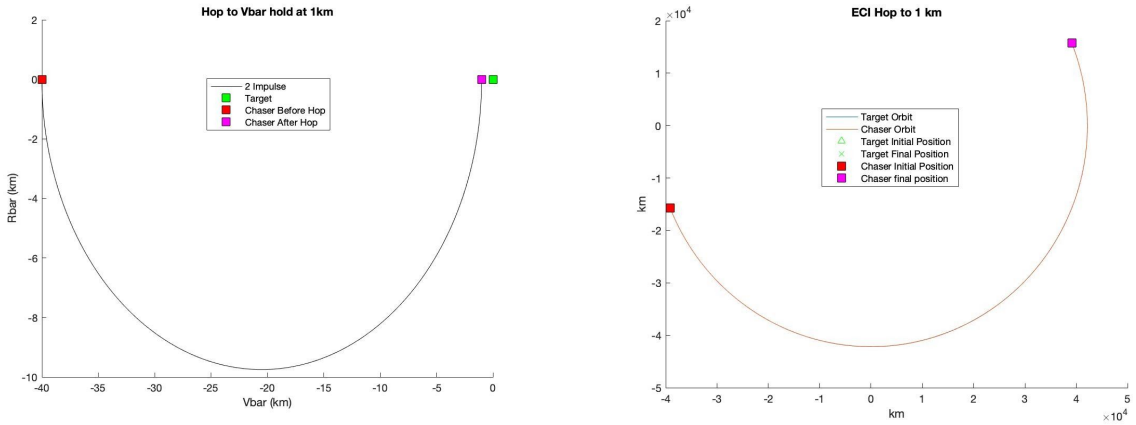


**Figure 5: Hop to $V_{bar}$ Hold at 1 km in CW and ECI**

After holding at 1 km for a day, the chaser will perform a hop onto a $V_{bar}$ hold at 300 m for another 24 hours with no relative velocity.

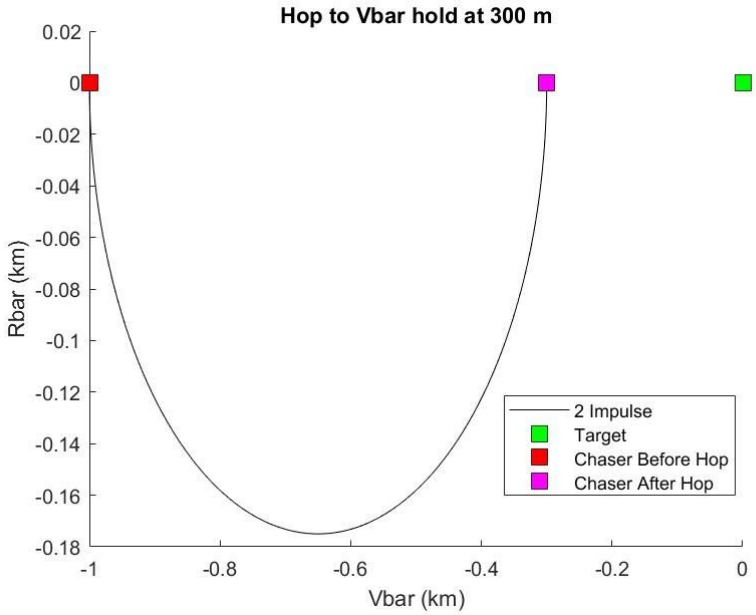


**Figure 6: Hop to $V_{bar}$ Hold at 300 m in CW**

For the final hold, the Chaser burns into an Rbar hold as is shown in Figure 7. Although the $R_{bar}$ approach is typically more $\Delta V$ heavy since it requires a continuous burn, it is used to incorporate a hold on the $R_{bar}$ with a relative distance of 20 m and a relative velocity. Due to such close proximity and the GEO altitude, the $\Delta V$ required is relatively low in this situation.

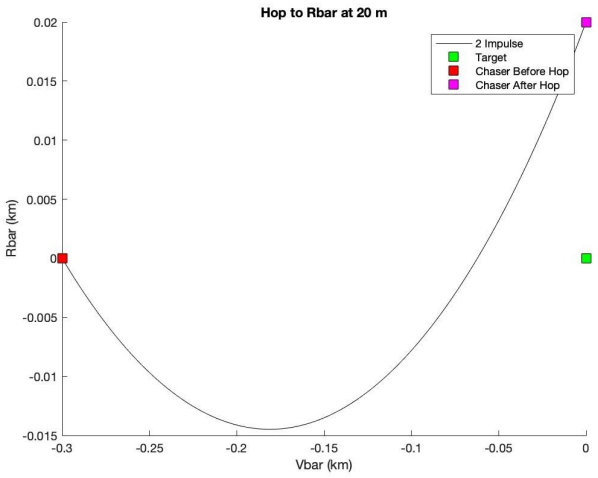


**Figure 7: Hop to $R_{bar}$ Hold at 20m in CW**

With the chaser held at 20 m on the $R_{bar}$ for 24 hrs it finally performs a hop to rendezvous with Spaceway 3 as shown in Figure 8. As an extra component, this hop is brute force optimized by testing different arrival times between 1 second and the period of the target. The Chaser is held at the rendezvous point for 24 hours to complete the mission

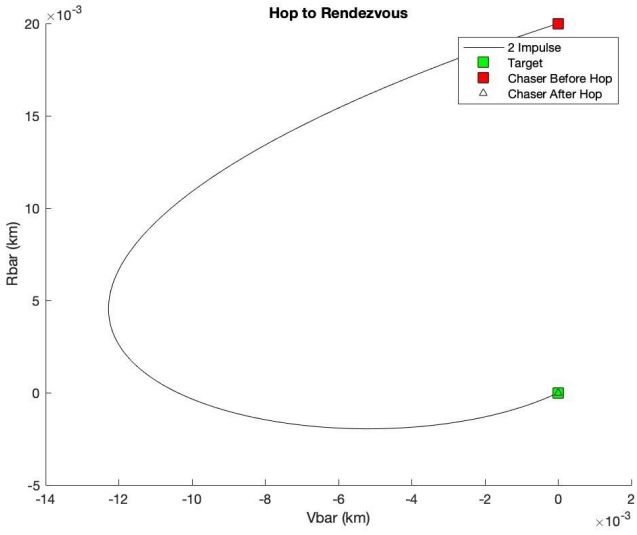


**Figure 8: Hop to Rendezvous in CW**

## Extra

The extra component performed is a forced optimization of the final burn in to rendezvous. To optimize the final hop, the $\Delta V$ is calculated for different arrival times between 1 second and the period of the target. In doing so, the hop from 20 m away on the $R_{bar}$ only requires a $\Delta V$ of 0.0054 m/s.

## Conclusion

In total, the maneuvers performed by the chaser require a $\Delta V$ of 4.9741 m/s, and take place over 7.8754 days (7 days, 21 hours, 0 minutes, and 35 seconds). The chaser holds between 20-40 km in a football orbit for a day and a half, and then holds at 1 km and 300 m on the $V_{bar}$ and finally at 20 m on the $R_{bar}$ for 24 hours each. The chaser performs its final hop to rendezvous with Spaceway 3 after the fourth hold. After this burn, the chaser is assumed to have the necessary means and docking mechanisms in order to mate/berth with Spaceway 3, and holds at rendezvous for another 24 hours.

## References


[1] Koblick, D (2012) ECI2RSW [Function]. https://www.mathworks.com/matlabcentral/fileexchange/39340-vectorized-clohessy-wiltshire-hill-linear-propagation

[2] Koblick, D (2012) CWHPropagator [Function]. https://www.mathworks.com/matlabcentral/fileexchange/39340-vectorized-clohessy-wiltShire-hill-linear-propagation

[3] Koblick, D (2012) Hill2ECI_Vectorized [Function]. https://www.mathworks.com/matlabcentral/fileexchange/39340-vectorized-clohessy-wiltShire-hill-linear-propagation

[4] Koblick, D (2012) ECI2Hill_Vectorized [Function]. https://www.mathworks.com/matlabcentral/fileexchange/39340-vectorized-clohessy-wiltShire-hill-linear-propagation

# Affidavit

**Drew**

- Worked together on choosing the object
- Worked together on stating assumptions
- Worked together on drafting the report
- Coded football orbits used
- ECI conversion from LVLH
- Plotted ECI
- Helped with debugging code

**Martin**

- Worked together on choosing the object
- Worked together on stating assumptions
- Worked together on drafting the report
- Brute force optimized the final rendezvous hop
- 2 impulse calculations
- Plotted LVLH
- Helped with debugging code