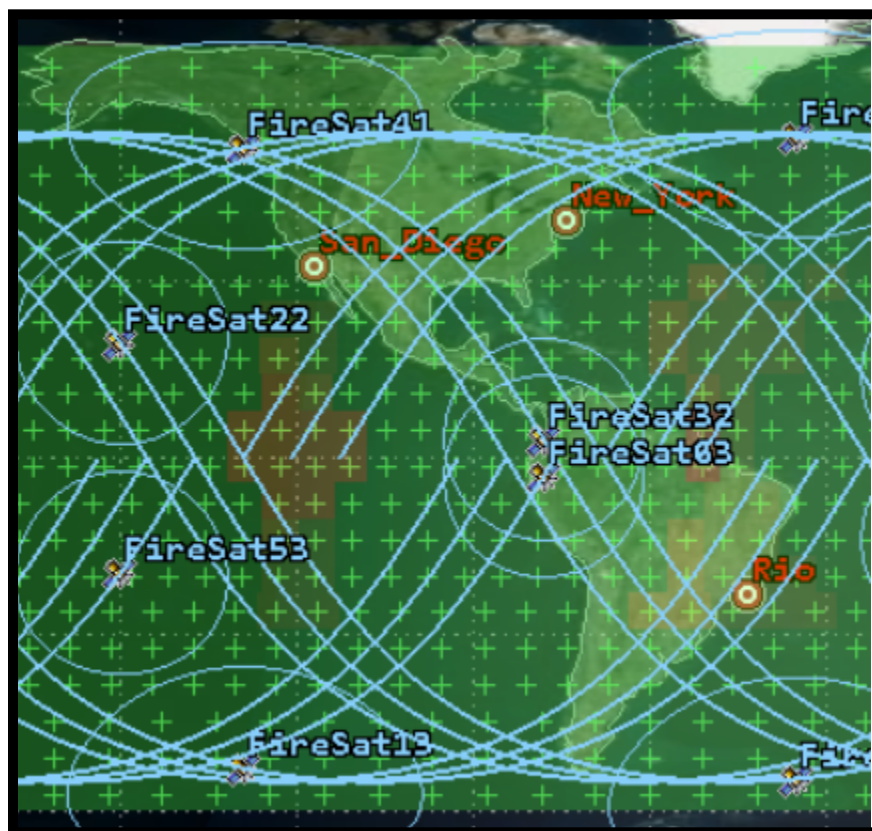


Fire Watch Constellation Technical Proposal



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Course: ME 456 Advanced Astrodynamics
Professor: Dr. Andrew Abraham
Due: 3/28/2025

Intended Recipient:
NOAA, DOI, FEMA, and similar Agencies

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Executive Summary

The Fire Watch Constellation is a 18 satellite, 6 plane Walker constellation with the intent of monitoring the non-polar landmasses of Earth for moderate to severe wild fires. This has practical applications primarily for wild fires but could also prove useful with home fire detection and addressing times. Through the design process, data refresh times of less than 30 minutes have been achieved with a spatial accuracy of less than 50 square meters. We see this design as an opportunity to provide an important resource to fire fighting teams globally at a reasonable cost.

Introduction and Mission Objectives

As climate change continues to increase global temperatures, the risk of wild fires follows suit. Since the start of 2025, California alone has suffered over 450 wildfires resulting in the destruction of ~58 thousand acres of forest land, fatalities of 29 people, and the destruction of over 16 thousand buildings, decreasing the land value alone between \$95 and \$164 billion [2][7][9]. This can also be said for other locations like Hawaii, Australia, and Canada recently, just to name a few [1].

While current satellite imaging for wildfire detection is available, it is often low resolution or unreliable in the speed in which the image updates. For example, the Sentinel-2 mission can detect fires within an incredible 10-20 meter range, but at the cost of only updating every 5 days at its slowest[4]. Similarly missions like the GOES can update data every 5 to 15 minutes, but can only provide a resolution of 2 km [3]. While these are both effective for their own respective purposes, we strive to find a happy middle ground that can provide fast and accurate data for fire control and containment globally.

The goal of this mission is to devise this method of monitoring Earth's surface quickly and precisely for a minimum cost. With current analysis, we have managed to obtain a temporal resolution of < 1 hour at any given observable point and a spatial resolution of $< 100 \text{ m}^2$. To help fund this project, we hope to obtain global investment or partnership from foreign world powers to help every country maintain fire safety for their citizens. Beyond simply detecting and warning of forest fires, we believe that the data recorded by these satellites will provide highly useful information on predicting the behaviors of future wild fires, leading to more efficient containment. We plan to accomplish all of this through creating a LEO satellite constellation system that implements high detail infrared imaging to accurately uncover the position and intensity of fires within our scope.

System Architecture

Constellation Design

The constellation formation we chose is a 18/6/1 Walker-Delta with an inclination of 55° and an altitude of 650 km as seen in Figure 1. This formation puts our satellites in the ideal range to view all of the non-polar regions of Earth. The intent of this is to monitor the regions of highest fire risk while also keeping response time fast. The chosen altitude was picked to maintain a certain level of spatial resolution that only a LEO orbit can offer, and to promote faster refresh times with an orbital period of just under 100 minutes. Similarly the 6 orbital planes, with 3 satellites per plane, were picked to maintain quick and even distribution of satellites across our desired region.

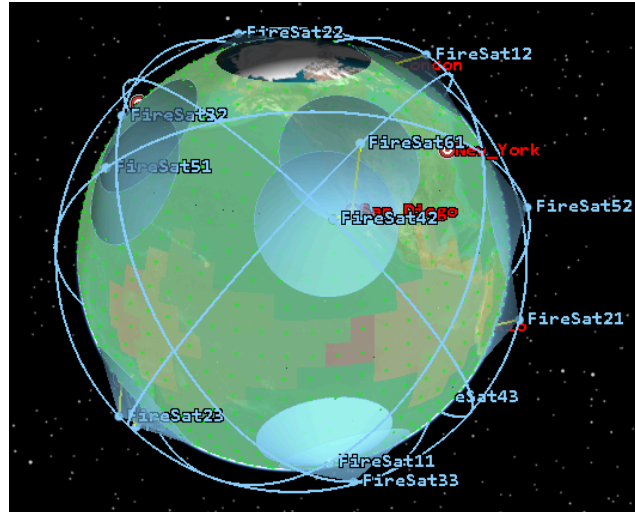


Figure 1

Satellite Design

Each Fire Watch satellite will have a dry mass of approximately 500 kg, with about 270 kg of that being dedicated to a high resolution, multi-spectral, infrared imager [5]. With fuel included, the total payload mass of each Fire Watch sat will be approximately 630 kg, offering ~500 m/s of delta V in the form of hydrazine monopropellant. With expected fuel consumption from the initial orbital alignment, station keeping, and disposal maneuver, we expect the lifetime of this system to be between 15 and 20 years.

Infrared Imager

The infrared imager on board each satellite will be approximately 1.4 m x 1.5 m x 0.9 m in volume [5]. The imaging capabilities are expected to produce a spatial resolution of just under 50 m x 50 m. At the altitude of 650 km from Earth's surface, a FOV angle of 63.5 degrees is offered, providing a swath width of ~1100 km. This imager was selected due to its capability for high precision, ability to penetrate smoke and clouds, and its ability to read between temperature ranges to discern active flames from residual smoldering fires [5].

Ground Stations and Data Transmission

For ground stationing and data transmission, we plan to utilize the networking services of Leaf Space. Leaf Space utilizes 27 ground stations globally to provide TT&C as well as data payload transmission to commercial satellites with near zero latency in LEO [20]. For our mission, we would primarily utilize their Ka band frequency for transmitting our high accuracy data quickly. Additionally, we plan to use a lossless compression format called GeoTIFF to compress our data packages to maintain speed and cost while retaining the data's usefulness and accuracy. In terms of hardware, we plan to include a small on-board processing device to detect, alert, and begin transmission when a moderate to major surface temperature change is detected. This will obviously come at the cost of weight and power but will save on what would be constant, higher volume communication costs.

Launch Strategy

For our purposes of implementing the Fire Watch system, we plan to take advantage of Araines's launch vehicle service, particularly, their Vega C rocket [21]. With 18 satellites planned and 6 planes to cover, utilizing this method of launch will save millions of dollars compared to outright purchasing launch vehicles. The Vega C vehicle can deploy our satellites at the proper altitude and inclination to the accuracy of ± 15 km and ± 0.15 degrees respectively [22]. This injection accuracy affords us the ability to have more delta V reserved for prolonging the mission. Additionally, with the Vega C's payload capacity of ~ 3000 kg to LEO, we can launch each plane at a time easily [22]. As for deciding against decreasing satellite size and going with smaller capacity rockets for launch, attempting to decrease the overall satellite size would require lowering the IR sensor dimensions and weight. Doing this would decrease pixel availability, which would in turn sacrifice spatial precision for our particular constellation setup. To counteract this, more satellites and more planes would be required to meet our mission needs which is indeed a viable solution, however to minimize satellite manufacturing cost and mission complexity, as well as maximize initial system lifetime, data accuracy, and instrument capabilities we decided for larger satellites, requiring medium scale launch vehicles. A similar example of this can be seen in the plans for the final performance of the OroraTech fire detection satellite system. While they also plan to receive 30 minutes or less response time, they will require nearly 100 satellites, ~ 12 planes meaning more launch vehicles, an altitude of ~ 550 km to maintain resolution, meaning more fuel cost per year and/or lower overall lifespans, and more frequent satellite replacement[25].

Expected Performance Metrics

As stated previously, each satellite will have a high resolution infrared observation device with a pixel size to cover a plot of land just ~ 46 m by 46 m. This combined with an orbital period of ~ 97 minutes offers great results within the 18/6/1 Walker constellation. As depicted in Figure 2, the coverage definition proves that under the planned Fire Watch constellation configuration, gap times are under 20 minutes $\sim 95\%$ of the time, with nearly 0% over 25 minutes within the entirety of our scope. This gives us tremendous global coverage of wildfire hotspots, with a temporal resolution high enough to detect, warn, and monitor the spread of fast moving forest fires.

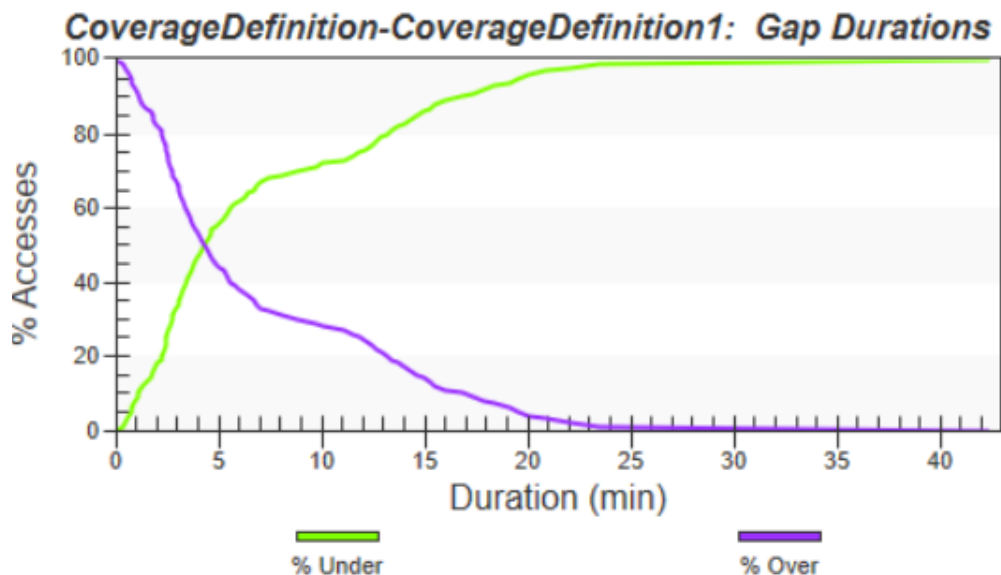
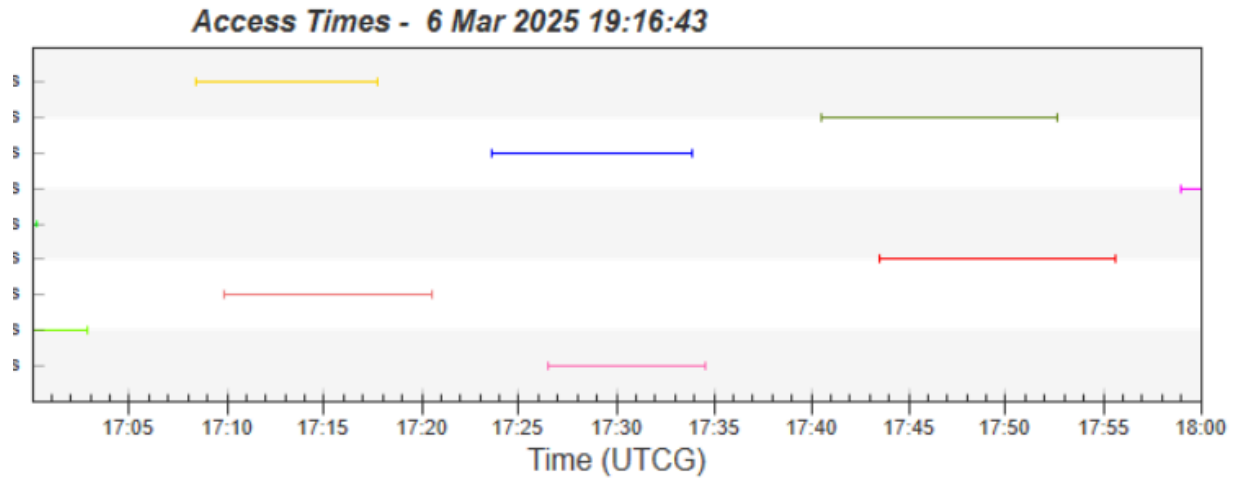


Figure 2

To get an idea of how this coverage affects specific locations, we pinpointed San Diego, CA. As can be seen in Figure 3, San Diego has nearly constant coverage with often two simultaneous points of access. There can be seen dead zones within the access graph, however they tend to be less than 5 minutes in interval at a time which still far exceeds the mission requirements. This figure displays a short snippet of time, being only about 1 hour, however, similar data applies for all points in time for this location. This can be seen in Appendix Figure 1. Similarly, equivalent data can be found globally, with some of the larger access gaps being localized around the equator, however, still within the acceptable range of data collection.

**Figure 3**

Timeline:

Phase	Expected Duration
Concept Exploration	6 to 12 months
Risk Reduction/Technology Development	6-12 months
Detailed Design Development	12 months
Production	12-24 months
Launch	Every 4 months, 24 months
TOTAL	5-7 years

[5]

From the planning stage to final product, we expect an approximate 5-7 year execution time. This is based on similar missions and the expected difficulty and scale of this project. Based on our expected delta v expenditure per year, $\sim 13 \text{ m/s}^*$ (but we will assume closer to 17 m/s for the worst case) due to station keeping maneuvers, we expect a mission life of between 15 and 20 years. This delta V value was calculated using the maximum perturbation setting for standard GMAT and a simple Matlab script shown in Appendix Figure 2. Upon the conclusion of this mission, we plan to initiate a final disposal maneuver that will use up approximately 120 m/s of delta v [5]. This maneuver will lower our perigee to $\sim 250 \text{ km}$ which will result in an orbital decay ending with full satellite reentry within ~ 150 days [5].

Budget & Cost Analysis

Overall Cost - Full Constellation

Category	Cost Estimate in Millions of USD
Satellite Manufacturing	~40/satellite, 640 total*
Launch Cost	288 , 48 per launch [17]
Ground Stations & Communication	180, 9/ year [19]
Operations	200, 10/year [5]
Licensing	2 [6][11]
Contingency 20%	262
Total	1572

*Based on the similar production of the COSMO-SKYMED satellite [10].

Single Plane Option

As an additional option opposed to just outright purchasing the entire constellation at once, we offer an analysis of the performance of a single plane Fire Watch constellation. Just one plane would cost about \$48 million in initial launching fees, \$120 million for the construction of the satellites, \$~50 million for communication, maintenance, and licensing, and with a 20% margin, the total cost for one plane would be ~\$262 million. Figure 4 shows the average gap duration exceeds 30 minutes ~10% of the time, with some wait times being as high as ~13 hours. Figures 5 and 6 support this data by highlighting that access times. During the periods of access, data refresh rates are fairly high, and somewhat similar to the full constellation, with the downside of large blind zones creating several hour long stretches of no access. While this method does not provide consistent coverage, it does provide useful data in a realistic time window using one sixth of the launch vehicles and satellites. This makes this a very useful option when discussing budgeting or trial running this system.

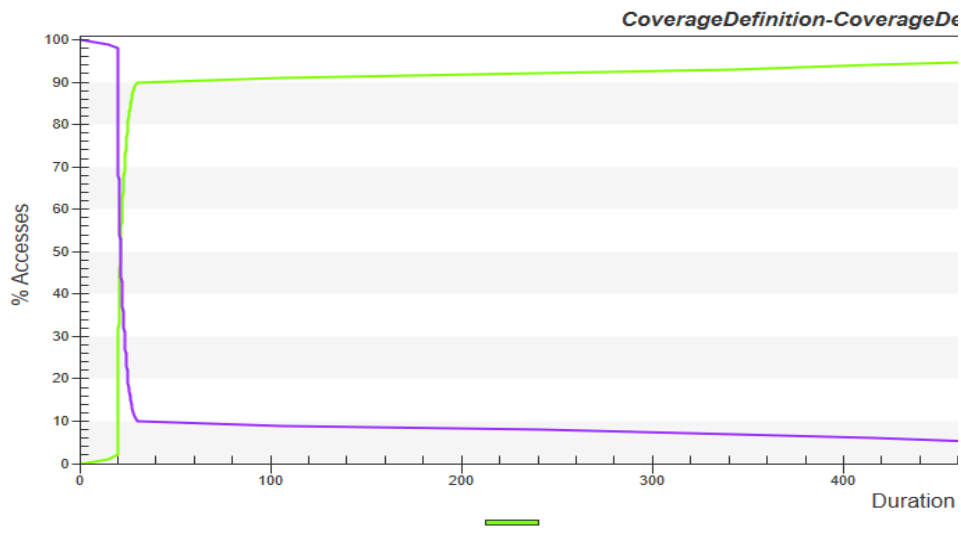


Figure 4

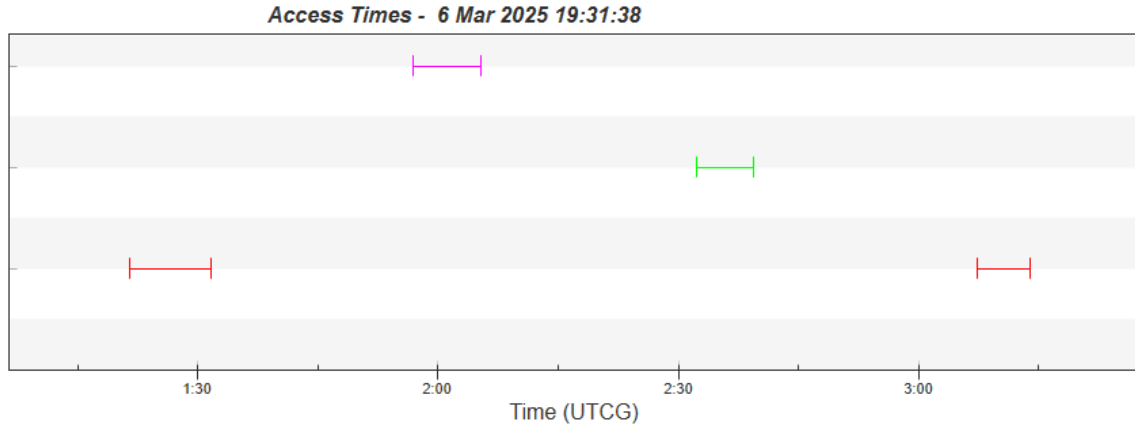


Figure 5

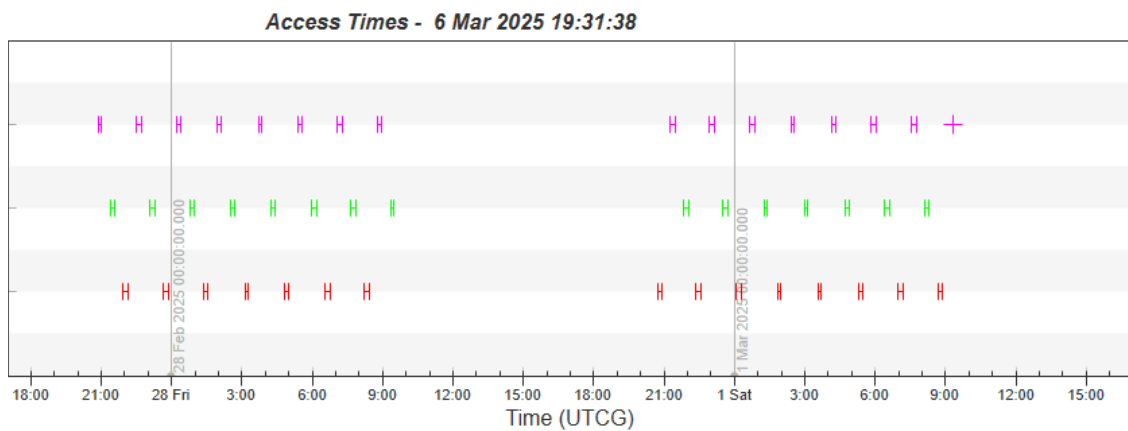


Figure 6

Potential ROI

Only counting the recent fires in Southern California as of this year, 2025, between \$95 and 164 billion dollars were lost in terms of property and capital, with only \$75 billion being insured[7][9]. Assuming this system can only help address forest fires 1% faster, of the low end \$20 billion, the United States/California alone poses to save itself ~\$200 million assuming no more damage from wildfires for the rest of the year. Obviously this has been a particularly hard year for wildfires, however wildfire rates continue to increase or remain consistent in recent history meaning there is still plenty of opportunity to help mitigate future disasters. With this as our potential return, we would propose an expected ROI for the United States/California alone of ~7.9 years. Considering the lifetime of the service is expected to be between 15 years and 20 years, as well as the fact that this is a low end estimate in terms of savings, this is truly something to consider. Additionally, as was designed, offering this service to other countries for a fee, or reducing costs by sharing this program with foreign space agencies would be another excellent way of recouping costs associated with this project considering countries like Canada and Australia both have had intense recent wildfires and have collaborated on missions like Landsat with the US. Canada is even planning on investing in a similar project to meet their current wildfire needs and potentially having a robust joint venture option would be something of interest for them [23]. Similar interest can also be found in countries like Brazil and Australia. Brazil in particular currently relies on American satellites to detect and address fires within the Amazon rainforest regions, so the potential for investment in this

project is great[24]. Particular US federal agencies of interest for purchasing this project would be NOAA, the DOI, and FEMA, however, even a state like California itself could afford a mission like the Fire Watch constellation with their yearly budget of around ~4 billion dollars dedicated to the support of their Nation Resource Agency's Department of Forestry and Fire Protection alone[18].

Licensing and Regulation

The completion of this mission will require several forms of licensing, including:

- Remote Sensing License through NOAA [8]
 - In order to distribute wildfire information outside of the US, even federally controlled satellites are required to adhere to this licensing.
- FCC Space Station Licensing [11]
 - To secure private communication frequencies between the Fire Watch satellites and its ground stations.
- FCC Form 312 and Schedule B, Earth Station Licensing [6]
 - To secure private communication frequencies between the Fire Watch satellites and its ground stations.
- DSP-5 License through ITAR [12]
 - For international export of remote sensing data abroad with potential for defense and national security risks
- Specific Export License for ECCN : 9D003 [Aerospace,Software,Technical Data] for EAR compliance through the BIS[13][14]
 - For international export of remote sensing data abroad for non military use.

NOTE: Partnering with other countries to provide global access to this data will likely require additional licensing in each country as adopted.

Mission Challenges

One potential challenge we see with this mission's formation is that the regions of slowest response rate (still typically under 25 minutes) are located directly around the equator, leaving regions like northern South America, central Africa, and Southeast Asia in zones of lower response rate within the warmer regions of the world, leaving locations like the Amazon rain forest in a more vulnerable position. If faster response times are required and demanded by those regions, additional planes of satellites can be positioned to decrease response times.

Another potential challenge could be found in the response from foreign powers to this mission. There is a chance that with global economic tensions rising, foreign countries will not be willing to help invest in this project, leading to a higher burden on the United States or the state of California to fund this campaign. Within that realm, a system that detects large fires would detect other space mission launches, which might create hesitancy to invest in a shared information network. Obviously, licensing and filtering can apply to deal with this issue but it is a consideration. That being said, with missions like the COSMO-SKYMED and FORMOSAT-3 in recent history where the United States recently collaborated with Italy and Taiwan respectively, as well as other countries like Canada actively pursuing this type of technology, risk of not finding any foreign investment is relatively low, especially with the current rates of wildfires globally[10][22][23].

Appendix

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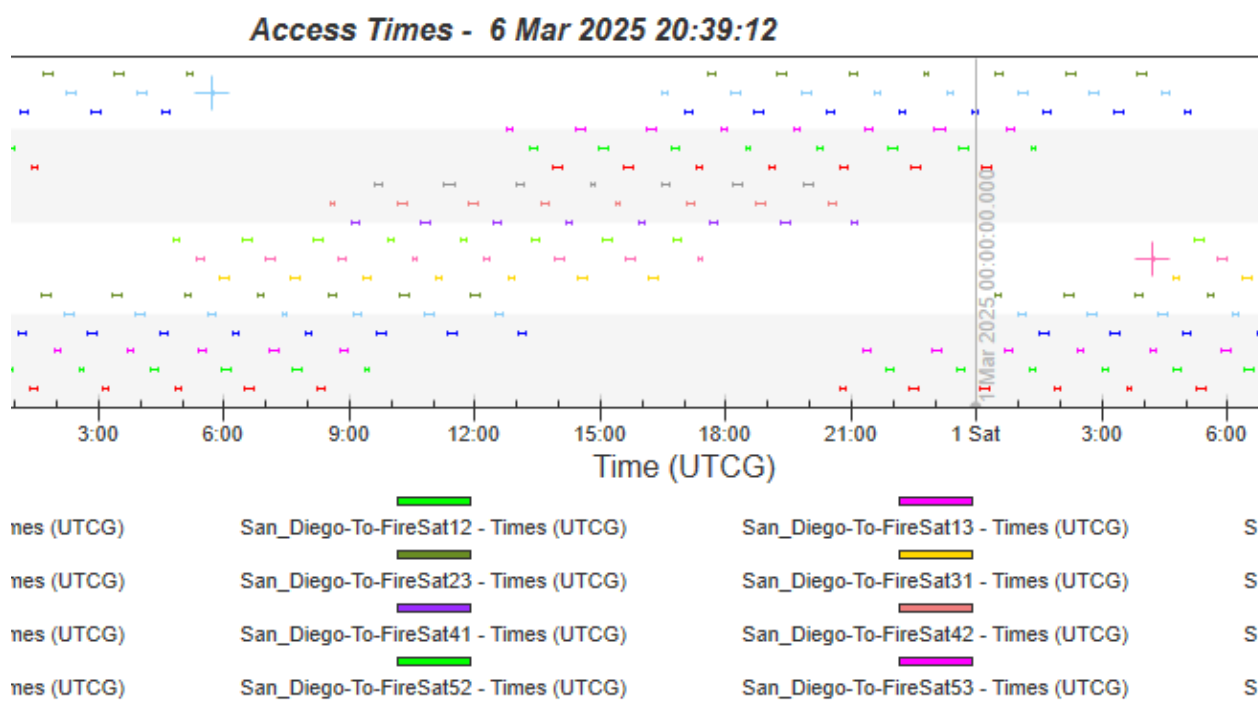


Figure 1

```

5      mu = 3.986e14; % (m^3/s^2)
6      r_Earth = 6378e3; % m
7      h = 650e3; % m
8      a = r_Earth + h; % m
9      r_1year = 7014e3; % m
10     a1 = r_1year; % m
11     at = (a1 + a) / 2; % m
12     Isp_hydra=220;
13     m=715;%kg
14     g0=9.81;%9.81
15
16     v_initial = sqrt(mu / a); % m/s
17     v_transfer = sqrt(mu * (2/a - 1/at)); %m/s
18     v_final = sqrt(mu / a1); % m/s
19     v_transfer2 = sqrt(mu * (2/a1 - 1/at)); % m/s
20
21     dv1 = v_transfer - v_initial; % m/s
22     dv2 = v_final - v_transfer2; %m/s
23     total_dv = abs(dv1) + abs(dv2); % m/s
24     v = sqrt(mu / a);
25     di=55-54.95939655190781;
26     di_per_year = di * (pi/180);
27     dV_inclination = 2 * v * sin(di_per_year / 2);
28
29     dV_total = total_dv + dV_inclination;
30
31     m_prop = m * (1 - exp(-dV_total / (Isp_hydra * g0)));

```

Command Window

```

ΔV due to drag per year: 7.512 m/s
ΔV due to inclination drift per year: 5.337 m/s
Total ΔV required per year: 12.849 m/s/year
Total Δm required per year: 4.244 kg/year
>>

```

Figure 2