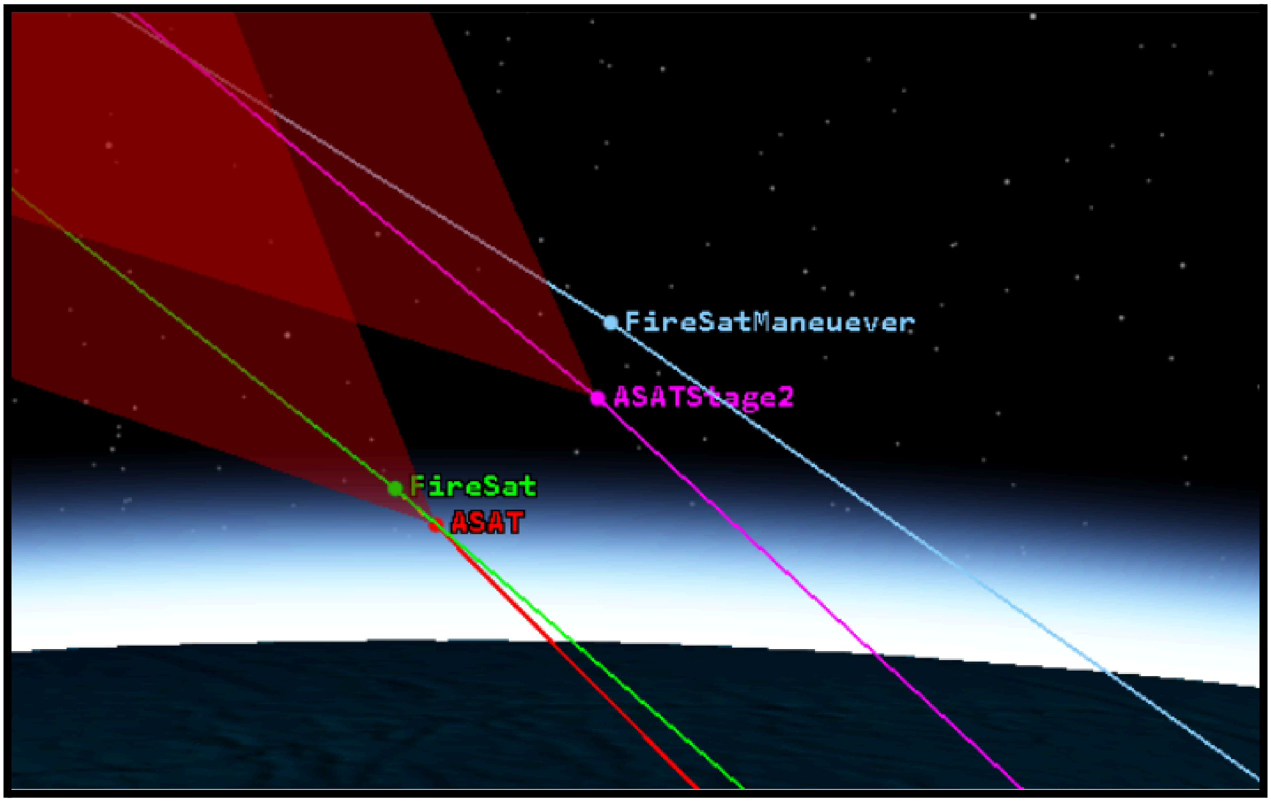
Project 3
Constellation Conflict
Defensive Analysis



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Representing Madagascar

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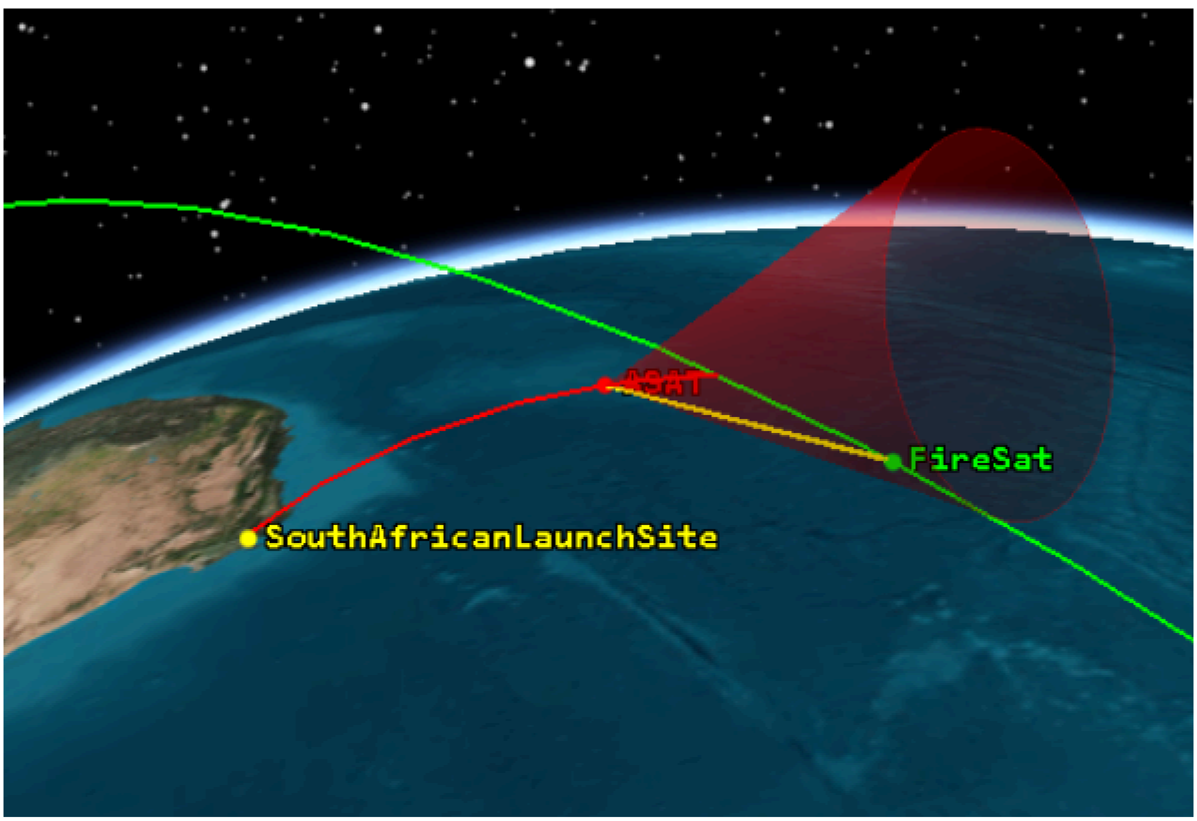
Abstract
As tensions continue to rise between the governments of Madagascar and South Africa due to threats of firebombing and destroying our wildfire detection satellite constellation with the intent of hindering our control of the damage, we are inclined to return with equivalent defensive measures. As representatives of the Firebomb Defense Organization of the country of Madagascar, we would like to analyze the incoming ASAT attacks, develop a automatic maneuver that will be triggered upon knowledge of incoming KKV, compare this to the available delta V budget, and use this data to predict a reasonable drawdown curve reflecting the adversary's successful removal of our Fire Watch satellites, or FWSs, to access the situation our country faces.

Introduction
Due to recent threats of firebombings from the country of South Africa, we have developed a procedure to be used in the event KKV ASATs are deployed against our fire detection and control constellation, Fire Watch. To develop this procedure, we have made agreements with our ally, France, to give our ground control stations early warning for unexpected launches coming out of South Africa. Their active warning constellation with the capability to notify us of launches is relatively low resolution but will provide us with accurate launch time and relative launch location for any incoming ASATs, allowing us to engage the maneuver to nearby FWSs. To find realistic data for this assessment, we designed the evasive maneuver situation to mimic the apparent capabilities of the Indian ASAT for Mission Shakti.



Example Fire Watch Satellite Targeted by KKV

Repeatable Maneuver Analysis

For this conflict, we have set out to design a repeatable maneuver to be engaged upon detection of incoming ASAT with the intent of defeating its max divert distance upon making IR visual contact. To develop this maneuver, several key variables must be addressed or determined:

Knowns:

- Each Fire Watch satellite:[1]
  - Has a mass of 630 kg
  - Holds 500 m/s worth of fuel
  - Reserves at least 120 m/s of delta V for its disposal orbit
  - Utilizes low thrust, hydrazine attitude adjustment for stationkeeping and in this case, maneuvering, ~25 N[2]

Assumptions:

- ASAT has ~80 seconds to adjust course using a finite burn[3]
- ASAT and original FWS orbits are approximately coplanar and opposing[4]
- Utilizing ally detection and warning resources, evasive maneuvers can be achieved ~2 minutes from launch[5]
- KKV launch to intercept time lasts ~5 minutes[3]
- KKV has a total mass of 100 kg[6]
- KKV has hydrazine terminal guidance thrusters with an approximate total thrust of 1000 N[7]

Preliminary Maneuver Specifications

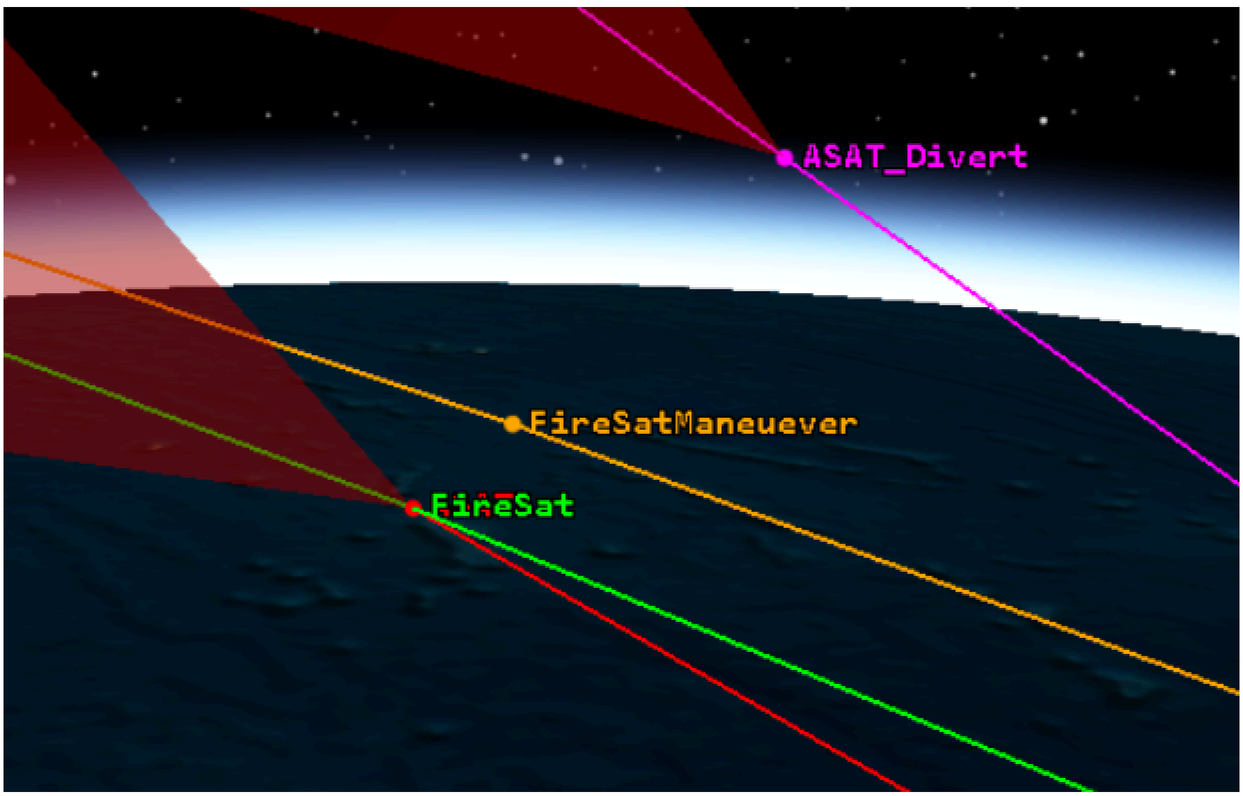
To undergo the largest distance departure from its predicted path, the FWS must burn along the following unit vector directions relative to the center of the satellite, along its velocity vector[8]:

- X (Velocity Direction):0.57735
- Y(Normal to Velocity Direction): 0.57735
- Z(Co-Normal to Velocity Direction): 0.57735

[1] All Fire Watch satellites knowns are detailed in Project 1: Fire Watch Constellation Proposal[1]
[2] Based on Ariane Group's Monopropellant Hydrazine Thruster[2]
[3] Observationally determined by The Aerospace Corporation's "Indian ASAT Demonstration video on Youtube, timestamp: 1:48-206 [3]
[4] Determined through analysis of available resources on the Shakti Mission [3][4][5]
[5] Approximated reasonable time allowance for imaginary scenario allowing for maneuver
[6] Approximation taken from The Aerospace Corporation's "EVALUATION OF THE 27 MARCH 2019 INDIAN ASAT DEMONSTRATION" due to its extremely high accuracy analysis[5]
[7] Approximated through assumed mass and visual capability demonstrated in an American missile defense KKV Youtube video showing a KKV capable of at least enough thrust to defy gravity[6]
[8] Determined using STK's optimization feature, searching for the vector direction of greatest departure distance from predicted satellite position at calculated impact time

Preliminary Analysis

Following our assumptions for a realistic scenario, we would like to access the capabilities and options for our FWSs. In the image below, the green line and point indicate the FED's original path and position, the red showing the original ASAT trajectory, the orange point indicates the max divert capability under the previous assumptions of the FWS, and the pink point is the max divert capability of the ASAT KKV. Unfortunately, this clearly shows that under the initial assumptions, the Fire Watch constellation would not be able to defeat the max divert capabilities of the South African KKV by a very large margin. Each FWS is capable of diverting ~8.36 km from its predicted path in the time provided whereas the ASAT is capable of diverting 32 km from its original target location after detecting its target. While this is far from ideal, the FWSs were not designed for high speed maneuvers, so an outcome along these lines was to be expected.

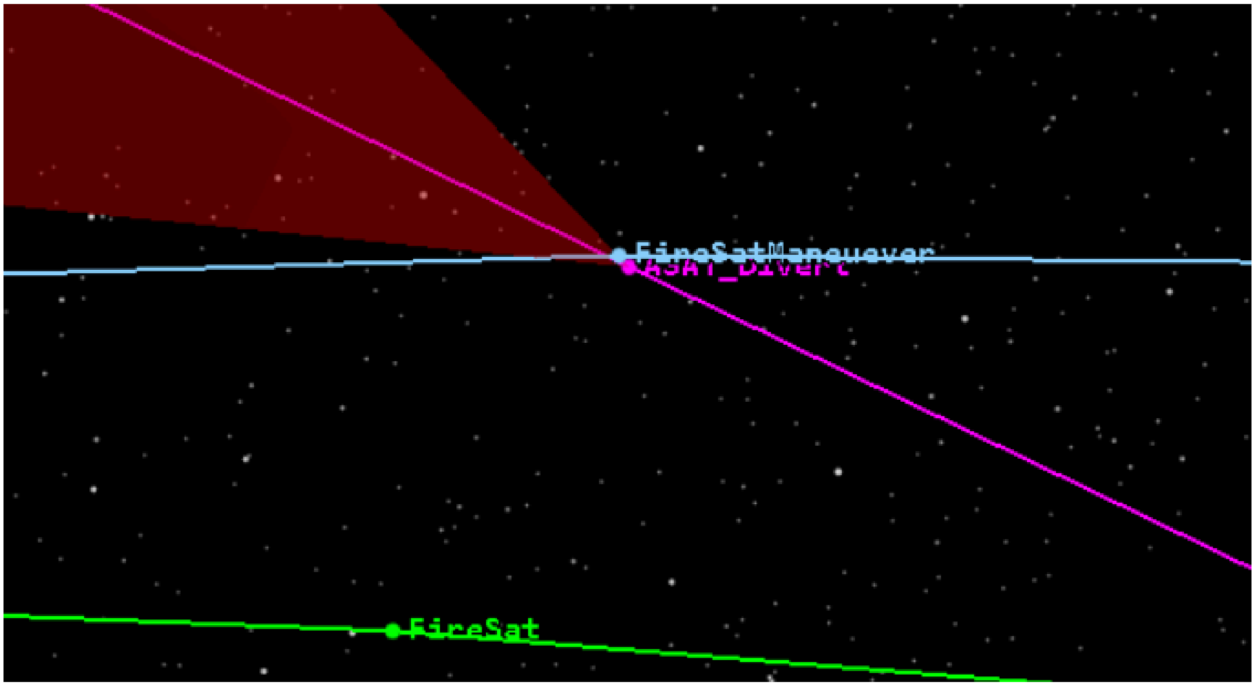


Initial Assumptions Analysis

Despite the seeming impossibility of avoiding the KKV, other options must first be explored before deciding on whether an immediate, full deorbit order is enacted on the Fire Watch constellation.

Warning Time Analysis:

Under the possibility of predicting the ASAT before its launch, with a total lead time of 6.5 minutes from impact, a 125 m/s maneuver can be performed, allowing for a very small margin of distance between the FWS and the KKV at time of closest pass, ~0.5 km. The method by which this lead time can be received or if it is possible would have to be determined outside of the scope of this analysis, however, it is a strong option to consider if the condition is met. This current solution is obviously for minimum time for reasonable delta V, however if a situation arises where we can predict launches far in the future, we could alter this design to be far more fuel efficient and with larger avoidance distances for safety.



Fire Watch Satellite Narrowly Avoiding ASAT with 6.5 Minute Reaction Time

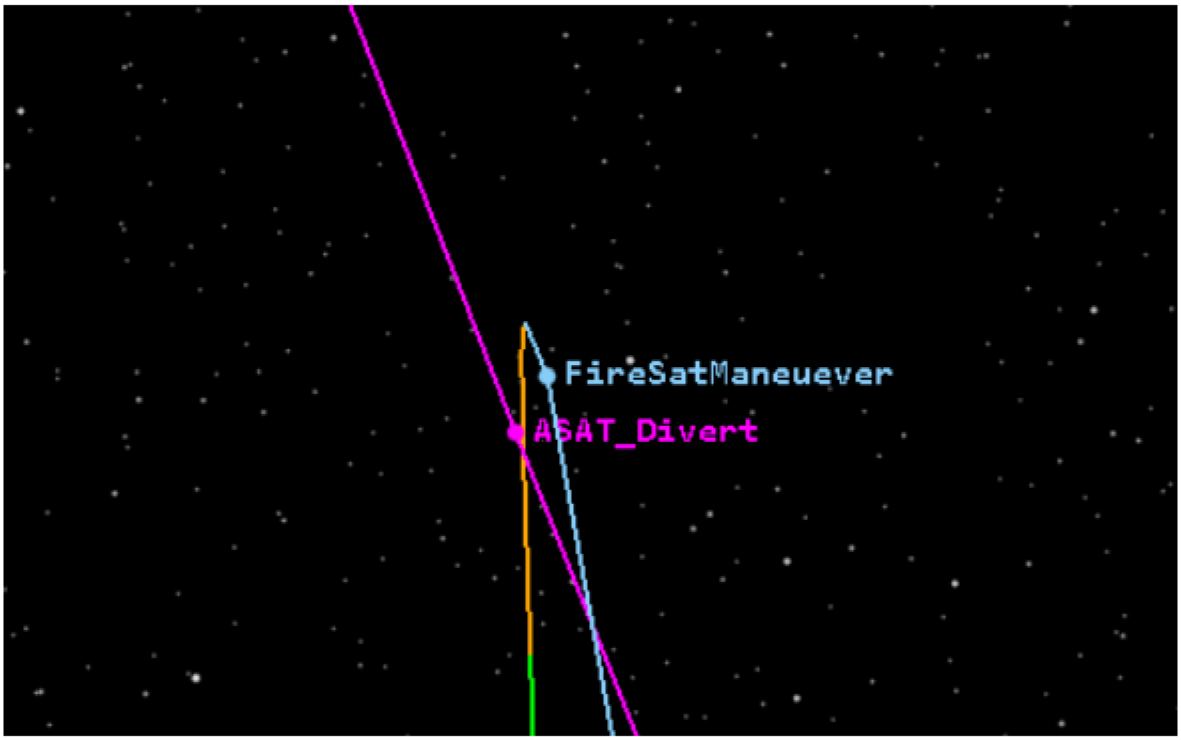
Changing Assumptions:

Due to the current impossibility of predicting launches far in advance, to potentially avoid the disasters of this assault, ranging from the lives at risk due fires as a result of the future bombings, to the loss of millions of dollars invested in this constellation, to the potential for huge amounts of space debris created in the destruction of each FWS, it is of utmost importance to attempt evasive action despite the current circumstances. Therefore for continued analysis, two major assumptions will be made:

- The KKV only has a lower level of thrust capability at ~500 N
- By straining resources with France and enacting a maneuver before properly identifying the threat, we can manage a response time of ~45 seconds from ASAT launch.

Considering the huge cost of high quality ASATs and the quantity of FWSs, it is not unreasonable to assume they cut capability under their own assumption our satellites would be unlikely or unable to maneuver in time, being unaware of our agreement with France. While making these assumptions are not ideal by any stretch, they allow us to move forward with a plan of defense stronger than admitting defeat and preemptively deorbiting our constellation before a conflict has even begun and are based in realistic possibilities. Under these new assumptions, the following maneuver can be performed at the previously stated vector direction:

Time Begun After ASAT launch: 45 seconds
Delta V: 120 m/s
Burn Duration: 265.171 seconds
Clearance Distance Between ASAT and Target at Nearest Point: 1.198384 km



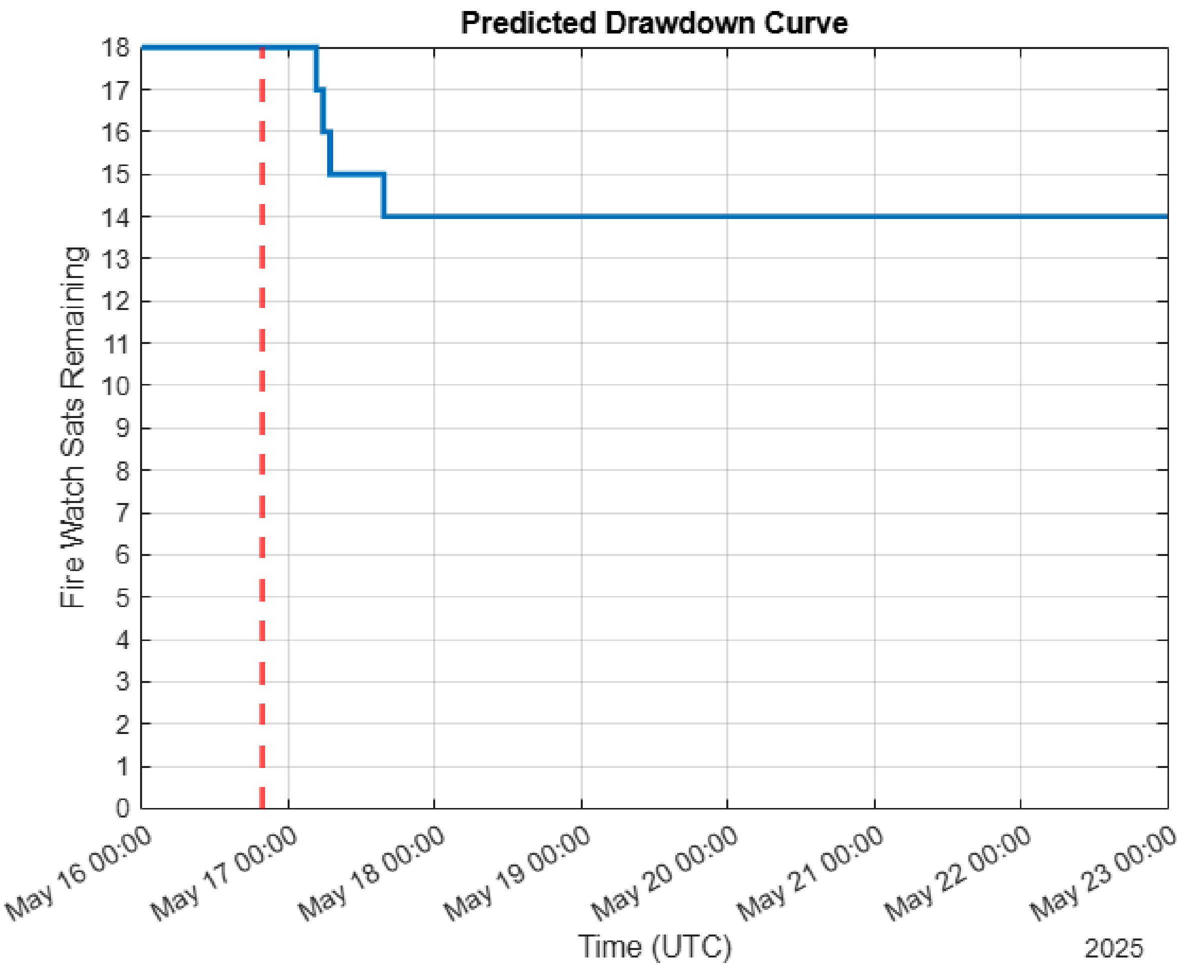
Fire Watch Satellite Defeating ASAT Max Divert Under New Assumptions

Fuel/Lifetime Analysis:

As previously stated, each FWS was equipped with a total fuel capacity equivalent to 500 m/s of delta V to promote a long lifespan for the relatively large satellites and reduce need for constant refresh. With the required fuel to safely deorbit the satellite being 120 m/s, this quantity must be preserved with a priority just under successfully avoiding KKV impact. By holding each of these conditions in high regard, we deny South Africa the ability to carelessly create large volumes of debris into the space around Earth carelessly. That being said, this means that each FWS has 380 m/s dedicated to station keeping which can be used in exchange for defensive maneuvers in the event they are required, trading the loss of the satellite for years off its lifespan. With the required delta V per preset maneuver being 120 m/s, 3 full maneuvers can be performed, with ~7.06 years of lifetime used each time.

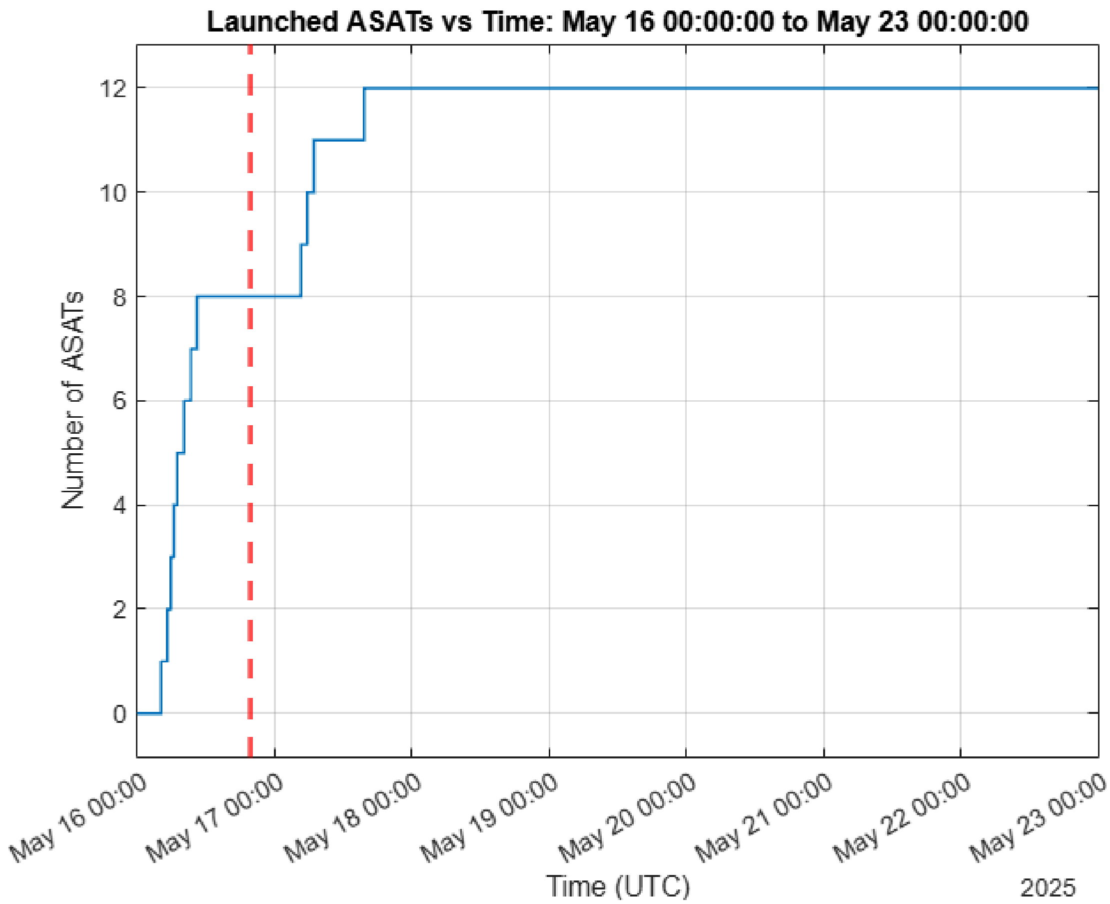
Drawdown Analysis

Looking at the access data for each Fire Watch satellite to check if it is in a reasonable range and angle in reference to the South African launching location, we can determine the approximate dates and times in which each satellite will be forced to lower into their disposal orbits, effectively obtaining a general prediction for the degradation of the constellation. We predict that they will attempt to destroy 4 FWSs to punch a sizable hole in its coverage and begin launches on the 16th of May at midnight due to recent data obtained via espionage.



This drawdown curve presents a rough estimate of what we could expect from their ASAT attack. To simulate apparent randomness as well as the realism that not every time a satellite passes over South Africa an effective shot can be taken, we chose 4 satellites and removed ¾ of their accesses at random to approximately represent the "true opportunities" similar to what was simulated earlier with the coplanar and opposing orbits for their tracking purposes, since terminal guidance systems are at a significant disadvantage attempting to contact a satellite from a non-coplanar trajectory. This graph shows that the targeted satellites will be defeated quite quickly, with the last directed to deorbit just after the 36 hour mark from the beginning of the attack. While difficult to rely on, it is possible to prevent the final ASATs from forcing a last evasive maneuver out of the FWSs by utilizing the counterattack detailed in Report 2, beginning on May 16th at 19:49:26 with a MRBM targeting a large Air Force base in Stellenbosch, which we predict is the central location for supplying the ASATs. To determine the remaining lifetime that would be expected of the FWSs, assuming the raid is successful, an ASAT launch analysis is required.

Predicted ASAT Launch Analysis



Based on this graph, there is a good chance that we can interrupt the final set of ASATs before they are launched at the targeted satellites within the ~12 hour gap caused by the shifting of the orbital planes in reference to the ground. This means that if our own raid is successful, ~140 m/s of delta V will be remaining in addition to the deorbit requirement, translating to ~8.23 years of lifetime. While this would be a massive victory, the targeted satellites will likely be in a fairly different orbit than they were designed for, meaning degraded data for their remaining lifetime, the extent of which must be determined after the attacks. In the event that the raid does not succeed at stopping the ASATs or that the FWSs they decide to attack are forced into final maneuvers before this approximated time, the final evasive maneuvers will be performed and then the FWSs will be promptly deorbited with their reserve burn as previously expected.

Risk Assessment in Relation to Cost

Assuming an ASAT worth ~$20 million, based on similar missile prices and accounting for modifications, launching 3 ASAT per satellite for 4 satellites equates to a total of $240 million that South Africa would have to spend in order to achieve their gap[7]. Along with the value they achieve by likely succeeding in their firebombing, they cost us ~87.34 million per satellite for each $60 million they pay. This implies it is of extreme advantage for them to destroy our constellation, meaning substantial risk for our own country and high likelihood an attack will take place. While this is not an ideal scenario, forcing them to expend 3

ASATs per satellite is a much better trade than preemptively deorbiting our satellites, costing them nothing for essentially an infinitely large gap. Additionally, for the country of Madagascar, lowering our entire constellation would open us up to extreme threat from the firebombing beyond even the constellation gap they planned for, essentially preventing us from responding to the disaster and potentially costing the lives of many citizens.

Conclusion

This all being said, it is incredibly important to remember that the final proposed maneuver is a limited solution, banking on the technology of South Africa being less capable than, albeit highly expensive and complex, KKV are capable of. This means that in the event that the South African KKV are up to modern capability, it is extremely likely that at least 1 satellite is destroyed, creating a tremendous amount of space debris. Because of this, we cannot fully support the use of the evasive maneuver plan in fear of sabotaging space travel around Earth for potentially thousands of years. Despite this, the option remains up for consideration. However, if Madagascar does decide to move forward with the evasive method and South African technology is beyond what we can handle, it is imperative that all remaining FWS are to immediately lower their perigee in order to deorbit to avoid being targeted and turned into a catastrophic amount of debris. Unfortunately, as of now, it is impossible to know when or even if South Africa will make the decision to destroy these satellites but it is important to have an effective plan of action to minimize risk and damages, and to weigh the outcomes accordingly.

Works Cited:

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[3]“Indian ASAT Demonstration” YouTube, uploaded by The Aerospace Corporation, 24 July 2019, .https://www.youtube.com/watch?v=RnofCyaWhI0.

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[6]“EKV/KV/KW/KKV/LEAP (Exoatmospheric Kill Vehicles) Hover Test - Compilation Video (SM-3, GBI, etc.)” YouTube, uploaded by CR0wm p, 12 August 2020, https://www.youtube.com/watch?v=RnofCyaWhI0

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