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Astro Classifier-To calculate and classify Atmospheric Re-entering Space Debris and Foreign Objects

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Abstract:

The project is called "Astro Classifier" which is a coded program used for classification and calculation of Atmospheric Re-entry of Space Debris. This paper discusses how calculations and classifications of re-entering objects in orbit can be done effectively through a combination of physics' theory and programming skills such as Python. The physics behind the simulation comprises of orbital mechanics and key formulas. It identifies the decaying orbit of the external body using Keplerian Orbital Elements to determine the object's future position through its size, shape and orientation in space collected from pre-existing data sets. The code utilises Nasa's API's and uses it to display the data required for the approaching object's trajectories and classification.

Keywords: Space Debris, Python, Orbital mechanics, Keplerian Orbital Elements, Nasa's API's,

Introduction:

Rationale:

I first got my idea from meteor showers when I saw the Nagpur meteor shower broadcast online. It really made me wonder, how do they calculate and classify the falling debris' trajectories? Wouldn't it be dangerous and disastrous if it fell over cities and damaged infrastructure? Through such a thought process I based my main idea upon Astrophysics and how we can identify the trajectories and material of extraterrestrial objects. My idea is based upon the global issue of satellite collision and how the debris of that may fall towards Earth, in large masses, damaging infrastructure and buildings nearby impact sites.

Therefore, I want to investigate the idea regarding how we can calculate the trajectories of such extraterrestrial objects coming from space, and whether the objects are always researchers classifying whether objects falling from space are always man-made debris or whether it is a biological extraterrestrial site from outer space worthy of investigation. Satellite collisions are rare but devastating events which can be quite dangerous if its debris lands on earth in inhabited areas, so the calculation of its trajectories helps researchers out with its pathway. Due to earth's exothermic atmosphere, the identification of an extraterrestrial object becomes quite difficult as it burns up falling down to Earth, so the identification between manmade objects and Outer space objects is also quite crucial.

Literature Review:

Many research papers have built their ideas around the threat of Space debris' and its trajectory calculations towards Earth. One of the authors named D.Kruzynska in the paper titled "TRAJECTORY PREDICTIONS FOR

HIGH ECCENTRICITY ORBITS OF SPACE DEBRIS OBJECTS" has demonstrated several perturbations in their force model: geopotential, luni-solar effects, solar radiation pressure, and influence of Earth's atmosphere, in order to calculate space debris orbit and its trajectories.

Similarly, in another research paper, the author Meiyung Liu in the paper titled "Space Debris Detection and Positioning Technology Based on Multiple Star Trackers" has demonstrated the use of multiple star trackers in order to improve and increase space surveillance. Through Space based observations, the research improves the possibility of cataloging and Space debris detection.

The research paper written by one of the authors named Gisu Park in the paper titled "Reentry trajectory and survivability estimation of small space debris with catalytic recombination" has demonstrated a method to determine the survivability of Space debris and calculate re-entry object's trajectories by using different shapes and materials.

The author Stoil Ivanov in the paper titled "Space Debris Identification, Classification and Aggregation with Optimized Satellite Swarms" has additionally demonstrated and addressed the growing threat of Space debris to LEO and MEO space infrastructure and its collisions with spacecrafts by researching methods to reduce the risks of space debris collisions and decrease their aggregation in specific orbits. Such detection is done by using databases and modelling and finding a pattern for space debris' trajectories for estimation and appropriation of its potential collision targets.

Finally, the author M. Cerf in the paper titled "Multiple Space Debris Collecting Mission—Debris Selection and Trajectory Optimization" has similarly demonstrated techniques to investigate the required costs for removing heavy space debris from low orbits. Through his methodology, he is proposing specific strategies and reference solutions as well as optimal solutions towards this issue.

Many of these papers are quite different from mine however, the idea of calculating the trajectories and locating the Space debris in the atmosphere remains the same. My research conducts this in a much more accurate and simplistic way as it is a simple code program which is ran in order to calculate based trajectories and classify objects.

Preliminary concepts and Methodology:

Aim:

The U.S. government tracks about 23,000 pieces of debris larger than a softball orbiting the Earth. There are half a million pieces of debris larger than 1 centimetre and 100 million pieces of debris about one millimetre or larger. Debris, particularly near the International Space Station, orbits the Earth 15 to 16 times a day, increasing the risk of collision. With many risks appearing from Space debris, it is getting difficult to track such objects in the atmosphere and if they are falling through Earth's atmosphere.

As the content of space debris increases, there is greater risk of satellite collisions, discouraging countries to put up satellites due to its high costs. If the positions of such crash sites are not calculated correctly, it can lead to catastrophic damages to the infrastructure and even casualties to people.

The aim of my research is to investigate the meteor trajectories and paths through lab simulations and calculate the approximate position of where the object lands towards. Similarly, my other objective is present to make sure to classify the object and whether that object is manmade or extra-terrestrial to help researchers discover these landing sites for potential new elements and unidentified objects. Furthermore, I want to create an efficient and effective method for researchers to instantly calculate a falling object's trajectory, its landing site, and its type. This can be tremendously helpful for estimation, and I want to provide convenience through my research.

By providing a quick and efficient way to instantly calculate the trajectories, and approximate physical dimensions of falling space debris', my project is going to be able to help researchers in receiving the most accurate data in times of need. Therefore, for my project to succeed, I would need to achieve its aim.

I will have achieved my aim if I have successfully executed my code using physics concepts and taking uncertainties into account whilst connecting my code with different API's and calculating accurate datasets. I need to model the datasets collected through API's visually and successfully classify meteors and asteroid's characteristics through my own code in Python. My code should be able to work effectively and properly even if API's are changed and that the datasets produced should be accurate to the nearest degree.

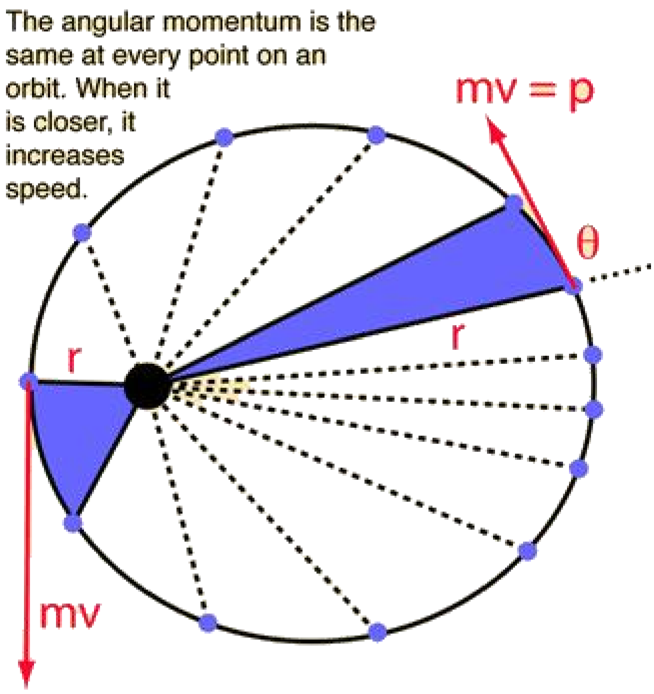
Background Knowledge:

Through my concepts of physics terminology and derivations, I was able to use them in the simulation as well as in the explanation for objects in decaying orbits. The equations can be represented as:

Decaying orbit:

Consider this an orbit of a satellite.

Angular momentum L = r × p where r and p are vectors.



(Figure 1 – Angular Momentum)

An amount that is conserved is angular momentum. The conservation of angular momentum dictates that, in a satellite whose orbit is decaying owing to air drag, when r shrinks due to energy loss, p must rise and, consequently, the velocity, since falling straight down would violate the principle of conservation of angular momentum. It requires a higher linear orbital velocity, not a smaller one, to sustain its orbit since the orbital velocity increases as the orbital radius shrinks.

In this equation, a lower orbit requires a higher velocity to be maintained, yet by definition of "decay," it is simply going through that orbit.
Air drag slows the satellite down more quickly as it enters the atmosphere, speeding up the decay. The orbit decays more quickly the lower the orbit is, the more drag there is, and this is a positive feedback system. A falling body will not complete even one additional "orbit" if its instantaneous velocity vector is parallel to any line that intersects both it and the larger body it is falling towards. This indicates that it is no longer helpful to consider the body to be in orbit; instead, consider it to be "falling."

Orbital Period Derivation:

Newton's law of gravitation: $F = \frac{-GMm}{r^2}$ (Equation 1)

The centripetal force equation: $F = \frac{mv^2}{r}$ (Equation 2)

The equation for the speed of an object traveling in a circle: $v = \frac{2\Pi r}{T}$ (Equation 3)

I put Newton's law of gravitation and the centripetal force equation equal to each other:

$$\frac{GMm}{r^2} = \frac{mv^2}{r}$$

Multiply both sides by r:

$$\frac{GMm}{r} = mv^2$$

Sub in $v = \frac{2\Pi r}{T}$ for v:

$$\frac{GMm}{r} = m(\frac{2\Pi r}{T})^2$$

Divide both sides by m:

$$\frac{GM}{r} = (\frac{2\Pi r}{T})^2$$

Root both sides:

$$\sqrt{\frac{GM}{r}} = \frac{2\Pi r}{T}$$

Flip both sides and divide by 2πr:

$$T = \frac{2\Pi\Gamma}{\sqrt{\frac{GM}{r}}}$$

Multiply both sides by $\sqrt{\frac{GM}{r}}$

$$T \times \sqrt{\frac{GM}{r}} = 2\Pi r$$

Square both sides:

$$T^2 \times \frac{GM}{\Gamma} = (2\Pi r)^2$$

Divide both sides by $\frac{GM}{r}$

$$T^2 = \frac{(2\Pi r)^2}{\frac{GM}{r}}$$

Take out r to get the final answer:

$$T^2 = \frac{(2\Pi)^2}{GM} r^3$$

If you take out the constant, you will get Kepler's law

$$T^2 = r^3$$

Keplerian elements (aka Satellite Orbital Elements)

The ellipse or hyperbola's form, its orientation around its central body, and the location of a satellite on the orbit are all determined by the collection of six independent constants that make up and define the position of a satellite in orbit. These traditional orbital elements include:

1. Eccentricity: The ellipse's shape, in which values near zero are more elongated and values near one are more circular.

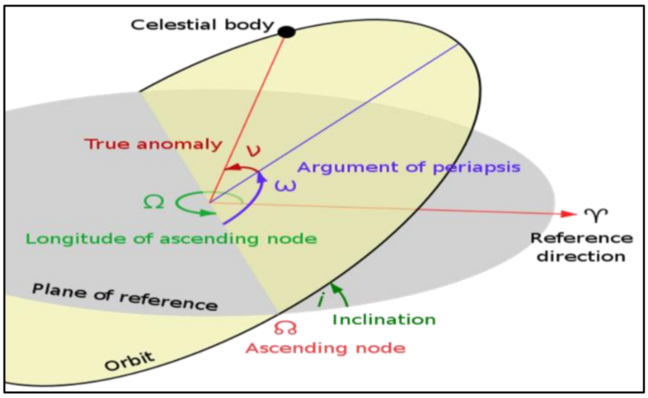
2. Semimajor Axis: The major axis of the asteroid's orbit that is only half as long.

3. The orbit's inclination with respect to the reference plane. The ecliptic plane, which is where the planets' orbits are situated, served as the reference plane in this situation.

4. The asteroid "ascends" out from the reference plane according to the longitude of the ascending node, which is the angle at which the orbit is rotated from the vernal point.

5. Periapsis's argument: The ellipse's orientation or the angle at which the orbit is rotated with respect to itself.

6. Mean Anomaly: The asteroid's locations over a specific time period.



(Figure 2 – Keplerian Orbital)

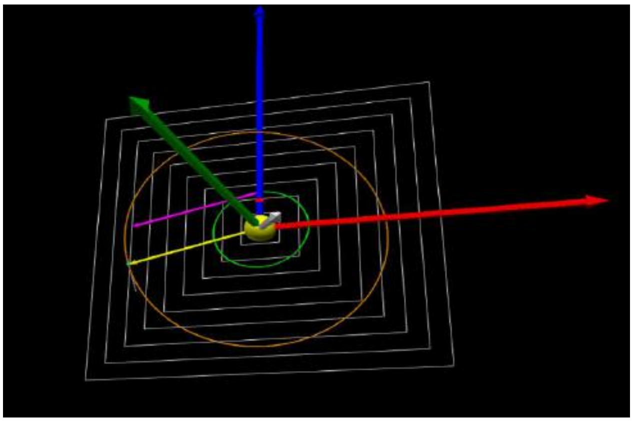
They were able to create a representation of the asteroid's orbit after identifying these components

The route and course of this asteroid might be satisfactorily explained by Kepler's three laws of motion. These motions consist of:

1. The sun serves as the focus or primary body for each planet's elliptical orbit around it. Kepler proposed that gravitational disturbances and other causes result in elliptical orbits rather than circular ones. Newton postulated that there are infinite gravitational pulls, however their forces diminish with distance and eventually vanish from view. Spacecraft orbiting the Earth are primarily influenced by the Earth's gravity and anomalies in its composition, but they also are influenced by the moon and sun and possibly other planets.

2. The radius vector sweeps out equal areas in equal amounts of time, such as the line from the center of the sun to the center of a planet, the center of the earth to the center of the moon, or the center of the earth to the center of gravity of a satellite.

3. The cube of a planet's mean distance from the sun times a constant equals the square of the planet's orbital period. This can be expanded to say that an orbital period for a satellite rises as its mean distance from the planet does.



(Figure 3 - Dimensions)

Methodology:

To affirm my hypothesis and build on the same, I conducted over 6 months of research, experimentation, and development. I conducted my work at my home, through my laptop, using secondary research as my main source of data collection as well as primary research in the form of practical's.

During the first 2 months of my research, I ensured to do detailed research on collecting data bases from past research papers and NASA's API's. From there, I devised my own code to calculate the orbiting bodies' characteristics while using NASA's live API's as well as my own implementation of physics formulas in order to receive the most accurate data possible. After building up the code, many trial tests were run, and data was collected as well as checked for its reliability. After many series of tests, I was able to figure out where different areas of my codes were going wrong and made sure to fix those areas. With many trial runs, the data collection done by the simulation now is much more reliable than before, and after working on this code for a while, I have successfully been able to classify as well as calculate the space debris' trajectories and its approximate positions.

This method is extremely accurate as the data taking up here is primarily from NASA's API's from their official website which allows me to collect data directly from their banks of datasets collected through observatories and radars. It also makes it quite a reliable source to collect data from. Furthermore, I can customize my own code and model it to fit to my means and narrow down my research to the falling object's specific characteristics. This method allows me to track real time data of falling space debris as the API's get updated every second so it is the closest method to which I will be able to obtain accurate and concise data.

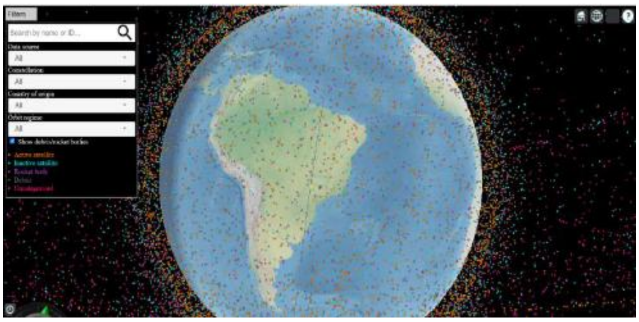
It is an extremely time-consuming process to collect data as you have to pick out specific characteristics every time you collect data about a specific asteroid. This is the reason why I devoted 2 months of my time just to research and collect data about specific types of asteroids in order to simulate my data. Furthermore, it does not take into account many of the other uncertainties applied in physics when I simulate my data to showcase a decaying orbit.

A separate method from this was to collect data regarding space debris and asteroids through websites which showcase live tracking of space debris. NASA releases such websites like AstriaGraph to showcase their live trackers to the public and so it was another method which I could have pursued.

An extremely easy way to collect data individually of live tracking motion objects orbiting Earth. Its individual characteristics would be very easily available, and it would be much more in detail per object. Furthermore, I would be able to classify objects separately using legends and indicators on the website to narrow my research.

This method is flawed in terms of not containing past records and datasets of falling Space debris as well as asteroids, since only real time tracking is used to collect data. Furthermore, it can also be an overload of data as each object in orbit is presented in extreme detail which is not required for my project. Additionally, it is also time consuming to collect data object by object in orbit in order to simulate it. It would take me more time to collect heavy datasets of thousands of space debris' and Asteroid's data.

Example:



Dataset of Space Debris DELTA 1 DEB (Fig 4)

DELTA 1 DEB	
Click here to download ephemeris	
Data Source	**(1) USSPACECOM**
Name	DELTA 1 DEB
Country	US
CatalogId	35535
NoradId	35535
BirthDate	1975-06-12
Data epoch	2022-12-17T06:09:42Z
Semi-major axis	7346.4 km
Eccentricity	0.0104
Inclination	98.9893°
RA of ascending node	42.9991°
Argument of perigee	101.0093°
Mean motion	0.0574 °/s
Orbital speed	7.4 km/s
Orbital period	104.4 min

Data Collection through Source AstriaGraph (Figure 5)

Through these 2 methods, I believe the first method was much more efficient for me, so I took a decision and went for it as it was much less time consuming and a much more efficient way to collect data. I chose to combine my Physics' theoretical knowledge and my Computer science programming skills and use it to simulate data as well as plot them in 2D models.

If I had used the second method, it would have taken me more than 6 months to complete my research and I would also lack in datasets as I would not have been able to access past records of space debris' and asteroid's atmospheric re-entry towards Earth. It would also be more prone to errors since some of the public websites using live tracking softwares may not all be accurate compared to NASA's official API's. (3.2)

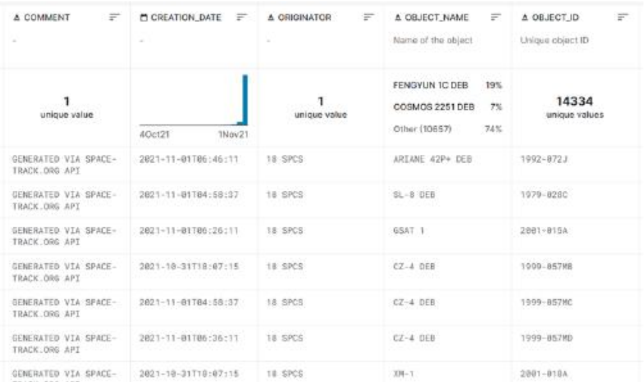
Results and Discussion

Experimentation and Research Conducted:

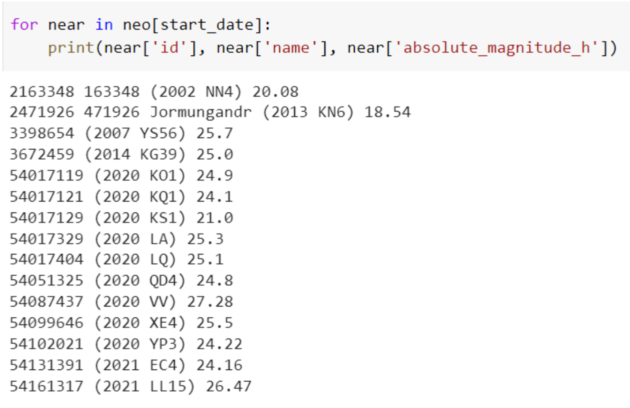
Through Python, the simulation is built from scratch and many simulating modules are used in order to execute the code. An API key is generated and used to produce a given range of data. I use a date and time format for calculating specific orbiting bodies positions at specific times. The start date and end date are specified, a request is executed, and I get the element count of the number of orbiting bodies present in orbit at that specific time period. From there, the simulation specifies details regarding all the orbiting object's names if they are asteroids and model numbers if they are space debris fallen from inactive satellites. Through Indexing, a specific orbiting body's characteristics are calculated including its absolute magnitude, estimated diameter in 4 different units, initial and relative velocities, and classification of the object. With the simulation having set all these data types, it simulates the orbiting object's future trajectories and visualizes it, mapping its positioning and giving us an approximate location of its landing site.

Such mapping techniques require the use of physics concepts of decaying orbit, Keplerian Orbital Elements and Orbital velocity to showcase the simulation. The simulation actively produces the body's velocity time graphs and displacement time graphs which expresses the body's exact speed and location and helps in comparing values. I could have used only coding to express the data visually, however, I wanted to explain the data clearly as well as take into account the conceptual knowledge in Physics to accurately represent the data. This is why, for easier comparison, the simulation showcases whenever objects enter decaying orbit with a red highlight on the body as it slowly follows its mapped trajectories, and each time a simulation is run, the data sets are collected, which helps to improve accuracy of the experiment for future trials.

Sample Data Table for Asteroids in Orbit from 2022-06-06 to 2022-06-07 (Fig 7) Experimental Results through API's and



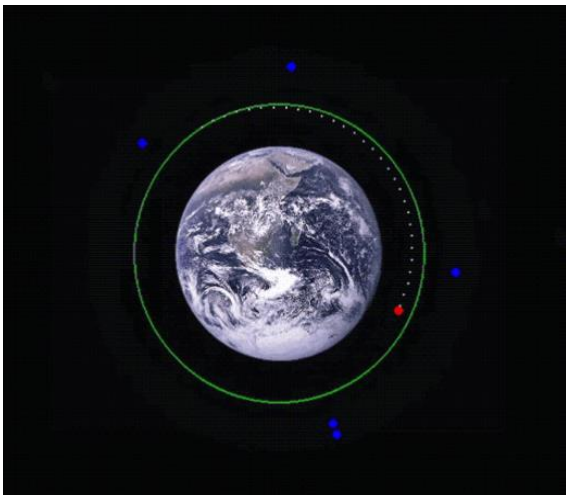
COMMENT	CREATION_DATE	ORIGINATOR	OBJECT_NAME	OBJECT_ID
-	-	-	Name of the object	Unique object ID
1 unique value	4Oct21 1Nov21	1 unique value	FENGYUN 1C DEB 19% COSMOS 2251 DEB 7% Other (10657) 74%	14334 unique values
GENERATED VIA SPACE-TRACK.ORG API	2021-11-01T06:46:11	18 SPCS	ARIANE 42P+ DEB	1992-072J
GENERATED VIA SPACE-TRACK.ORG API	2021-11-01T04:58:37	18 SPCS	SL-8 DEB	1979-028C
GENERATED VIA SPACE-TRACK.ORG API	2021-11-01T06:26:11	18 SPCS	GSAT 1	2001-015A
GENERATED VIA SPACE-TRACK.ORG API	2021-10-31T18:07:15	18 SPCS	CZ-4 DEB	1999-057MB
GENERATED VIA SPACE-TRACK.ORG API	2021-11-01T04:58:37	18 SPCS	CZ-4 DEB	1999-057MC
GENERATED VIA SPACE-TRACK.ORG API	2021-11-01T06:36:11	18 SPCS	CZ-4 DEB	1999-057MD
GENERATED VIA SPACE-	2021-10-31T18:07:15	18 SPCS	XM-1	2001-018A



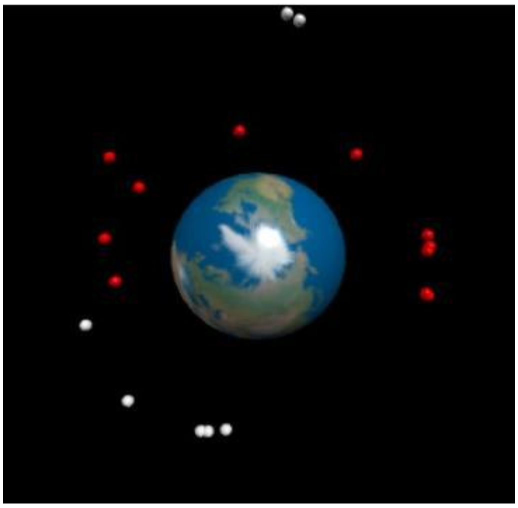
```
for near in neo[start_date]:
    print(near['id'], near['name'], near['absolute_magnitude_h'])

2163348 163348 (2002 NN4) 20.08
2471926 471926 Jormungandr (2013 KN6) 18.54
3398654 (2007 YS56) 25.7
3672459 (2014 KG39) 25.0
54017119 (2020 KO1) 24.9
54017121 (2020 KQ1) 24.1
54017129 (2020 KS1) 21.0
54017329 (2020 LA) 25.3
54017404 (2020 LQ) 25.1
54051325 (2020 QD4) 24.8
54087437 (2020 VV) 27.28
54099646 (2020 XE4) 25.5
54102021 (2020 YP3) 24.22
54131391 (2021 EC4) 24.16
54161317 (2021 LL15) 26.47
```

Datasets (Fig 6)

Simulations:
Simulation through Python of Decaying Orbits



(Decaying Orbit – Figure 9)



(Highlighted Decaying Orbit – Figure 10)

The simulations were executed with live data, which expressed the visual aspect of an orbiting body very accurately. Both the simulations produced a range of graphs which gave us accurate values of the orbiting bodies' characteristics and dimensions. To verify the validity of our tests, I evaluated the data from an existing asteroid using a simulation. Therefore, we discovered highly accurate results that roughly gave us the same values as those given in the data sets of the asteroid's landing site. I went through this process ten times for each orbiting body in order to make sure each and every data set simulated and calculated was accurate and on point with the experimentations we were doing.

Through the Simulation, we were also able to calculate when the orbiting body will approach Earth and whether or not it will miss Earth.

Conclusion and Future Scope:
Evaluation:

Throughout my journey, I experimented a lot with the Astro Classifier using a variety of APIs, including asteroid's NeoWS, DONKI, EONET, and many more, on a variety of orbiting asteroids and Space Debris'. I gathered accurate data sets, and as I ran more simulations, the experimentation got better. With the help of my machine learning model, the simulation became considerably more accurate as more simulations were conducted, increasing accuracy with each test run and producing reliable findings for the categorization and calculation of the paths of orbiting debris. By attempting this project individually, I learned many skills in terms of time management and delegation of work. As this was an extremely large project to take upon, I had to persevere and dedicate a lot of my time towards it, building it from scratch, and undergoing through many test runs of my codes in Python in order to perfectly simulate my data. Furthermore, I was able to combine my passion of physics with computer science and explore this interdisciplinary area at a deeper level.

Learning Python from scratch to advancing to data analysis, I had undergone through extensive training and learned many technical skills in order to develop this project for submission. Aiming to present this project at many different science fairs, I was able to think of many aspects to take into account when approaching this project such as the external factors in Physics which should be kept constant as well as the margin of error of my data. However, I realized many of my mistakes as repeatedly tried to code the perfect algorithm to simulate my data. Even after doing many courses, I had a lot to improve upon in Python as I had no past experience in practical areas. Furthermore, there were many times where I made silly mistakes in collecting data, leading to me repeating the dataset collection which was extremely time consuming.

I encountered many issues as well while trying to create my own code to extract details from the API's. Firstly, I was limited to the range of datasets I could obtain since I had to input a "start_date" and "end_date" in order to get all the data of Space debris and Asteroids which may have entered Earth's orbit. I could not have this range too far as that would lead to an overload of information, not allowing my code to work. Furthermore, I faced issues in trying to maximise the efficiency of my code to narrow down to the most minute characteristics of re-entering atmospheric bodies. Since NASA's API's contains extensive data regarding all information about the atmospheric re-entering bodies and I only required their physical dimensions and characteristics, I had to code up my program to be very specific and this took many trial and errors throughout this process.

However, I was able to solve such issues along the way as I gained expertise from my mentors and looked up past research papers where people have used Python in order to gather datasets regarding the characteristics of orbiting bodies. Through secondary research, I was able to narrow down my code quite effectively, and use it also for specific bodies in space as well. I thought creatively and instead of creating an extensive complex coding program requiring many modules, I took up a simple module which were "requests" and "pprint" and used basic commands to extract data from the datasets in order to make it quite simple to use. This would help anyone else or researchers trying to use my code to find specific information regarding any orbiting bodies through NASA's API's. It would also make the code easy to read and also efficient in conveying its purpose. Through such ideas, I was able to draft such solutions throughout my journey of writing this research paper. With the help of secondary sources, as well as my mentors, I was able to overcome many of my technical problems since I did not have to do any on hand practicals also.

Conclusion:

Looking ahead, I believe I would need to focus much more on my technical skills as well as my conceptual knowledge in Physics in order to reduce uncertainties in the project. If I were to repeat this project, I would take more factors into account other than the characteristics of the asteroid's and Space Debris' such as the atmospheric conditions of the exosphere, the exact locations where the objects may land, and more graphical representations of the trajectories of the falling objects. Another improvement this project could have been that if I would work with someone else who is as dedicated towards research as me, I would be able to achieve more, and dedicate time to academics as well as my extracurriculars as this project took a lot of time to execute and implement alone. Finally, I could have researched more ways in terms of simulating data in 3D models instead of 2D to showcase the data in much more detail and showcase it in a clear picture.

The orbiting bodies' easy classification helped a lot in showcasing the simulation's trajectory mapping and its results as the material of an object changes, its trajectory varies. With different materials, magnitudes, and diameters, the estimation had to be accurate, keeping all the other variables constant while simulating the experiment. The convenience and effectiveness of my simulation's results proves its reliability in its initial stage as these 2 features make it very easy to use for researchers trying to calculate a live falling asteroid or space debris' data.

Future stages of Astro Classifier will include improved visual graphing of simulations, 3D mapping, precise names of landing sites, and faster simulation testing periods; however, at its current phase, it has proved to be very efficient in its calculations with up to 98% accuracy.

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Appendix 1

https://github.com/ActionNetra/Codes-For-CREST.git