VELOCITY ANALYSIS OF A PATH DEVIATING PROJECTILE

A Project Report Submitted to

Visvesvaraya Technological University, Belagavi

in partial fulfillment of requirements of V semester Project work 20AE5DCMP1 of

BACHELOR OF ENGINEERING in AEROSPACE ENGINEERING

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Certificate

Certified that the project entitled **Velocity Analysis Of A Path Deviating Projectile** is a Bonafide work carried out by

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in partial fulfillment for the award of Bachelor of Engineering in Aerospace Engineering of the Visvesvaraya Technological University, Belgaum, during the year 2021-22. It is certified that all corrections / suggestions indicated for internal assessment have been incorporated in the report deposited in the departmental library. The project report has been approved as it satisfies the academic requirements in respect of Mini Project work (20AE5DCMP1) prescribed for the said degree.

Signature of Guide

(Dr. Y S Rammohan)

Signature of HOD

Signature of Principal

Semester End Examination

Name of the Examiners

Signature with Date

1.

2.

Declaration

We hereby declare that the project work entitled **Velocity Analysis Of A Path Deviating Projectile** has been independently carried out by us at the Department of Aerospace Engineering, under the guidance of Dr. Y S Rammohan, HOD., and Kamesh JV, Professor, Department of Aerospace Engineering, B. M. S. College of Engineering, Bengaluru, in partial fulfillment of the requirements of the degree of Bachelor of Engineering in Aerospace Engineering of Visvesvaraya Technological University, Belagavi.

We further declare that we have not submitted this report either in part or in full to any other university for the award of any degree.

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Abstract

As we are evolving with all our might in the technological domain, the number and complexity of threats to our planet Earth also keeps on increasing. Every year we are challenged with a new conundrum to solve, and as of NASA's available knowledge, one such problem is on its way to Earth, in the near future. Bennu, an asteroid as big as the Empire State Building, traveling at 28,000 meters per second, has a close probability of colliding with the Earth on September 24, 2182. This collision though will not wipe out life entirely, it will cause severe wreckage of roughly 1000-2000 times the size of the asteroid itself. NASA has already launched a mission to test the Kinetic Impact Theory on a Binary Asteroid System (Didymos and Dimorphos) on 24 November 2021. Double Asteroid Redirection Test was developed, by Johns Hopkins Applied Physics Laboratory with the assistance of several NASA centers, to deliberately crash itself into the moonlet (Dimorphos) at a speed of approximately 6.6 km/s. DRACO, the onboard camera, and its sophisticated autonomous navigation software will guide the payload at the time of collision. The collision will bring both the asteroids closer to each other, so that its orbit is shortened by at least 10 minutes. This collision, though, will not be of any help directly to saving our solar system, but will help us in understanding and getting better equipped with the upcoming situation with Bennu.

Keywords: Bennu, Double Asteroid Redirection Test, Johns Hopkins Applied Physics Laboratory, Kinetic Impact Theory, Didymos, Dimorphos, DRACO.

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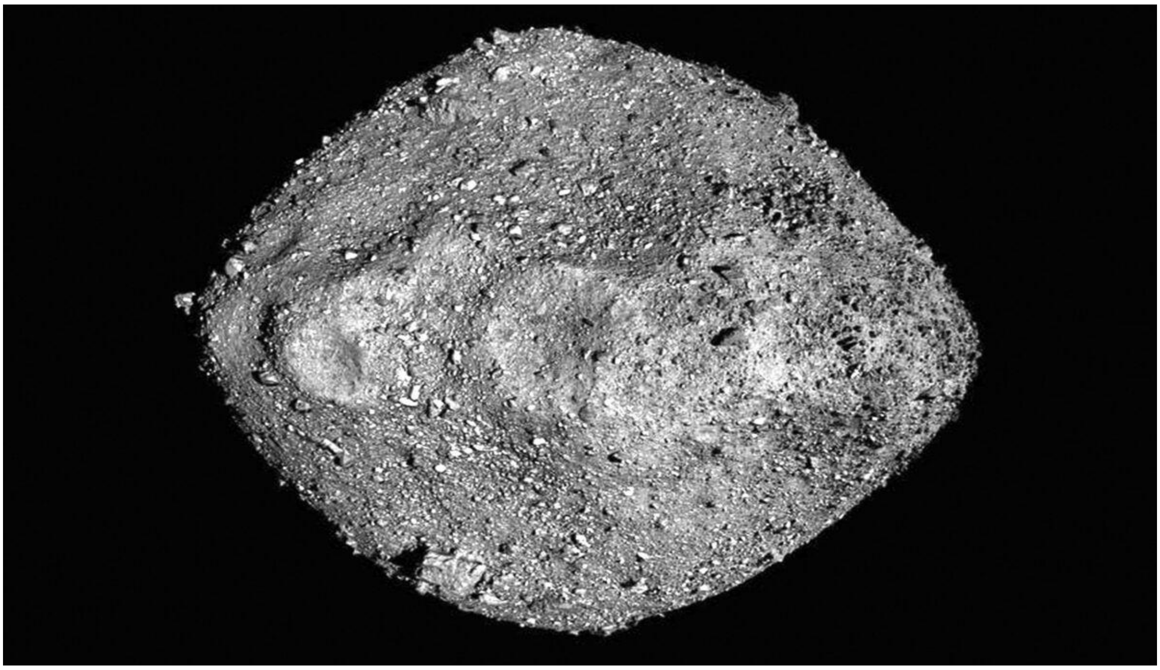
Chapter 1
Introduction

Bennu

101955 Bennu (provisional designation 1999 RQ36) The LINEAR Project identified a carbonaceous asteroid in the Apollo group, on September 11, 1999. It's a potentially hazardous object that's featured on the Sentry Risk Table and has the Palermo Technical Impact Hazard Scale's highest cumulative rating. It has a 1-in-1,800 chance of colliding with Earth between 2178 and 2290, with the highest risk on September 24, 2182. Bennu has a diameter of 490 meters (1,610 feet; 0.30 mile) and has been widely monitored using the Arecibo Observatory planetary radar and the Goldstone Deep Space Network. Bennu was chosen as the target of the OSIRIS-REX mission, which will return samples to Earth in 2023 for further investigation. After a two-year trip, the OSIRIS-REX spacecraft landed at Bennu on December 3, 2018. [18] It orbited Bennu and mapped out the asteroid's surface in great detail, looking for possible sample collecting sites. The orbits' analysis allowed the mass and distribution of Bennu to be calculated. On June 18, 2019, NASA announced that the OSIRIS-REx spacecraft has closed in on Bennu's surface and obtained a picture from a distance of 600 meters (2,000 feet). OSIRIS-REx safely landed on the surface of Bennu in October 2020, collected a sample with an extending arm, safeguarded the material, and prepared to return to Earth.OSIRIS-REx successfully completed its departure from the Bennu asteroid on May 10, 2021, while still carrying the asteroid rubble sample.



Discovery And Observations

Bennu was discovered on September 11, 1999, by the Lincoln Near-Earth Asteroid Research Center during a Near-Earth asteroid survey (LINEAR). [3] As a near-Earth asteroid, the asteroid was given the temporary name 1999 RQ36. As Bennu approached Earth on September 23, 1999, the Arecibo Observatory and the Goldstone Deep Space Network used radar imaging to observe it extensively.

Naming

Bennu was chosen from over 8,000 student entries from dozens of nations across the world that entered the University of Arizona, The Planetary Society, and the LINEAR Project's "Name That Asteroid!" contest in 2012. Michael Puzio, a third-grade student from North Carolina, proposed the name in honor of the Egyptian mythological bird Bennu. The OSIRIS-REx spacecraft, with its extended TAGSAM arm, reminded Puzio of the Egyptian god Horus, who is usually represented as a heron.

Physical Characteristics

Bennu is shaped like a spinning top and has an approximately spheroidal form. Bennu's axis of rotation is 178 degrees away from its orbit, and revolution around its axis is retrograde in relation to its orbit. While early ground-based radar observations suggested Bennu had a fairly smooth shape with one prominent 10–20 m boulder on its surface, high resolution data from OSIRIS-REx revealed that the surface is much rougher, with more than 200 boulders larger than 10 m on the surface, the largest of which is 58 m across. The boulders feature veins of high albedo carbonate minerals that are thought to have formed due to hot water channels on the much larger parent body prior to the formation of the asteroid.

Along Bennu's equator, there is a well-defined ridge. Because of its low gravity and quick rotation, the presence of this ridge shows that fine-grained regolith particles have accumulated in this location (about once every 4.3 hours). Bennu is revolving faster over time, according to observations by the OSIRIS-REX satellite. The YORP effect, or the Yarkovsky–O'Keefe–Radzievskii–Paddack effect, is what causes Bennu's rotation to alter. Bennu's rotation period reduces by around one second every 100 years due to the uneven emission of heat radiation from its surface when it rotates in sunlight. Spitzer Space Telescope observations of this minor planet in 2007 yielded an effective diameter of 48410 m, which is consistent with prior research. With a visible geometric albedo of 0.0460.005, it has a low visible albedo. Thermal inertia was measured and found to change by about 19% during each rotational interval. Scientists (incorrectly) projected a moderate regolith grain size, ranging from several millimeters to a centimeter, equally dispersed, based on this discovery. Around Bennu, no emissions from a possible dust coma have been identified, putting a limit of 106 g of dust within a radius of 4750 km.

Between 1999 and 2013, astronomical measurements revealed that 101955 Bennu is influenced by the Yarkovsky effect, causing the semimajor axis of its orbit to move by an average of 2841.5 meters each year. The bulk density of = 119013 kg/m3, which is only slightly denser than water, was calculated using gravitational and thermal effects. As a result, the anticipated macroporosity is 4010 percent, implying a rubble pile structure or perhaps hollows in the interior. (7.3290.009)1010 kg is the estimated mass.

OSIRIS-REx

The Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx) spacecraft was launched on Sept. 8, 2016, and it traveled to Bennu (formerly 1999 RQ36), a near-Earth asteroid. It collected a sample of rocks and substance from the surface, which it will return to Earth in 2023. Scientists will use the mission to understand more about how planets form and how life originated, as well as to better comprehend asteroids that may collide with Earth.

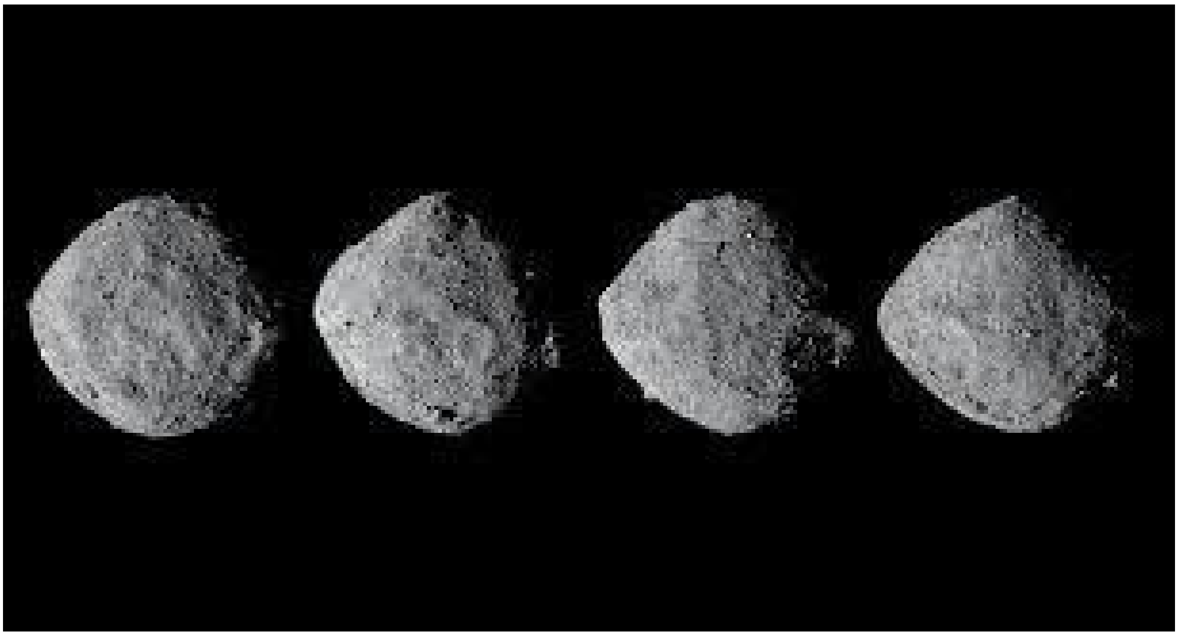
Photometry And Spectroscopy

Bennu has a synodic rotation period of 4.29050.0065 h, according to photometric data made in 2005. It is classified as a B-type asteroid, a sub-category of carbonaceous asteroids. Bennu belongs to the rare F subclass of carbonaceous asteroids, which is generally associated with cometary characteristics, according to polarimetric studies. A phase function slope of 0.040 magnitudes per degree was measured over a range of phase angles, which is similar to other low-albedo near-Earth asteroids.

Prior to OSIRIS-REx, spectroscopy revealed a link to the CI and/or CM carbonaceous chondrite meteorites, including the carbonaceous-chondrite material magnetiteDante Lauretta (University of Arizona) predicted that Bennu would be water-rich, and that it would be detectable while OSIRIS-REx was still theoretically approaching.

OSIRIS-REx confirmed magnetite and the meteorite-asteroid association in preliminary spectroscopic studies of the asteroid's surface.Phyllosilicates, for example, may store water. On approach, Bennu's water spectra were detectable,External scientists reviewed it, and it was confirmed from space. OSIRIS-REx observations have yielded a (self-styled) conservative estimate of around 7 x 108 kg water in one form alone, without accounting for other forms. This is a water content of 1% or more, with the possibility of much more. As a result, this points to transient water pockets beneath Bennu's regolith. Surficial water may be lost in the sample collection. If the sample return capsule, on the other hand, maintains low temperatures.

Bennu is a living asteroid, releasing periodic plumes of particles and rocks up to 10 cm (3.9 in),(not dust, defined as tens of micrometers). The releases could be generated by thermal fracturing, volatile release from phyllosilicate dehydration, pockets of subterranean water, and/or meteoroid impacts, according to scientists. Bennu had polarization similar to Comet Hale-Bopp and 3200 Phaethon, a rock comet, prior to the arrival of OSIRIS-REx. Active asteroids include Bennu, Phaethon, and the inactive Manx comets. B-type asteroids, in particular those with a blue hue, could be dormant comets. Bennu's comet designation would be P/1999 RQ36 if the IAU considers it a dual-status object (LINEAR).



Surface Features

All geological features on Bennu are named after various species of birds and bird-like figures in mythology. The first features to be named were the final four candidate OSIRIS-REx sample sites, which were given unofficial names by the team in August 2019. On 6 March 2020 the IAU announced the first official names for 12 Bennu surface features, including regions (broad geographic regions), craters, dorsa (ridges), fossae (grooves or trenches) and saxa (rocks and boulders).

Origin And Evolution

Bennu's carbonaceous material arose from the fragmentation of a much larger parent body, a planet or a proto-planet. The origins of its minerals and atoms, like practically all other matter in the Solar System, can be discovered in dead stars like red giants and supernovae. According to the accretion theory, this material came together during the formation of the Solar System 4.5 billion years ago.Bennu's basic mineralogy and chemical nature would have been established during the first 10 million years of the Solar System's formation, when carbonaceous material underwent geologic heating and chemical transformation inside a much larger planetoid or proto-planet capable of producing the required pressure, heat, and hydration (if necessary)—into more complex minerals. As a result of the Yarkovsky effect and mean motion resonances with big planets like Jupiter and Saturn, the orbit began to wander. The asteroid's spin, shape, and surface features may have been altered as a result of various interactions with the planets combined with the Yarkovsky effect.Based on similarities in spectroscopic features with known comets, Cellino et al. hypothesized that Bennu may have a cometary origin. Comets are thought to make up 5% of the population of near-Earth objects. This includes the asteroid 3200 Phaethon, which was found as an asteroid and is still classified as such.

Orbit

Bennu currently orbits the Sun with a period of 1.20 years (437 days). Earth gets as close as about 480,000 km (0.0032 au) from its orbit around 23 to 25 September. On 22 September 1999 Bennu passed 0.0147 au from Earth, and six years later on 20 September 2005 it passed 0.033 au from Earth. The next close approaches of less than 0.09 au will be 30 September 2054 and then 23 September 2060, which will perturb the orbit slightly. Between the close approach of 1999 and that of 2060, Earth completed 61 orbits and Bennu 51. An even closer approach will occur on 25 September 2135 around 0.0014 au (see below). In the 75 years between the 2060 and 2135 approaches, Bennu completes 64 orbits, meaning its period will have changed to 1.17 years (427 days). The Earth approach of 2135 will increase the orbital period to about 1.24 years (452 days). Before the 2135 Earth approach, Bennu's maximum distance from the Earth occurs on 27 November 2045 at a distance of 2.34 AU (350 million km). Every 130,000 years or so, an asteroid with a diameter of 500 m (1,600 ft; 0.31 mi) is projected to collide with Earth. Andrea Milani and partners anticipated a series of eight probable Bennu Earth impacts between 2169 and 2199 in a dynamical research published in 2010. The cumulative chance of collision is based on physical features of Bennu that were unknown at the time, but it was shown to be less than 0.071 percent for all eight encounters. The scientists realized that determining the size and direction of the Yarkovsky effect would require a comprehensive shape model and more observations (either from the ground or from spacecraft visiting the object) in order to accurately calculate 101955 Bennu's chance of Earth impact.

2060/2135 Close Approaches

Bennu will pass 0.005 au (750,000 km; 460,000 mi) from Earth on 23 September 2060, while the Moon's average orbital distance (*Lunar Distance, LD*) is 384,402 km (238,856 mi) today and will be 384,404 km in 50 years time. It will be too dim to be seen with common binoculars.[J] The close approach of 2060 causes divergence in the close approach of 2135. On 25 September 2135, the Earth approach distance is 0.00136 au (203,000 km; 126,000 mi) ±20 thousand km. There is no chance of an Earth impact in 2135. The 2135 approach will create many lines of variations and Bennu may pass through a gravitational keyhole during the 2135 passage which could create an impact scenario at a future encounter. The keyholes are all less than ~20 km wide with some keyholes being only 5 meters wide.

Gravitational Keyholes

A gravitational keyhole is a small region of space where the gravity of a planet alters the orbit of a passing asteroid, causing the asteroid to collide with that planet at some point in the future. The term "keyhole" refers to the disparity between the huge uncertainty of trajectory estimates (from the time of the asteroid's sightings and the first collision with the planet) and the comparatively small bundle(s) of essential trajectories. P. W. Chodas invented the phrase in 1999. When it became obvious in January 2005 that the asteroid 99942 Apophis would miss the Earth in 2029 but may pass through one or more keyholes, causing impacts in 2036 or 2037, it aroused popular attention. However, further research has been done since then.

2182

The most dangerous simulated impactor will occur on September 24, 2182, with a 1 in 2,700 chance of colliding with Earth, but the asteroid might be as far away as the Sun from Earth. On September 25, 2135, Bennu must pass through a keyhole about 5 kilometers wide in order to impact Earth on September 24, 2182. 2187 (1:14,000) and 2192 (1:14,000) are the next two most dangerous years (1:26,000). Between 2178 and 2290, there is a 1 in 1,800 possibility of an Earth impact.
Bennu's orbit, like that of all NEOs, is essentially dynamically unstable. We tracked 1,000 virtual "Bennus" over 300 Myr, including the gravitational perturbations of the planets Mercury–Neptune, to provide probabilistic insights regarding Bennu's future evolution and likely fate beyond a few hundred years. According to our findings, Bennu has a 48 percent chance of colliding with the Sun. Bennu has a 10% chance of being ejected from the inner Solar System, most likely following a near collision with Jupiter. Venus has the highest chance of colliding with another planet (26%), followed by the Earth (10%) and Mercury (5%). (3 percent). Bennu's chances of colliding with Mars are only 0.8 percent, with a 0.2 percent chance.

The OSIRIS-REx selection committee chose Bennu from a pool of approximately half a million identified asteroids. Closeness to Earth was the major criterion for selection, as proximity indicates a low impulse (v) necessary to approach an object from Earth orbit. An asteroid with a low eccentricity, low inclination, and an orbital radius of 0.8–1.6 au met the criteria. In addition, the potential asteroid for a sample-return mission must contain loose regolith on its surface, which means it must be larger than 200 meters in diameter. Asteroids that are smaller than this spin too quickly to hold dust or tiny particles. Finally, a desire to identify an asteroid that contained clean carbon material from the early Solar System, maybe comprising volatile chemicals and organic compounds, narrowed the field even more.

On Dec. 3, 2018, NASA's first mission to return a sample from an old asteroid, Bennu, arrived at its objective. The Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer, or OSIRIS-REx, is a seven-year mission that will end when at least 2.1 ounces (60 grammes) of sample is delivered to Earth, with the possibility of up to nearly four and a half pounds (two kilogrammes) of sample being delivered. It is expected to be the largest return of alien material from space since the Apollo missions. In September 2019, scientists marked the 20th anniversary of the asteroid's discovery, and they've been gathering data ever since. Here's what we know (and what we want to learn) about this exquisite relic from the past.

Bennu is a B-type asteroid, which implies it has a lot of carbon in both its minerals and its atmosphere. Bennu's carbon composition results in a surface on the asteroid that reflects about 4% of the light it receives — which isn't much. Venus, the brightest planet in the solar system, reflects roughly 65 percent of incoming sunlight, whereas Earth reflects about 30 percent. Bennu is a carbonaceous asteroid that hasn't experienced severe, composition-altering changes, meaning that chemicals and rocks from the formation of the solar system can be found on and beneath its deeper-than-pitch-black surface.

Bennu was blasting forth streams of particles a few times every week, according to the spacecraft's navigation camera. Bennu is not just a rare active asteroid (only a few have been discovered so far), but it may also be related to Ceres, which was discovered by NASA's Dawn mission and is one of the first of its sort that humanity has seen from orbit. The mission crew recently discovered that sunlight on Bennu can break rocks and that it has fragments of another asteroid spread over its surface. As the mission progresses, more parts will be added to Bennu's cosmic puzzle, each bringing the solar system's evolutionary past into closer relief.

Recent Updates From NASA

Bennu is expected to get within 125,000 miles of Earth — about half the distance to the moon. Right now, the PDCO is keeping a close eye on two particularly threatening space rocks, one of them being Bennu.
The Bennu asteroid: NASA discovered the Bennu asteroid in 1999. It's currently almost 200 million miles away from us, but it's expected to get within 125,000 miles in 2135 — that's about half the distance between Earth and the moon.

An object Bennu's size … would pretty much devastate things up and down the coast.

Bennu is about one-third of a mile (half a kilometer) wide, and if it were to impact Earth, it could cause serious destruction.

"[A] half-kilometer-sized object is going to create a crater that's at least five kilometers in diameter, and it can be as much as 10 kilometers in diameter," PDCO Director Lindley Johnson told the New York Times.

“But the area of devastation is going to be much, much broader than that, as much as 100 times the size of the crater,” he continued. “So an object of Bennu's size impacting on the Eastern Seaboard states would pretty much devastate things up and down the coast.”

The OSIRIS-REx mission: To find out as much about the Bennu asteroid as possible, NASA launched the OSIRIS-REx spacecraft in 2016.

The craft spent two years studying Bennu up close, recording data from its orbit and even landing on the asteroid to collect rock samples — a first for NASA.

Those samples won’t be in NASA’s hands until 2023 (OSIRIS-REx is still making the journey home), but NASA has already used what it’s learned from the probe to update its predictions about the Bennu asteroid.

“The OSIRIS-REx data give us so much more precise information, we can test the limits of our models and calculate the future trajectory of Bennu to a very high degree of certainty through 2135,” study lead Davide Farnocchia said in a press release.

“We’ve never modeled an asteroid’s trajectory to this precision before,” he added.

What’s new: According to NASA, the chance of the Bennu asteroid hitting Earth between now and 2300 is about 1 in 1,750. That’s a slight change from its previous prediction (a 1 in 2,700 chance of impact between now and 2200).

Didymos And Dimorphos System

The 65803 Didymos asteroid is an asteroid which was first discovered in 1196 by the Spacewatch survey at Kitt Peak. This asteroid is classified as a potentially hazardous asteroid.It has a small satellite asteroid called Dimorphous which was discovered in 2003.It is the minor-planet moon of 65803 Didymos, the parent asteroid in a synchronous binary system.

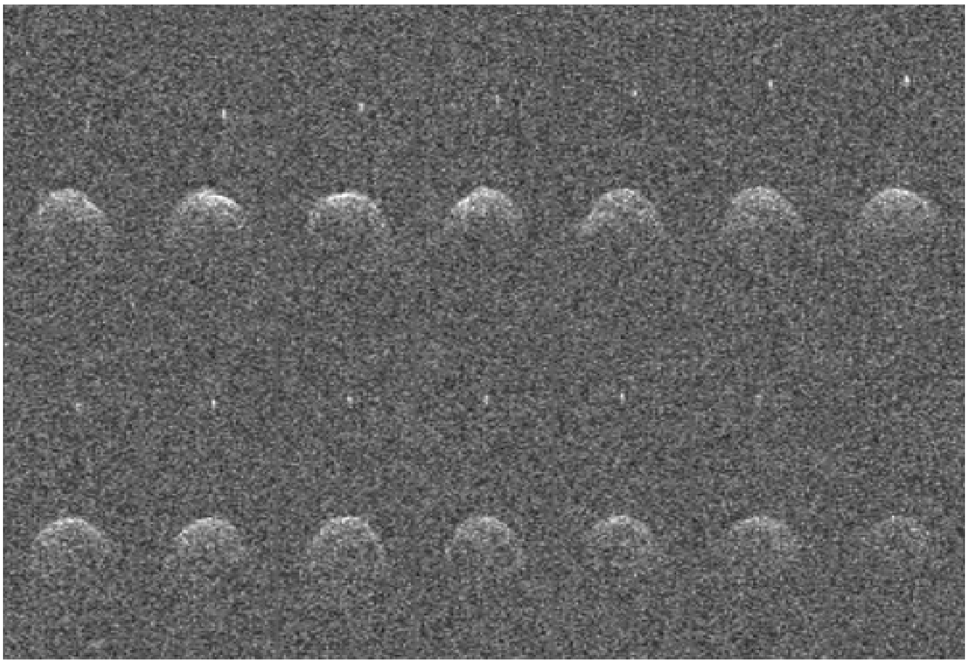
Didymos was identified on April 11, 1996, by the Spacewatch survey conducted by the University of Arizona Steward Observatory and the Lunar and Planetary Laboratory at Kitt Peak National Observatory in Arizona. Others identified the asteroid's double nature; suspicions of binarity initially surfaced in Goldstone delay-Doppler echoes, which were confirmed on November 23, 2003, by an optical lightcurve analysis and Arecibo radar imaging.

Didymos, which is the larger asteroid of the binary system also called Didymos A is 780 meters in diameter.The asteroid duo approaches Earth's orbit as it orbits the Sun, occasionally reaching relatively close to our planet. It was only 0.048 AU away from Earth in 2003. (The distance between the Sun and Earth is measured in astronomical units, abbreviated as AU.) Didymos is around 3 AU away at its furthest point, when it is on the other side of the Sun from Earth, just beyond Mars' orbit.Didymos also goes very close to Mars on occasion: 4.69 million kilometers in 2144.

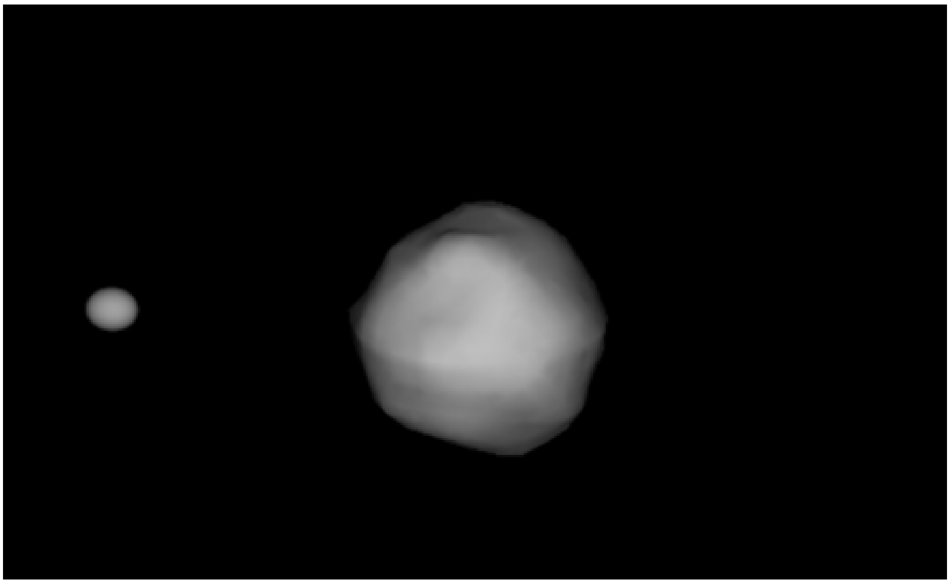
Didymos' orbit ranges from just outside Earth's orbit (approximately 1 AU) to just beyond Mars' orbit (about 2.27 AU) and is slightly inclined by about 3 degrees with respect to the plane of the planets (called the ecliptic). Each orbit of the Sun takes 2.11 years to complete.Didymos is part of the Amor group of asteroids, which is named after the asteroid 1221 Amor. (For the technically inclined, the Amors are near-Earth asteroids having orbits outside of Earth's orbit in which half of the long axis of their orbital ellipse, known as the semi-major axis, is between 1 and 1.3 AU [that is, interior to Mars' orbit]). Didymos rotates rapidly, around once every 2.26 hours. Every 11.9 hours, the moonlet circles around the bigger body. The primary asteroid and its moonlet are 0.62 miles (1 kilometer) apart in orbit.

Didymos has a spinning top form with a raised ridge running along its equator, which is a common structure among binary asteroids. The asteroid's high rotation is assumed to be driving material toward the equator, generating a bulge in the centre.The structure of the moonlet is unknown, except that it appears to be rather elongated.

It's unclear whether binary asteroids develop in the same way or by many different processes. Didymos' rapid spin suggests that the moonlet was produced by a process known as rotational fission, in which material is ejected from the asteroid due to its rapid rotation. Didymos is assumed to have begun spinning faster as a result of uneven emission of infrared light from its Sun-warmed surface, causing a twisting force, or torque. This process could have built up enough momentum over millions of years to release material from the surface, which eventually accumulated into the moonlet. Other alternatives, though, haven't been ruled out completely.Although the surface of Didymos cannot be viewed in great detail from Earth, astronomers believe it is comparable to the surfaces of similarly shaped asteroids visited by spacecraft, including Bennu and Ryugu. Both asteroids have highly rough surfaces that are littered with pebbles of varying sizes. They don't have the fine-grained regolith, or loose, dust-rich outer layer, that the Moon and other asteroids do. There is no atmosphere, magnetosphere, rings, or potential for life in Didymos.



The radar images of Didymos and its satellite(Dimorphous) taken by the Arecibo Observatory in 2003.



Shape model of *Didymos* and its satellite *Dimorphous*, based on photometric light curve and radar data

In 2003, Dimorphos, a tiny asteroid satellite, was discovered. It is the minor-planet moon of 65803 Didymos, the parent asteroid in a synchronous binary system. The International Astronomical Union's Working Group Small Body Nomenclature (WGSBN) granted the satellite its official name on June 23, 2020, after it was initially designated as S/2003 (65803) 1 and given nicknames such "Didymos B" and "Didymoon." It is one of the tiniest astronomical objects to be given a permanent name, with a diameter of 170 meters (560 feet).

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Joe Montani of the University of Arizona's Spacewatch Project discovered the main asteroid in 1996. Didymos was given official approval in 2004. In 2003, Petr Pravec of the Czech Republic's Ondřejov Observatory discovered that the asteroid had a satellite orbiting it. From the Arecibo radar delay-Doppler images, he and his collaborators confirmed that Didymos is a binary system.The name comes from the Greek word Dimorphos, which means "two forms." Kleomenis Tsiganis, a planetary scientist at Thessaloniki's Aristotle University, suggested the name. "As the target of the DART and Hera space missions, it will become the first celestial body in cosmic history whose form was drastically changed as a result of human action (the DART impact")," the reason for the new name states. Tsiganis went on to say that the name "has been chosen in anticipation of the changes that would occur. It will be known to us in two distinct forms, one observed by DART prior to the collision and the other by Hera a few years later ".The name "Didymoon" was used in official communications before the IAU naming.

Didymos has a diameter of around 160 meters.The European Space Agency (ESA) compares Dimorphous' size to that of Egypt's Great Pyramid. DART is 100 times smaller than dimorphous,because of which a collision with the spacecraft will just modify the asteroid's direction rather than blast it.

Didymos, the binary system's primary body, circles the Sun every 2 years and 1 month (770 days). In that orbit the Didymos and Dimorphous system pass close to Earth approximately 11 kilometers. It passed near earth in 2022.The orbit's path has an eccentricity of 0.38 and a 3° inclination relative to the ecliptic. Dimorphous orbits Didymos in a nearly equatorial, almost circular orbit with an orbital period of 11.9 hours. Dimorphous always faces the same side of Didymos because its orbital motion is synchronized with Didymos' rotation. The orbit of a Dimorphous is retrograde (rotational motion of an object in the opposite direction of its primary).

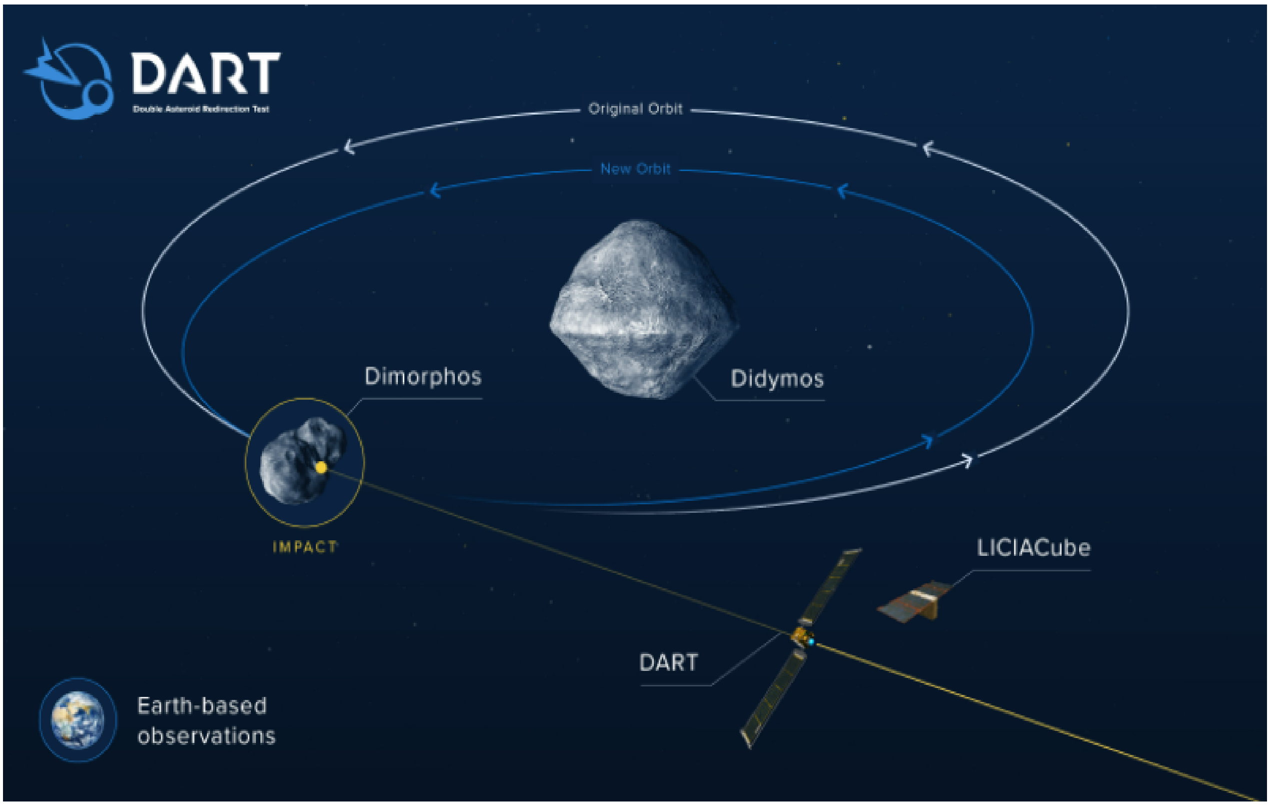
In 2022, NASA's Double Asteroid Redirection Test (DART) mission will reach Didymos, an asteroid that will be used to demonstrate an asteroid deflection device that will divert a space rock away from an Earth collision. The exercise is focused on Didymos' moon, which was given the temporary name "Didymos B" until the International Astronomical Union adopted the new name "Dimorphous".The spacecraft is expected to crash into Dimorphous at a speed of around 15,000 mph (6.6 km/s) between 26 September and 1 October 2022.The collision is expected to bring Dimorphous and Didymos closer to each other. Dimorphous will then circle Didymos faster than before, so that its orbit is shortened by at least 10 minutes.Didymos B(dimorphous) is moving at 50 cm/sec. So if you change the speed by a millimeter a second then it will be easier to measure.Mostly we want to change the speed of the incoming object by maybe a centimeter per second or so. That is not so fast but if you do enough second in advance then it will cause to miss earth entirely.DART is designed to have a kinetic impact, which means it will collide with Dimorphous in an attempt to nudge it. If it works, this technology might be used to redirect a potentially dangerous asteroid away from Earth.

Illustration of The DART impactor and CubeSat just before impact with Dimorphos

The spacecraft is under ground control, but we turn it over to the sophisticated navigation system four hours out. All we see is a single brilliant dot, perhaps 2-3 pixels in size, which is the Didymos system. The spaceship will now be able to manage what it is doing and will aim for the asteroid. Didymos B (Dimorphous) begins to pop out Didymous A around 80 minutes. We're attempting to hit the target in the middle. SmartNav is attempting to generate an image of what you imagine this moon to be like, despite the fact that you have no idea what its shape is and that sections of it may be completely dark.

DART : Double Asteroid Redirection Test

An important test that NASA and other organizations want to conduct before any actual need arises is an on-orbit demonstration of asteroid deflection. The DART mission is NASA's demonstration of kinetic impactor technology, which involves crashing into an asteroid to change its speed and trajectory. DART will be the first space mission to demonstrate asteroid kinetic impactor deflection. The spacecraft launched from Vandenberg Space Force Base in California on a SpaceX Falcon 9 rocket.



Didymos—The Ideal Target for DART's Mission

The binary asteroid system Didymos is DART's target. Didymos means "twin" in Greek, which explains the term "double" in the mission's name. Didymos is the ideal candidate for humanity's first planetary defense project, despite the fact that it is not on a collision course with Earth and hence poses no threat to the planet. The system is made up of two asteroids: Didymos (diameter: 780 meters, 0.48 miles) and Dimorphos (diameter: 160 meters, 525 feet), which orbits Didymos. Dimorphos will be hit nearly head-on by the DART mission, cutting the time it takes the small asteroid moonlet to orbit Didymos by several minutes.

As observed from Earth, the Didymos system is an eclipsing binary, meaning Dimorphos passes in front of and behind Didymos as it orbits the bigger asteroid. As a result, Earth-based observatories can determine Dimorphos' orbit by measuring the regular variation in brightness of the combined Didymos system. By comparing measurements taken before and after the impact, this same technique will indicate the shift in Dimoprhos' orbit. The DART impact is scheduled for fall 2022 to decrease the distance between Earth and Didymos, allowing for the best possible telescopic observations. At the time of the DART collision, Didymos will still be roughly 11 million kilometers (6.8 million miles) from Earth, but telescopes around the world will be able to see it.

The DART demonstration has been well-thought-out. DART's energy impulse to the Didymos binary asteroid system is low enough that it cannot destroy the asteroid, and Didymos' orbit does not cross Earth's at any point in current forecasts. Furthermore, Dimorphos' orbit has been altered in order to bring it closer to Didymos. The DART mission is a demonstration of capability to respond to an asteroid impact danger, should one be identified in the future. DART is a spaceship that will crash into an asteroid as a technology demonstration. The asteroid that DART is tracking is not a threat to Earth. Should an Earth-threatening asteroid be discovered in the future, this asteroid system provides an ideal testing ground to evaluate if purposely crashing a spacecraft into an asteroid is an efficient approach to redirect its trajectory. While no known asteroid larger than 140 meters has a good chance of colliding with Earth in the next 100 years, only around 40% of those asteroids have been discovered as of October 2021.

DART Impactor

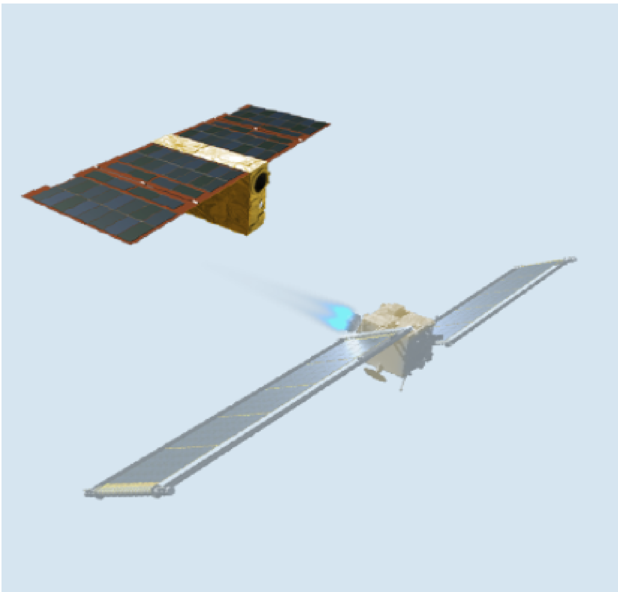
The DART spacecraft is a low-cost spacecraft. The spacecraft's basic structure is a box with dimensions of 1.2 1.3 1.3 meters (3.9 4.3 4.3 feet), from which other structures extend to give the spacecraft dimensions of 1.8 meters (5.9 feet) in width, 1.9 meters (6.2 feet) in length, and 2.6 meters (8.5 feet) in height. The spacecraft contains two massive solar arrays, each measuring 8.5 meters (27.9 feet) in length when completely extended. DART will travel to collide with Dimorphos at a speed of about 6.6 kilometers per second (4.1 miles per second). At launch, the DART spacecraft weighs around 1,345 pounds (610 kilograms), and at impact, it weighs about 1,210 pounds (550 kilograms). DART carries both hydrazine (approximately 110 pounds, or 50 kilogrammes) and xenon (about 130 pounds, or 60 kilogrammes) propellants for spacecraft maneuvers and attitude control, as well as xenon (about 130 pounds, or 60 kilogrammes) for the ion propulsion technology demonstration engine. The xenon used by the spaceship will be no more than 22 pounds (10 kilogrammes).

Payload: DRACO

The Didymos Reconnaissance and Asteroid Camera for Optical Navigation is the only instrument on the DART payload (DRACO). DRACO is a high-resolution imager developed from the New Horizons LORRI camera that will be used to aid navigation and targeting, as well as to estimate the size and shape of the asteroid target and the impact site and geologic context. DRACO is a 0.29-degree field-of-view narrow-angle telescope with a 208-millimeter aperture. To establish Dimorphos' relative location and facilitate SMARTNav, it contains a complementary metal-oxide semiconductor (CMOS) detector and a sophisticated onboard image processor. DRACO's photos will be transmitted back to Earth in real time before the kinetic impact. DRACO will help describe the impact site in its last moments by producing high-resolution, scientific photos of Dimorphos' surface.

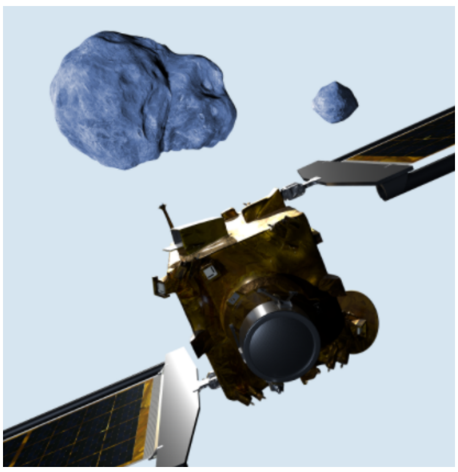
LICIACube

LICIACube, a CubeSat supplied by Agenzia Spaziale Italiana (ASI), will also be carried by DART (Light Italian CubeSat for Imaging of Asteroids). LICIACube will be launched by the DART spacecraft around ten days before the DART collision with Dimorphos. The DART hit, the resulting ejecta cloud, and possibly a view of the impact crater on Dimorphos' surface will all be captured by LICIACube. The LICIACube spacecraft is built on a 6U platform created by Argotec, an aerospace company. LICIACube has two instruments: LEIA (LICIACube Explorer Imaging for Asteroid), a narrow field panchromatic camera that can capture images from a long distance with high spatial resolution, and LUKE (LICIACube Unit Key Explorer), a wide field RGB camera that can analyze the asteroidal environment in multiple colors.



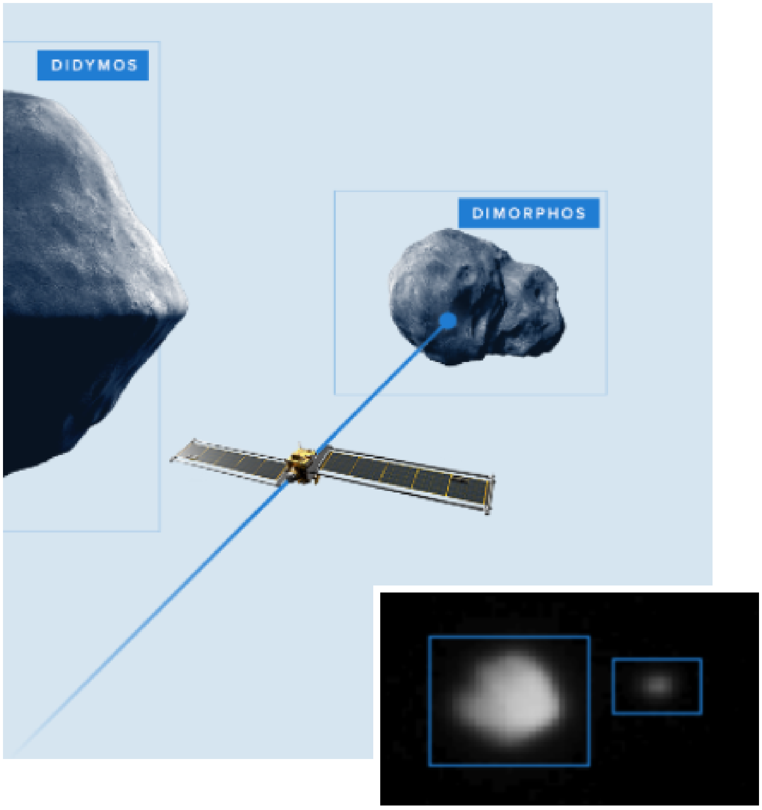
Technologies

DART is a NASA-funded technical demonstration of a kinetic impactor that might be used to counteract the threat of a potentially harmful asteroid. The DART experiment will show how a spacecraft can direct itself to a successful impact on a target, as well as measure the collision's effect on a natural asteroid.The investigation will aid NASA in better preparing for asteroids that could pose a threat to Earth's people in the future, as well as demonstrating other technologies that could be used in future missions.



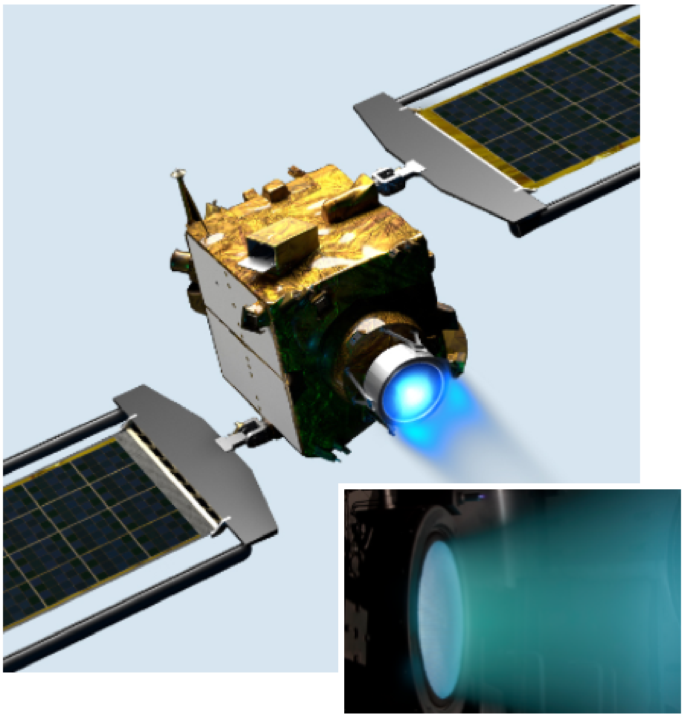
GNC and SMART Nav

When Dimorphos, the small moonlet of Didymos, a 160-meter-diameter target, is 11 million kilometers away from Earth, DART's key task is to successfully aim and squarely impact it. The DART team has developed SMART Nav algorithms as part of guiding, navigation, and control (GNC) (Small-body Maneuvering Autonomous Real Time Navigation).Within an hour of impact, this autonomous optical navigation system will recognise and distinguish between the two bodies at Didymos, then drive the spaceship toward the smaller body, Dimorphos, in collaboration with the other GNC parts. The DART team is relying on decades of missile guidance algorithms created at APL to successfully route to the asteroid using onboard equipment.



Advanced Ion Propulsion

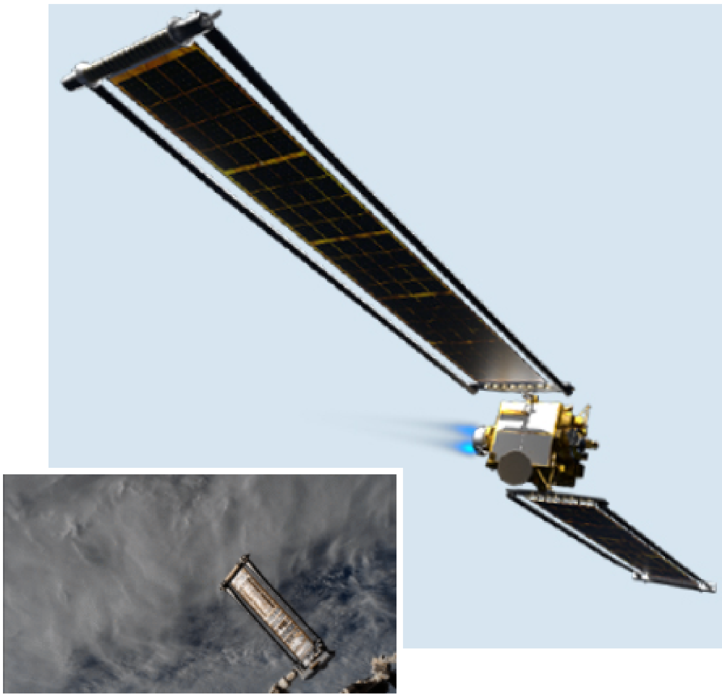
NASA's NEXT–C (NASA's Evolutionary Xenon Thruster–Commercial) ion propulsion technology will be used by DART, which was developed by NASA Glenn Research Center and Aerojet Rocketdyne. The NEXT-C is a solar-powered electric propulsion system that employs a gridded ion engine that generates thrust by electrostatic acceleration of ions (electrically charged atoms) produced from xenon propellant.NEXT–C outperforms the ion propulsion systems used on NASA's earlier planetary missions, Dawn and Deep Space 1, in terms of performance (specific impulse and throughput), fuel efficiency, and operational flexibility.



Roll-Out Solar Array (ROSA)

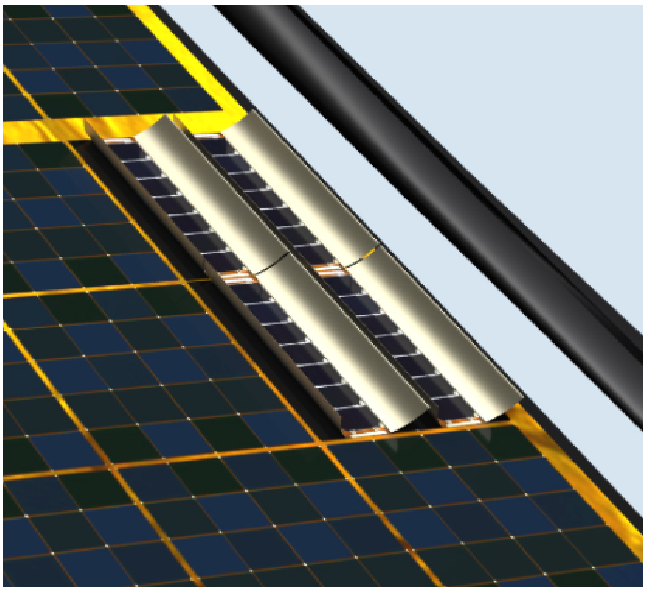
ROSA, which has been demonstrated on the International Space Station, has a small footprint and low bulk for launch, but once in space, it expands into two huge arrays, each measuring 8.6 meters in length. Despite their size, the flexible and rollable "wings" are lighter and more compact than standard solar arrays. This technology was successfully tested on the International Space Station for the first time in 2017, with upgraded versions being installed in June 2021 for full-time use.

The new arrays will be flown for the first time on a planetary spacecraft, clearing the way for their usage on future discovery missions. Redwire's Deployable Space Systems, a commercial manufacturing business in Goleta, California, is developing ROSA.



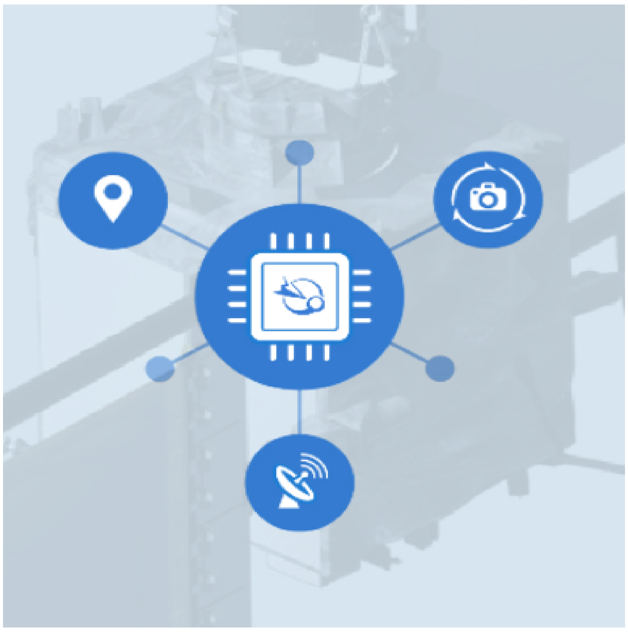
Transformational Solar Array

A tiny piece of the DART solar array is configured to exhibit Transformational Solar Array technology, which features very high-efficiency solar cells and reflecting concentrators that provide three times the power of current solar array technology, using ROSA as the structure. This method would allow solar arrays to be smaller while still producing enough power. Future expeditions to Jupiter and beyond may not require expensive nuclear power sources for energy as a result of this capacity, perhaps lowering the entire cost of future missions.



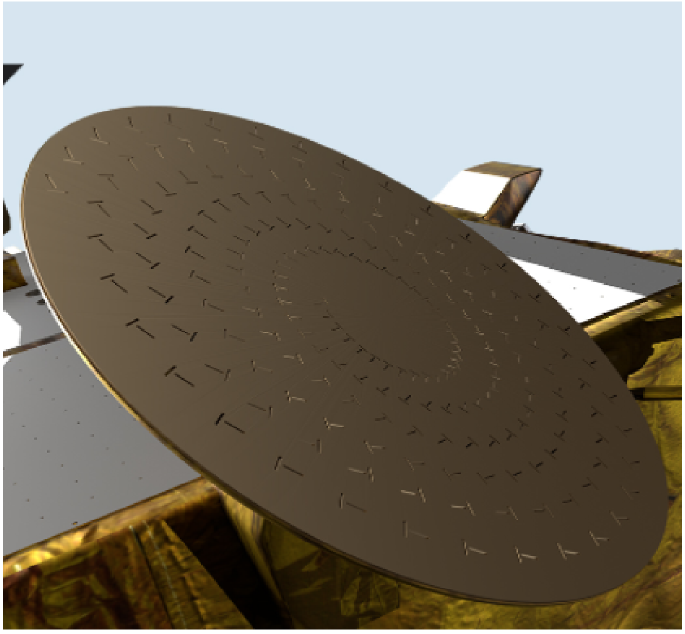
CORE Small Avionics suiTe (CORESAT)

To offer flexible control and data handling for the spacecraft's navigation, image processing, communications, and propulsion systems, the DART avionics system uses a single-board computer and an interface module, both with field-programmable gate array (FPGA)-based electronics.



Radial Line Slot Array (RLSA)

In a compact, planar design, this low-cost, high-gain antenna offers high-efficiency communications. The DART antenna is a novel approach to slot-array technology that has been around for decades but has never been used in this way before. It has the ability to send and receive data.



Chapter 2
Current Status & Timelines

DART's Timeline

MARCH 2021:- Outfitting the DART Spacecraft with Thermal Blankets

Building a spacecraft necessitates the collaboration of numerous teams and individuals, each of whom plays a critical part in getting a mission off the ground. Elisabeth Abel is the DART mission's primary thermal engineer. She is in charge of the spacecraft's thermal design and analysis, thermal hardware acquisition, fabrication and installation, and thermal testing. Thermal blankets are a vital part of prepping a spacecraft like DART for its journey through space since they can keep it warm or cool depending on the conditions.

May 2021:- Testing for Electromagnetic Interference on DART

Ken Watson, DART's lead engineer for electromagnetic compatibility and interference, creates specifications and tests to ensure that the spacecraft's many electronic systems work before and after launch. Because a spacecraft is not normally evaluated as a whole until just before launch or, in some cases, even after launch, this effort is crucial. It's critical for the team to spot any issues early on so that the spacecraft can continue collecting valuable science data.

July 2021:- SMARTNav: Giving Spacecraft the Power to Guide Themselves

When NASA's Double Asteroid Redirection Test (DART) spacecraft starts its final mission phase, it will see nothing but a few very weak spots of light in a 4-megapixel image. It's been four hours and is around 54,000 to 61,000 miles away from its target, a tiny asteroid moonlet named Dimorphos, whose orbital path DART will significantly change. A small maneuvering error at this distance might mean the difference between hitting Dimorphos and speeding past it at almost 13,000 mph. DART won't even be able to see Dimorphos until around an hour before the collision, and maximizing the likelihood that DART hits this dim, mostly unknown asteroid requires a new navigation system that can direct a spacecraft entirely on its own without any human intervention.

SMART Nav is a suite of computing algorithms on DART that, in conjunction with the rest of the spacecraft's guidance and navigation system, will detect Dimorphos and navigate the spacecraft into it independently. Scientists recognised from the start of DART's development that it would require an autonomous component, but it had to be unlike anything else on the market — something that could self-inform and make judgments on its own.

"With SMART Nav, it's no longer just about maintaining a predetermined orientation or performing correction operations. Mark Jensenius, a guidance and navigation control engineer on the SMARTNav team at the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland, said, "It's about conducting the entire last four hours of the mission without any human interference." "It's about finding objects in space, picking the right asteroid, calculating trajectory corrections, and directing movements on the fly to meet the higher-level directive of 'strike Dimorphos.'"

August 2021:- DART Gets Its Wings: Spacecraft Integrated with Innovative Solar Array Technology and Camera

DART is starting to look like the brave spacecraft that will shoot itself directly into an asteroid next fall, perched atop a stand in the middle of a high-ceilinged sterile room. The spacecraft is nearly fully integrated with the addition of its compact Roll-Out Solar Arrays (ROSA) coiled into two gold cylinders that flank the spacecraft's sides, as well as its less visible but still critical imager, the Didymos Reconnaissance and Asteroid Camera for Optical (DRACO) navigation tucked safely beneath its panels.

DART will complete its 10-month voyage toward its asteroid target using a mix of existing and new technologies, some of which will be shown for the first time.

The Double Asteroid Redirection Test, or DART, is a carefully planned demonstration that will help NASA determine whether kinetic impactor technology, which involves flying a spacecraft directly into a small solar system body at speeds of around 15,000 miles per hour with the goal of changing its course, can serve as a reliable method of asteroid deflection in the event that such a hazard ever approaches Earth. NASA is continually scanning the skies and has already detected about 40% of potentially hazardous asteroids larger than 140 meters (459 feet), none of which are expected to collide with Earth, including the binary system chosen for this first-ever deflection test.

The DART mission, however, will attempt to push an asteroid and safely adjust its orbit in space to demonstrate that our planet can handle the unexpected. The spacecraft for this mission has been developed and manufactured at the Johns Hopkins Applied Physics Laboratory (APL) in Laurel, Maryland, during the past two years. The spacecraft is now being finished by APL, which is leading the project for NASA.

ROSA and DRACO, which were just put on the spacecraft, are two crucial technologies that will allow it to travel through space and reach the Didymos asteroid system. Despite their size, the flexible and rollable modular "wings" are lighter, more compact, and stiffer than standard solar arrays; in orbit, each array will progressively unfold to a length of 28 feet, roughly the length of a bus. The equipment was successfully tested on the International Space Station (ISS) for the first time in 2017, and upgraded versions were installed in June for full-time use on the station. The new arrays will be flown for the first time on DART, clearing the door for their usage on future missions. Redwire created the technology at their plant in Goleta, California, and delivered ROSA to APL in May, working closely with the APL team in the weeks following to safely place them onto the spacecraft. While DRACO isn't wholly "new" (it was inspired by the New Horizons LORRI camera), it will be the spacecraft's only instrument. It will play a critical role in assisting DART in navigating through space and identifying the correct asteroid to aim for when combined with the autonomous navigation programme SMART Nav (Small-body Maneuvering Autonomous Real-Time Navigation).

"Traditional navigation approaches would only get DART within around 9 miles of the target asteroid," stated DRACO lead engineer Zach Fletcher of APL. "We need to eliminate the rest of that inaccuracy by onboard optical navigation in order to meet our mission objectives." DRACO begins sending photos to DART's onboard autonomous guidance system more than 50,000 miles from its target, four hours before the impact, and is critical to DART's kinetic impact on Dimorphos."

The photos of the target asteroid Dimorphos returned by DRACO, including a last-second look of the asteroid's own impact site, will be critical in assessing the DART test results and comprehending how the asteroid was harmed.

DART has been put through its paces over the previous few months, undergoing a battery of environmental testing and analysis as the craft's final elements began to fall into place. Similarly, the SMART Nav programme has undergone extensive testing, allowing the team to confidently hand over control of DART in the final hours before it collides with Dimorphos. The DART spacecraft completed vibration testing in late July with DRACO and ROSA on board to check that all of its hardware is safe and ready for the rigors of launch.

The Italian Space Agency's Light Italian CubeSat for Imaging of Asteroids, or LICIACube, will be one of the final components to board DART before it is transferred to the launch site in October. LICIACube will launch around five days before the DART impact, capturing photographs of the spacecraft's final moments, the ejecta plume, and the asteroid's rear side that DRACO will never witness.

"DART is the culmination of years of hard effort by a devoted team and partners who overcame unique difficulties to achieve firsts in both technological development and planetary protection," stated Betsy Congdon, DART mechanical engineer and team leader during the installation. "We're quite optimistic that DART is ready to complete its final system testing and evaluations before shipping to the launch site, thanks to the successful installation and testing of two crucial technologies, DRACO and ROSA."

The spacecraft will launch in November from Vandenberg Space Force Base near Lompoc, California, on a SpaceX Falcon 9 rocket. DART will target Dimorphos, the smaller moonlet orbiting the larger Didymos asteroid, in the fall of 2022. The moonlet's orbit around the parent body will be sped up by several minutes as a result of its collision with Dimorphos. Despite being 6.8 million miles from Earth at the time of collision, the asteroid system will be visible to ground-based observatories, allowing scientists to measure the exact shift in orbital period.

October 2021:- DART Gets Its CubeSat Companion, Its Last Major Piece

The Light Italian CubeSat for Imaging Asteroids, or LICIACube, was ready for installation on NASA's Double Asteroid Redirection Test (DART) spacecraft, dangling from a crane inside one of the high bays at the Johns Hopkins Applied Physics Laboratory (APL) in Laurel, Maryland. The 6U CubeSat, weighing 31 pounds (14 kilograms) and measuring roughly the length of an adult's hand and forearm, was carefully moved into place by a team of American and Italian engineers.

The team spent about an hour getting the box perfectly positioned and screwing in the final bolt. However, by 10 a.m. on Wednesday, Sept. 8, LICIACube was fully integrated, completing months of environmental tests and analysis as each of DART's components was mounted.

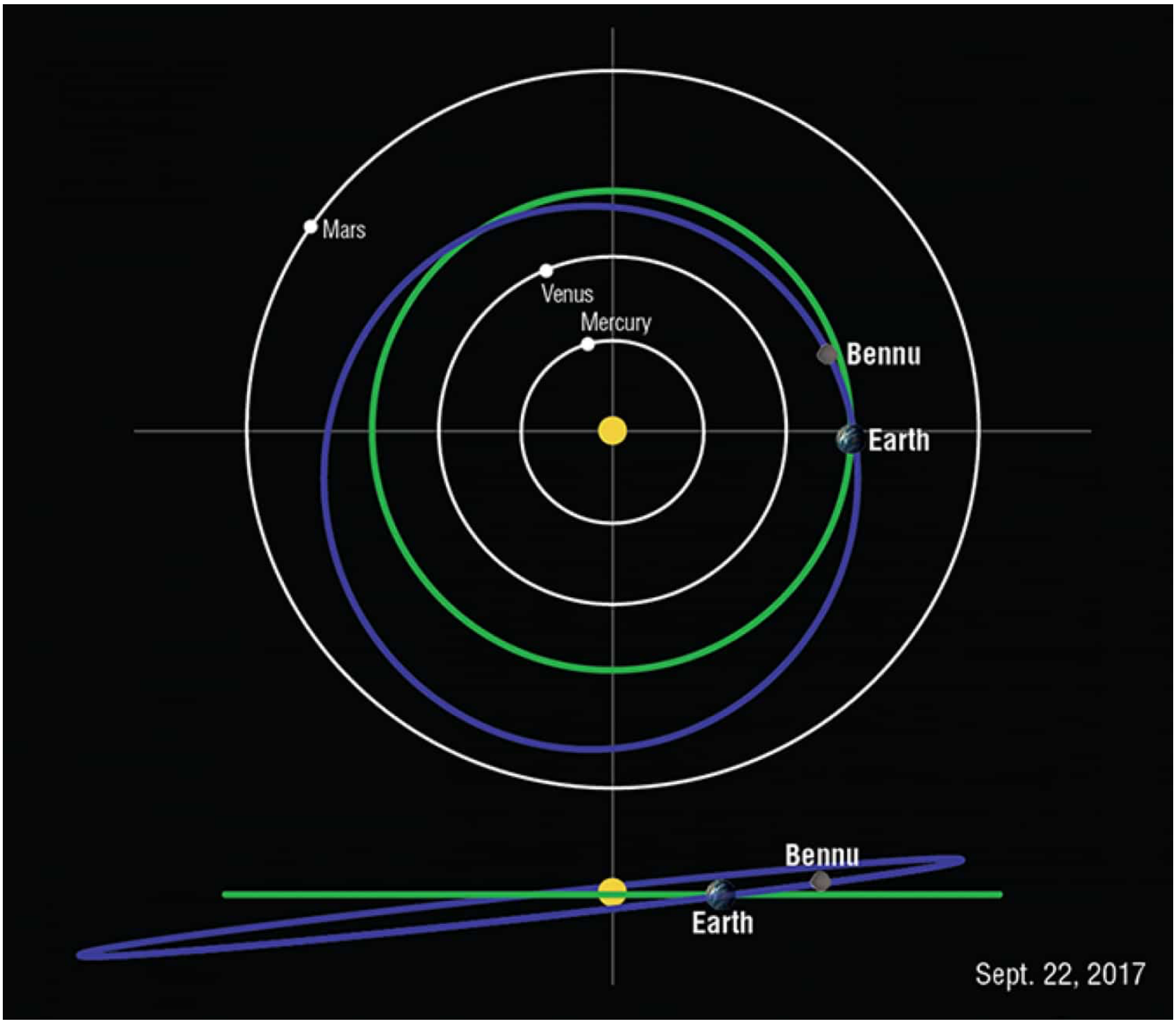
LICIACube, which was funded by the Italian Space Agency (ASI) and conceived, manufactured, and maintained by the Italian aerospace engineering firm Argotec, is responsible for monitoring DART's final maneuver - an intentional collision with an asteroid - and its consequences.

DART's mission goal, which was developed, built, and is managed by APL, is to see if crashing a spacecraft into a tiny solar system body at speeds of around 15,000 miles per hour could be a reliable method of deflecting an asteroid if one were ever detected on a collision course with Earth.

The CubeSat will launch 10 days before DART's kinetic impact, launching at a speed of 2.5 miles per hour from its spring-loaded box. LICIACube will then use its onboard propulsion system to change its course, offsetting itself so that it flies past Dimorphos three minutes after the DART collision. Because of the delay, LICIACube will be able to take photographs of the impact's aftermath, including as the ejecta plume and perhaps the freshly formed impact crater, as well as the backside hemispheres of Didymos and Dimorphos, which DART will miss.

DART departed for Vandenberg Space Force Base near Lompoc, California, in the latter week of September, with plans to launch in late November on a SpaceX Falcon 9 rocket. In the fall of 2022, the spacecraft will collide with Dimorphos, changing the duration of the moonlet's 12-hour orbit around the parent body by several minutes. Ground-based telescopes will be used to determine the exact change in orbital period. Over the months following DART's collision, LICIACube's X-band communication system will transmit the spacecraft's pictures back to Earth.

Current position of Bennu



Bennu is currently 291,325,637 km from us, traveling at a speed of 10 km relative to us. Every second it gets 10km/s closer. Since midnight last night, it has traveled 556,339 km. Since you started looking at this page it has traveled 7,315 km.

It is expected to pass by Earth on Sep 25, 2135, which is around 41,000 days from now. According to current calculations, the spacecraft will pass within 367,353 kilometers of Earth, which is 1x the distance between the Earth and the Moon. The probability of colliding with the Earth is 1 in 2,700. Although the chances appear to be in our favor, if the projections are incorrect, Bennu, a 79 billion kilogram space rock, might collide with Earth in a massive impact.

A meteor impact should only happen once or twice every century, according to theory. However, due to the incompleteness of the near-Earth-object (NEO) catalog, an impact could happen at any time. Thousands of NEOs larger than 140m have yet to be discovered.

Chapter 3
Velocity & Collision Analysis

Position Of Striking The Spacecraft and Bennu

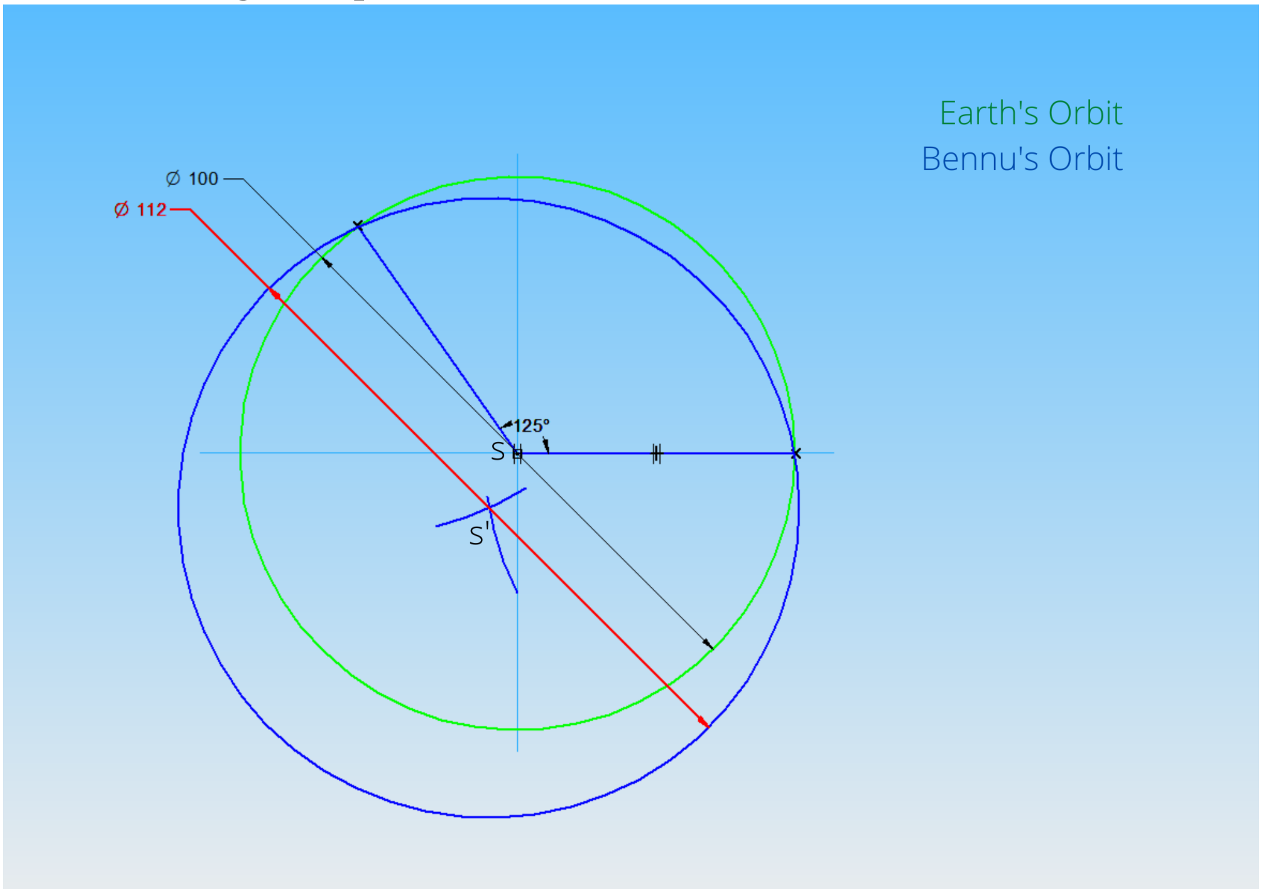


Image Scaling: 1cm = 30 Million Kms

Derivation Of Average Launch Velocity

Assumptions Made:

- Bennu and Earth orbit around the sun in Circular orbits.
- Both the bodies maintain uniform velocities in their orbit [dv/dp =0].
  Where 'p' is the position, a function of x & y coordinates.
- Bennu has an apparent position of the Sun about which it orbits.
- The orbits of Bennu and Earth are in the same plane.

Observational Data:

- Radius of Earth's orbit around the Sun = 149.6 Million kms
- Radius of Bennu's Orbit around the Sun = 168 Million kms
- Linear Velocity of Earth = 30 km/s
- Linear Velocity Of Bennu = 28 km/s
- Cycle period of Earth = 365 days = 3.154e+7 seconds
- Cycle period of Bennu = 436 days = 3.767e+7 seconds

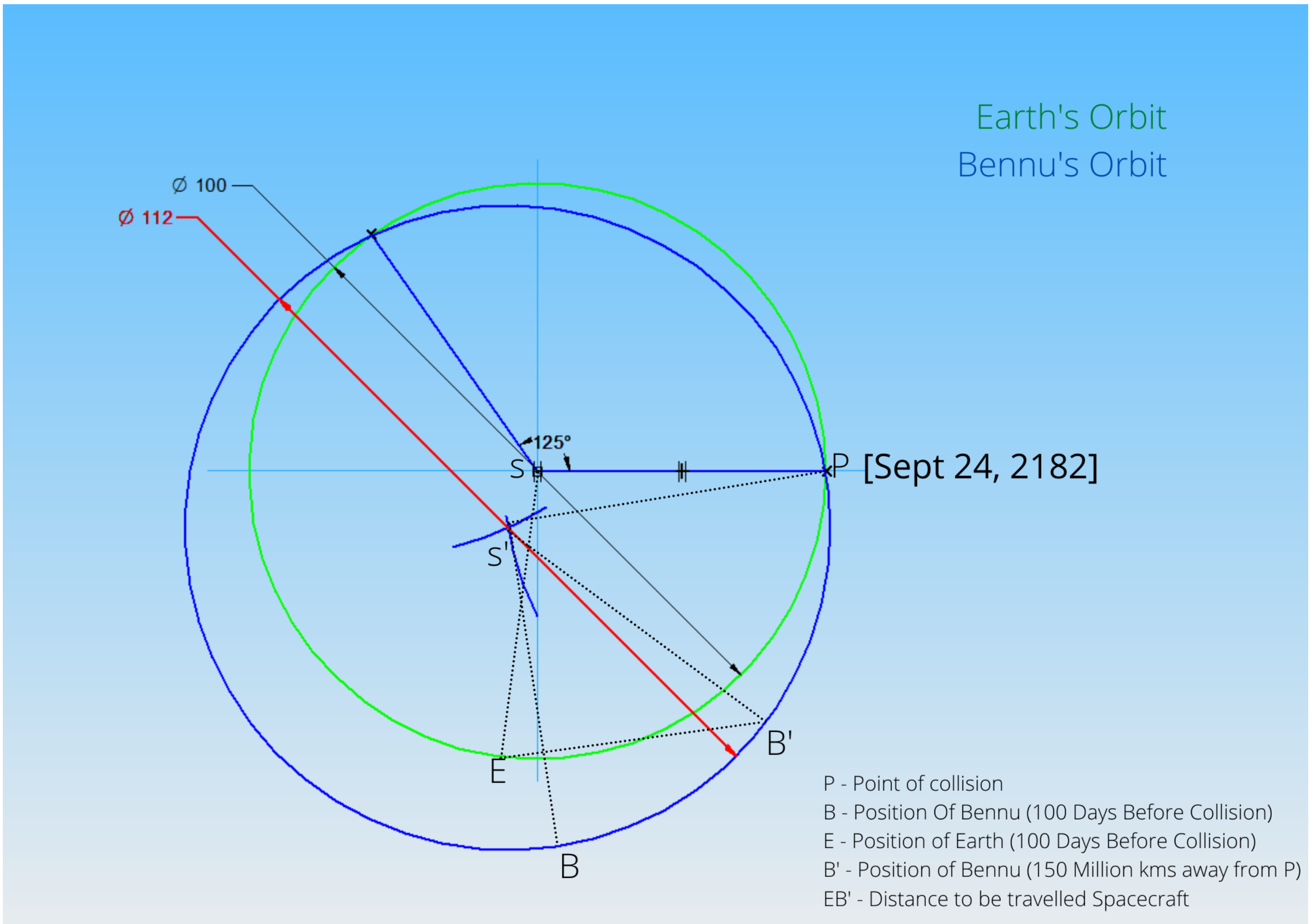
C - Code To Find Out The Average Velocity Of Spacecraft

```
#include <stdio.h>
#include <math.h>

float distEP (int n, float cEO)
{
 return cEO * n / 365;
}

float distBP (int n, float cBO)
{
 return cBO * n / 436;
}

float theta (float l, float r)
{
 return l / r * 57.296;
}

int main ()
{
   float pi = 3.141592654;
   float rEO = 149600000;      //radius of Earth's Orbit around Sun (in km)
   float rBO = 168000000;      //radius of Bennu's Orbit around Sun (in km)

   float sE = 30;              // Speed of Earth = 30 km/sec
   float sB = 28;              // Speed of Bennu = 28 km/sec

   // float sED = 2419200; // Speed of Earth (in km/day)
   // float sBD = 2592000; // Speed of Bennu (in km/day)

   float cEO = 2 * pi * rEO;   // Circumference of Earth's orbit
   float cBO = 2 * pi * rBO;   // Circumference of Bennu's Orbit

   printf ("Circumference Of Orbit Of Earth: %0.2f Kms\n", cEO);
   printf ("Circumference Of Orbit Of Bennu: %0.2f Kms\n\n", cBO);

   /* So @ time of Collision (Sep 24, 2182)
     Both Bennu & Earth are in the exact same location
     We can find out where they will be 'n' days before the Collision
```

```
    By approximating

    365 days before Collision, Earth is cEO kms away from the point &
    436 days before collision, Bennu is cBO kms away from the point

    100 days before collision;
    Earth = cEO*100/365;
    Bennu = cBO*100/436;
  */

  int n;
  printf ("Enter days before collision (Within 365 Days) : ");
  scanf ("%d", &n);

  float dEP = distEP (n, cEO);
  printf ("\nEarth is %0.2f kms away from Point Of collision\n", dEP);

  float dBP = distBP (n, cBO);
  printf ("Bennu is %0.2f kms away from Point Of collision\n\n", dBP);

  // Angle made by the (line joining the bodies & sun) & (line joining P and Sun)
  // l = r * theta ; l-> length of arc (dBP,dEP), r -> radius (rEO,rBO), theta-> angle (in radians)
  // theta = (l/r * 57.296) Deg

  float thetaEP = theta (dEP, rEO);
  printf("Angle made by Earth wrt collision Point with Sun as Center: %0.2f Deg\n",thetaEP);

  float thetaBP = theta (dBP, rBO);
  printf("Angle made by Bennu wrt collision Point with Sun as Center: %0.2f Deg\n\n",thetaBP);


  // if we want to strike the asteroid at 'd' distance from collision Point
  float d;
  printf("Enter the desired distance of Bennu from Collision (Asteroid & Earth) point before Strike (Asteroid
& Spacecraft) in Million kms: ");
  scanf("%f", &d);
  d = d*1000000;

  float thetaB2P = theta(d,rBO);
  printf("\nAngle made by Position B' wrt P with Sun as the Center is: %f Deg\n",thetaB2P);

  // Time taken By Bennuto reach from B -> B2
  float timetaken = (dBP - d)/sB;
  printf("Time Taken by Bennu to Reach from B -> B' is: %0.2f  Seconds OR %0.2f Days\n\n", timetaken,
timetaken/86400);
```

```
// Speed required = distance / timetaken
float dEB2;
printf("Enter the distance EB' (From the graph- In Million Kms): ");
scanf("%f", &dEB2);
dEB2 = dEB2*1000000;

float sr = dEB2/timetaken;
printf("\nMinimum Average Speed Required to reach Bennu is %0.2f Km/s\n",sr);


return 0;

}
```

Using the above formula, we can know the minimum average velocity of Spacecraft required to make a strike with Bennu.



Inputs:

- Launch date = 100 Days Before Collision
- Distance at which Spacecraft will strike Bennu = 100 Million kms
- Distance to be traveled by Spacecraft EB' from Graph = 5.7 cms
  = 5.7 * 30 = 171 Million kms

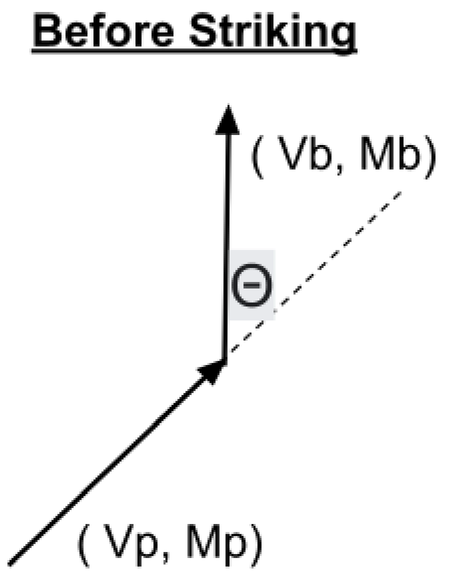
```
Circumference Of Orbit Of Earth: 939964544.00 Kms
Circumference Of Orbit Of Bennu: 1055575168.00 Kms

Enter days before collision (Within 365 Days) : 100

Earth is 257524544.00 kms away from Point Of collision
Bennu is 242104400.00 kms away from Point Of collision

Angle made by Earth wrt collision Point with Sun as Center: 98.63 Deg
Angle made by Bennu wrt collision Point with Sun as Center: 82.57 Deg

Enter the desired distance of Bennu from Collision (Asteroid & Earth) point before
Strike (Asteroid & Spacecraft) in Million kms: 100

Angle made by Position B' wrt P with Sun as the Center is: 34.104763 Deg
Time Taken by Bennu to Reach from B -> B' is: 5075157.00  Seconds OR 58.74 Days

Enter the distance EB' (From the graph- In Million Kms): 171

Minimum Average Speed Required to reach Bennu is 33.69 Km/s
```

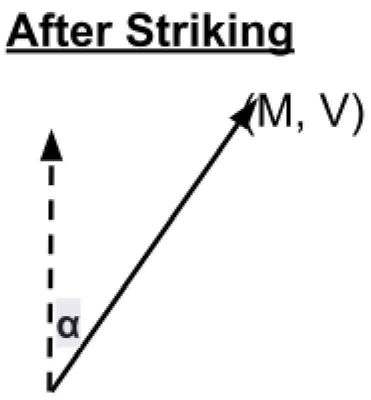
Output:

- Minimum Speed required by Spacecraft = 33.69 km/s
- Time taken = 5075157 seconds = 58.74 days

Momentum Conservation During The Strike

During the strike, the total momentum of the system will be conserved, using this relation, we can calculate the angle and velocity at which the strike should take place for Bennu to get deflected by a desired angle.





Vp = Velocity of projectile
Mp = mass of projectile
Mb = mass of Bennu = 78 Billion kg
Vb = velocity of Bennu = 28 km/s
V = Velocity of System after collision
M = Mb+Mp = total mass of system after collision

Assumptions Made:

- The spacecraft will merge into the asteroid after collision.
- No energy is lost due to collision, and gravitational force effects.
- Ignoring the effects of **Yarkovsky thrust.**
- No mass is detached from the asteroid during collision.

Along Vertical Axis: $Mb*Vb + Mp*Vp*Cos\theta = M*V*Cos\alpha$

Along Horizontal Axis: $Mp*Vp*Sin\theta = M*V*Sin\alpha$

Yarkovsky Thrust

The Yarkovsky effect occurs when the temperature of an object warmed by radiation (and thus the intensity of thermal radiation from the object) lags behind changes in the incoming radiation. That is, when the object is first lit, it takes time for the surface to warm up, and it takes time for the surface to cool down when the lighting is turned off.

Solar radiation warms the surface of a spinning body lit by the Sun (such as an asteroid or the Earth) during the day and cools it at night. Because there is a lag between the absorption of radiation from the Sun and the release of radiation as heat due to the thermal characteristics of the surface, the warmest point on a rotating body occurs around the "2 PM" site on the surface, or slightly after noon. This causes a difference in the directions of radiation absorption and re-emission, resulting in a net force along the orbit's motion direction. If the object is a prograde rotator, the force acts in the orbit's motion direction, causing the orbit's semi-major axis to progressively increase; the object spirals away from the Sun. The rotator of a retrograde rotator spirals inwards. For bodies larger than 100 m in diameter, this is the most important factor.

Using the given equations we can determine the velocity and angle at which the strike should take place to get the desired angle of deflection in Bennu's orbital path, where Mp will be known.

Chapter 4
Conclusion

The purpose of this experiment is to determine the required velocity and angle of the payload just before striking the asteroid, which can be determined using the equations given in Chapter 3. While we may succeed in obtaining the values, we have to keep in mind that the solutions obtained will be effective only as long as the assumptions are, once the assumptions start getting too vague, the solution will no longer be helpful. Some of the assumptions made during these calculations may cause major problems, which we hope will be solved with the use of better and more accurate technologies. Determining the position and speed of the asteroid at any point is a crucial step to plan the launch, and it also plays a major role in determining the required speed of the spacecraft. An important note to be mentioned is that, in Chapter 3, during the derivation of Minimum average velocity required, the spacecraft is assumed to be traveling in a straight line from Earth to Bennu, which is not possible in the real world. We would like to omit these assumptions and make calculations aligned more towards the real scenarios in the upcoming times, when we have a better understanding of Space Dynamics, Gravitational Effect, Space fabrication, and Energy due to the Sun's heat.

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