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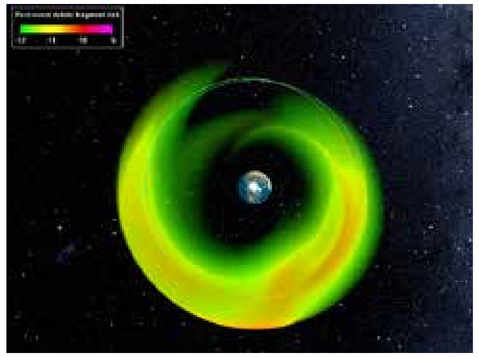
# SIMULATION *Accelerates Space Exploration*

Ansys

# Simulation Helps Keep NASA Satellites in Orbit

By Laura Carter, Staff Writer, Ansys Advantage



CAM GEO-Post-Collision-Debris

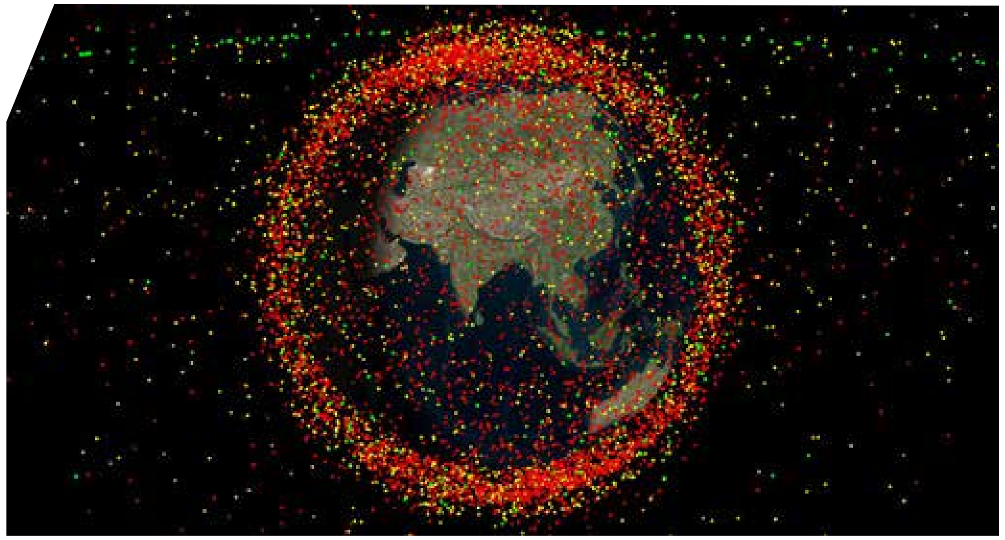
Right now, there are thousands of satellites orbiting Earth, and several orbiting the Moon. We need them for weather monitoring, GPS navigation, the internet, and for space-based surveillance critical to national security, among other things. Like too many cars on a congested freeway, satellites are crowding into the same space — but they're traveling at thousands of miles per hour.

To make matters worse, all this activity is happening with few formal standards or controls in place. As the number of satellites in orbit continues to grow, any collision event only compounds matters by creating debris for other spacecraft to avoid.

To address these risks, efforts are underway to publish standards and behavioral norms to follow when sending a satellite into orbit. For instance, NASA has published the "NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook." Similarly, the United States Space Command (USSPACECOM) published a "Spaceflight Safety Handbook for Operators," which details processes for on-orbit conjunction assessment and collision avoidance. In addition, the Federal Aviation Administration (FAA) and the Federal Communications Commission (FCC) review operators' collision avoidance plans before granting launch and operating licenses.

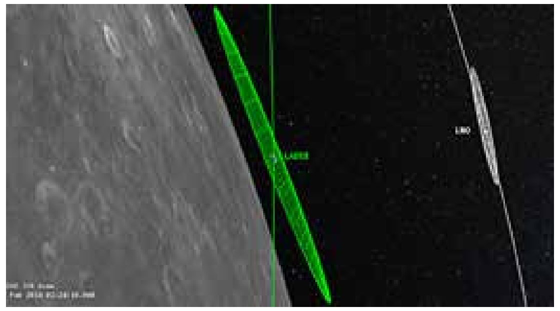
Spacecraft operators are also promoting safe operations protocols — and in fact, Ansys is one of many companies that endorsed the Space Safety Coalition's "Best Practices for the Sustainability of Space Operations." The aim of this publication is to create industry standards and improve collaboration around the world to mitigate the growing space debris problem. Still, many satellite operators have questions about how to respond to these recommendations.

"The tricky part is how do you implement these safe and sustainable best practices," says John Carrico, owner and CTO of Space Exploration Engineering (SEE), which has designed, planned, and operated a number of satellite missions.



**An Ansys Systems Tool Kit (STK) simulation of the thousands of satellites and debris pieces floating in orbit around Earth**

"We know that each satellite operator has the goal of making sure their spacecraft can accomplish its mission. The fortunate thing is that when the satellite operations team performs their job in a non-negligent way, it not only keeps their mission safe, but it also prevents harm and interference with other spacecraft. While it's easy to say we want to



**Ansys Systems Tool Kit (STK) image of the orbit geometry of the NASA LADEE, provided by Ansys Orbital Determination Tool Kit (ODTK), and LRO spacecraft near their closest approach on February 27, 2014**

perform operations in a sustainable way, it actually requires carefully planned activities that rely on precise calculations, and Ansys software has been specifically designed to enable this."

### SIMULATION YIELDS SAFER PASSING DISTANCES FOR NASA SATELLITES

In February 2014, Carrico, as part of the flight dynamics team for the NASA Lunar Atmosphere and Dust Environment Explorer (LADEE) satellite, was at NASA's Ames Research Center doing orbit determination and planning maneuvers. An important element of Carrico's job was using Ansys Systems Tool Kit (STK) and Ansys Orbit Determination Tool Kit (ODTK) to analyze the trajectories of satellites in space, then planning a collision avoidance maneuver (CAM) to prevent them from making unwanted contact with other satellites or space debris.

Originally there was an orbit maintenance maneuver scheduled for LADEE later that month. After the team shared the satellite's anticipated trajectory based on an exchange of predicted ephemeris files (tables of astronomical positions of spacecraft trajectories at a particular time), it appeared that LADEE and another spacecraft — the Lunar Reconnaissance Orbiter (LRO) — were going to come too close for comfort. The inherent uncertainty in the predicted orbits made the probability of collision too risky to ignore.

At the time, both satellites were orbiting the Moon. The job of the LRO[1] was to map the Moon's surface, enabling discoveries about the origin and evolution of Earth and the solar system, while LADEE[2] gathered information about the structure and composition of the lunar atmosphere. It was important scientific work. A collision would have brought these efforts to a permanent halt, costing NASA two satellites worth hundreds of millions of dollars and adding more debris for other satellites to avoid. Relying on the predictions from STK and ODTK, the LADEE and LRO teams came together and decided to cancel an originally scheduled collision avoidance maneuver, thereby enabling the spacecraft to pass each other at a safe distance.

Scenarios like this aren't "one-and-done" situations by any means. Commercial and federal spacecraft operators maintain dedicated teams that receive continual updates on the position of satellites relative to each other and any detectable space debris as they orbit Earth or the Moon, to avoid the possibility of collision.

Every satellite will most likely encounter other satellites or debris multiple times over the course of its travels. Sometimes the best course of action is no action, while other times, mitigation requires a maneuver. These maneuvers must be planned well in advance — anywhere from a few hours to a week — based on predictions using simulation.

## DID YOU KNOW?

In addition to supporting NASA and other organizations in their launch efforts, Ansys also works with companies that are using simulation to remove objects from orbit. These companies are exploring ideas for devices like satellite nets, robotic arms, and magnetic grappling hooks — there are even sponge-like materials being designed to reduce the speed of shrapnel and trap it to mitigate the risk of collision with a spacecraft.

**REFERENCES:**
1. Lunar Reconnaissance Orbiter (nasa.gov)
2. LADEE - Lunar Atmosphere Dust and Environment Explorer | NASA
3. Explained: How India's Lunar Orbiter Chandrayaan-2 avoided Collision with NASA's LRO, WION, updated June 1, 2022.

***"During a collision, the hypervelocity impact and shock waves can rip an entire structure apart. One satellite mission could create dozens of orbital objects including satellites, payload fairings, and spent rocket stages"***

### PLOTTING A DIFFERENT COURSE

When satellites from different agencies are involved, simulation can help fill in the gaps left by a lack of international standards. For example, the Indian Space Research Organization (ISRO), like NASA, has launched a series of spacecraft, including the Chandrayaan-2. The Chandrayaan-2 consisted of a lunar orbiter and a lunar rover, and its objective was to study lunar surface composition and the abundance of water on the Moon. It just so happened that NASA's LRO shared a similar mission.

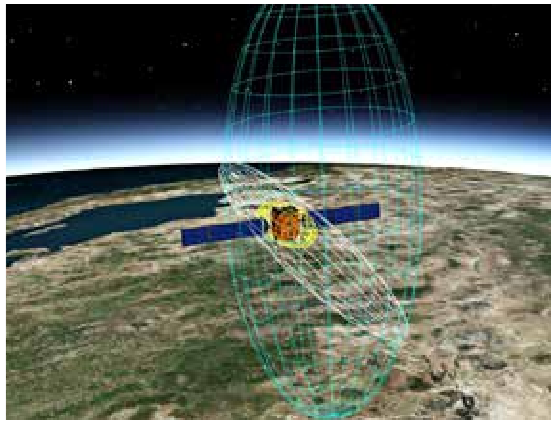
In October 2021, both spacecraft were scheduled to come very close to each other as they were both studying the Moon from a polar orbit. Using STK, the team determined that the spacecraft would be less than 100 meters apart. With support from Ansys software and a mutual agreement with NASA, ISRO executed a CAM based on this information, and it added calculations based on a new orbit that would help both satellites avoid close passes like this in the future.[3]

"In the case of the Chandrayaan-2 orbiter and the LRO, most of the international data available could not necessarily capture the information needed to plot these maneuvers successfully," says Ravnish Luthra, CEO of ITGlobe, an Ansys partner supporting ISRO. "Simulation provided the truest picture of what was happening around the Chandrayaan-2, enabling ISRO to execute a precise CAM and plot a different course for the future."

While the travels of the LRO may not be governed by a definitive set of codified rules, they are supported by a dedicated team of scientists, engineers, and other experts using simulation to make predictions about the trajectory of satellites in space. For them, Ansys simulation delivers real-time, accurate data with near-perfect precision that leads to more positive outcomes.

### MAKING A POSITIVE IMPACT ON SATELLITE COLLISION AVOIDANCE

With so many governments and commercial organizations relying on satellites, we need to contend with the challenges of congestion that could eventually impede our efforts to look beyond Earth's atmosphere. The result of satellite collisions — the tremendous amount of debris they leave behind — has the potential to create even greater congestion, which could lead to even more collisions.



**Iridium 33 - Cosmos 2251 satellite collision debris field reconstructed from measured data using Ansys Systems Tool Kit (STK)**

"During a collision, the hypervelocity impact and shock waves can rip an entire structure apart," says Adam Gorski, Enterprise Account Manager, Aerospace and Defense Sales at Ansys. "One satellite mission could create dozens of orbital objects including satellites, payload fairings, and spent rocket stages. Then there have been collisions where one satellite became thousands of pieces of trackable, potentially catastrophic debris."

While there may not be any universally accepted rules in space now, commercial and federal space operators are working toward establishing clear standards and governance for the space domain. Through collaborative data and models, simulation is helping to build an essential bridge to make space safer for now. And, once those rules are in place, simulation will be essential to complying with them.

# Simulation
## Helps Artemis Keep in Touch and on Track to the Moon

By **Jamie J. Gooch**,
Executive Editor,
Ansys Advantage

In the 1820s Baron Franz von Paula Gruithusen, a German physicist and astronomer, turned his small telescope toward the Moon and saw what he imagined was a city there, which he named Wallwerk. “Imagination will often carry us to worlds that never were,” said the American scientist Carl Sagan more than 150 years later. “But without it we go nowhere.” And in 2022, the first Artemis Moon mission launched, paving the way for humankind to not only return to the Moon after a 50-year absence — but to live and work there.

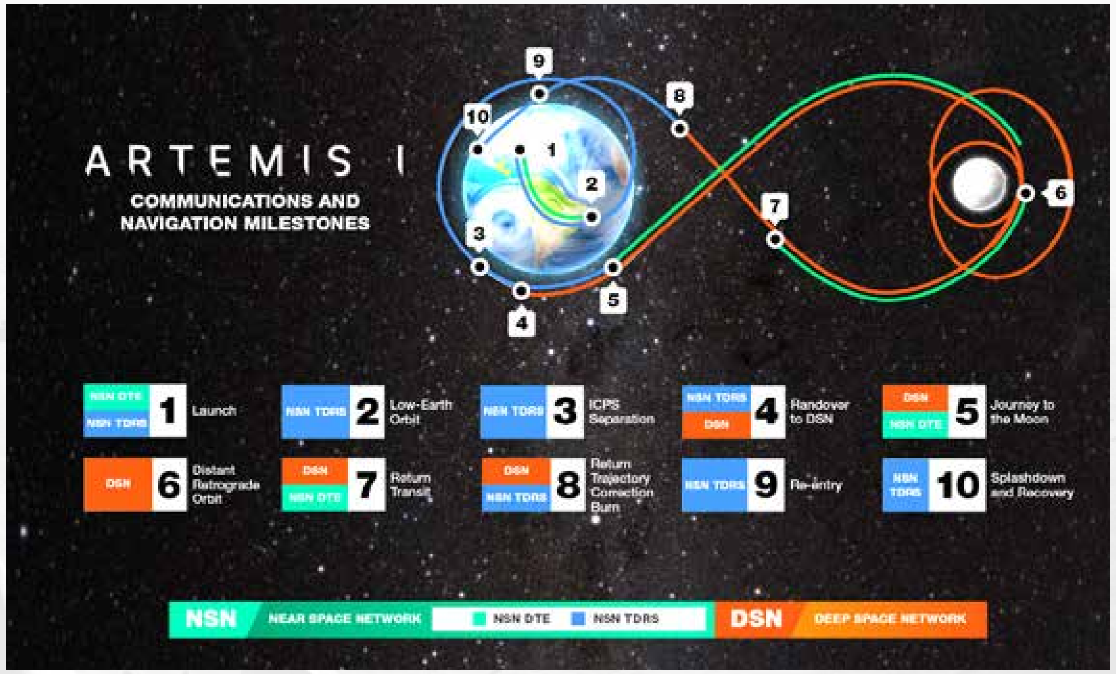
Artemis I is the first of three increasingly complex missions. The uncrewed mission is a test of NASA’s deep space exploration systems, including the Orion spacecraft that will carry astronauts from Earth to lunar orbit and back, the Space Launch System (SLS) rocket — the most powerful rocket in the world — and ground systems needed to support the launch and recovery of the spacecraft after its 1.4-million-mile journey beyond the moon and back. Future missions are planned to land astronauts on the Moon, deploy a spaceship in lunar orbit to act as a long-term gateway to the Moon, and to build a base camp on the Moon. What is learned from the Artemis missions could be used to explore destinations farther from Earth, including Mars.

### CONNECT AND COMMUNICATE

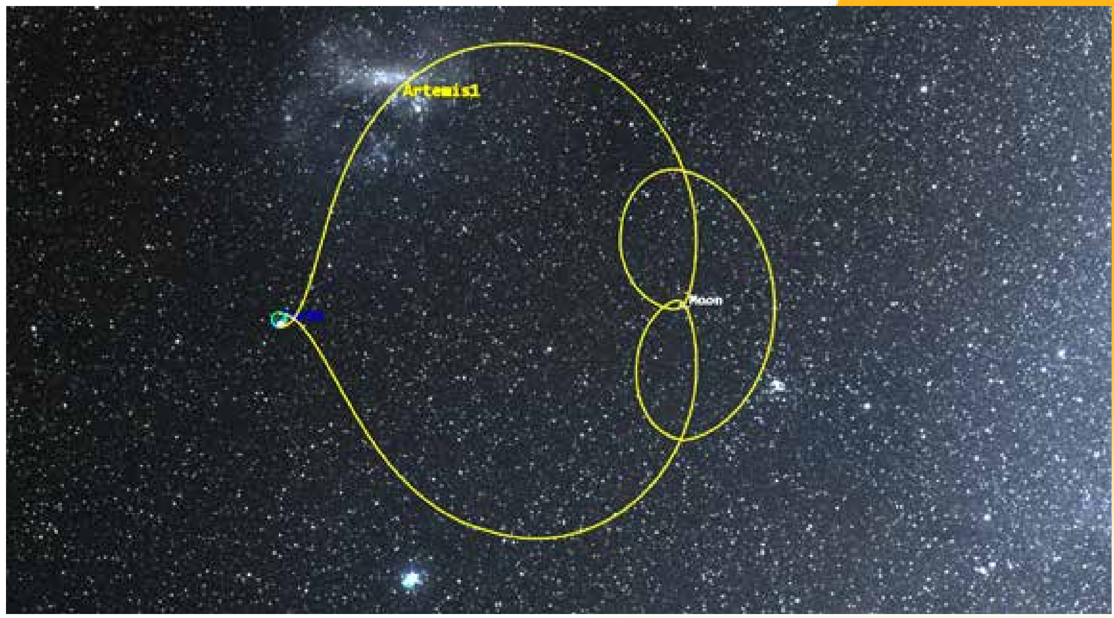
Artemis is a prime example of digital mission engineering (DME), which is defined as the use of digital modeling, simulation, and analysis to incorporate the operational environment and evaluate mission outcomes and effectiveness at every phase of the life cycle. Since its inception, every state in America has made a contribution to the success of the Artemis program, not to mention the systems being designed in Europe. The system complexity and collaboration involved are astounding, and Ansys is proud that our software has played several roles in the Artemis mission.

For example, the RF Communications Team at NASA’s Marshall Space Flight Center routinely uses Ansys HFSS 3D electromagnetic simulation software and Ansys Systems Tool Kit (STK), a physics-based modeling environment for analyzing platforms and payloads. For the Artemis missions, the team is using STK for all of its SLS communication link analysis, and to visualize flight trajectories, contact with ground stations, and antenna radiation patterns.

Seamless communications are critical, of course, to send and receive data at each stage of the mission — enabling flight controllers to send commands to the spacecraft and receive data from Orion, the SLS, and the rocket’s upper stage. Navigation, or tracking, services enable the flight controllers to calculate where the spacecraft are along their trajectory through space.




**NASA’s constellation of tracking and data relay satellites (TDRS) provides near-continuous communications services during launch and the low-Earth orbit phases until the interim cryogenic propulsion stage (ICPS), when the Deep Space Network takes over.** *Image courtesy: NASA*




**A depiction of the Artemis 1 trajectory constructed with STK Astrogator. The animation (right) captures the general structure of the Artemis 1 trajectory and illustrates the unique path the spacecraft follows, a path that harnesses the simultaneously combined gravitational influence of both the Earth and the Moon. Also sharing a ride up with the Artemis 1 spacecraft are several ride-share missions. Some of these missions utilize both the Astrogator capability set within Ansys Systems Tool Kit (STK) as well as the Ansys Orbit Determination Tool Kit (ODTK).**

NASA's communication network is divided into two parts: the Near Space Network (NSN), which links to both Orion and SLS during prelaunch and launch for Artemis I, and the Deep Space Network (DSN), which is used for communications beyond low Earth orbit. The two networks work together to support navigation for Orion via three-way Doppler tracking. With two ground stations on Earth in contact with Orion simultaneously — one from each network — NASA can triangulate Orion's location relative to the ground stations.

**WHAT'S BREWING IN ARTEMIS' SECONDARY PAYLOADS?**

The Artemis missions' ultimate goal is something that has only been seen in science fiction: to establish a long-term presence on the Moon where astronauts can live, explore, and advance our scientific knowledge. But there is a lot of science to be done along the way. Some of that science is being conducted with the help of 10 tiny spacecraft. The 6U CubeSats measure just 10 cm x 20 cm x 30 cm and weigh less than 30 pounds, but they're packed with technology … and yeast, in one instance.

International space agency partners and universities are involved with several of the secondary payloads, which were deployed from the Orion stage adapter after NASA's Orion spacecraft separated and was a safe distance away. To ensure the shoebox-sized spacecraft got where they're going, some of the secondary payloads used the Ansys Orbital Determination Tool Kit (ODTK) for navigation, including BioSentinel and LunIR.

**BioSentinel's microfluidics card, designed at NASA's Ames Research Center in Silicon Valley, California, is being used to study the impact of interplanetary space radiation on yeast. The in-orbit growth and metabolic activity of the yeast will be measured.**
*Image courtesy: NASA/Dominic Hart*

BioSentinel uses single-celled yeast to study the impact of deep-space on living organisms over a long period of time. The CubeSat flew by the Moon to a spot beyond Earth's protective magnetic field. The BioSentinel team at NASA's Ames Research Center are triggering a series of experiments remotely, activating two strains of the yeast *Saccharomyces cerevisiae* to grow in the presence of space radiation. Samples of yeast will be activated at different time points throughout the six- to-12-month mission.

Other CubeSats are being used to map near-surface hydrogen, function as a space weather station, image the Earth's plasmasphere, investigate an asteroid, observe the interim cryogenic propulsion stage with advanced optics, compete in NASA's Space Derby, and even attempt to land the smallest ever (weighing just 700 grams) spacecraft on the Moon. The range of science being carried out by the CubeSats is indeed exciting, including several firsts for humankind.

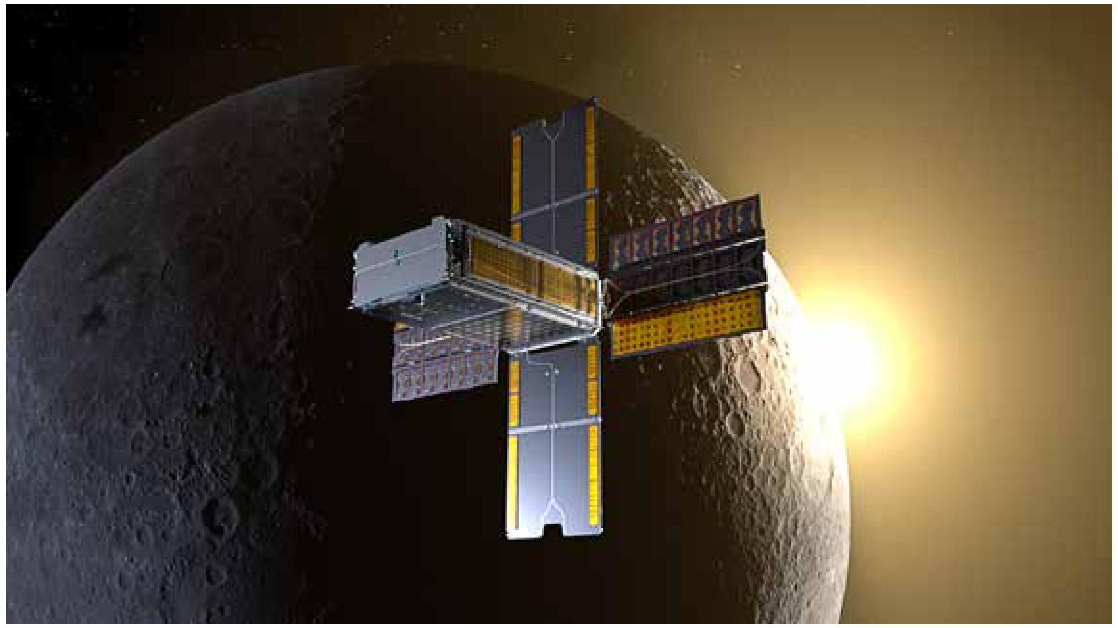


**Illustration of BioSentinel's spacecraft flying past the Moon.**
*Image courtesy of NASA/Daniel Rutter. Image courtesy: NASA*

However, what scientists will learn about safely sending a crew to the Moon and back from the broader mission is difficult to measure. The Artemis I Orion spacecraft splashed down in the Pacific ocean and arrived back at NASA's Kennedy Space Center December 30. It flew farther away than any spacecraft built for humans has ever flown and returned faster and hotter than ever before.

"NASA's Space Launch System rocket has laid the foundation for the Artemis Generation and the future of spaceflight in deep space," said John Honeycutt, SLS Program manager in a press release. "The correlation between actual flight performance and predicted performance for Artemis I was excellent. There is engineering and an art to successfully building and launching a rocket, and the analysis on the SLS rocket's inaugural flight puts NASA and its partners in a good position to power missions for Artemis II and beyond."

Artemis I could lay the foundation for a space economy and for human exploration of ever-more-distant regions of our solar system — something Baron Gruithusen no doubt imagined hundreds of years ago.



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# How the Double Asteroid Redirection Test (DART) Hit a Bullseye

By **Jamie J. Gooch**, Executive Editor, *Ansys Advantage* magazine

Anyone who has played darts knows that it takes some skill to hit a bullseye. You have to account for trajectory, speed, distance, and any anomalies that might stop the dart from flying true. Now imagine if the dart was the size of a bus and the bullseye was seven million miles away — and moving.

On November 24, 2021, NASA and the Johns Hopkins Applied Physics Laboratory (APL) took that shot, hitting a bullseye 10 months later on September 26, 2022. The Double Asteroid Redirection Test (DART), a joint project between NASA and APL, sent a spacecraft hurtling through space at roughly 14,000 miles per hour (22,530 kilometers per hour) to hit an asteroid measuring about 525 feet (160 meters) in width.

> ***"DART is turning science fiction into science fact and is a testament to NASA's proactivity and innovation for the benefit of all."***
>
> — **BILL NELSON**, *NASA Administrator*

Commonly referred to as Earth's first planetary defense test mission, DART aimed to test the kinetic impactor theory to determine if it was possible to change the orbital period of Dimorphos around Didymos, a pseudo-stable binary asteroid system. What does that mean? A slightly simplified and imperfect explanation is that Dimorphos is a moonlet that "orbits" the larger Didymos. The objective was to determine if it's possible to change Dimorphos' speed by the slightest amount. In the event of an asteroid bound for Earth, this nudge could mean the difference between a direct hit and a near miss.

"DART is turning science fiction into science fact and is a testament to NASA's proactivity and innovation for the benefit of all," said NASA Administrator Bill Nelson in a press release. "In addition to all the ways NASA studies our universe and our home planet, we're also working to protect that home, and this test will help prove out one viable way to protect our planet from a hazardous asteroid, should one ever be discovered that is headed toward Earth."

To be clear: Neither Dimorphos nor Didymos posed any hazard to Earth before or after DART's controlled collision with Dimorphos.

Prior to DART's impact, it took Dimorphos 11 hours and 55 minutes to orbit its larger parent asteroid, Didymos. Since DART's intentional collision with Dimorphos on September 26, astronomers have been using telescopes on Earth to measure how much that time has changed. Now, the investigation team has confirmed the spacecraft's impact altered Dimorphos' orbit around Didymos by 33 minutes, shortening the orbit to 11 hours and 23 minutes. This measurement has a margin of uncertainty of approximately plus or minus one minute.

"DART has given us some fascinating data about both asteroid properties and the effectiveness of a kinetic impactor as a planetary defense technology," said Nancy Chabot, the DART coordination lead from APL in Laurel, Maryland, via a press release. "The DART team is continuing to work on this rich dataset to fully understand this first planetary defense test of asteroid deflection."

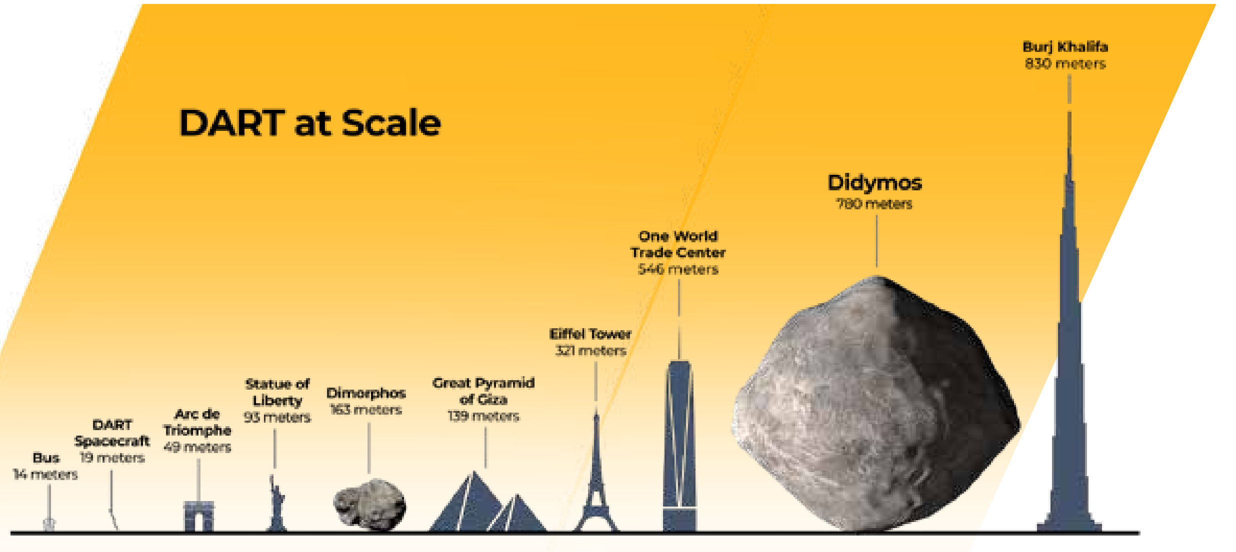
To date, three papers have been written based on analysis of data collected via the DART mission.

**CONFIDENCE THROUGH SIMULATION**

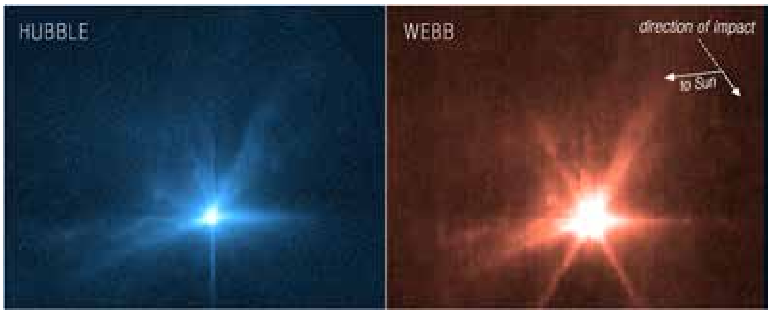
This early mission planning performed by Johns Hopkins APL relied extensively on Ansys Systems Tool Kit (STK). The formulation of

**Illustration of NASA's DART spacecraft and the Italian Space Agency's (ASI) LICIACube prior to impact at the Didymos binary system.**
*Credit: NASA/Johns Hopkins APL/Steve Gribben*

DART's trajectory to the double-asteroid system was largely planned using STK, and the team continued to use STK to visualize relevant vectors and attitude throughout the mission-planning process. The thermal team appreciated STK's full mission environment when checking the location of the Sun relative to the satellite during critical slews and maneuvers.




**Everything is relative. The size of DART and its target — the asteroid Dimorphos — relative to objects on Earth** *Credit: NASA/Johns Hopkins APL*




**These images, from the Hubble Space Telescope on the left and the James Webb Space Telescope on the right, show observations of the Didymos-Dimorphos system several hours after NASA's Double Asteroid Redirection Test (DART) intentionally impacted the moonlet asteroid.**
*Credit: Science: NASA, ESA, CSA, Jian-Yang Li (PSI), Cristina Thomas (Northern Arizona University), Ian Wong (NASA-GSFC); image processing: Joseph DePasquale (STScI), Alyssa Pagan (STScI).*

STK was also used in the DART Mission Operations Center (MOC) from launch until impact. The 3D graphics, physically accurate trajectory, and six-degrees-of-freedom satellite simulation allowed the operations team to visualize the DART trajectory and attitude of the spacecraft. STK also helped the team visualize thruster pulses performed by the satellite as it used its onboard automatic control system to navigate to the asteroid system.

### EYES IN SPACE

One aspect of this mission that some may overlook is that footage of this event was livestreamed from the DART spacecraft using its imager — the Didymos Reconnaissance and Asteroid Camera for Optical navigation (DRACO).

As part of this same mission, LICIACube, an Italian CubeSat, monitored the collision and sent images back in the days, weeks, and months that followed.

The James Webb Space Telescope, another incredible feat that relied on Ansys solutions, and the Hubble Space Telescope were also able to observe from a distance by capturing the collision across a wide array of wavelengths, which provided the first signs that the impact was much greater than anticipated.

## DART by the Numbers

After a **10-month journey** of almost **7 million miles** (11 million km) in space, a **1,345-pound** (570-kg) spacecraft, traveling at **14,764 mph** (23,760 kph), hit a **525-foot-wide** (160 meters) asteroid after flying autonomously for the final **4 hours** and altered the asteroid's orbit by **33 minutes.**