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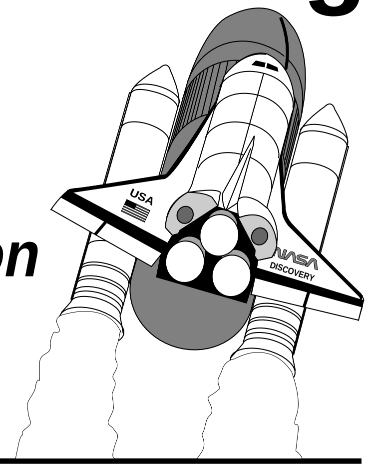



## *Tethered Satellite — Forces and Motion*

## Video Resource Guide

VRG-010-2/95

**Topic:** Physical Science
**Recommended Level:** 9-12
**Video Length:** 21:11
**Description:** Demonstrates and explains the application of forces and motion as they relate to tethered satellite deployment.

**Shuttle Mission Facts**
Orbital scenes were taken during the STS-46 mission.
**Orbiter:** *Atlantis*
**Mission Dates:** July 31-August 8, 1992
**Commander:** Loren J. Shriver (Col., USAF)
**Pilot:** Andrew M. Allen (Maj., USMC)
**Payload Commander:** Jeffrey A. Hoffman (Ph.D.)
**Mission Specialist:** Franklin R. Chang-Diaz (Ph.D.)
**Mission Specialist:** Marsha S. Ivins
**Mission Specialist:** Claude Nicollier (ESA)
**Payload Specialist:** Franco Malerba (Ph.D.) (ASI)
**Mission Duration:** 7 days, 23 hours, 16 minutes
**Distance Traveled:** 5,393,500 kilometers
**Orbit Inclination:** 28.45 degrees
**Number of Orbits:** 127
**Orbital Altitude:** 229 kilometers
296 kilometers
426 kilometers

**Payloads and Experiments:**
- Tethered Satellite System (TSS)-1
- European Retrievable Carrier (EURECA)-1L
- Evaluation of Oxygen Interaction With Material/ Two Phase Mounting Plate Experiment (TEMP)
- Consortium for Materials Development in Space Complex Autonomous Payload (CONCAP)
- Limited Duration Space Environment Candidate Materials Exposure (LDCE)
- Pituitary Growth Hormone Cell Function (PHCF)
- IMAX Cargo Bay Camera (ICBC)

## Background

Following a perfect launch on July 31, 1992, the Space Shuttle *Atlantis* and its international crew of seven astronauts reached a 426-kilometer-high orbit to begin an ambitious schedule of deploying a retrievable free-flying satellite and a tethered satellite. The crew included a mission specialist from the European Space Agency and a payload specialist from the Italian Space Agency.

Upon arrival in orbit, the crew began two-shift, around-the-clock operations to prepare the satellites for release. Following operations with the EURECA satellite, the crew lowered the orbit of *Atlantis* to 296 kilometers for the deployment of the Tethered Satellite System.

The Tethered Satellite System is a joint venture of the United States' National Aeronautics and Space Administration (NASA) and Italy's Agenzia Spaziale Italiana (ASI, the Italian Space Agency). Both NASA and ASI sponsored experiments to address the goals of the TSS-1 mission. ASI developed the reusable satellite, while NASA's responsibility included developing the deployer system and the tether, integrating the payload, and providing transportation into space.

The primary objective of the mission was to demonstrate the technology of long tethered systems in space and to demonstrate, through scientific investigations, that such systems are useful for research.

Manipulating a satellite on a tether from the orbiter is a unique engineering challenge. Because gravity, centrifugal acceleration, and atmospheric drag vary with altitude, each of the two bodies in a tethered system, one orbiting above the other, is subject to different influences. Consequently the primary engineering goals of TSS-1 were to deploy, stabilize, and retrieve a tethered satellite in space and operate it as an electrically conducting system.

After extension of a 12.2 meter boom, placing the satellite high over the cargo bay, small thrusters on the satellite gave the initial push for the tether to begin to unreel. The first attempt at deployment was unsuccessful. The crew tried again, and this time the satellite began to move away from the Shuttle. However, the tether jammed at 179 meters and again at 256 meters.

The crew and flight controllers were able to release the tether on both occasions, although the cause of the problem was not discovered. As part of a troubleshooting procedure, the tether was reeled in a short distance. At this point, yet another tether jam occurred.

On the ground, flight controllers studied the TSS-1 systems for several hours to determine a course of action. Given the unforeseen difficulties with the tether system, they agreed that if the tether could be freed, the crew should not further attempt to deploy the satellite but should continue the retrieval. The crew was given the task of lowering and raising the deployment boom to try to free the tether, which controllers felt was jammed at the top of the boom. This worked, and the crew proceeded to retrieve the satellite.

Although the major science objectives of the TSS-1 mission were not completed, the satellite and tether did demonstrate stability, were able to be actively controlled, and confirmed some theories of tether dynamics. The tether itself also generated sufficient voltage to be able to drive and fire the electron beam generator units in the payload bay.

The TSS-1 system will be reflown in space in 1996 onboard the STS-75 mission. The satellite will be deployed 20 kilometers, attached to the Shuttle by its conductive tether. This mission will further test the electrodynamic effects of moving such a tether through Earth's magnetic field. The experiment will also test techniques for managing the tethered spacecraft at great distances.

**Mathematical Equations Illustrated In the Video**

To explain the dynamics of the tethered satellite system, the following equations appear in the video:

<u>Newton's Second Law of Motion</u>

$$F = ma$$

Force equals mass times acceleration.

<u>Universal Law of Gravitation</u>

$$F \propto \frac{m_1 m_2}{r^2}$$

For two masses, the attractive force of gravity between them is proportional to the product of their masses and inversely proportional to the square of the distance between their center of masses.

During the video, students are challenged to verify the relationship between the distance the tethered satellite moves during deployment and the distance the Space Shuttle moves. The following data was provided.

Mass of the Space Shuttle - 100,000 kg
Mass of the Tethered Satellite - 500 kg
Distance the Space Shuttle moves - 100 m
Distance the Tethered Satellite moves - 20,000 m

$$m_{ts} \times d_{ts} = m_{ss} \times d_{ss}$$

$$500kg \times 20{,}000m = 100{,}000kg \times 100m$$

# Terms

**Angular momentum -** The product of an object's rotational velocity and its rotational inertia about an axis.

**Center of Mass -** A single point about which the mass of an object is considered to be concentrated.

**Conservation of Angular Momentum -** As long as no external torques are exerted, the angular momentum of an object remains constant.

**Conservation of Energy -** Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes.

**Coriolis Effect -** The deflection of a moving object into a curved path due to Earth's rotation.

**Equilibrium -** The state of an object when not acted upon by a net force or net torque.

**Force -** a push or pull that causes an object to accelerate.

**Gravity Gradient Force -** Differences in the force of gravity felt in various parts of a system due to varying distances from the center of Earth.

**Gravity -** An attractive force felt between two or more objects due to their mass.

**Inertia -** A property of matter causing it to resist changes in motion.

**Inverse Square Force (law) -** A law relating the intensity of an effect to the inverse square of the distance from the cause.

**Newton -** A unit of force: 1 Newton accelerates a mass of 1 kilogram 1 meter per second per second.

**Rendezvous -** In space flight, the close approach of two spacecraft traveling in the same orbit.

**Resonance -** Vibrations created in an object at its natural vibration frequency caused by a second object vibrating at that same frequency.

**Restoring Force -** A force that returns equilibrium to a system.

**Tethered Satellite -** A satellite attached to another space vehicle by means of some sort of cord.

**Torque -** A product of force and lever-arm distance, which tends to produce rotation in an object.

# Classroom Activities

The following hands-on activities demonstrate some of the concepts presented in this videotape.

### Conserving Angular Momentum

Materials
Rotating stool or rotating platform
Two exercise hand weights (1 to 2 kg each)

Procedure:
1. Place the rotating stool or platform in the middle of a clear area at least 2-3 m across.
2. Have a student carefully sit on the stool or stand on the platform.
3. Give the student the two hand weights and ask the student to extend his or her arms.
4. Gently start the student spinning while standing nearby to help the student maintain balance.
5. On command, the student should move the weights to his or her chest. What happens to the student's rotation rate? Is the student gaining momentum?
6. Once the student becomes accustomed to balancing on the stool or platform, the rotation rate can be increased slightly to dramatize the effect.

7. If needed, refer to a physics textbook under the topic of "conservation of angular momentum" for a complete description of what is happening. How does this activity relate to figure skaters and tethered satellites?

**Seesaw**

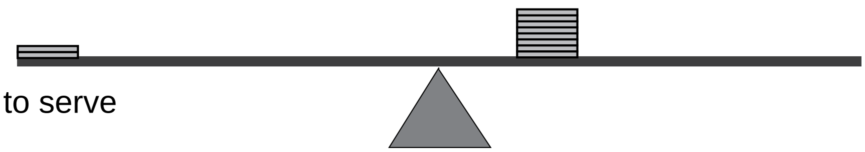
Material

Moment of Force Apparatus or the items listed below:

Meter stick

10 large metal washers

Small triangular block or other object to serve as a fulcrum



Procedure

(Follow the instructions that come with the moment of force apparatus or use these instructions with the alternative apparatus)

1. Place the meter stick on the fulcrum so that it comes into balance.
2. Divide the washers into two equal piles and place them on opposite sides of the fulcrum. Adjust the positions of the piles to bring the stick into balance by moving them closer or farther from the fulcrum. How far is each pile from the fulcrum?
3. Divide the washers into two piles of two and eight washers respectively. Place them on the meter stick and adjust their positions until the stick is in balance. How far is each pile from the fulcrum?
4. Is there a mathematical relationship between the masses of the two piles and their distances from the fulcrum? How does this activity relate to the deployment of tethered satellites.

# References

Additional information on the Tethered Satellite mission and other NASA research can be obtained by contacting NASA through NASA Spacelink.

Flight Crew Operations Directorate
NASA Johnson Space Center 2/95

NASA SPACELINK provides information about current and historic NASA programs, lesson plans, and the text from previous Mission Watch and Mission Highlights fact sheets. Anyone with a personal computer, modem, communications software, and a long distance telephone line can communicate directly with NASA SPACELINK. Use your computer to dial 205-895-0028 (8 data bits, no parity, and 1 stop bit). NASA SPACELINK may also be accessed through Internet through the following address:

World Wide Web: http://spacelink.msfc.nasa.gov
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Gopher: spacelink.msfc.nasa.gov
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Internet TCP/IP address: 192.149.89.61

## STS-46 Crew Biographies

**Commander: Loren J. Shriver (Col., USAF).** Loren Shriver was born in Jefferson, Iowa, but considers Paton, Iowa, to be his hometown. He earned a bachelor of science degree in aeronautical engineering from the United States Air Force Academy and a master of science degree in astronautical engineering from Purdue University. After graduation from the Air Force Academy, Shriver served as a T-38 academic instructor pilot, and completed F-4 combat crew training. Following an overseas tour in Thailand, he graduated from the USAF Test Pilot School at Edwards Air Force Base, California. He participated in the Air Force development tests and evaluations of the F-15 fighter and T-38 lead-in fighter aircraft. Shriver, who has logged more than 6,000 hours in jet aircraft, became an astronaut in 1979 and has flown in space as the pilot on the STS-51C mission and as commander on the STS-31, and STS-46 missions.

**Pilot: Andrew M. Allen (Maj., USMC).** Andrew Allen was born in Philadelphia, Pennsylvania. He received a bachelor of science degree in mechanical engineering from Villanova University. Following graduation from the United States Marine Corps flight school, he flew F-4 Phantoms and was later selected for fleet introduction of the F/A-18 Hornet. Allen also is a graduate of the Navy Fighter Weapons School (Top Gun) and the U.S. Navy Test Pilot School. He has logged over 4,000 flight hours in more than 30 different aircraft. He became an astronaut in 1988 and has flown as pilot aboard the STS-46 and STS-62 missions.

**Mission Specialist (ESA): Claude Nicollier.** Claude Nicollier was born in Vevey, Switzerland. He holds a bachelor of science degree in physics from the University of Lausanne and a master of science degree in astrophysics from the University of Geneva. In 1978, he was selected by the European Space Agency (ESA) as a payload specialist to train for the Spacelab-1 mission. Through an agreement between NASA and ESA he became mission specialist astronaut in 1980. He holds a commission as captain in the Swiss Air Force and has logged 4,650 hours flying time, including 3,200 hours in jet aircraft. He also flew DC-9s for three years (1974-1976), and is a 1988 graduate of the Empire Test Pilot's School. Nicollier has flown in space on the STS-61 and STS-46 missions.

**Mission Specialist: Marsha S. Ivins**. Marsha Ivins was born in Baltimore, Maryland. She earned a bachelor of science degree in aerospace engineering from the University of Colorado. She worked as an engineer in Man Machine Engineering, as a flight simulation engineer on the Shuttle Training Aircraft, and as co-pilot of the NASA administrative aircraft at the Johnson Space Center. Ivins was selected as an astronaut in 1984. Ivins, who has logged more than 4,700 hours in civilian and NASA aircraft, flew in space as a mission specialist on the STS-32, STS-46, and STS-62 missions.

**Mission Specialist: Jeffrey A. Hoffman (Ph.D.)**. Jeffrey Hoffman was born in Brooklyn, New York, but considers Scarsdale, New York, to be his hometown. He earned a bachelor of arts degree in astronomy from Amherst College, a doctor of philosophy degree in astrophysics from Harvard University, and a master of science degree in materials science from Rice University. After receiving his Ph.D., he worked at Leicester University in England and at the Massachusetts Institute of Technology in the field of X-ray astronomy. He became an astronaut in 1979 and has flown in space as a mission specialist on the STS-51D and STS-35, as the payload commander on the STS-46 mission, and as an EVA crew member on STS-61 mission. Hoffman has conducted four space walks (three for servicing the Hubble Space Telescope).

**Mission Specialist: Franklin R. Chang-Diaz (Ph.D.)**. Franklin Chang-Diaz was born in San Jose, Costa Rica. He earned a bachelor of science degree in mechanical engineering from the University of Connecticut and a doctorate in applied plasma physics from the Massachusetts Institute of Technology. During graduate school at MIT, he worked in the United States' controlled fusion program. He has logged over 1,500 hours of flight time. Dr. Chang-Diaz was named an astronaut in 1981. After being selected as an astronaut, he was appointed Visiting Scientist with the MIT Plasma Fusion Center where he lead the Plasma Propulsion Group. Dr. Chang-Diaz is an Adjunct Professor of Physics and Director of the Advanced Space Propulsion Laboratory at the University of Houston. He has flown in space as a mission specialist on the STS-61C, STS-34, STS-46, and STS-60 missions.

**Payload Specialist (ASI): Franco Malerba (Ph.D.).**
Franco Malerba was born in Genova, Italy. He received two doctorate degrees from the University of Genova: one in electronics engineering and telecommunications and the other in physics. In 1977, he was chosen by the European Space Agency as a payload specialist candidate for the first mission of Spacelab and worked at the ESA-ESTEC technical center in Noordwijk, The Netherlands, on the development of the space plasma physics experiment "PICPAB" which flew aboard the first Spacelab (STS-9) mission. Malerba has also done extensive work in computer networks engineering and telecommunications technology and has served as a reserve officer in the Italian Navy. He flew in space as a payload specialist on the STS-46 missions. Malerba is now working with the Itallian Space Agency's manned space flight program.

# *Tethered Satellite - Forces and Motions*

## Videotape and Video Resource Guide
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