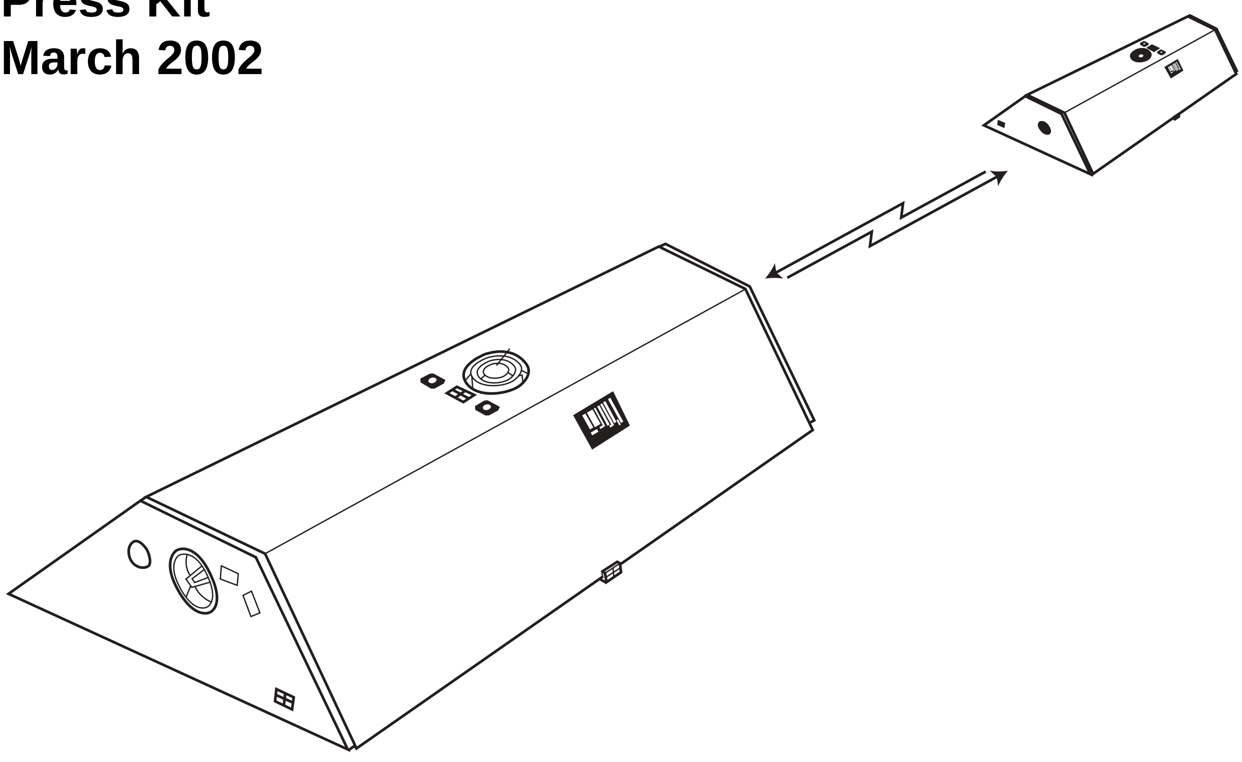
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# GRACE Launch

**Press Kit**
**March 2002**



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**RELEASE: 02-46** **March 7, 2002**

**GRACE SPACE TWINS SET TO TEAM UP TO TRACK EARTH'S WATER AND GRAVITY**

NASA and the German Space Agency are preparing to launch the Gravity Recovery and Climate Experiment (GRACE), a scientific pathfinder mission that will test a novel approach to tracking how water is transported and stored within the Earth's environment. The mission will precisely measure the planet's shifting water masses and map their effects on Earth's gravity field, yielding new information on effects of global climate change.

The twin GRACE satellites are set to launch March 16, 2002, from Russia on a five-year mission that will revolutionize understanding of changes in the Earth's gravity field over time and space. The mission will provide measurements of the gravity field that are far more accurate and sensitive than any that can be obtained by ground-based observations or single remote-sensing spacecraft.

"GRACE marks the first launch of NASA's Earth System Science Pathfinder program, designed to develop new measurement technologies for studying our Earth system," said Dr. Ghassem Asrar, associate administrator for NASA's Earth Science Enterprise, NASA Headquarters, Washington. "Through NASA's continuing investment in technology development, we've been able to create an innovative mission at a fraction of the cost of missions formulated just a decade ago. GRACE will provide us with a new view of our home planet and help us to better understand climate change and its global impacts such as changes in sea level and the availability of water resources," Asrar said.

A more precise gravity map of Earth is expected to increase the accuracy of many techniques used by scientists who study Earth with space-based instruments. These techniques -- ranging from satellite altimetry and radar interferometry to digital terrain models covering large land and ice areas -- provide critical input to many scientific models used in oceanography, hydrology, glaciology, geology and related disciplines.

As they race around the globe 16 times a day, the satellites will sense minute variations in the Earth's surface mass below and corresponding variations in the Earth's gravitational pull. Regions of slightly stronger gravity will affect the lead satellite first, pulling it slightly away from the trailing satellite. By measuring the constantly changing distance between the two satellites and combining that data with precise positioning measurements from Global Positioning System (GPS) instruments, scientists will be able to construct a precise Earth gravity map.

GRACE is the first Earth-monitoring mission in the history of space flight whose key measurement is not derived from electromagnetic waves bounced off the Earth's surface. Instead, the mission will use a microwave ranging system to accurately measure changes in the speed and distance between two identical spacecraft flying in a polar orbit about 220 kilometers (137 miles) apart, 500 kilometers (311 miles) above Earth. The ranging system is so sensitive it can detect separation changes as small as 10 microns -- about one-tenth the width of a human hair over a distance of 220 kilometers.

An additional instrument aboard the satellites called an atmospheric limb sounder will measure the amount by which the GPS satellite signals are distorted by Earth's atmosphere. Scientists will use these data to improve the accuracy of key atmospheric observations, which serve as input for weather forecast models.

GRACE is a joint partnership between NASA and the German Center for Air and Space Flight (Deutsches Zentrum fur Luft und Rumfahrt, or DLR). The U.S. portion of the project is managed for NASA's Office of Earth Science, Washington, by NASA's Jet Propulsion Laboratory (JPL), Pasadena, Calif. Science data processing, distribution, archiving and product verification are managed under a cooperative arrangement between JPL and the University of Texas' Austin-based Center for Space Research in the United States and Germany's Earth Research Center (or GeoForschungsZentrum).

More information about the GRACE program is available on the mission’s web site at:

**http://www.csr.utexas.edu/grace**

Information on NASA's Earth System Science Pathfinder Program may be found at:

**http://essp.gsfc.nasa.gov**

**- End of General Release -**

# Media Services Information

## NASA Television Transmission

NASA Television is broadcast on the satellite GE-2, transponder 9C, C band, 85 degrees west longitude, frequency 3880.0 MHz, vertical polarization, audio monaural at 6.8 MHz. The tentative schedule for television transmissions for GRACE activities is described below; updates will be available from the Jet Propulsion Laboratory, Pasadena, Calif.; the Goddard Space Flight Center, Greenbelt, Md.; and NASA Headquarters, Washington.

## Briefings and Television Feed

A mission and science overview news conference will be presented in a news briefing broadcast on NASA Television originating from NASA Headquarters at 2 p.m. EST on March 7, 2002.

NASA plans to broadcast the launch live on NASA Television via a feed from the German space agency.

The launch be broadcast live, accessible via webcast at URL:

**http://www.jpl.nasa.gov/webcast/gracelaunch.html**

## Status Reports

Status reports on mission activities will be issued by NASA. They may be accessed online as noted below.

## Launch Media Credentialing

News media representatives who wish to cover the launch in person must be accredited through the DLR Public Relations Office in Cologne, Germany. For information on launch accreditation, contact Vanadis Weber at +49 (0) 2203/601-3068.

## Internet Information

Information on the GRACE mission, including an electronic copy of this press kit, press releases, fact sheets, status reports and images, is available from a variety of sources.

The GRACE web site is operated by the University of Texas' Center for Space Research at:

**http://www.csr.utexas.edu/GRACE**

Additional information may be found at the Jet Propulsion Laboratory's home page at:

**http://www.jpl.nasa.gov**

Information is also available at a Goddard Space Flight Center web page at:

**http://ilrs.gsfc.nasa.gov/ilrs/grace.html**

A web page on NASA’s Earth System Science Pathfinder program is at:

**http://essp.gsfc.nasa.gov/GRACE**

The DLR home page is at:

**http://www.dlr.de**

A web page at Germany's Earth Research Center is at:

**http://op.gfz-potsdam.de/grace/index_GRACE.html**

And a web page at the German Space Operations Center is at:

**http://www.gsoc.dlr.de/rb1/rd/proj_grace.html**

# Quick Facts

**Spacecraft**
*[The following describes each of the twin satellites]*
Size: 1.942 meters (76.5 inches) wide; 3.123 meters (123 inches) long; 0.72 meters (28.3 inches) high
Mass: 487 kilograms (1,074 pounds)
Power: Four panels of silicon solar cells mounted on satellite's top and side exterior surfaces
Batteries: 10 nickel-hydrogen cells providing up to 16 amp-hours of 28-volt power
Instruments: Microwave ranging instrument, accelerometer, star camera, Global Positioning System receiver

**Launch Vehicle**
Type: Three-stage Rockot
Height: 29 meters (95 feet)
Weight: 97,170 kilograms (214,223 pounds)
Fuel: Liquid (unsymmetrical dimethyl hydrazine and nitrogen tetroxide)

**Mission**
Launch: March 16, 2002, 12:23 p.m. local time (4:23 a.m. EST) from Plesetsk Cosmodrome, Russia
Primary mission: Five years
Orbit altitude: 500 kilometers (311 miles)
Orbit inclination to Earth's equator: 89 degrees (near-polar)
Separation between spacecraft: 220 kilometers (137 miles) +/- 50 kilometers (31.1 miles)

**Program**
Cost: NASA portion approximately $97 million, including instrument development
German portion approximately $30 million, including launch vehicle and mission operations

# Why Study Gravity?

Gravity is Newton's apple and the stuff of Einstein's theories of relativity, but it is also the law that we all learn to obey from our first breath of life. Gravity is the mutual attraction that pulls two masses together and keeps us firmly planted on the Earth.

Sir Isaac Newton first revealed the law of gravity more than 300 years ago. During the 20th century when geophysicists developing techniques to locate mineral deposits and underground formations using spatial changes in the Earth's gravity field that laid the modern foundation for the science of geodesy. Geodesy is the study of the shape of the Earth, and relies on obtaining precise measurements of land and ocean surface topography, as well as the gravity field.

Today, scientists use measurements from several dozen satellites to develop models of the Earth's geoid -- an imaginary surface upon which the pull of gravity is equal everywhere. If the oceans were motionless and homogeneous, the sea surface would coincide with the geoid. Oceanographers use this concept to define dynamic topography - the difference between the ocean's surface and the geoid, thereby measuring ocean circulation from satellite altimeters. In order to more precisely know ocean circulation, we must match our knowledge of topography with an equally accurate knowledge of the geoid surface. Today's ocean altimeters seek to measure the ocean's surface to better than four centimeters. However, in many areas of the world our knowledge of the geoid ranges from 20 to 90 centimeters.

Newton defined the pull of gravity as a function of mass and distance from that mass. Our weight is our mass times the pull of the Earth's gravity field. The denser a material is, the more mass it has for a given volume. The more massive an object is, the greater the gravitational force that it exerts. As an example, rock is denser than water -- that's to say, it contains more mass per unit of volume. Cold water is denser than warm water and therefore the gravitational attraction. A given volume of warm water is less than that of the same volume of cold water, or ice.  According to Newton, any object, no matter how small, exerts some gravitational force on objects around it. So, for example, there is a very tiny gravitational force between your eyes and the paper or computer screen that contains these words that you are reading. In these cases the gravitational force is extremely minute, however, and is overwhelmed by the much stronger gravitational force exerted by the more massive Earth.

If Earth were a smooth sphere of uniform density, there would be no need for a mission like GRACE -- it would measure no changes in the gravity field. However, Earth isn't smooth and homogeneous -its surface includes mountains, valleys, oceans and ice caps. Within the Earth, differences in temperature and density drive the motion of the Earth's tectonic plates, generate volcanic features such as Iceland and Hawaii, and even produce the Earth's geomagnetic field. Studying gravity allows us to better understand these forces that shape our Earth. For example, since ice is less dense than liq-

## NASA's Earth System Science Pathfinder Program

GRACE was selected under NASA's Earth System Science Pathfinder program in May 1997, and will be that program's inaugural flight. A component of NASA's Earth Science Enterprise, the Earth System Science Pathfinder program sponsors missions intended to address unique, specific, highly focused scientific issues, and provide measurements required to support Earth science research.

Missions are small- to- medium-sized, and are capable of being built, tested and launched quickly. They support a variety of scientific objectives related to Earth Science, including studies of the atmosphere, oceans, land surface, polar ice regions and solid Earth.

uid water, the gravity in one area of the world will change subtly as an ice sheet or glacier forms or melts. Such uneven distribution of mass on Earth's surface manifests itself as "lumps" in the planet's gravity field.

Earth's shape departs most significantly from a sphere in a distinctive flattening at the north and south poles. This is called Earth's "oblateness." Overall, however, this flattening and other sources of unevenness are very slight, changing Earth's gravity in any given spot by less than one percent. Nevertheless, they are important, as tiny changes in gravity from place to place and over time can reveal a great deal about the oceans and our planet's hidden interior -- and, in turn, the forces that drive climate change.

If you look at a current map of Earth's geoid generated from data collected by previous satellite missions, you can easily see this "lumpiness" and many interesting details about our planet. Hudson's Bay, Canada, shows a low in the gravity field that is the footprint of the great continental glaciers that defined the last ice age. The great weight of these glaciers pushed the Earth's crust downward, like a great drum head. Gravity also has been used to map the ocean floor. The gravitational attraction of valleys and undersea mountains in the ocean floor produces changes in the geoid that are detected by ocean altimetry satellites. Topographic maps were generated using these data, thereby draining the oceans of their water, to reveal the ocean floor.

GRACE will build on the heritage of a predecessor mission called the Challenging Minisatellite Payload, or "Champ." Built by Germany's Earth Research Center (GeoForschungsZentrum) and launched in July 2000, Champ's instruments and its orbit have allowed it to generate simultaneous, highly precise measurements of Earth's gravity and magnetic field. It can measure how both fields vary across Earth's surface as well as how they change with time. Scientists can also collect useful information by studying how the satellite's signal changes as it passes behind Earth's edge from a particular observing station. In addition, Champ has tested the use of Global Positioning System (GPS) instruments flown in orbit to study Earth's atmosphere and ionosphere, with potential applications in weather prediction and weather monitoring from space.

While Champ has significantly advanced the field of geodesy, scientists have long desired an even more advanced mission based upon dual satellites flying in formation. The unique design of the GRACE mission is expected to lead to a hundred-fold improvement in existing gravity maps and allow much improved resolution of the broad- to finer-scale features of Earth's gravitational field over both land and sea, while also showing how much the Earth's gravitational field varies with time. Current models of the geoid are accurate from 20 to 90 centimeters at horizontal scales of 300 kilometers (186 miles). GRACE aims to have an accuracy of 400 microns at these scales.

The measurement accuracy of Earth observing satellites and altimeters also are affected by gravity. GRACE will increase our ability to precisely identify the positions of these satellites on orbit, and allow for more accurate measurements from them.

# Practical Applications

GRACE will add an important new data set to a scientists' toolkit for studying Earth's climate and geology. The improved gravitational field measurements it provides are expected to lead to discoveries about gravity and Earth's natural systems that will substantially impact our understanding of climate change.

The mission will allow us to "see" various ways that mass is transported around our planet, as well as how much mass is in motion and how mass redistribution varies over time. Gravity is the "shadow" thrown by mass, and mass is a crucial part of the equation for many physical phenomena. From the thinning of ice sheets, to the flow of water through aquifers, to the slow currents of magna inside Earth, having direct measurements of the amount of mass involved will enable scientists to reach better conclusions about these important natural processes.

The mission is expected to help with applications including the following:

- Tracking water movement on and beneath Earth's surface;
- Tracking changes in ice sheets and in global sea level;
- Studying ocean currents both near the surface and far beneath the waves;
- Tracking changes in the structure of the solid Earth.

**Tracking Water Movement On and Beneath Earth's Surface**

Perhaps the most interesting and the least well-measured cause of fluctuations in Earth's gravitational field is the movement of water over Earth's surface. Water in solid, liquid and vapor form circulates over, under and above the planet's surface, moving in significant quantities throughout Earth's water cycle at a rapid rate relative to other processes that redistribute mass over Earth's surface. Gravity fluctuations match up with variations in the density of the land surface below, and can be exploited to track water movement. Gravity changes over time will be used to follow these individual water masses. In effect, gravity becomes a tracer to track water movement our eyes cannot see.

Data from the mission will be combined with observations from other NASA satellites - including the recently launched Jason mission, along with the upcoming Aqua and IceSat missions, which have instruments that will detect soil moisture, track ocean topography and ice volume - as well as data from aircraft and ground-based measurements. This will allow scientists to improve current models of water movement between the oceans and the land, and to study such movements on both a continental and regional basis.

For example, GRACE will detect month-to-month variations in the water stored in individual river basins. In general, GRACE can map water storage changes to a height of within about 1 centimeter (0.4 inch) or better for basins ranging in size on the order of 600 kilometers (approximately 370 miles).

Since the mission will provide a framework for studying the gravitational signatures of large underground water reservoirs, or aquifers, an exciting potential benefit may be the tracking of available fresh water, something of extreme interest to populations located in Earth's arid regions.

**Tracking Changes in Ice Sheets and Global Sea Level**

The mission can tell us about the movement of solid water as well - in the form of ice caps and glaciers at the polar ice caps and in Greenland. When combined with height variations measured through ground-based aircraft and satellite measurements from instruments such as the laser altimeter on the upcoming IceSat mission, data from the mission will allow for improved computations of changes in the mass of ice sheets. GRACE will be able to precisely measure very small changes in Earth's gravitational field that result from these changes in mass.

An important question in the study of climate change is whether ice caps and glaciers are shrinking or growing, and if the melting water is entering the ocean and contributing to sea level rise. Data from the mission will help scientists answer this question. As ice sheets melt, the increased surface area of open water absorbs more heat, raising temperatures, melting more ice and also contributing to sea level rise.

Satellites equipped with altimeters such as Topex/Poseidon and Jason can measure the total overall change in sea level. However, altimeters alone cannot distinguish between what portion of the change can be attributed to warming of the ocean and what part is due to water being added from melting ice sheets. Data from Grace, used in conjunction with such altimeter measurements, should help scientists better distinguish between the overall ocean level changes due to thermal expansion and those due to actual redistribution of water.

Data from the mission also will allow scientists to more accurately determine the extent to which sea level is impacted by a phenomenon called "post-glacial rebound." This is the name used to describe the slow rebounding of Earth's crust now that the weight of the ice from the last ice age is no longer present. Post-glacial rebound accounts for the vertical movement of land in many parts of the world. These shifts affect relative sea level at the coastline in a way that varies from place to place. Such movements can confound tide gauge records obtained from coastal sites and thus complicate efforts to track the overall change in global sea level. Data from GRACE will be combined with altimeter readings to get a better understanding of how much of the perceived change in sea level is attributable to the phenomena of post-glacial rebound and how much might be attributed to global climate change.

**Studying Ocean Currents Both Near the Surface and Far Beneath the Waves**

With a better idea of the contribution of gravity, scientists will be able to more accurately draw conclusions about the temperatures and currents of the oceans - vital information for understanding the global climate. Data from the mission are expected to significantly improve our understanding of ocean currents and global ocean circulation and the critical role they play in regulating climate.

Free from other influences, the ocean surface would tend to take the shape of the geoid. Swept by winds and seething with waves, the ocean is actually in ceaseless motion, flowing in gigantic currents and gyres directed by what is known as the Coriolis effect of Earth's rotation. (Due to the Coriolis effect, air currents in the northern hemisphere are deflected to the right, and in the southern hemisphere are deflected to the left.)  The shape of the sea surface is dynamic, departing from the static shape or topography caused by gravity alone. This departure, called dynamic ocean topography, ranges in altitude around the world by about 2 meters (6.6 feet) - barely one percent of the altitude range caused by variations in gravity. However, only dynamic topography contains information about the speed and direction of ocean currents. By examining the slope of the ocean's dynamic topography, scientists can estimate the speed and direction of ocean surface currents.

Two measurements are needed to determine ocean dynamic topography: sea surface height from satellite altimeters, and a model for the Earth's geoid. In order to study ocean currents using dynamic topography measurements, the measurement must be very precise. Very precise sea height measurements are available from satellite altimeters such as Topex/Poseidon and Jason; however, measurements of the geoid to date have lacked sufficient precision to allow for ocean current studies. GRACE promises to improve the precision of the geoid measurement by several orders of magnitude over the existing best estimate. When combined with measurements from Topex/Poseidon and Jason, it should allow for advances in the study of ocean currents using dynamic topography.

Understanding ocean currents is important because Earth's oceans are huge heat reservoirs. "Heat exchange flux" - which is to say, the movement of warm waters by ocean currents from the equator to the poles -- plays a critical role in regulating Earth's climate. Data from the mission should help improve the accuracy of these measurements. Changes in the nature of these currents can have a profound impact on weather all around the world.

## Tracking Changes in the Solid Earth

Data from the mission will improve our understanding of forces operating beneath the Earth's surface. Changes in ice thickness will change the load on the Earth's crust and will therefore create basins such as Hudson's Bay or the Baltic Sea. As glaciers melt and the Earth recovers from their weight, the gravity field will provide a measure of the strength of the Earth's crust. More precise measurements of changes in the Earth's gravity field may lead to an improved estimate of the strength of the Earth's interior to such loads, and better estimates of ice concentrations during past glacial cycles.

The forces driving the Earth's surface and the mantle beneath are the subject of differing models. Questions remain regarding this layer's thermal and compositional nature, thickness and mechanical properties. Improved understanding of the gravity field will be especially important when examining active tectonic boundaries such as the Pacific Ring of Fire, or over mantle plumes such as the Hawaiian and Icelandic "hot spots." GRACE will help scientists distinguish between competing models of the viscosity or thickness of the molten rock in Earth's lower mantle, and contribute to an improved understanding of how molten rock rises and falls within the mantle.

## Atmospheric Profiling

Weather prediction today depends on complex numerical models. Major improvements to our ability to forecast weather will depend on our ability to collect precise measurements of key parameters such as temperature and humidity in a more timely way, more often and with increased coverage across Earth's surface. GRACE will carry an instrument called an atmospheric limb sounder that will provide an innovative and cost-effective technique to measure how much signals from GPS satellites are distorted by the atmosphere. Scientists will use this information to improve the accuracy of key atmospheric observations, which serve as input for weather forecast models.

GRACE's atmospheric limb sounder will obtain 200 to 250 measurements each day using a technique known as occultation. As GRACE orbits Earth, it will use forward- and aft-looking antennas to measure the signals from the slower-orbiting GPS satellites as they appear to rise or set behind Earth's limb. GRACE also will measure signals from higher-elevation GPS satellites not affected by the atmosphere as a standard of comparison. Measurements by GRACE's limb sounder will be unaffected by weather conditions such as clouds or storms that hinder or block sensors on other satellites.

Instruments called limb sounders measure how radio waves are delayed as they pass through and are bent by Earth's atmosphere. Just as light is refracted or bends as it enters water because of the slower speed of light in the water, GPS signals are refracted as they pass through Earth's atmosphere. By observing the changing signal delay as the GPS satellites rise or set, profiles of atmospheric pressure, temperature and humidity can be created, and the variability of the ionosphere can be measured down to an altitude of 100 kilometers (about 62 miles). These clues can help scientists predict weather around the planet.

The ionosphere is the region of Earth's upper atmosphere above 100 kilometers (62 miles) in altitude. It is called the ionosphere because it is home to a great number of charged particles, or ions. The speed of radio waves is affected by the density of electrons in the ionosphere. Measurements of signals from GPS satellites can distinguish between the influence of the ionosphere and that of the atmosphere because the effect of the ionosphere varies with radio frequency, whereas atmospheric delay does not.

Scientists expect the limb sounding technology aboard the mission's twin satellites to extend and complement other spaceborne atmospheric sensors. GPS-based studies of the continuously changing ionosphere will advance our understanding of the Sun's influence upon Earth's environment, including its effects on climate, weather, radar and radio communications. Limb sounding also will be studied as a means of detecting rapid vertical changes of Earth's surface such as volcanic explosions, earthquakes, tsunamis and other such phenomena thought to cause disturbances in the ionosphere.

### Helping Pinpoint the Cause of Mass Movements

Scientists will combine mission data with many other sources of information, such as rainfall data, ocean bottom pressure instruments, ocean thermal measurements and other geographic knowledge collected by scientists on the ground and from other satellites.

Since geodesy is a relatively new science, methods for drawing conclusions based on the mission's data will take some time to refine. To pinpoint the cause of a shift in mass in a particular region of Earth, scientists will first subtract the effects of motions of the atmosphere using data from GRACE's atmospheric limb sounders.

Meteorologists will then use a variety of techniques to determine what kind of mass movement (water, ice or magma) the mission's satellites are observing. Each type of mass movement involves different processes and typical time scales. Surface waters such as lakes and rivers may be expected to produce faster changes than ocean currents, and ocean currents should produce faster changes than deep magma flows.

The effects of convection currents in the Earth's mantle could be observable anywhere, for example. An event could involve a flow of mass hundreds of kilometers under Earth's surface, but such events are not expected to change month to month. On the other hand, a movement of mass that is matched with rainfall or snow is most likely an event springing from the planet's water cycle.

Once the amount of mass involved in an event has been determined, scientists will then be able to combine that knowledge with other data into a synergy for analysis.

# Science Objectives

The mission's primary objective is to obtain extremely high-resolution global models of Earth's gravity field, including how it varies across time. These estimates will provide a comprehensive understanding of how mass is distributed globally and how that distribution varies over time.

To do this, the mission will make extremely precise measurements of the distance between the two GRACE satellites flying at a low altitude in the same, near-polar orbit. Changes in the distance between the two satellites will be measured using a microwave ranging system. In addition, each satellite will carry a high-precision GPS receiver and a high-accuracy accelerometer that will enable scientists to precisely map Earth's gravity field and to factor out the effects of non-gravitational forces on the relative orbits of the satellites.

An additional science objective is to advance the study of Earth's atmosphere through the use of a technique called GPS limb sounding. Using this technique, scientists will be able to determine how much GPS measurements are delayed due to bending of the signals as they pass through Earth's ionosphere and atmosphere. Hundreds of globally distributed measurements a day will be obtained, which can be used to measure total electron content and/or refractivity in the ionosphere and troposphere, respectively.

Data, in conjunction with other information, will be used to construct monthly maps of Earth's gravity field. These estimates will be combined with other space-based measurements, ground measurements and geophysical models to determine how Earth's mass changes over time as a result of various geophysical processes, and the relationship of these changes to the Earth's geoid.

# Mission Overview

The mission will launch two identical satellites into a near-polar orbit around Earth with one satellite trailing the other by about 220 kilometers (137 miles). This configuration will allow their instruments to sensitively measure Earth's gravity field and make other science observations.

**Launch Vehicle**

The twin satellites will be lofted into space on a single Rockot launch vehicle from the Plesetsk Cosmodrome in northern Russia.

The Rockot vehicles are manufactured by Russia's Khrunichev State Research and Production Space Center, which also makes the Proton launch vehicles and made the Mir space station. In 1997, the Khrunichev center entered into a partnership with Daimler-Chrysler Aerospace of Germany to market Rockot launches commercially under the name Eurockot GmBH.

The payload consisting of the GRACE satellites is assembled onsite and then transported to the launch pad, which has been modified to accommodate the Rockot launch vehicle. The Plesetsk Cosmodrome provides telemetry and tracking services by way of ground stations.

**Launch Timing**

On March 16, 2002, the 10 minute launch window opens at 12:23 p.m. local time in Plesetsk (4:23 a.m. EST). If launch does not take place on March 16, the window on subsequent days falls earlier by 2 minutes, 12 seconds each day.

**Liftoff**

Seconds before liftoff, the Rockot's first stage engine will ignite. Approximately two minutes, 16 seconds after liftoff, the vehicle's first and second stages will separate. At five minutes, 19 seconds, the vehicle's second and third stages will separate, and the third stage will fire its engine. At 15 minutes, 1 second, the third stage will be shut down.

The launch vehicle will fly northward over the Arctic Ocean, then passing over Alaska and flying south across a long stretch of the Pacific Ocean before sailing above Antarctica. On its northward leg it will pass over Africa and Europe. During much of this time, the Rockot will be in a 65-minute coast phase.

The third-stage engine will be re-ignited at 80 minutes, 38 seconds for a brief 16-second burn that will circularize the orbit. Separation of the twin GRACE satellites occurs at a mission elapsed time of 85 minutes, 38 seconds, above northern Africa. A few minutes after separation, GRACE will come into tracking range of the German Space Operations Center ground stations in Weilheim and Neustrelitz, Germany.

**Launch and Early Operations Phase**

The two and one-half week launch and early operations phase provides frequent opportunities for monitoring the satellites' status so that controllers can intervene from the ground if required.

Throughout the mission lifetime, telemetry and commanding activities will be carried out by the German Space Operations Center at its mission control center in Oberpfaffenhofen, communicating with the satellites via ground stations in Weilheim and Neustrelitz, Germany. In addition to the German ground stations, NASA tracking stations at McMurdo Station, Antarctica; at Spitzbergen, Norway; and at Poker Flats, Alaska, will be available for both telemetry and command transmission during this phase.

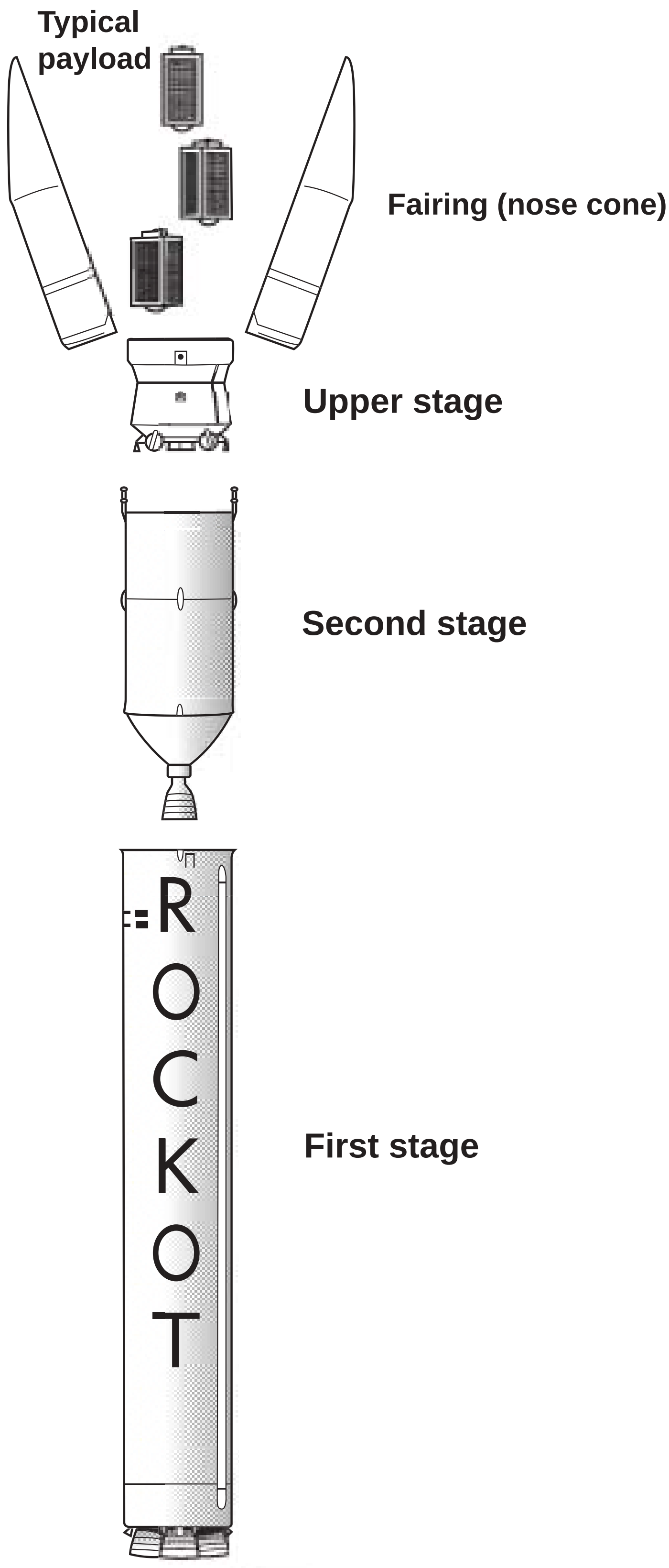
After the satellites are simultaneously ejected from the Rockot's third stage, the leading satellite will pull away from the trailing satellite with a relative speed of about 0.5 meters (1.6 feet) per second. Separation from the launch vehicle causes systems onboard the satellites to activate. Less than a minute later, a boom that holds each satellite's RF antenna is deployed, and the low-rate radio transmitter is activated.

Following their first pass over Germany, the two satellites will come within radio range of Spitzbergen, Norway, and then Poker Flats, AK. These two NASA ground stations will be used to receive telemetry and to relay commands issued by the German Space Operations Center. On later orbits, the performance of both satellites will be verified and commands will be issued as needed.

The orbits of the two satellites will evolve naturally for the remainder of the mission. Due to differences in drag forces, the separation between the satellites will vary between 170 and 270 kilometers (106 and 193 miles). Station keeping maneuvers will be carried out every 30 to 60 days, as necessary, to keep the two satellites at their desired separation.

To insure uniform exposure and aging of the K-band microwave antennas on each satellite, once during the mission the leading and trailing satellites will exchange positions. The altitudes of the two satellites will decay in tandem, from near 500 kilometers (310 miles) at the beginning of the mission to 300 kilometers (186 miles) and lower at the end of the mission.

Approximately 62 megabytes of science data, including both gravity and GPS occultation measurements, will be sent to Earth via radio in the S-band from each satellite every day.




*Rockot launch vehicle*

**Commissioning Phase**

After the orbit and basic satellite operations are well-established, ground controllers will turn their attention to a "commissioning phase" during which science instruments are powered-up and evaluated. Some of the activities that occur during this phase include:

- ❑ Turn-on and checkout of science instruments, the instruments processing unit and star camera

- ❑ Establishment of the link between the two satellites, and characterization of its performance

- ❑ Precise orbit calculations are obtained and verified using ground-based laser tracking data

- ❑ Initial calibration and trim of center of mass offsets in three axes. This alignment of the center of mas with the accelerometer sensor will improve the quality of the GRACE measurements.

- ❑ Update power and thermal budgets based upon measured variations

- ❑ Software patches and parameter updates

**Validation Phase**

Following the successful completion of the commissioning phase, the mission enters a six-month validation phase focused on providing an end-to-end characterization of the science instrument and data systems. During this phase, the following activities occur:

- ❑ Continuous records of science data are received from the satellites, and data flow problems are resolved

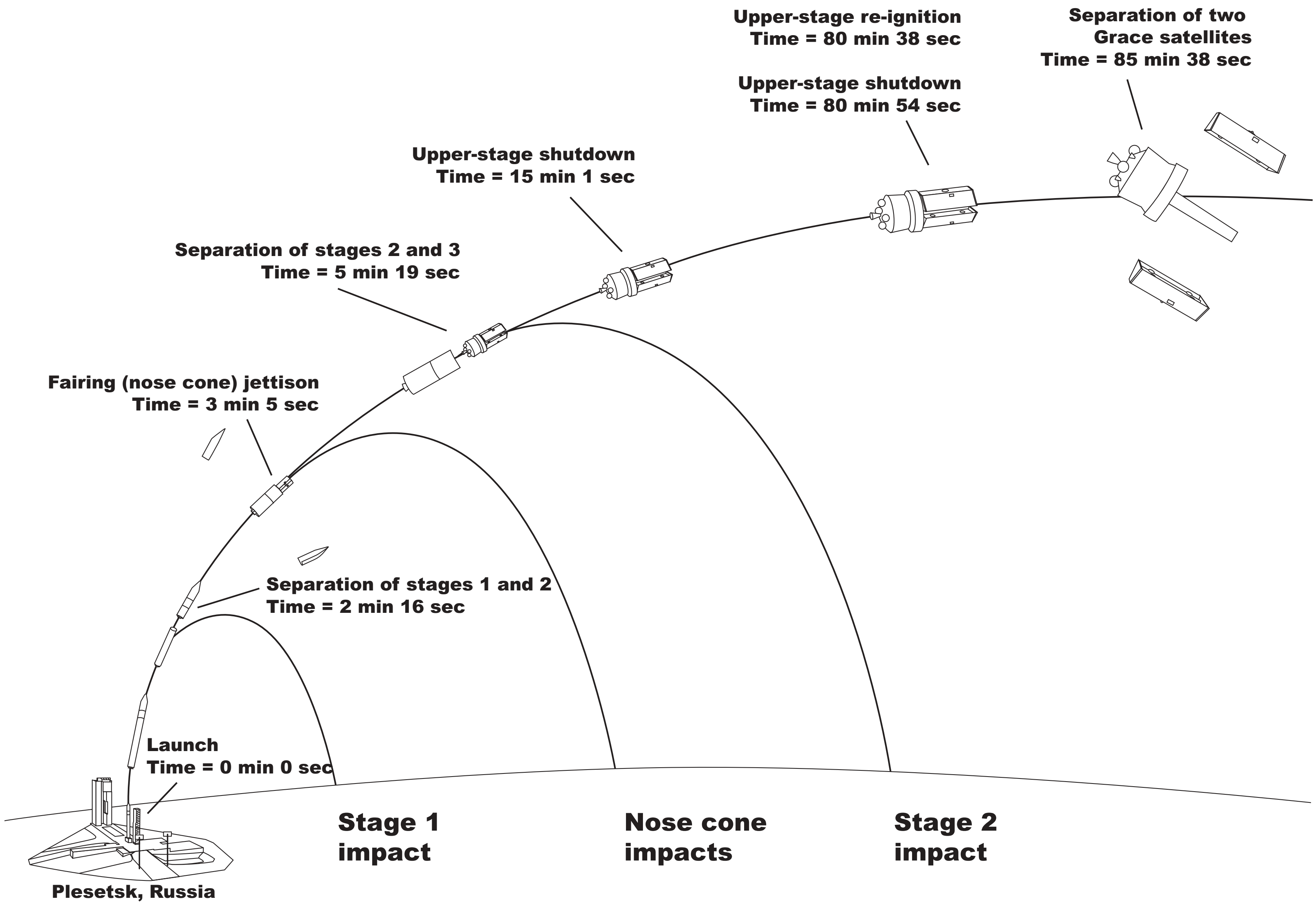
- ❑ The K-band ranging system boresight alignment is calibrated and verified

- ❑ Initial calculations for the gravity field, along with accelerometer calibration, are carried out

- ❑ Preliminary gravity field calculations are verified through a combination of internal consistency checks and comparisons with data gathered on the ground.

**Observational Phase**

Following science instruments validation, the mission enters the observational phase, in which science data are routinely gathered from the science payload. This phase




*Launch sequence*

continues until the end of the mission, with the exception of brief periods for orbit maintenance and recalibrations.

## Science Data Processing and Archiving

System development, data processing and archiving are performed in a shared science data system between JPL, the University of Texas' Center for Space Research and Germany's Earth Research Center. Telemetry data are received by a GRACE raw data center at DLR in Neustrelitz, Germany.

The first level of data processing is performed at JPL. Data are sent to the University of Texas and Germany's Earth Research Center, where, along with JPL, the gravity field is derived from calibrated and validated data. Data are archived for distribution to the science community at JPL's Physical Oceanography Distributed Active Archive Center and at the Earth Research Center's Integrated System Data Center.

Data products will include 30-day estimates of gravity fields as well as profiles of air mass, density, pressure, temperature, water vapor and ionospheric electron content.

# Mission Systems

The project is divided into five systems: satellite system, science instrument system, launch vehicle system, mission operations system and science data system.

**Satellite System**

JPL led the development of the satellites in partnership with Space Systems/Loral and Astrium GmbH. Engineers at JPL developed the GPS receiver. Astrium GmbH designed and built the satellites, providing major elements of the two satellites based on the existing small satellite designed for the Champ mission. Space Systems Loral provides the attitude control system design, which maintains satellite orientation, as well as microwave instrument electronics.

**Science Instrument System**

This system is managed by JPL and includes all elements of the ranging system between the two satellites, the GPS receivers, and associated sensors such as the star cameras and accelerometers. This system is also responsible for joining instruments to the spacecraft (or "integrating" them), assuring their compatibility with each other and the satellite.

**Launch Vehicle System**

This system includes the three-stage Rockot launch vehicle, the hardware to carry and release the multiple satellites, and the personnel, test equipment and facilities for preparation, integration and launch of the satellites. It is managed by the launch vehicle manager at DLR and is supported by JPL and its contractors.

**Mission Operations System**

This system consists of facilities and resources of the German Space Operations Center, as well as tracking antennas at Weilheim and Neustrelitz and other stations and facilities needed to support launch and early orbit procedures and contingency operations. These facilities are used to monitor and control the satellite, perform initial processing of the telemetry data and deliver all data to the science data system for further processing and generating science products. In addition to real-time operations, the mission operations system provides the central checkout system for ground testing using command and data interfaces. The operations team also monitors satellite performance and health throughout the duration of the mission. Mission operations are conducted at the German Space Operations Center control center in Oberpaffenhofen, Germany.

**Science Data System**

This system includes science data processing, distribution, archiving and product verification. This system is distributed between several partners, is managed by JPL, and performed in a cooperative approach by JPL and the University of Texas' Center for Space Research in the United States and the Earth Research Center in Germany. This cooperative approach includes sharing of processing tasks, coordination of product archives and validation/comparison of products. Data and products to be processed and archived by the science data system include gravity field products, corrected inter-satellite range and accelerometer measurements, and GPS orbit and occultation data. The science data system also receives, processes and archives ancillary data (i.e. meteorological information) necessary for data processing and verification.

# Spacecraft

Built by Astrium GmbH with major subsystems from JPL and Space Systems/Loral, GRACE builds upon the legacy of the existing Champ satellite.

GRACE is different from most Earth observing satellite missions because it will not carry a suite of independent scientific instruments beyond the limb sounder. The two satellites themselves act in unison as the main instrument to obtain data for models of Earth's gravity field. Each is identical except for transmit and receive frequencies. Separated by 220 kilometers (137 miles), the two satellites fly facing each other - one forward and the other backward - so that they can point their microwave K-band antennas at each other.

Each GRACE satellite measures 1,942 millimeters (76.5 inches) in width, is 3,123 millimeters (123 inches) long, and 720 millimeters (28.3 inches) high and has a mass of 487 kilograms (1,074 pounds).

**K-Band Ranging System**

The key science instrument for GRACE is the microwave K-band ranging instrument. This provides precise (within 1 micron, or the width of a human hair) measurements of the distance change between the two satellites -- and, in turn, fluctuations in Earth's gravity -- by measuring microwave signals sent between the two satellites. Each satellite transmits signals to the other at two frequencies, allowing for ionospheric corrections.

The K-band ranging assembly consists of an ultra-stable oscillator, a K-band ranging horn, sampler and instruments processing unit.

The ultra-stable oscillator serves as the frequency and clock reference for the GRACE satellites.

The K-band ranging horn transmits and receives K-band (24 GHz) and Ka-band (32 GHz) carrier signals to and from the other GRACE satellite.

The sampler downconverts and samples the incoming K and Ka band carrier phase.

The instruments processing unit is the nerve center for the science instruments for the spacecraft. It provides the digital signal processing functions for the K and Ka band signals, as well as for the GPS signals. It also provides various clocks for the satellite and performs data processing for the star camera attitude quaternions.

The K-band ranging system was manufactured by JPL with equipment from Space Systems/Loral and the Applied Physics Laboratory.

### Accelerometers

The satellites may speed up or slow down for reasons other than changes in Earth's gravity field. These other forces acting on the satellites are measured using instruments called accelerometers mounted at the center of gravity of each satellite. These instruments allow scientists to distinguish between gravity influences and those caused by air drag in the atmosphere. The accelerometers were developed by ONERA, a French national research laboratory.

### GPS Receivers

The GPS receivers -- known by the name "Black Jack" receivers --- are used as references to determine the precise location of the two satellites in orbit. The receivers measure changes in the distance of the GRACE satellites to the constellation of GPS satellites circling Earth. The receivers also provide the capability to conduct atmospheric occultation experiments.

The system uses three antennas. One antenna is used to collect navigation data. In addition, two other antennas are used for backup navigation and atmospheric occultation data collection. It also provides digital signal processing functions for the K-Band ranging instrument and the star cameras.

The Black Jack GPS receivers were manufactured by JPL.

### Star Cameras

Two star cameras are mounted close to the accelerometer on each satellite. Used both for science as well as attitude and orbit control, they precisely determine each satellite's orientation by tracking their relative position in reference to the stars. The star cameras have a field of view of 18 degrees by 16 degrees. They were developed by Danish Technical University, Copenhagen, Denmark.

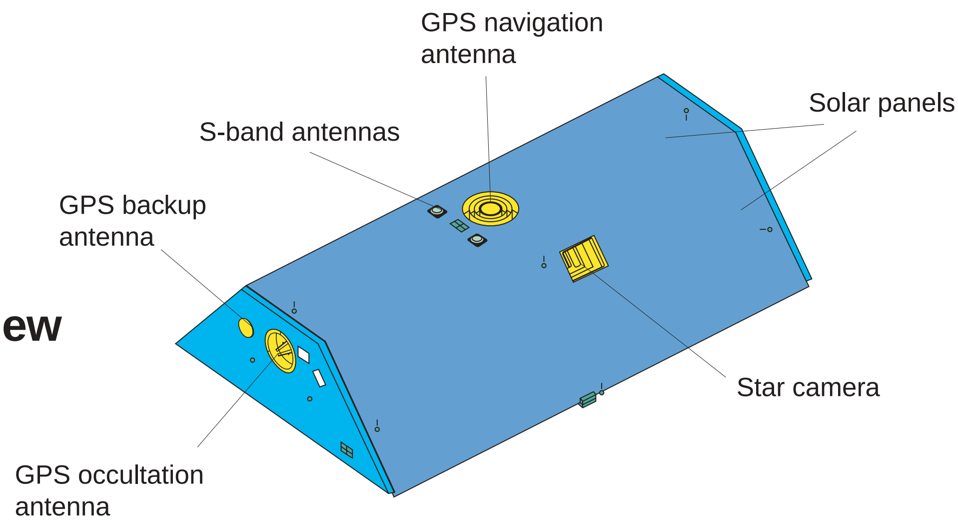
### Laser Retro-Reflectors

The laser retro-reflectors mounted on the underside of each satellite provide a means of terrestrial laser tracking of the GRACE satellites for backup and orbit verification purposes. Ground controllers can verify the satellite's orbits by firing lasers upward toward the satellites, where the laser beam bounces off of the reflector. They are manufactured by GFZ.

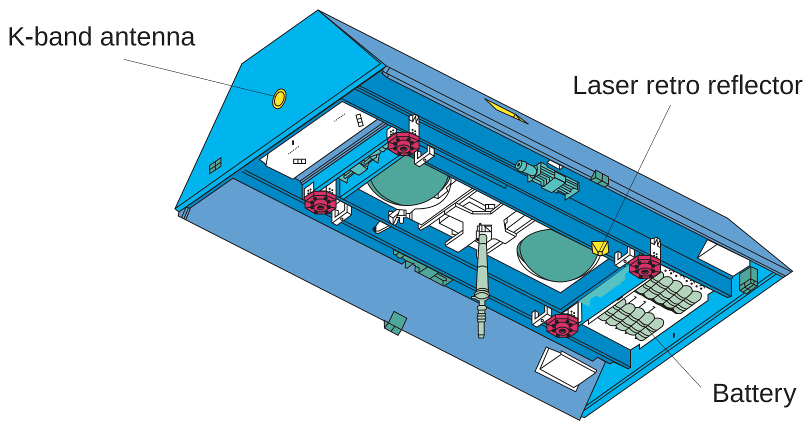
### On-Board Data Handling

The on-board data handling system provides the central processor and mass memory software resources for the spacecraft and management of the science and housekeep-

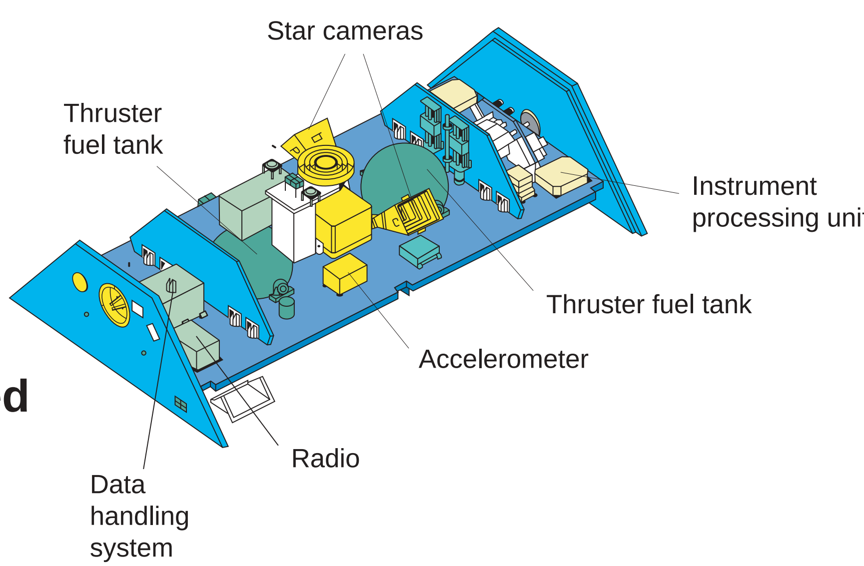
## Top view




## Bottom view with thermal radiator removed




## Top view with solar panels removed




*One of the twin Grace satellites*

ing data. It provides necessary input and output capabilities for the attitude and orbit control system, power and thermal systems operations. In addition, it performs spacecraft health functions, including fault detection, isolation and recovery operations.

**Radio Frequency Electronics Assembly**

The radio frequency electronics assembly takes the data from the on-board data handling system and prepares it for the S-band transmission to the ground data system.

**Telecommunications**

The telemetry and telecommand subsystem allows the satellites to communicate with Earth via radio systems in the microwave S-band spectrum. A single S-band boom antenna on each satellite is deployed after launch by a pyrotechnic device. There are small backup antennas on the bottom and top of each satellite to provide backup communication as required. Each satellite uses a separate set of S-band frequencies for transmission and reception.

The telemetry and telecommand subsystem is supplied by Astrium.

**Power System**

The power system is responsible for generation, storage, conditioning and distribution of electrical power in accordance with instrument and satellite bus user needs. Electrical energy is generated using silicon solar cell arrays that cover the outer shell of each satellite. They consist of four panels on each satellite - two mounted on each satellite's side panels, and two on the top of the satellite. Excess energy is stored in a battery of 10 nickel-hydrogen cells that provide up to 16 amp-hours of 28-volt power per satellite. A power conditioning, distribution and control unit is responsible for managing the power distribution and control on-board the spacecraft.

The power system is manufactured by Astrium.

**Attitude and Orbit Control System**

The satellite's "attitude," or orientation and orbit control are controlled by a system consisting of sensors, actuators and software. The primary sensor is the star camera assembly. Three additional sensors are also included. The coarse Earth/Sun sensor provides coarse attitude determination during all mission phases. The gyro provides attitude rates during spacecraft emergency modes. The magnetometer provides coarse attitude based on the satellite's position as determined by on-board GPS position and a model of the Earth's magnetic field. An inertial reference unit, used in survival modes, provides three-axis rate information. The satellites are "three-axis stabilized," meaning that their orientation is fixed in relation to space and they do not spin for stability. A Forster magnetometer is mounted on the deployable boom to provide additional rate information. Two kinds of attitude actuators are available. A reaction control system with a set of 12 10-millinewton thrusters is available, using gaseous nitrogen stored in the two tanks along the main satellite axis. Fine corrections of orientation can be adjusted using six 30-Amp-m2 magnetorquers, which help to minimize the satellite fuel consumption over the mission lifetime.

Each GRACE satellite can adjust its orbit by firing its two orbit-control thrusters mounted on the rear-panel of the satellite. Each of which provides 40 millinewtons of thrust. The thrusters use gaseous nitrogen as propellant.

The attitude and orbit control system is designed by Space Systems Loral and implemented by Astrium and its team of subcontractors.

**Mass Trim System**

For the accelerometer to measure only non-gravitational forces, it is important that the spacecraft center of gravity be placed at the center of the proof-mass of the accelerometer. The mass-trim mechanism and associated mass-trim electronics serve this function. The six mass-trim mechanisms each consist of a mass moving on a spindle, with each pair providing center of gravity trim along one axis.

**Main Equipment Platform**

All science instruments, fuel tanks and batteries and other satellite subsystems are mounted on a carbon-fiber reinforced plastic platform. This material, which has a very low coefficient of thermal expansion, provides the dimensional stability necessary for precise range change measurements between the two spacecraft.

**Thermal Control**

The thermal control subsystem is responsible for maintaining temperatures of each component on the satellites within allowable limits. It does this using a combination of active and passive control elements. It consists of 64 independent thermistor-controlled heater circuits for in-flight temperature housekeeping, monitoring and heater control, as well as for on-ground verification testing.

The thermal control subsystem is an integral part of the satellite manufactured by Astrium.

**Backups**

Most systems on the satellites are fully redundant. This means that, in the event of a device failure, there is a backup system or function to compensate.

# Program/Project Management

GRACE is a joint project between NASA and the German Center for Air and Space Flight (Deutsches Zentrum fur Luft und Rumfahrt, or DLR). NASA's Jet Propulsion Laboratory, Pasadena, Calif., manages the project for NASA's Earth Science Enterprise and has responsibility for project science. NASA's Goddard Space Flight Center, Greenbelt, Md., is responsible for the Earth System Science Pathfinder program, under which the mission has been developed.

Dr. Ghassem Asrar is the associate administrator for NASA's Earth Science Enterprise, NASA Headquarters, Washington. Dr. Jack Kaye is director of the Earth Science Enterprise Research Division, and Dr. John LaBrecque is manager of the Solid Earth and Natural Hazards program at NASA Headquarters.

At JPL, the GRACE project manager is Dr. Edgar (Ab) Davis, and the project scientist is Dr. Michael Watkins.

At Goddard, Rick Fitzgerald is the manager in the Earth System Science Pathfinder office responsible for Grace.

The GRACE principal investigator is Dr. Byron Tapley of the University of Texas' Center for Space Research. The co-principal investigator is Dr. Christoph Reigber of DLR and Germany's Earth Research Center.