Delta II GRAIL

Mission Overview
Cape Canaveral Air Force Station, FL

ULA
United Launch Alliance

DELTA

United Launch Alliance (ULA) is proud to launch the Gravity Recovery And Interior Laboratory (GRAIL) mission. The Delta II will deliver the dual GRAIL spacecraft into a lunar orbit, where they will begin their mission to improve our understanding of our moon through global mapping of the moon's gravitational field.

GRAIL is the third of five critical missions ULA is scheduled to launch for NASA in 2011. These missions will address important questions of science — ranging from climate and weather on planet earth to life on other planets and the origins of the solar system. We are delighted that NASA has chosen the Delta II for this mission developed by the Jet Propulsion Laboratory (JPL) and built by Lockheed Martin Corporation.

ULA is focused on attaining Perfect Product Delivery for the GRAIL mission, which includes a relentless focus on mission success (the perfect product) one launch at a time, and also excellence and continuous improvement in meeting all of the needs of our customers (the perfect delivery).

I congratulate the entire ULA team and our mission partners for their significant efforts in bringing GRAIL to launch.

Go Delta, Go GRAIL!

Jim Sponnick
Vice President,
Mission Operations

GRAIL SPACECRAFT | Overview

A United Launch Alliance Delta II 7920H-10 rocket will launch GRAIL in September 2011 from Space Launch Complex-17B (SLC-17B) at Cape Canaveral Air Force Station, Fla.

GRAIL will unlock the mysteries of the moon. By mapping the lunar gravitational field globally – not just on the nearside – to unprecedented accuracy and resolution, GRAIL will peer deep inside the moon to reveal its internal structure and thermal history. Knowledge acquired about the moon from GRAIL will be extended to understand the broader evolutionary histories of the other rocky planets in the inner solar system: Earth, Venus, Mars, and Mercury. Indeed, the moon is a linchpin for understanding how the terrestrial planets evolved.

Within the mission objective, all science requirements are derived from six distinct science objectives. These science objectives are:

- map the structure of the crust and lithosphere
- understand the moon's asymmetric thermal evolution
- determine the subsurface structure of impact basins and the origin of mascons
- ascertain the temporal evolution of crustal brecciation and magnetism
- constrain deep interior structure from tides
- place limits on the size of the possible inner core

The GRAIL mission is an element of the Discovery Program within the NASA Science Mission Directorate. GRAIL will place twin spacecraft in a low-altitude (50 km), near circular, polar lunar orbit to perform high-precision range-rate measurements between the two spacecraft using a Ka-band instrument. Subsequent analysis of the spacecraft-to-spacecraft range-rate data provides a direct measure of the lunar gravity.

GRAIL was developed by JPL in collaboration with Lockheed Martin Space Systems Company in Denver, Colorado, who built the spacecraft and associated subsystems, and with science leadership from Massachusetts Institute of Technology and Goddard Space Flight Center. Launch management is the responsibility of NASA's Launch Services Program at the Kennedy Space Center in Fla.

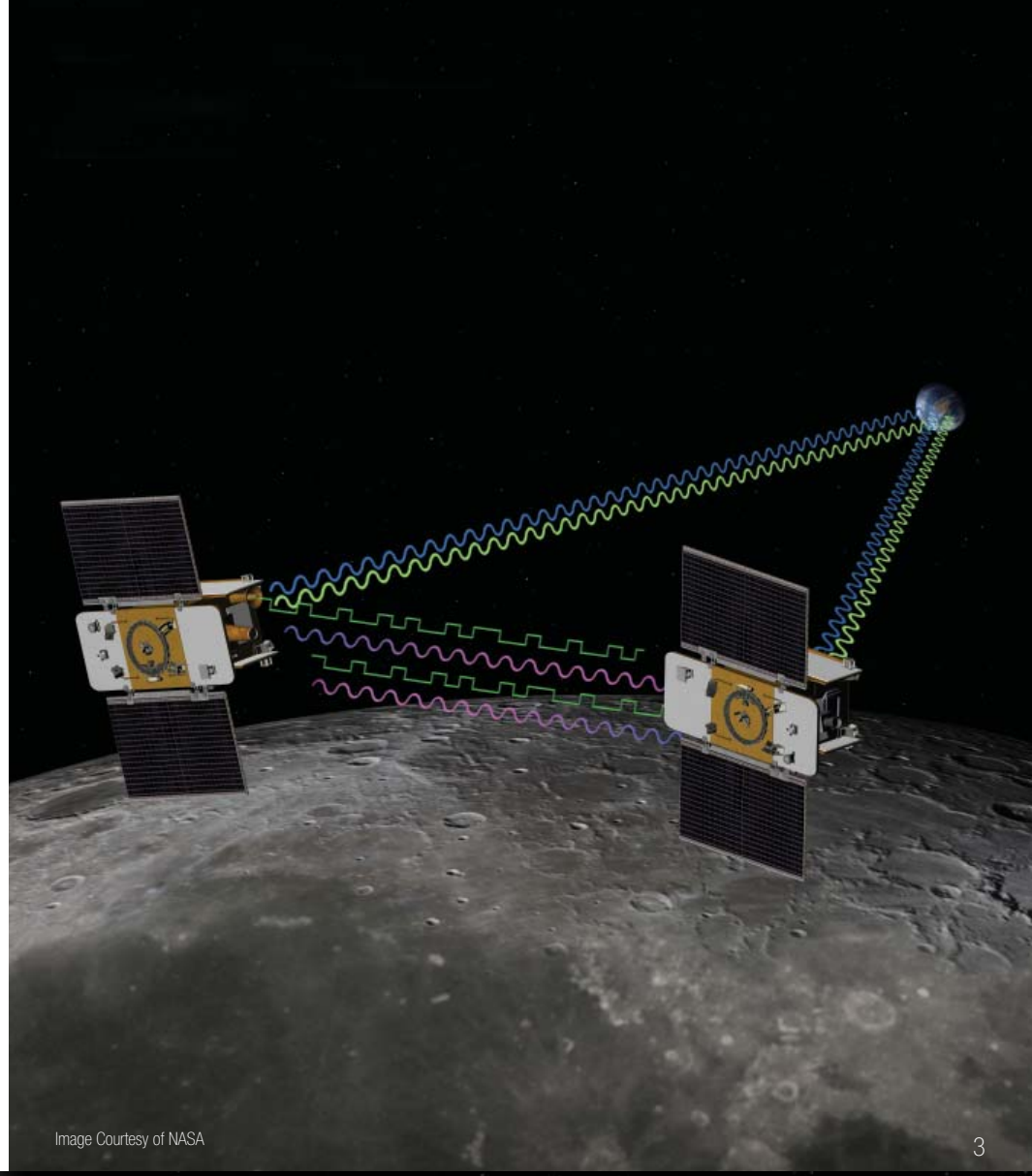


Image Courtesy of NASA

DELTA II 7920H-10 LAUNCH VEHICLE | Overview

The Delta II 7920H-10 consists of the Delta II booster stage, the Delta II hypergolic second stage, nine solid rocket motors (SRM), and a 10-foot diameter payload fairing (PLF).

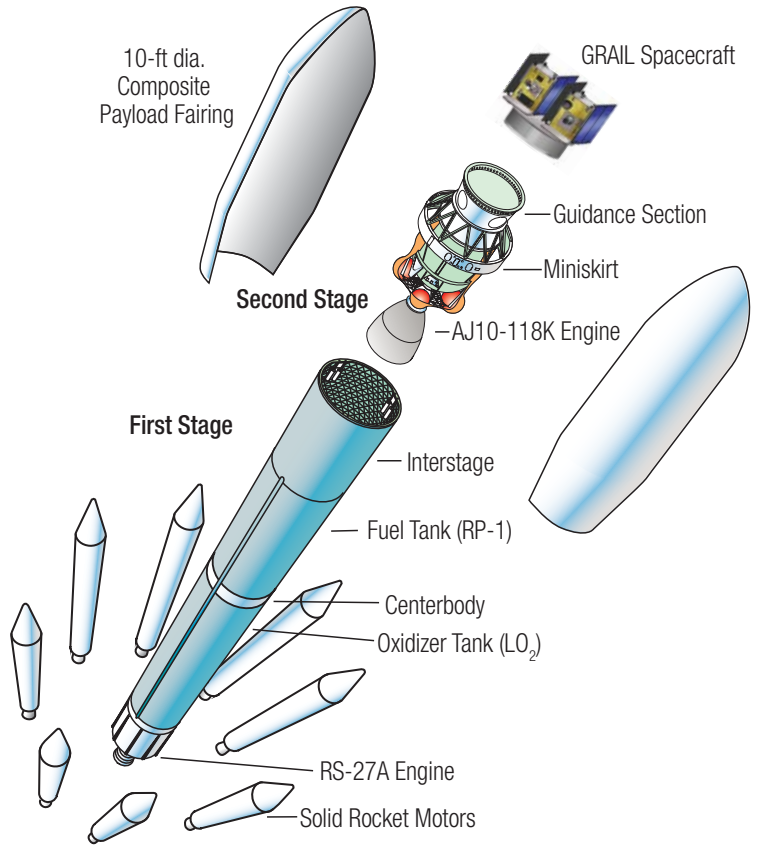
The Delta II booster is 8 ft in diameter and approximately 87 ft in length. The booster's fuel and oxidizer tanks are structurally rigid and constructed of stiffened isogrid aluminum barrels and spun-formed aluminum domes. The booster structure is completed by the centerbody; which joins the fuel and oxidizer tanks. Delta booster propulsion is provided by the RS-27A engine. The RS-27A burns RP-1 (rocket propellant-1 or highly purified kerosene) and liquid oxygen, and delivers 200,000 lb of thrust at sea level. The Delta II booster is controlled by the second-stage avionics system, which provides guidance, flight control, and vehicle-sequencing functions during the booster and second-stage phases of flight.

The Heavy configuration employs nine SRMs approximately 46 in. in diameter. The SRMs are constructed of a graphite epoxy composite with the throttle profile designed into the propellant grain. The SRMs are jettisoned by structural thrusters following a 78-second burn.

The second stage is 8 ft in diameter and approximately 20 ft in length. Its propellant tanks are constructed of corrosion resistant stainless steel. The Delta II second stage is a hypergolic-(Aerozine 50 and Nitrogen Tetroxide) fueled vehicle. It uses a single AJ10-118K engine producing 9,850 lb of thrust. The propellant tanks are insulated with Dacron/Mylar blankets. The second stage's miniskirt/guidance section provides the payload's load path to the booster, the structural support for the second-stage propellant tanks and the PLF, mountings for vehicle electronics, and the structural and electronic interfaces with the spacecraft. The second-stage, other than the miniskirt, is nested inside the interstage adapter.

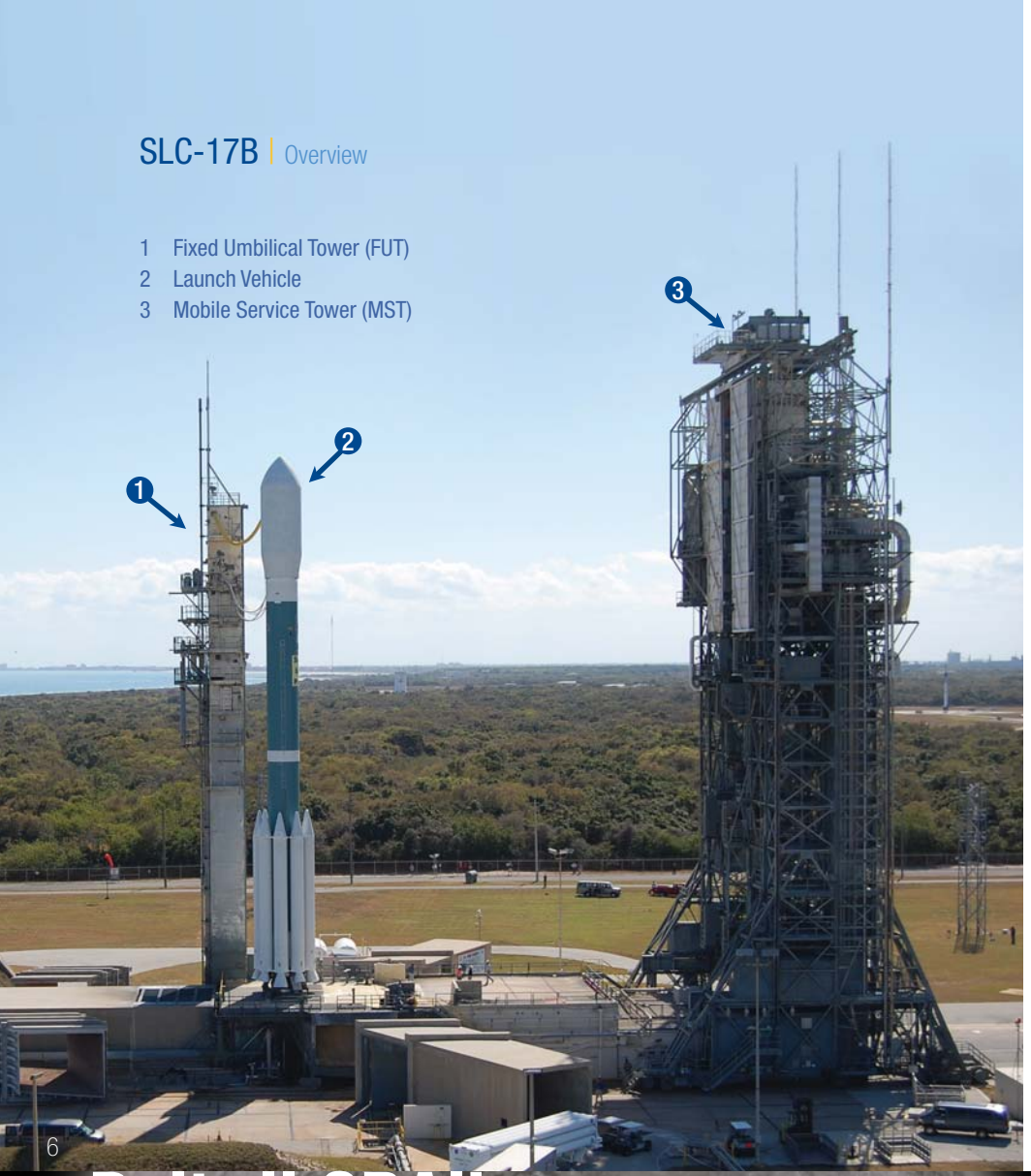
The dual GRAIL spacecraft are encapsulated in the 10-ft diameter PLF. The 10-ft PLF is a sandwich composite structure made with a structural foam core and graphite-epoxy face sheets. The bisector (two-piece shell) PLF encapsulates the second stage's miniskirt/guidance section and the spacecraft; and separates using a debris-free pyrotechnic actuating system. The vehicle's height with the 10-ft PLF is approximately 128 ft.

DELTA II 7920H-10 LAUNCH VEHICLE | Expanded View



SLC-17B | Overview

1 Fixed Umbilical Tower (FUT)
2 Launch Vehicle
3 Mobile Service Tower (MST)



Delta II GRAIL

DELTA II GRAIL | Mission Overview

The Delta II vehicle will launch the GRAIL spacecraft down a flight azimuth of either 99° or 93° from true north. The 93° flight azimuth will be used for the first launch attempt on a given day while the 99° flight azimuth will be used for the second attempt on a given day. The 1-second opportunities are separated by approximately 39 minutes.

Six ground-lit solid rocket motors are ignited at approximately 0.2 seconds prior to liftoff and are jettisoned in sets of three at 80.5 and 81.5 seconds after liftoff. Three air-lit solid rocket motors are ignited at 79 seconds and are jettisoned at 159.5 seconds.

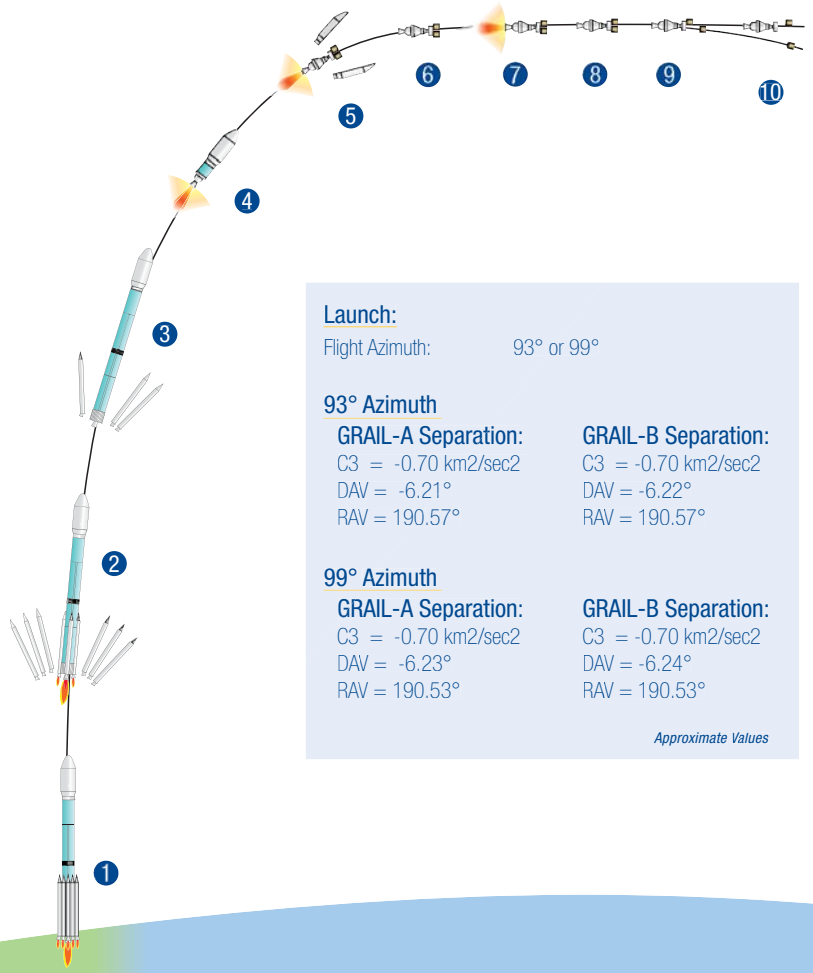
Main engine cutoff occurs 263.2 seconds after liftoff when booster propellants are depleted. First-stage separation follows 8 seconds later with second-stage ignition occurring at 276.7 seconds. Payload fairing jettison occurs at 281 seconds when the free molecular heating rate has dropped below 0.1 BTU/ft2-sec (1135 W/m2).

The first burn of the second stage places the vehicle into a 90-nmi circular orbit with an inclination of 28.50° (93° azimuth) or 29.28° (99° azimuth) and concludes approximately 430 seconds after liftoff. The second stage then performs two sets of attitude reorientation maneuvers and a thermal conditioning maneuver during a variable duration coast phase, prior to the 272-second restart burn.

Following second-stage engine cutoff (SECO-2), the stage is re-oriented to the desired attitude for separation of the GRAIL-A spacecraft which occurs 9 minutes 30 seconds after SECO-2. The stage is then re-oriented to the desired attitude for separation of the GRAIL-B spacecraft which occurs 17 minutes 45 seconds after SECO-2.

The spacecraft separations occur in view of the tracking and data relay satellite (TDRS) system for telemetry coverage and Vandenberg Tracking Station (GRAIL-A only) and the White Sands Test Facility for video coverage of separation and post-separation events. The separation events conclude the primary Delta II mission at approximately 90 minutes after liftoff.

FLIGHT PROFILE | Liftoff to Spacecraft Separation



Launch:

Flight Azimuth: 93° or 99°

93° Azimuth

GRAIL-A Separation:	GRAIL-B Separation:
C3 = -0.70 km2/sec2	C3 = -0.70 km2/sec2
DAV = -6.21°	DAV = -6.22°
RAV = 190.57°	RAV = 190.57°

99° Azimuth

GRAIL-A Separation:	GRAIL-B Separation:
C3 = -0.70 km2/sec2	C3 = -0.70 km2/sec2
DAV = -6.23°	DAV = -6.24°
RAV = 190.53°	RAV = 190.53°

Approximate Values

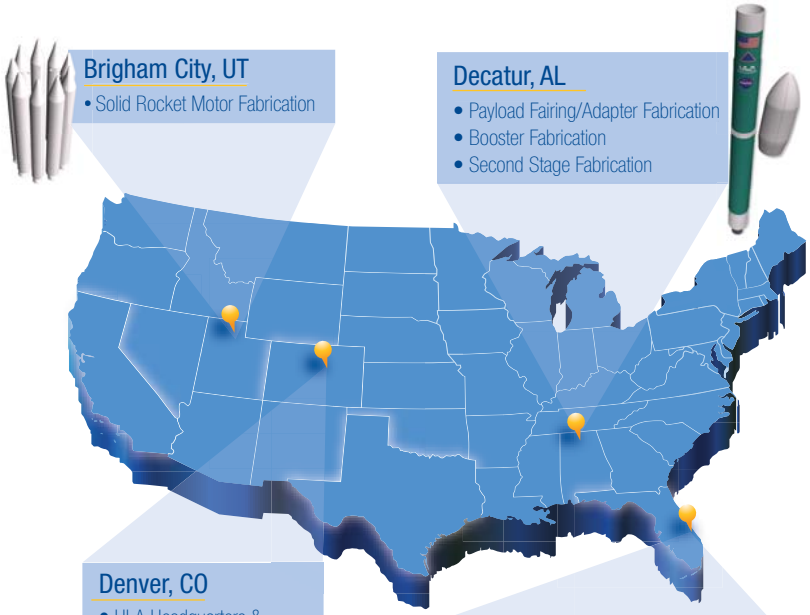
SEQUENCE OF EVENTS | Liftoff to Spacecraft Separation

Event		93° Azimuth Time (seconds)	93° Azimuth Time (hr:min:sec)	99° Azimuth Time (seconds)	99° Azimuth Time (hr:min:sec)
1	Liftoff	0.0	0:00:00.0	0.0	0:00:00.0
	Ground-lit SRM Ignition (6)	0.2	0:00:00.2	0.2	0:00:00.2
	Mach 1	29.0	0:00:29.0	29.0	0:00:29.0
2	Air-lit SRM Ignition (3)	79.0	0:01:19.0	79.0	0:01:19.0
	Ground-lit SRM Jettison (6)	80.5	0:01:20.5	80.5	0:01:20.5
3	Air-lit SRM Jettison (3)	159.5	0:02:39.5	159.5	0:02:39.5
	Main Engine Cutoff (MECO)	263.2	0:04:23.2	263.2	0:04:23.2
	First-Stage Separation	271.2	0:04:31.2	271.2	0:04:31.2
4	Second-Stage Ignition	276.7	0:04:36.7	276.7	0:04:36.7
5	Payload Fairing Jettison	281.0	0:04:41.0	281.0	0:04:41.0
6	First Cutoff—Second Stage (SECO-1)	429.7	0:07:09.7	430.4	0:07:10.4
7	First Restart—Second Stage	4076.7	1:07:56.7	3951.0	1:05:51.0
8	Second Cutoff—Second Stage (SECO-2)	4348.8	1:12:28.8	4222.7	1:10:22.7
9	Spacecraft Separation—GRAIL-A	4918.8	1:21:58.8	4792.7	1:19:52.7
10	Spacecraft Separation—GRAIL-B	5413.8	1:30:13.8	5287.7	1:28:07.7

All Times Approximate

Delta II GRAIL

DELTA II PRODUCTION & LAUNCH | Overview



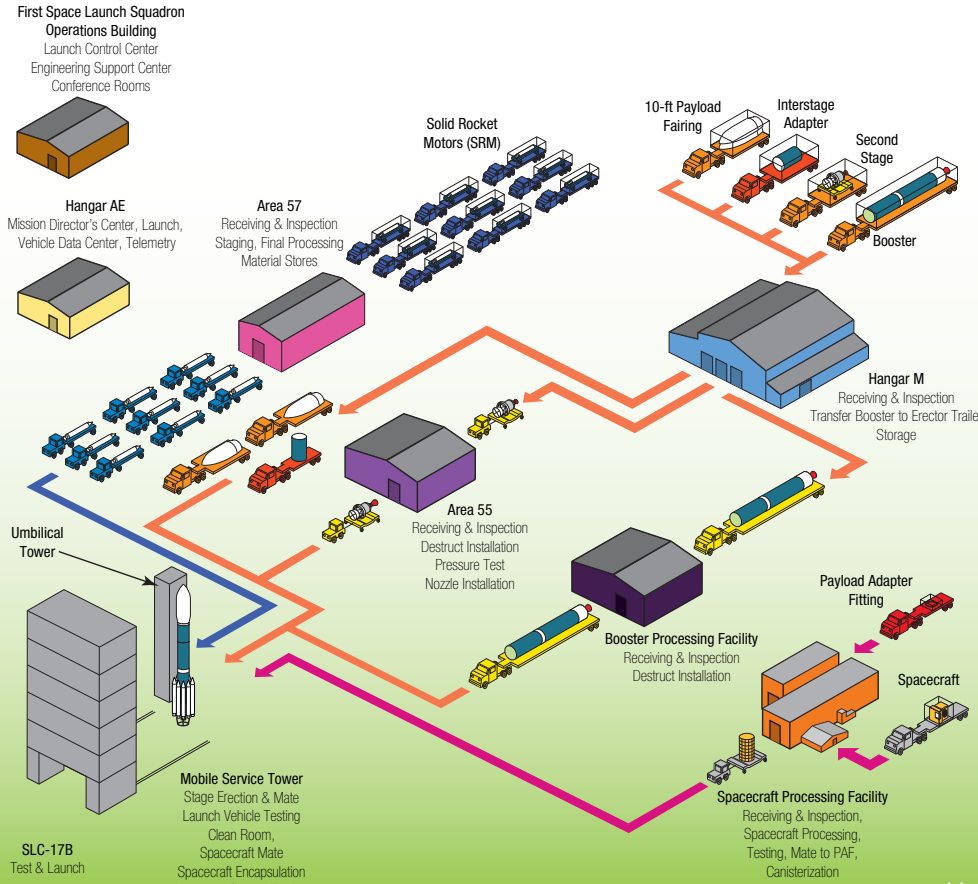
Brigham City, UT
- Solid Rocket Motor Fabrication

Decatur, AL
- Payload Fairing/Adapter Fabrication
- Booster Fabrication
- Second Stage Fabrication

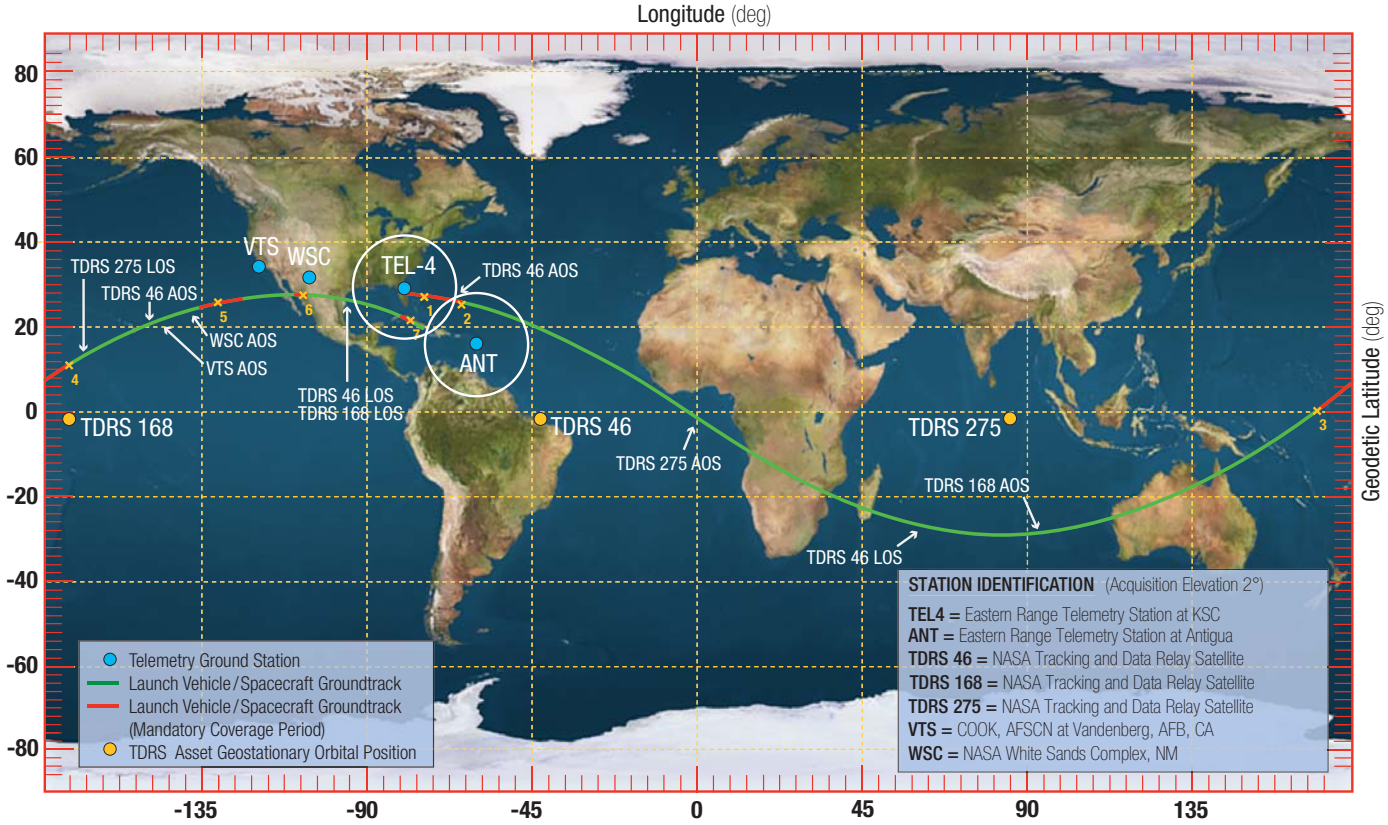
Denver, CO
- ULA Headquarters & Design Center Engineering

Cape Canaveral Air Force Station, FL
- Payload Processing & Encapsulation
- Launch Vehicle Processing
- Encapsulated Payload Mate
- Launch

DELTA II PROCESSING | Cape Canaveral



GROUND TRACE | Liftoff to Spacecraft Separation

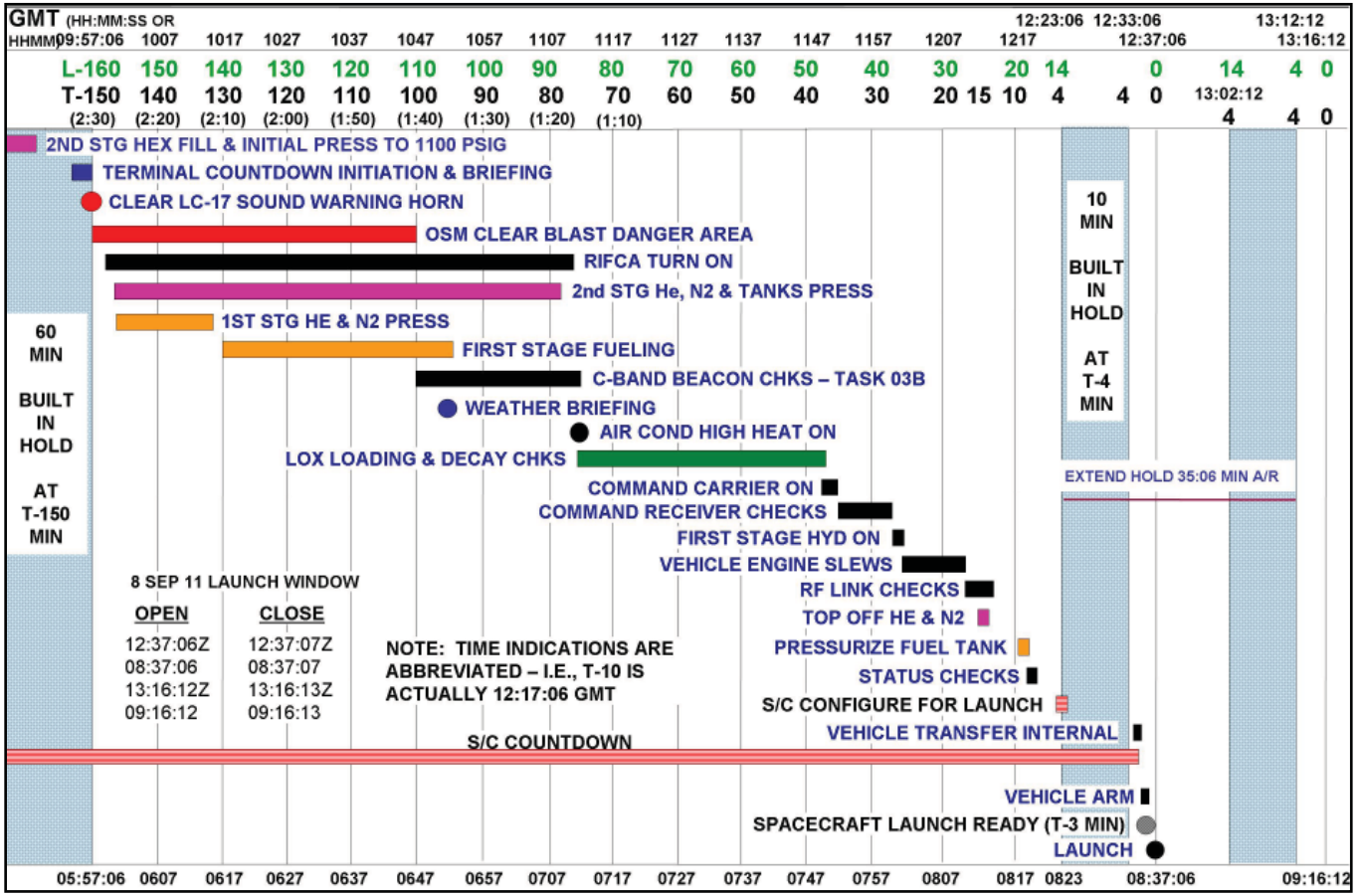


93° Azimuth **1 =** MECO (0:04:23.2) | **2 =** SECO1 (0:07:09.7) | **3 =** Second-Stage, Second Burn Ignition (01:07:56.7) | **4 =** SECO2 (01:12:28.8)
5 = GRAIL-A Separation (01:21:58.8) | **6 =** GRAIL-B Separation (01:30:13.8) | **7 =** Second-Stage Depletion Burn (01:59:10.0)

99° Azimuth **1 =** MECO (0:04:23.2) | **2 =** SECO1 (0:07:10.4) | **3 =** Second-Stage, Second Burn Ignition (01:05:51.0) | **4 =** SECO2 (01:10:22.7)
5 = GRAIL-A Separation (01:19:52.7) | **6 =** GRAIL-B Separation (01:28:07.7) | **7 =** Second-Stage Depletion Burn (01:59:10.0)

All Times Approximate

COUNTDOWN TIMELINE | Launch Day



All Times Approximate

NOTES

United Launch Alliance | P.O. Box 277005 Littleton, CO 80127-7005 | www.ulalaunch.com