National Aeronautics and Space Administration

SPACE SHUTTLE MISSION

STS-134
Final Flight of *Endeavour*

PRESS KIT/April 2011

United Space Alliance

www.nasa.gov

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STS-134 MISSION OVERVIEW

Endeavour at Kennedy Space Center's Launch Pad 39A

Endeavour is targeted to launch on its final flight at 3:47 p.m. EDT Friday, April 29, for STS-134's 14-day mission to the International Space Station. The shuttle will deliver the Alpha Magnetic Spectrometer-2 (AMS), a particle physics detector designed to operate from the station and search for various types of unusual matter.

Also onboard for delivery will be station spare parts on the ExPRESS Logistics Carrier 3 (ELC3), including two S-band communications antennas, a high-pressure gas tank, an ammonia tank assembly, circuit breaker boxes, a Canadarm2 computer and a spare arm for the Dextre robot. The ELC3 also houses a suite of Department of Defense (DoD) experiments that will test systems and materials concepts for long duration spaceflight in low Earth orbit.

STS-134 includes four spacewalks that focus on station maintenance, experiment swap out and transferring Endeavour's orbiter boom sensor system (OBSS) to the station. The crew will leave the boom as a permanent fixture to aid future station spacewalk work, if needed.

NASA astronaut Mark Kelly (right foreground), STS-134 commander, and European Space Agency astronaut Roberto Vittori (left foreground), mission specialist, participate in a simulation exercise in the motion-base shuttle mission simulator in the Jake Garn Simulation and Training Facility at NASA's Johnson Space Center. Photo credit: NASA

The mission also features Endeavour's approach back toward the station after undocking to test new sensor technologies that could make it easier for future space vehicles to dock to the International Space Station.

Mark Kelly (Capt., U.S. Navy) will command Endeavour and the veteran astronaut crew. Gregory H. Johnson (Ret. Col., U.S. Air Force) is the pilot. They will be joined by Mission Specialists Mike Fincke (Col., U.S. Air Force), European Space Agency astronaut Roberto Vittori (Col., Italian Air Force), Andrew Feustel and Greg Chamitoff.

Kelly previously served as pilot of STS-108 in 2001, STS-121 in 2006 and commander of STS-124 in 2008. Johnson was the pilot on STS-123 in 2008. Fincke has logged more than 365 days in space and more than 26 hours of spacewalk time in six spacewalks throughout Expedition 9 as a station flight engineer and

Expedition 18 as station commander. Vittori has flown to the International Space Station twice as part of two crews that delivered new Soyuz spacecraft to the complex. Feustel flew on the fifth and final Hubble Space Telescope servicing mission, STS-125, and accumulated more than 20 hours of spacewalk time during three excursions. Chamitoff served on Expeditions 17 and 18, logging a total of 183 days in space.

Endeavour and crew will spend two days heading toward a rendezvous with the International Space Station. On the second day of the flight, the crew will perform the standard scan of the shuttle's thermal protection system using the OBSS attached to the end of Endeavour's robotic arm. While the inspection is underway, Fincke and Feustel will work on preparing the spacesuits onboard the shuttle that will be transferred to the station after docking for use during the mission's four spacewalks. After the inspection and the boom extension is stowed, the shuttle robotic arm will be attached to the ELC3 to be ready for the cargo carrier's installation on the station soon after docking.

NASA astronaut Mark Kelly, STS-134 commander, dons a training version of his shuttle launch and entry suit in preparation for a training session in the fixed-base shuttle mission simulator in the Jake Garn Simulation and Training Facility at NASA's Johnson Space Center. United Space Alliance suit technician Andre Denard assists Kelly. Photo credit: NASA

On the third day of the flight, Endeavour will approach and dock with the space station. The Sensor Test for Orion Rel-nav Risk Mitigation, or STORRM, system will begin gathering information on a laptop inside the shuttle during rendezvous and docking. The unique re-rendezvous with the station will occur later in the flight for the heart of the test.

After the hatches are opened between the two spacecraft, both crews will begin working on using the shuttle's robotic arm to remove the ELC3 from inside the shuttle's payload bay, hand it to the station's robotic arm, and install it in the upper outboard attach position on the port side of the station's truss structure. The weight of the ELC3 is approximately 14,023 pounds with the spares installed.

The AMS will be installed on flight day 4. Similarly to the ELC3, the shuttle and station robotic arms will work together to place AMS on the upper inboard attach position on the starboard side of the station's truss. The crews also will begin transferring equipment and supplies between the spacecraft and make preparations for the first spacewalk. Both crews will walk through the choreography of the spacewalk, and Feustel and Chamitoff will spend the night camped out inside the Quest airlock.

Each of the four spacewalks will last about six hours and will be conducted by three of Endeavour's crew members. Feustel is the lead spacewalker on STS-134. He has conducted three spacewalks previously and will wear a suit with solid red stripes. Fincke has conducted six spacewalks and will wear an unmarked white suit. Chamitoff will be making his first spacewalks on STS-134 and will wear a suit with broken red stripes.

On flight day 5, during the spacewalk, Feustel and Chamitoff will retrieve two material exposure experiments and install a new package of experiments on ELC2. They will install jumpers between the port 3/port 4 truss segments and the port 5/port 6 truss segments for ammonia refills, vent nitrogen from the Port 6 (P6) early ammonia servicer, and install an external wireless communication antenna on the Destiny laboratory that will provide wireless communication to the ELCs mounted on the P3 and S3 truss segments.

The crew will hand Endeavour's orbiter boom sensor system from the station robotic arm to the shuttle robotic arm on flight day 6. The boom extension is then ready for any focused inspection tasks on this day, if required, and the inspection activities later in the flight. The afternoon will be off-duty time for the crews and then Feustel and Fincke will campout in the airlock for the next spacewalk.

During the second spacewalk, on flight day 7, Feustel and Fincke will refill the P6 truss radiators with ammonia. They also will complete venting the early ammonia system on P6, lubricate the race ring on the port solar alpha rotary joint and lubricate the latching end effector on Dextre.

Flight day 8 includes the transfer of equipment and supplies and additional off-duty time. At the end of the day, Feustel and Fincke will not campout in the airlock since the third spacewalk will feature a new pre-breathe protocol that prepares the spacewalkers' bodies to prevent decompression sickness while wearing their low-pressure spacesuits.

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The new spacewalk preparation, dubbed "in-suit light exercise," does not require a campout in the airlock and is expected to use less oxygen from the stores onboard than a campout or the original cycling exercise regimen. After putting on the suits on the morning of the third spacewalk, Feustel and

Fincke will exercise lightly by “walking” in place for 50 minutes, and then rest for 50 more minutes. Following the spacewalk, the crew members and ground support team will assess the new process to determine if it will be used for the fourth excursion.

That third spacewalk, on flight day 9, will see Feustel and Fincke install a power and data grapple fixture (PDGF) and the associated power and data cables on the Zarya module to support robotic operations based from the Russian segment. They also will install additional cables to provide redundant power channels to the Russian segment.

The “late inspection” of Endeavour’s heat shield to check for damage from space debris will be conducted on flight day 10 while the orbiter is still at the station. This is usually completed after undocking, but the inspection boom will be left at the station when Endeavour leaves. A similar procedure was conducted during STS-131 so that the inspection data could be sent to Mission Control via the space station’s system because the space shuttle Discovery’s Ku-band system was not functioning.

On the station, crew members will begin three days of scheduled maintenance work on a machine that scrubs the atmosphere of carbon dioxide. Fincke and Chamitoff plan to campout in the Quest airlock overnight, unless there is sufficient information from the new prebreathe process used before the third spacewalk to implement it on the next spacewalk.

On flight day 11, during the fourth and final scheduled spacewalk, Fincke and Chamitoff will attach the OBSS for storage on the interface between the starboard 0 and starboard 1 trusses. The boom could serve as extension for the station robotic arm, possibly aiding future spacewalkers reach distant worksites around the complex. They also will retrieve the PDGF from the P6 truss, remove the electrical grapple fixture from the OBSS and replace it with the P6 PDGF. They then will release restraints from one of the arms on Dextre and replace thermal insulation on one of the gas tanks on the Quest airlock.

The fourth spacewalk of STS-134 is the final scheduled spacewalk by a space shuttle crew. The single spacewalk scheduled during STS-135 is to be conducted by space station residents Mike Fossum and Ron Garan.

Flight day 12 of STS-134 includes the organization of spacewalking gear and more transfer work before the hatches are closed between the two spacecraft near the end of the workday.

Flight day 13 begins with Endeavour’s undocking from the space station, and continues with the primary objective of STORRM.

Once Endeavour undocks from the station, plans still call for Johnson to fly the shuttle in a lap around the International Space Station complex. The shuttle crew will take detailed photographs of the external structure of the station, which serves as important documentation for the ground teams in Houston to monitor the orbiting laboratory.

Once the loop around the station is finished, Endeavour will fire its engines to move away from the station. A second firing of the engines, which would normally take the shuttle further away, will serve as the first of multiple maneuvers to bring Endeavour back toward the station for the sensor test.

The re-rendezvous will mimic the Orion vehicle's planned rendezvous trajectory and will approach no closer than 600 feet to the station. Endeavour is targeted to approach the station to a point 1,000 feet below and 300 feet behind the station at its closest point.

The test will characterize the performance of sensors in Endeavour's payload bay and their acquisition of reflectors on a docking target at the station. Nearly five hours after undocking, Endeavour's engines will fire again to depart the station's vicinity for good.

Flight day 14 will be spent checking out Endeavour's Reaction Control System (RCS) jets and the flight control surfaces. Both of these systems will be put through their paces to ensure that they are ready to support Endeavour's return to Earth. The RCS jets will be used during the early part of entry, up until the atmosphere builds up enough for the flight control surfaces to take over and steer the shuttle toward the runway.

Endeavour's final landing is scheduled on flight day 15 at the Kennedy Space Center in Florida. At the time of its scheduled landing, Endeavour will have travelled more than 100 million miles during 25 flights and spent more than 294 days in space.

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STS-134 TIMELINE OVERVIEW

Flight Day 1

- Launch
- Payload bay door opening
- Ku-band antenna deployment
- Shuttle robotic arm activation and payload bay survey
- Umbilical well and handheld external tank photo and TV downlink

Flight Day 2

- Endeavour’s Thermal Protection System Survey with shuttle robotic arm/Orbiter Boom Sensor System (OBSS)
- Extravehicular mobility unit checkout
- Centerline camera installation
- Orbiter docking system ring extension
- Rendezvous tools checkout

Flight Day 3

- Rendezvous with the International Space Station
- Rendezvous pitch maneuver photography of Endeavour’s thermal protection system by Expedition 27 crew members Nespoli and Coleman
- Docking to Harmony/pressurized mating adapter 2
- Hatch opening and welcoming
- Shuttle robotic arm grapple of Express Logistics Carrier-3, unberthing from Endeavour’s payload bay, handoff to Canadarm2 and installation on the Port 3 truss segment

Flight Day 4

- Shuttle robotic arm unberth of the Alpha Magnetic Spectrometer-2 (AMS), handoff to Canadarm2 and installation of AMS on the Starboard 3 truss segment
- Spacewalk 1 procedure review
- Spacewalk 1 campout and prebreathe by Feustel and Chamitoff

Flight Day 5

- Spacewalk 1 by Feustel and Chamitoff (MISSE experiment retrieval and installation, ammonia jumper installation between Port 3 and Port 6 truss segments, Destiny lab wireless communications hardware installation)

Flight Day 6

- Orbiter boom sensor system (OBSS) grapple by Canadarm2 and handoff to shuttle robotic arm
- Crew off-duty period
- Spacewalk 2 procedure review
- Spacewalk 2 campout and prebreathe by Feustel and Fincke

Flight Day 7

- Spacewalk 2 by Feustel and Fincke (Port Solar Alpha Rotary Joint cover removal and lubrication, Starboard 1 truss radiator grapple bar stowage, early ammonia servicer venting, refill of the Port 1 Ammonia Tank Assembly, Dextre robot latching end effector lubrication)

Flight Day 8

- Crew off-duty period
- Spacewalk 3 procedure review

Flight Day 9

- In-Suit Light Exercise (ISLE) prebreathe by Feustel and Fincke
- Spacewalk 3 by Feustel and Fincke (Zarya PDGF installation, PDGF data cable installation, vision system installation, Strela adapter relocation)

Flight Day 10

- Late inspection of Endeavour's thermal protection system heat shield
- Spacewalk 4 procedure review
- Spacewalk 4 campout and prebreathe by Fincke and Chamitoff

Flight Day 11

- Spacewalk 4 by Fincke and Chamitoff (install the OBSS at the Starboard 0/Starboard 1 truss interface, swap out of the OBSS grapple fixtures, retrieval of the Port 6 truss segment power and data grapple fixture, release of retention systems on the Dextre spare robotic arm; *this is the final scheduled spacewalk by Shuttle crew members*)

Flight Day 12

- Post-spacewalk spacesuit reconfiguration
- Joint crew news conference
- Farewells and hatch closure
- Rendezvous tools checkout

Flight Day 13

- Undocking and flyaround of ISS
- STORRM detailed test objective for re-rendezvous demonstration
- Final separation

Flight Day 14

- Cabin stowage
- Flight control system checkout
- Reaction control system hot-fire test
- Deorbit preparation briefing
- Ku-band antenna stowage

Flight Day 15

- Deorbit preparations
- Payload bay door closing
- Deorbit burn
- KSC landing

MISSION PROFILE

CREW

Commander:	Mark Kelly
Pilot:	Gregory H. Johnson
Mission Specialist 1:	Mike Fincke
Mission Specialist 2:	Roberto Vittori (ESA)
Mission Specialist 3:	Drew Feustel
Mission Specialist 4:	Greg Chamitoff

LAUNCH

Orbiter:	Endeavour (OV-105)
Launch Site:	Kennedy Space Center, Launch Pad 39A
Launch Date:	April 29, 2011
Launch Time:	3:47 p.m. EDT (preferred in-plane launch time)
Launch Window:	10 Minutes
Altitude:	122 nautical miles (140 miles) orbital insertion; 188 nautical miles (216 statute miles) rendezvous
Inclination:	51.6 degrees
Duration:	14 days

VEHICLE DATA

Shuttle Liftoff Weight:	4,524,863 pounds
Orbiter/Payload Liftoff Weight:	268,580 pounds
Orbiter/Payload Landing Weight:	203,354 pounds
Software Version:	OI-34

Space Shuttle Main Engines:

SSME 1:	2059
SSME 2:	2061
SSME 3:	2057
External Tank:	ET-122
SRB Set:	BI-145
RSRM Set:	113

SHUTTLE ABORTS

Abort Landing Sites

RTLS:	Kennedy Space Center Shuttle Landing Facility
TAL:	Primary – Zaragoza, Spain Alternates – Morón, Spain and Istres, France
AOA:	Primary – Kennedy Space Center Shuttle Landing Facility Alternate – White Sands Space Harbor

LANDING

Landing Date:	May 13, 2011
Landing Time:	9:28 a.m. EDT
Primary landing Site:	Kennedy Space Center

PAYLOADS

ExPRESS Logistics Carrier 3 (ELC3)
Alpha Magnetic Spectrometer-2(AMS)

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MISSION OBJECTIVES

1. Dock space shuttle Endeavour to the Pressurized Mating Adapter-2 port and perform mandatory crew safety briefing for all crew members

2. Install Alpha Magnetic Spectrometer-2 (AMS) to S3 upper inboard Payload Attach System 2 (PAS-2) using shuttle and International Space Station robotic arms and provide keep-alive power

3. Install Expedite the Processing of Experiments to the Space Station (ExPRESS) Logistics Carrier (ELC) 3 to P3 Upper Outboard Unpressurized Cargo Carrier Attach System 1 (UCCAS-1) using shuttle and station robotic arms and provide keep-alive power

4. Transfer critical items per flight ULF6 Transfer Priority List (TPL)

5. Transfer mandatory items per Flight ULF6 TPL

6. Transfer oxygen to the station’s Quest airlock high-pressure gas tanks

7. Retrieve Materials International Space Station Experiment (MISSE) Payload Experiment Carriers (PECs) 7A and 7B from ELC2 and stow in payload bay for return [Extravehicular Activity (EVA)]

8. Install and deploy MISSE 8 PEC on ELC2 [EVA]

9. Activate Space Test Program – Houston 3 (STP-H3) payload on ELC3

10. Activate AMS for experiment operation

11. Perform Sensor Test for Orion Rel-nav Risk Mitigation (STORRM)

    – Obtain data during undocking and re-rendezvous

    – Obtain data during rendezvous, proximity op and docking

    – Photograph STORRM targets post docking and prior to undock for photogrammetric analysis

12. Perform daily high priority payload activities

13. Perform daily station payload status checks

14. Transfer remaining cargo items per flight ULF6 TPL

15. Transfer nitrogen from the shuttle to the space station

16. Transfer water from the shuttle to the space station

17. Transfer OBSS to space station

18. Remove and replace Node 3 Carbon Dioxide Removal Assembly rear bed

19. Complete the following EVA tasks:
    - Install the OBSS on the S1 truss
    - Refill P6 Photovoltaic Thermal Control System (PVTCS) ammonia
    - Install FGB Y power feed cables for channels 1/4 and 2/3
    - Install external wireless communication antenna system
    - Lubricate port Solar Alpha Rotary Joint (SARJ) race ring
    - Remove Special Purpose Dexterous Manipulator (SPDM) spare arm EDF bolts
    - Install multi-layer insulation over HPGT grapple fixture
    - Lubricate SPDM latching end-effector snares
    - Reinstall Starboard SARJ cover No. 7
    - Install S1 radiator grapple bar stowage beam assemblies
    - Inspect OTP long-duration tie-down tethers and recinch if necessary
    - Install PDGF on FGB
    - Retrieve P6 PDGF
    - Remove Electrical Flight Releasable Grapple Fixture from OBSS and install adapter plate and PDGF

MISSION PERSONNEL

KEY CONSOLE POSITIONS FOR STS-134

	Flt. Director	CAPCOM	PAO
Ascent	Richard Jones	Barry Wilmore Lee Archambault (Wx)	Kyle Herring
Orbit 1 (Lead)	Gary Horlacher	Megan McArthur	Kyle Herring
Orbit 2	Paul Dye	Steve Robinson	Brandi Dean
Planning	Kwatsi Alibaruho	Shannon Lucid	Josh Byerly
Entry	Tony Ceccacci	Barry Wilmore Terry Virts (Wx)	Kyle Herring
Shuttle Team 4	Richard Jones	N/A	N/A
ISS Orbit 1	Dana Weigel	Rob Hayhurst	N/A
ISS Orbit 2 (Lead)	Derek Hassmann	Lucia McCullough	N/A
ISS Orbit 3	Dina Contella	Dan Tani	N/A
Station Team 4	David Korth		

JSC PAO Representative at KSC for Launch – Nicole Cloutier-Lemasters/Doug Peterson

KSC Launch Commentator – George Diller

KSC Launch Director – Mike Leinbach

NASA Launch Test Director – Jeff Spaulding

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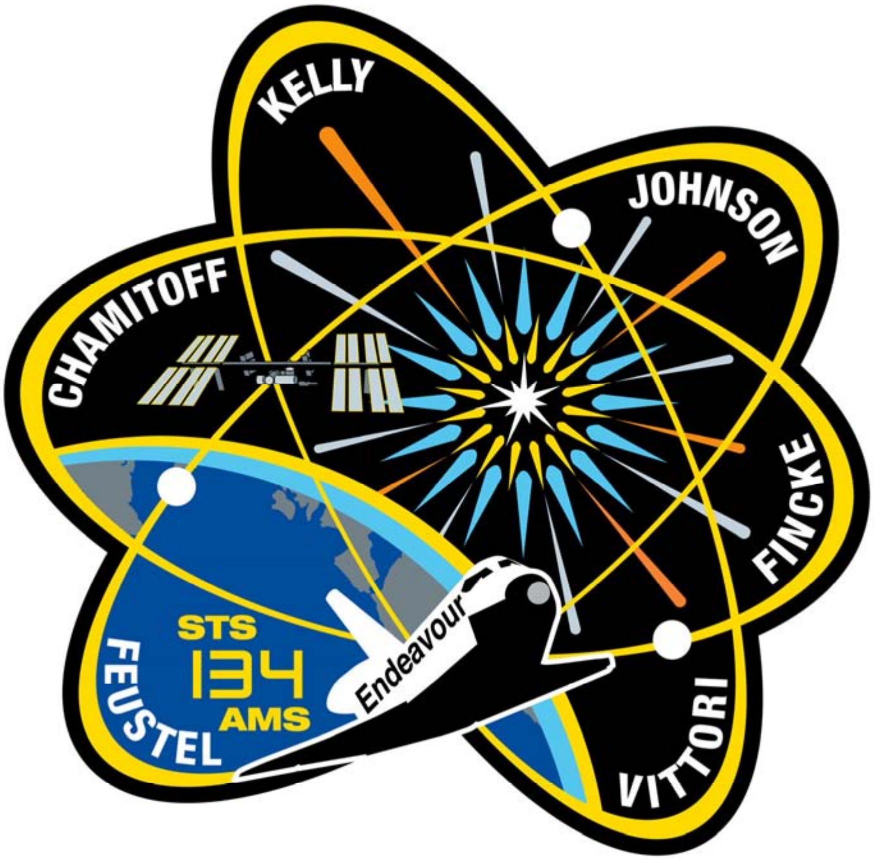
STS-134 ENDEAVOUR CREW



STS-134 Mission Patch

The design of the STS-134 crew patch highlights research on the International Space Station focusing on the fundamental physics of the universe. On this mission, the crew of space shuttle Endeavour will install the Alpha Magnetic Spectrometer-2 (AMS) experiment – a cosmic particle detector that uses the first ever superconducting magnet to be flown in space. By studying subatomic particles in the background cosmic radiation and searching for antimatter and dark matter, it will help scientists better understand the evolution and properties of our universe. The shape of the patch is inspired by the international atomic symbol, and represents the atom with orbiting electrons around the nucleus. The burst near the center refers to the big-bang theory and the origin of the universe. The space shuttle Endeavour and space station fly together into the sunrise over the limb of Earth, representing the dawn of a new age, understanding the nature of the universe.

Attired in training versions of their shuttle launch and entry suits, these six astronauts take a break from training to pose for the STS-134 crew portrait. Pictured clockwise are NASA astronauts Mark Kelly (bottom center), commander; Gregory H. Johnson, pilot; Michael Fincke, Greg Chamitoff, Andrew Feustel and European Space Agency's Roberto Vittori, all mission specialists.

Short biographical sketches of the crew appear in this package.

More detailed biographies are available at http://www.jsc.nasa.gov/Bios/astrobio.html

CREW BIOGRAPHIES

Mark Kelly

Veteran astronaut and a captain in the U.S. Navy, Mark Kelly will lead STS-134 and its crew. In his role as commander, he has overall responsibility for the safety and execution of the mission, orbiter systems operations and flight operations, including landing. In addition, he will fly Endeavour through its rendezvous and docking to the International Space Station.

Kelly previously served as pilot of STS-108 in 2001, STS-121 in 2006 and commander of STS-124 in 2008. He has logged 38 days in space.

Greg H. Johnson

Greg H. Johnson, a retired colonel in the U.S. Air Force, will be making his second trip into space as pilot on STS-134. He will be responsible for orbiter systems operations, will assist Kelly with rendezvous and will fly Endeavour during undocking and the fly around. Following initial astronaut training, Johnson was assigned to the Shuttle Cockpit Avionics Upgrade council – redesigning cockpit displays for future shuttle missions. He was also a key player on the External Tank foam impact test team investigating the cause of the Columbia accident in 2003. Currently, Johnson is the Astronaut Safety Branch Chief.

Johnson was the pilot on STS-123 in 2008. He has logged more than 4,000 flight hours in more than 40 different aircraft.

Michael Fincke

A colonel in the U.S. Air Force, Michael Fincke will serve as a mission specialist on STS-134. Selected by NASA in 1996, Fincke was assigned technical duties in the Astronaut Office Station Operations Branch serving as an International Space Station Spacecraft Communicator (ISS CAPCOM), was a member of the Crew Test Support Team in Russia and served as the International Space Station crew procedures team lead. He is qualified to fly as a left-seat flight engineer (co-pilot) on the Russian Soyuz TM and TMA spacecraft.

Fincke has logged more than 365 days in space and more than 26 hours of spacewalk time in six spacewalks throughout Expedition 9 and Expedition 18.

Roberto Vittori

Roberto Vittori is a member of the European Space Agency (ESA). A colonel in the Italian Air Force, he was selected as an astronaut by the Italian Space Agency (ASI), in cooperation with the ESA, and later joined the European Astronaut Corps. Arriving at Johnson Space Center in 1998, he worked in the Space Shuttle Operations System Branch of NASA's Astronaut Office and then supported the New Generation Space Vehicles Branch.

Vittori has flown to the International Space Station twice as a spaceflight participant.

Andrew Feustel

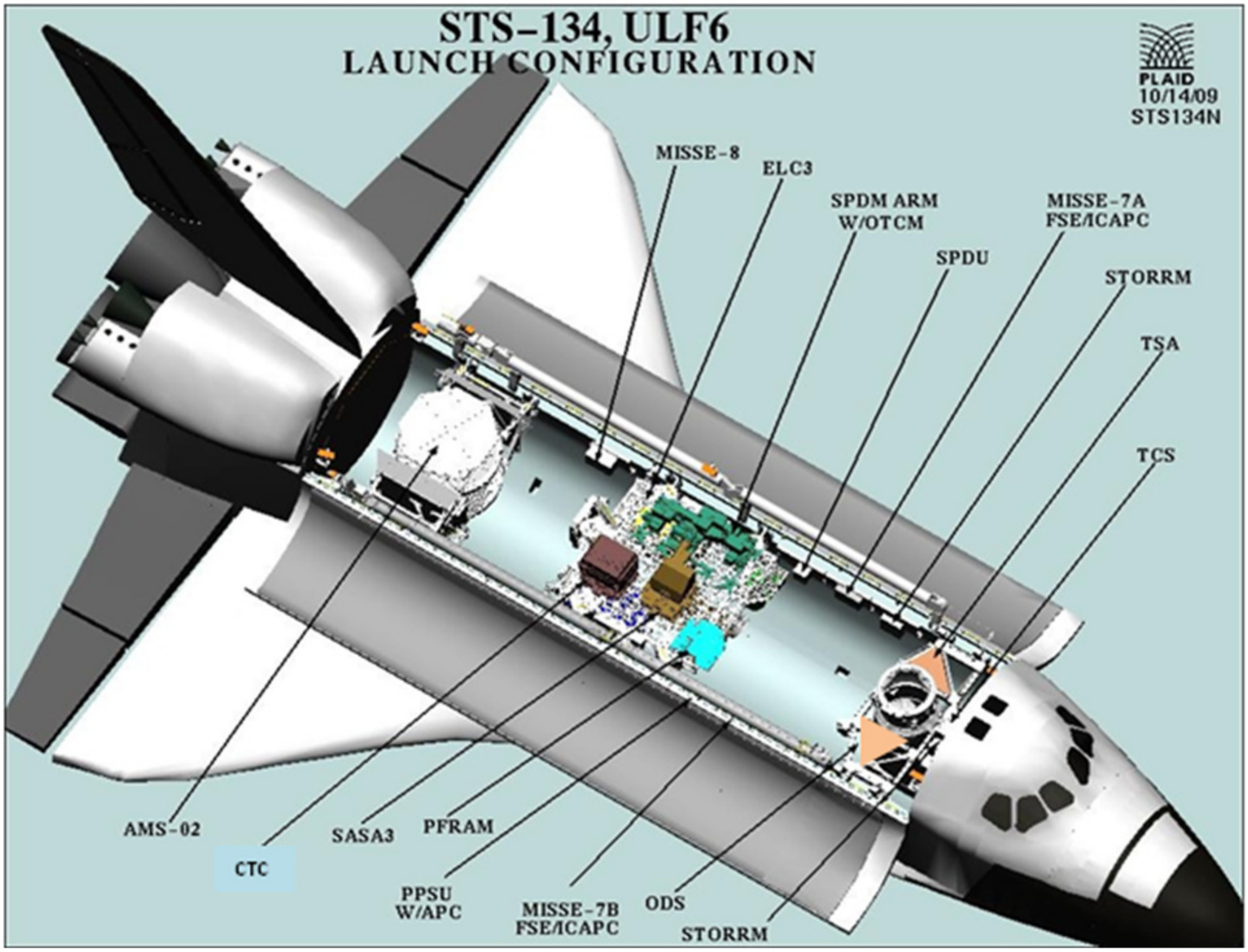
Making his second trip into space, Andrew Feustel will serve as a mission specialist on STS-134. Selected by NASA in 2000, he worked in the Astronaut Office Space Shuttle and Space Station Branches upon completion of astronaut training. Feustel flew on the fifth and final Hubble servicing mission, STS-125, and accumulated nearly 13 days in space and more than 20 hours of EVA time in three spacewalks.

Greg Chamitoff

Greg Chamitoff will serve as a mission specialist on STS-134. Joining the Mission Operations Directorate at Johnson Space Center in 1995, he developed software applications for spacecraft attitude control monitoring, prediction, analysis and maneuver optimization. One of these applications is the 3D "big screen" display of the station and shuttle used by Mission Control. After initial training with the astronaut class of 1998, he completed assignments within the Astronaut Office including space station procedure and display development, crew support for Expedition 6, lead CAPCOM for Expedition 9 and space station robotics.

Chamitoff was a crew member of the Aquarius undersea research habitat for nine days as part of the NASA Extreme Environment Mission Operations (NEEMO) 3 mission. In addition, he served on Expedition 17/18, logging 183 days in space.

PAYLOAD OVERVIEW



ALPHA MAGNETIC SPECTROMETER-2

WEIGHT:	15,251 pounds (6,917 kg)	**VOLUME:**	1,650 cubic feet (46.7 m^3)
HEIGHT:	11 feet	**POWER:**	2,400 watts
WIDTH:	15 feet	**DATA CHANNELS:**	300,000
LENGTH:	10 feet	**DATA DOWNLINK RATE:**	6 megabits/second
MAGNETIC FIELD INTENSITY:		1250 Gauss (4,000 times stronger than the Earth’s magnetic field)	
LIFETIME:		Through 2020 and beyond – until the space station is deorbited	
COST:		$2 billion (estimated, divided between contributors and not including launch and operations costs)	
ENGINEERS, SCIENTISTS, AND TECHNICIANS INVOLVED:	600		
INSTITUTIONS INVOLVED:	56	**COUNTRIES INVOLVED:**	16

Overview

Packed away inside Endeavour's cargo bay is a science experiment 16 years in the making, with the potential to help us answer questions that have been asked for millions of years.

The Alpha Magnetic Spectrometer-2 (AMS) is a state-of-the-art particle physics detector to be delivered to the International Space Station. Using a large magnet to create a magnetic field that will bend the path of the charged cosmic particles already traveling through space, eight different instruments will provide information on those particles as they make their way through the magnet. Armed with that information, hundreds of scientists from 16 countries are hoping to determine what the universe is made of and how it began, as the AMS searches for clues on the origin of dark matter and the existence of antimatter and strangelets. And if that's not enough, there is also the information it could provide on pulsars, blazers and gamma ray bursters and any number of phenomena that have yet to be named.

The AMS is not the only experiment looking into these concepts – there are several large, high-energy experiments here on Earth, and a number of telescopes and explorer missions studying the universe from space. But, AMS is unique. Where telescopes – which measure light, whether visible or not – look at space, the AMS will sift through it, measuring cosmic particles. And unlike similar experiments on the ground, its study will not be limited to the particles that make it through Earth's atmosphere or can be artificially created.

In space, the AMS will naturally cross paths with particles of energies much higher than those obtainable in accelerators built on the ground. And they will come in much greater quantities, as well. The Earth's atmosphere protects us from the vast majority of the cosmic particles moving through the universe. Sitting on the ground at Kennedy Space Center, the AMS measured an average of 400 particles per second. In space, it is expected to see 25,000 particles per second.

What can these particles tell us? That is yet to be seen. The expectation is that they will answer fundamental physics questions. For instance, the Hubble Space Telescope has shown that the visible matter of the universe accounts for only a fraction of the mass needed to explain the current rate of the universe's expansion – about one sixth. One possible explanation for that is that there is a vast amount of matter we cannot see – or dark matter – which increases the total mass of the universe and accounts for the faster expansion.

If dark matter exists, the AMS will be able to detect it. For instance, one candidate for the particles that are dark matter is the hypothetical, elementary neutralino particle. If neutralinos exist, their collision could create excesses of electrons and anti-electrons – positrons – that could then be detected by the AMS.

The AMS could also detect antimatter and help answer another key question. Antimatter is made up of particles identical to those of regular matter, but with opposite electric and magnetic properties. The Big Bang theory assumes that there were equal amounts of matter and antimatter present when the universe began, in the complex form of helium anti-nuclei or heavier elements has never been found in nature. If it still exists, the AMS should be able to detect it – in the 10 years or more that the AMS will be in operation at the International Space Station, its detectors will see at least one (and possibly many) antihelium nucleus, if such a thing exists. If the detectors never see one, the AMS team will be able to affirm that they do not exist in the visible universe.

In studying these and other questions, the AMS brings together two scientific fields that have not historically interacted: astronomers who have seen the effects of these phenomena through their telescopes for centuries and high-energy physicists who have spent decades trying to explain them from the ground. The AMS team hopes to find answers where the two worlds meet.

History

The AMS project began in 1994, when Professor Samuel Ting, a Nobel Laureate from the Massachusetts Institute of Technology was considering a new high-energy physics experiment. The concept of an International Space Station had just been announced in 1993, and after having conducted experiments on the ground for many years, Ting and his collaborators saw an opportunity for doing new groundbreaking science in space. So, led by Ting, a group of particle physicists from the United States, China, Italy, Finland, Russia and Sweden called The Antimatter Study Group published the concept for "An Antimatter Spectrometer in Space." The United States Department of Energy agreed to sponsor the project, NASA agreed to put it in space, and the AMS team grew.

To prove the concept, an early version of the AMS spent 10 days in space aboard space shuttle Discovery on the STS-91 mission in 1998. In the 103 hours that the experiment was turned on, the AMS collected nearly 100 million cosmic rays. The data gathered provided the first accurate measurement of the composition of primary cosmic rays, and seven scientific papers were published.

Work on the current version of the AMS began in 1998. After some uncertainty about its future following the announcement of the retirement of the space shuttle fleet, the AMS was finished and shipped from CERN – the European Organization for Nuclear Research – in Geneva to Kennedy Space Center in Florida in August 2010 to await its launch aboard space shuttle Endeavour.

Elements

The AMS is composed of a magnet and eight detectors that provide the scientists on the ground with information about the particles that travel through the magnet. All of the information is collected in the nanoseconds it takes a particle to travel through the AMS, and then sent down to scientist on the ground for analysis.

The Magnet

At the center – and the heart – of the AMS is the Permanent Magnet. Without it, cosmic particles would fly directly through the detectors in a straight line, offering no clues as to their charge.

The Permanent Magnet, which also flew on space shuttle Discovery in the early version of the AMS experiment, is a 1.105 meter by 0.8 meter cylinder made up of more than 6,000 2-by-2-by-1-inch blocks of Neodymium-Iron-Boron glued together with epoxy. Neodymium-Iron-Boron magnets are the strongest permanent magnets, providing the AMS with a magnetic field 3,000 times stronger than that of the Earth. However it does not draw the cosmic particles to the International Space Station. In fact, the magnetic draw will not be felt at all, outside of the AMS – otherwise it might change the space station's orientation or draw astronauts to it on spacewalks.

Instead, it takes advantage of the cosmic particles already traveling in the space station's path, and bends their trajectory as they pass through the magnet. The direction of the curve will provide the scientists on the ground with information about the charge of the particle (whether it is positive or negative).

The Permanent Magnet's strength should last through 2020 – the planned life of the space station – and beyond.

The Transition Radiation Detector

The first detector that a particle will pass through as it enters the AMS is the Transition Radiation Detector (TRD). The TRD has the ability to distinguish between electrons and protons by detecting X-rays emitted by some particles.

The TRD is made of 328 modules, arranged in 20 layers. Each module contains 16 straw tubes filled with a Xenon-rich gas mixture and 20 millimeters of radiator made of polypropylene/polyethylene fiber fleece. When an electron passes through these layers, it will emit an X-ray. Protons will not.

On the other hand, positrons – the antimatter counterpart of electrons – will emit an X-ray. Positrons have the same mass as an electron, but a positive charge, like a proton. The TRD will allow scientists to tell protons and positrons apart in the search for antimatter.

The Time-of-Flight Detectors

The two Time-of-Flight (ToF) detectors (one at the top of the magnet and one at the bottom) act as the AMS's stopwatch. When one is triggered by a particle entering the magnet, it starts the other detectors; when the particle exits from the opposite side, the other detectors stop.

The ToF can also provide scientists information on the direction a particle is traveling, which is important for antimatter identification, as electrons can be mistaken for their positron counterparts, if one does not know the direction of a particle. And it assists in identifying the charge of a particle, which will help scientists determine which element a particle is.

Each of the ToF detectors is made up of two scintillation counters. (Scintillation is a flash of light created when a particle going through the ToF emits a photon.) The top and bottom ToFs are about 4 feet apart and are precise down to 150 picoseconds. This allows the detectors to measure particles traveling at speeds up to 98 percent of the speed of light.

The Silicon Trackers

Without the magnet, particles would travel in a straight line through the AMS, but without the silicon trackers, we would not know the difference. There are nine tracker planes arranged throughout the AMS – one at the top, one at the bottom, and seven within the magnet. Each of them works together to provide data on the curvature of the trajectory a particle takes through the AMS, as it is influenced by the magnet: A positively charged particle will curve in the opposite direction of a negatively charged particle. This information, when combined with the information provided by the other detectors, allows scientists to distinguish between matter and antimatter.

The tracker panels are made of 2,264 double-sided silicon sensors, with a total of 200,000 sensor channels. The trackers require their own radiator to keep them cool.

The Tracker Alignment System

Because the curvature of the particles is so crucial to the AMS experiment, it is important to know that the tracker panels are measuring the particles' paths accurately. To do so, they must be precisely aligned, or corrections must be made for any misalignment they might experience in space. Otherwise, what looks like a particular curve could actually be caused by a particle moving through misaligned trackers.

The Tracker Alignment System monitors the positions of the trackers themselves, using 20 (10 going up and 10 going down) straight laser beams that mimic the tracks of particles. It is able to detect changes in the tracker positions of down to five micrometers or less.

The Anti-Coincidence Counter

Although cosmic particles will enter the AMS from all angles, only the ones that enter from the top and exit at the bottom are certain to make it through all of the AMS detectors. The instruments will not be able to gather all the necessary information on the other eight-tenths of the particles, and the extra particles traveling in abnormal directions can confuse the silicon trackers.

So, rather than gather incomplete information and risk spoiling the data on the desirable particles, the Anti-Coincidence Counters act as the ToF detector for these rogue particles, but for the opposite reason – rather than turning on the other detectors when a particle passes through it, it tells them not to track the particle.

The Ring Imaging Cherenkov Detector

One of the distinguishing characteristics of a particle is its mass, however, the AMS has no instrument that measures a particle's mass. Instead, the mass determined indirectly using a formula that requires the particle's curvature, its charge and its speed. The Ring Imaging Cherenkov (RICH) detector provides the speed part of the equation.

The RICH is named for and makes use of the Cherenkov Effect, which describes the way particles that are traveling at a speed somewhere between the speed of light in a vacuum and the speed of light through glass emit cones of light when they travel through certain mediums – in this case, the RICH's radiator. The cone of light can take the shape of a circle or an ellipse, and the shape can be used to determine the particle's speed.

The RICH is made up of a radiator plane, a conical mirror and a photon detection plane.

The Electromagnetic Calorimeter

To determine the energy of the particles passing through the AMS, the Electromagnetic Calorimeter (ECAL) was added. The ECAL is a 3-by-3-by-.75-foot block of lead with thousands of fiberoptic lines running through it. Depending on the energy of a particle, when it passes through lead, it may break up and produce an electromagnetic shower or a hadronic shower. The shapes of the two showers are very different, and from the shape, scientist can pick out the one positron from as many as 100,000 protons, or one antiproton from 100 electrons.

The ECAL is made up of nine super-layers, each of which contains 11 leaves of thick lead foil alternating with layers of scintillating fibers, glued together.

Electronics

The AMS uses about 300,000 electronics channels to provide power to the detectors and record the data they collect. That is about the same number of channels in this one experiment as the rest of the International Space Station requires in total.

The AMS computers were specifically designed and tested for space applications, so every piece of electronics, including each computer, on the AMS is at least 10 to 100 times faster than any available aerospace component. The experiment will gather more than seven gigabits of data, per second. That data will then be analyzed, compressed by 650 computers onboard the station and readied for transmission to Earth at approximately six megabits per second.

The Star Trackers and GPS

To correlate the findings of the AMS with those of other scientific instruments in space, it is important to know where the AMS is looking as it gathers its information. To track its position and the direction its pointing, the AMS has two Star Trackers (pointed in different directions, so that when one is pointing at the sun and therefore blinded, the other can still provide information) and a GPS. The Star Trackers will take one photo of the sky in a 6-degree field-of-view per second. The photos can then be compared to stellar maps to determine the AMS's orientation.

The GPS antenna is fixed on the top of the Transition Radiation Detector, and the receiver is on top of the AMS.

Team

Led by Principle Investigator and Spokesperson Samuel Ting of the Massachusetts Institute of Technology and Deputy Spokesperson Roberto Battiston, of the University of Perugia, Italy, the AMS team includes some *600* physicists from 56 institutions in 16 countries. The various participants built their particular contributions, which were all integrated when the AMS was built at CERN in Geneva.

During the STS-134 mission and for the first several months afterward, about 40 members of the AMS team will monitor the experiment and analyze the data it sends down from the Payload Operations Control Center at Johnson Space Center in Houston. Eventually AMS operations will move back to CERN, where the AMS team will continue monitoring the experiment 24 hours a day, gathering data for as long as the space station is in orbit.

Countries participating

Europe:	Denmark. Finland, France, Germany, Italy, The Netherlands, Portugal, Romania, Russia, Spain, Switzerland
Asia:	China, South Korea, Taiwan
North America:	United States, Mexico

Institutions and agencies participating: http://www.ams02.org/partners/participating-institutions/

NASA Participation and the STS-134 Mission

The AMS will be launched into space aboard space shuttle Endeavour as part of the STS-134 mission, and installed on the S3 segment of the International Space Station's truss system.

As soon as Endeavour makes it into orbit and the cargo bay doors are open, the AMS team on the ground will turn the experiment on to make sure that it survived launch intact. Then, after arriving at the space station on flight day 3, the STS-134 crew members on flight day 4 will install the AMS robotically from inside the station and shuttle. Mission Specialists Roberto Vittori and Andrew Feustel will use the space station's robotic arm to lift the experiment out of the shuttle's cargo bay. They will hand it over to the space station's robotic arm, with Pilot Greg H. Johnson and Mission Specialists Greg Chamitoff at the controls, for installation on three guideposts (called a Payload Attach System) on the truss.

Once it is installed, the astronauts will have very little involvement with the AMS, but the experiment will benefit in many ways from being installed on the space station. The space station will provide it with power and a way to send data back to scientists on the ground, and since it is able to orbit as part of the space station, it has no need of any independent control or maneuvering system.

NASA has been a part of the AMS project since 1994, overseeing the integration of the various parts of the experiment at CERN and providing advice on making them hardy enough to survive in the extreme environments of space.

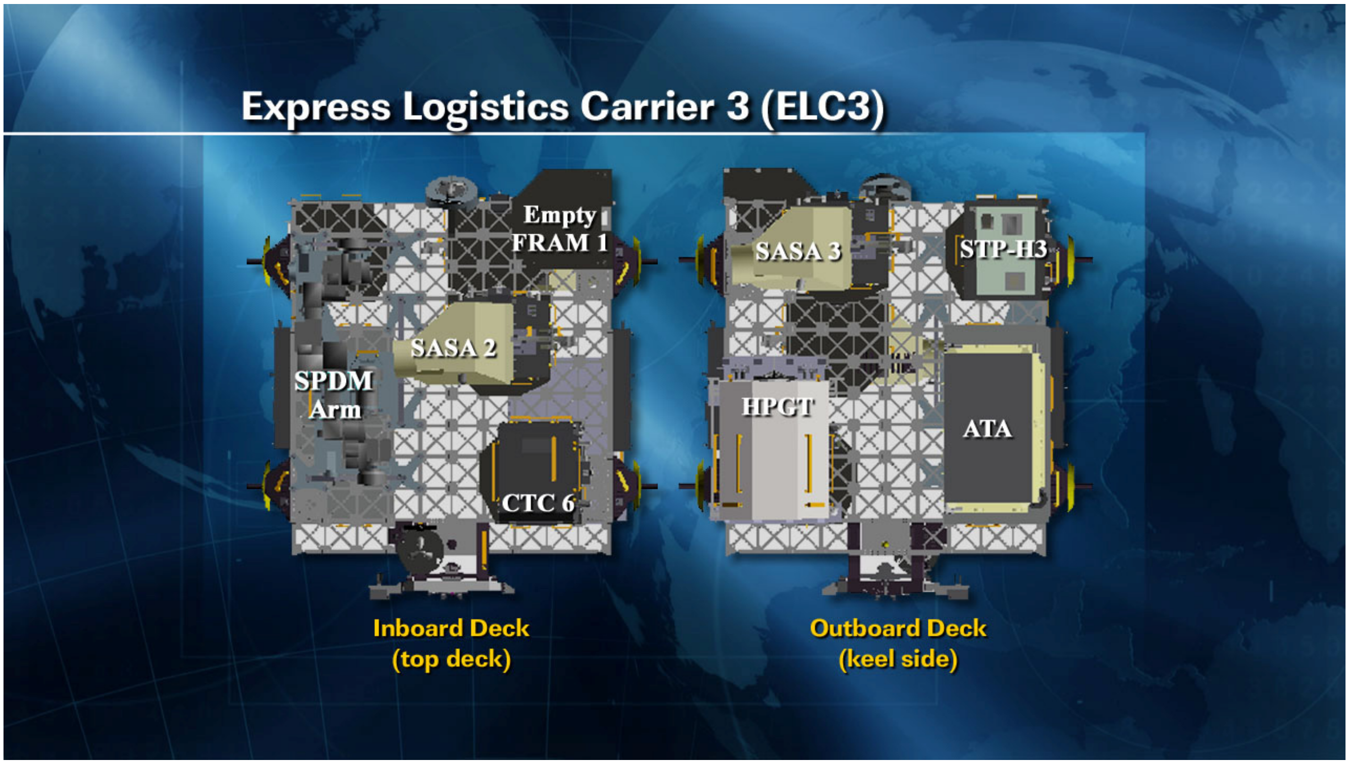
Results

It is difficult to anticipate exactly what scientists might learn from the AMS – historically, few of the major physics experiments that have been performed discovered what they originally set out to look for. Much work has been done ahead of time by the AMS team to ensure that the instrument will work as its intended, and so long as it does, they will consider any new information they uncover a success.

EXPRESS LOGISTICS CARRIER 3

Space shuttle Endeavour's STS-134/ULF6 payload includes the ExPRESS Logistics Carrier (ELC) 3 and the AMS. The total payload weight, not counting the middeck, is 29,323 pounds. The space shuttle will carry on its middeck a variety of experiments and supplies.

The OBSS will go up on the space shuttle, but will be stored on the truss structure on the International Space Station. The OBSS is being stored on two pieces of Orbital Support Equipment (OSE) that are attached to the zenith trunnion pins of the Starboard one (S1) truss segment.



ELC3 Layout

The OBSS is being stored on the station for the purposes of having it available as a contingency tool during a spacewalk. The OBSS serves as an "extension" to the Space Station Remote Manipulator System (SSRMS) when grappled to it. In the event that a crew member is required to work beyond the typical reach of the SSRMS, the SSRMS can grapple onto the OBSS (after it is removed from the OSE) and increase its usable length by the 50-foot OBSS. An example might be if one of the solar arrays needed repair while in the fully deployed/rotated orientation.

Boeing provided the OSE hardware and thermal/structural analysis that ensures the OBSS could be safely stored in orbit. The OBSS can be safely stored in orbit indefinitely.

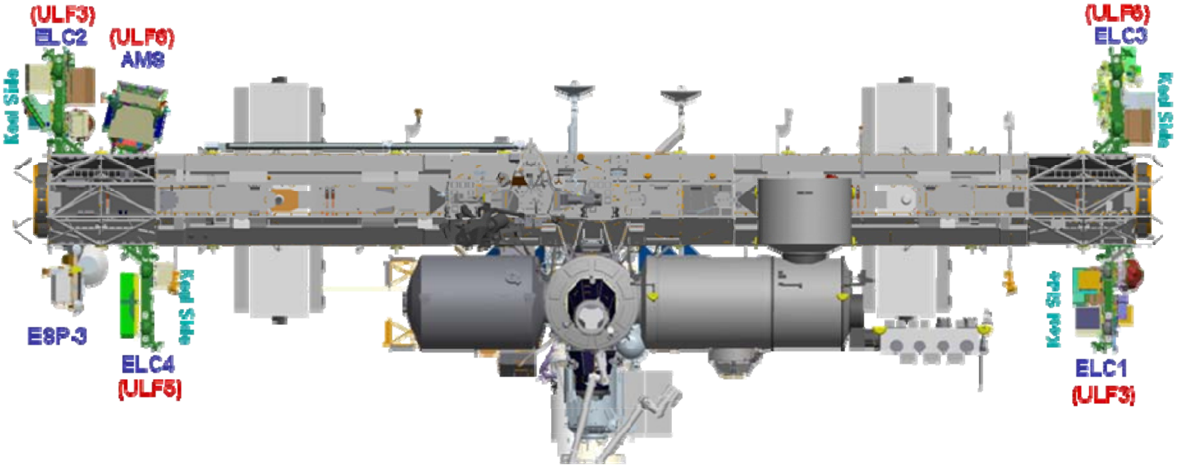
The Expedite the Processing of Experiments to the Space Station (ExPRESS) Logistics Carrier (ELC) is a platform designed to support external payloads mounted to the International Space Station starboard and port trusses with either deep space or Earthward views. Each pallet spans the entire width of the shuttle's payload bay, can carry science experiments, and serve as a parking place for spare hardware that can be replaced robotically once in orbit. The ELC is capable of carrying as many as 12 fully integrated payloads, Orbital Replacement Units (ORUs), or other loads of outfitting cargo.

STS-134 will carry ELC 3 to the station where it will be placed on the Port 3 truss upper inboard Passive Attachment System (PAS). ELC 1 and 2 were placed on the station's truss structure during STS-129. ELC-4 was carried to the station on STS-133 and was installed on the Starboard 3 truss lower inboard PAS. ELC 1 is mounted on the Port 3 truss element Unpressurized Cargo Carrier Attachment System (UCCAS) while ELC 2 was placed on the Starboard 3 truss upper outboard PAS.

Remmele Engineering, based in Minneapolis, Minn., built the integral aluminum ELC decks for NASA. Engineers from Goddard Space Flight Center's Carriers Development Office developed the challenging, lightweight ELC design, which incorporates elements of both the ExPRESS Pallet and the Unpressurized Logistics Carrier. Orbital Science Corporation built the ELC.

Each ELC can accommodate 12 Flight Releasable Attachment Mechanism (FRAM)-based cargos which includes two payload attached sites with full avionics accommodation. The mass capacity for an ELC is 9,800 pounds (4,445 kg) with a volume of 98 feet (30 meters) cubed. The empty weight of ELC 3 is around 4,000 pounds. The station provides power to the ELCs through two 3 Kilowatt (kW), 120 Volts direct current (V dc) feeds at the station to ELC interface. The ELC power distribution module converts the 120 V dc power to 120 V dc and 28 V dc. Both power voltages are provided to each payload attached site by separated buses. 120 V dc power is also provided to the other cargo attached site.

ELC 3 is the final of four ELCs total to be attached to the station before the scheduled retirement of the space shuttle. Two ELCs attached to the Starboard truss 3 (S3) and two ELCs mated to the Port truss 3 (P3). By attaching at the S3/P3 sites, a variety of views such as zenith (deep space) or nadir (Earthward) direction with a combination of ram (forward) or wake (aft) pointing allows for many possible viewing opportunities. Cargo stationed on the ELC is exposed to the microgravity and vacuum environments of space for extended periods of time while docked to the station, unshielded from incident radiation and orbital debris.

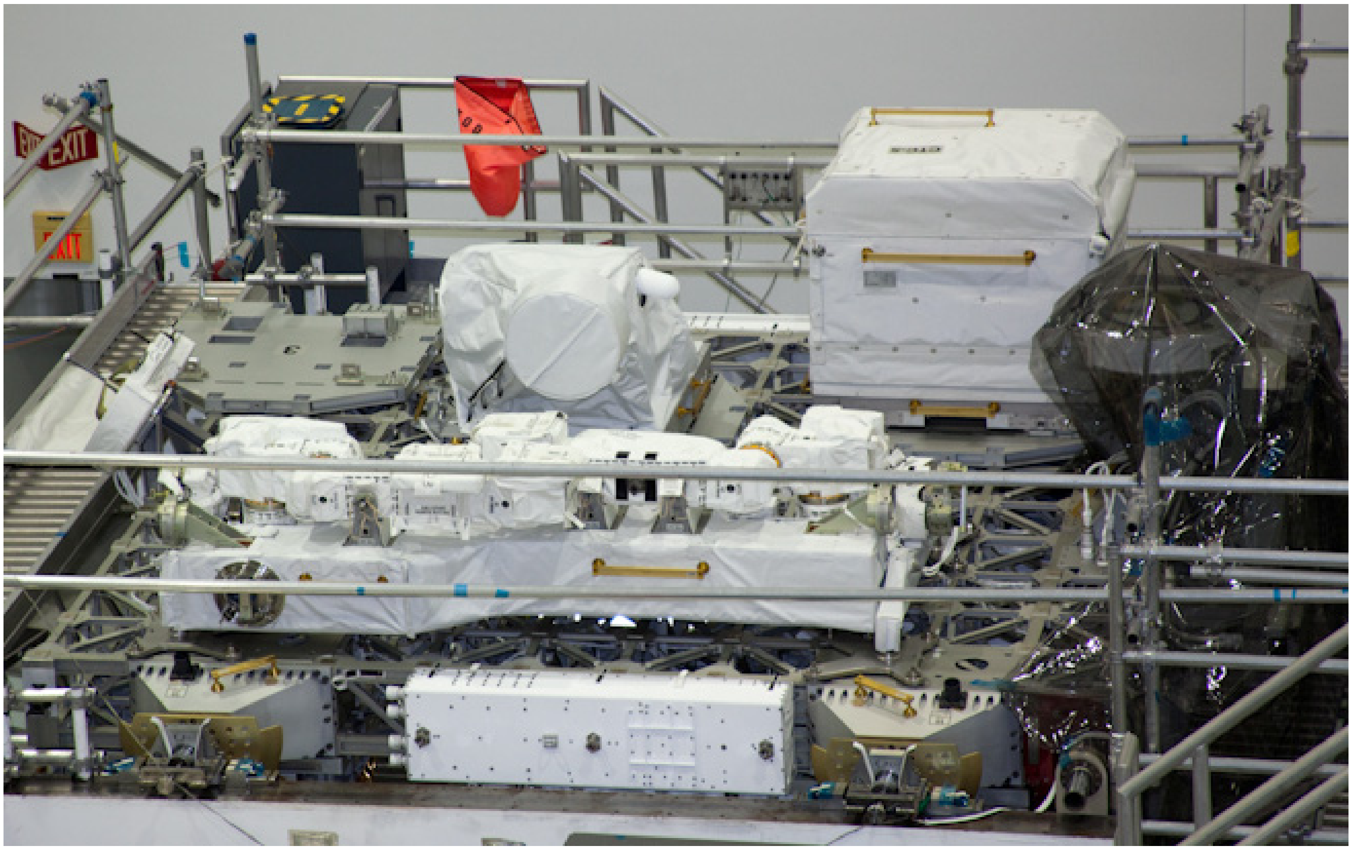


The International Space Station contains several unpressurized platforms that include ExPRESS Logistics Carriers (ELC) 1-4 and External Storage Platforms (ESP) 1-2

ExPRESS Logistics Carrier 3 (ELC 3)

ELC 3 contains one site designated to accommodate payloads launched on other missions. NASA uses a system on the external carriers to attach to ORUs and payloads consisting of the Flight Releasable Attachment Mechanism (FRAM). This mechanism has an active side with moving mechanical components, and a passive side that the active side engages with mechanically driven pins and latches. The active FRAM is driven by an EVA astronaut using a Pistol Grip Tool, or the station's robotic arm. These FRAM mechanisms are mounted to the ELC on PFRAM Adapter Plate Assemblies (PFAPs) and also provide an electrical connection that can be used if needed by the ORU or payload being attached. This empty PFRAM will be used for a future payload.

Boeing has the responsibility under its Checkout, Assembly and Payload Processing Services (CAPPS) contract with NASA, for payload integration and processing for every major payload that flies on each space shuttle flight. The Boeing processing team provides all engineering and hands-on work including payload support, project planning, receiving of payloads, payload processing, maintenance of associated payload ground systems, and logistics support. This includes integration of payloads into the space shuttle, test and checkout of the payload with the orbiter systems, launch support and orbiter postlanding payload activities.



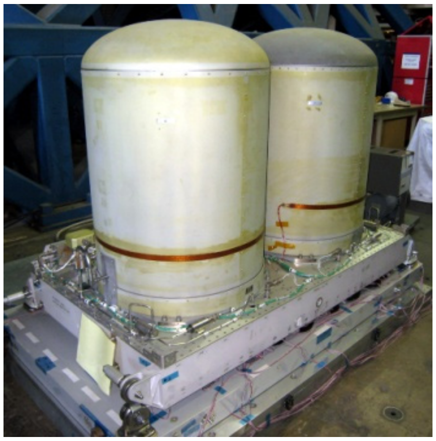
Top view of the ELC 3

Bottom (keel) view of the ELC 3

ELC 3 will carry seven ORUs and one empty PFAP. The weight of the ELC 3 is approximately 14,023 pounds with the ORUs installed. The following is a description of those items:

Ammonia Tank Assembly

The primary function of the Ammonia Tank Assembly (ATA) is to store the ammonia used by the External Thermal Control System (ETCS). The major components in the ATA include two ammonia storage tanks, isolation valves, heaters, and various temperature, pressure and quantity sensors. There is one ATA per loop located on the zenith side of the Starboard 1 (Loop A) and Port 1 (Loop B) truss segments. Each is used to fill their respective ETCS loop on startup (loops are launched with nitrogen in the lines) and to supply makeup fluid to that loop. It also assists the Pump Module (PM) accumulator with ammonia inventory management, and provides the capability to vent the PM and ATA by connection to an external nonpropulsive vent panel. The length is 57 inches by 80 inches width with a height of 45 inches. A new ATA, with 600 pounds of Ammonia, weighs approximately 1,702 pounds.



Cover is removed on the Ammonia Tank Assembly

Cargo Transportation Container

ELC 3 will carry a Cargo Transportation Container (CTC) 2 that will contain 10 Remote Power Controller Modules (a large circuit breaker box) and 11 RPCM ORU Adapter Kits (OAKs) – basically brackets installed in the CTC to hold the ORUs. The empty RPCM OAK is used for a "fast swap" as the RPCM has a limited thermal clock, this allows the arm to remove the bad RPCM first, open the lid, place that in the blank spot, grab the replacement and install it in the shortest amount of time.

In addition, the CTC will contain an Arm Computer Unit (ACU) ORU. The ACU is the heart of the computer subsystem of Canadarm2 – the station's Canadian-built robotic arm. The ACU is programmed to receive and process commands from the station crew or from ground control for moving Canadarm2. The ACU is being launched on STS-134 to add to the inventory of Canadian pre-positioned spares in orbit.

Orbital Sciences Corporation delivered five CTCs to NASA for use in conjunction with the resupply of the International Space Station. Each CTC measures about 4 feet by 3 feet by 3 feet. The CTC weighs in at 809 pounds. (680 pounds is the weight of the box only). Depending on internal configuration it can weigh up to a total of 1,300 pounds, for this mission it is coming in at a total of 1,050 pounds.

Cargo Transportation Container

The CTCs can be opened and their contents retrieved either through robotic methods or by astronauts performing extravehicular operations.

High-Pressure Gas Tank

High pressure oxygen onboard the space station provides support for EVAs and contingency metabolic support for the crew. This high pressure O2 is brought to the station by the High-Pressure Gas Tanks (HPGTs) and is replenished by the space shuttle by using the Oxygen Recharge Compressor Assembly (ORCA). There are several drivers that must be considered in managing the available high pressure oxygen on the station. The amount of oxygen the space shuttle can fly up is driven by manifest mass limitations, launch slips; and in-orbit shuttle power requirements. The amount of oxygen that is used from the station's HPGTs is driven by the number of shuttle docked and undocked EVAs, the type of EVA prebreathe protocol that is used, contingency use of oxygen for metabolic support, and emergency oxygen. The HPGT will be transferred from ELC 3 to the Quest airlock. The HPGT measures 5 feet by 6.2 feet by 4.5 feet and weighs approximately 1,240 pounds of which 220 pounds is gaseous oxygen at 2,450 pounds per square inch of pressure. The HPGT was provided by Boeing.

High-Pressure Gas Tank with the cover removed

S-Band Antenna Support Assembly

The S-band Antenna Support Assembly (SASA) is an assembly that consists of the Assembly Contingency Radio Frequency Group (RFG, or ACRFG), SASA Boom and Avionics Wire Harness.

The SASA supports the RFG in each of the two redundant strings of S-Band hardware on the Port 1 (P1) and Starboard 1 (S1) trusses. The major functions of the RFG are to receive a modulated radio signal from the S-band Transponder, amplify it to a power level necessary to be acquired by the Tracking Data and Relay Satellite (TDRS), and broadcast that signal through the selected antenna. Also, the RFG receives a signal from the TDRS through the antenna, amplifies it, and sends it to the Transponder for demodulation. The RFG consists of three units: the Assembly/ Contingency (S-Band) Transmitter/Receiver Assembly (ACTRA), a High Gain Antenna (HGA), and a Low Gain Antenna (LGA).

The SASA boom assembly consists of a mast, an EVA handle, a harness, a connector panel, a mounting surface for the RFG, and a baseplate fitting. The baseplate fitting is the structural interface for mounting the SASA to the truss on the station. The Avionics Wire Harness is installed on the SASA Boom Assembly. Through the harness, operational and heater power are provided to the RFG; command and status signals and RF transmit and receive signals are sent to and from RFG.

The total envelope of the RFG is 36" × 59" × 33" (maximum dimensions). The SASA boom is 61" × 30¼" × 43". The entire SASA weighs 256 pounds. The unit that is being flown on this mission was provided by MacDonald Dettwiler and Associates Ltd. (MDA).

In addition to the two SASAs in use, there is currently an external in-orbit spare, delivered on STS-129 and installed on the Zenith 1 (Z1) truss. ELC 3 will hold two additional spare SASAs, one on the "top" side, the other on the "keel" side.

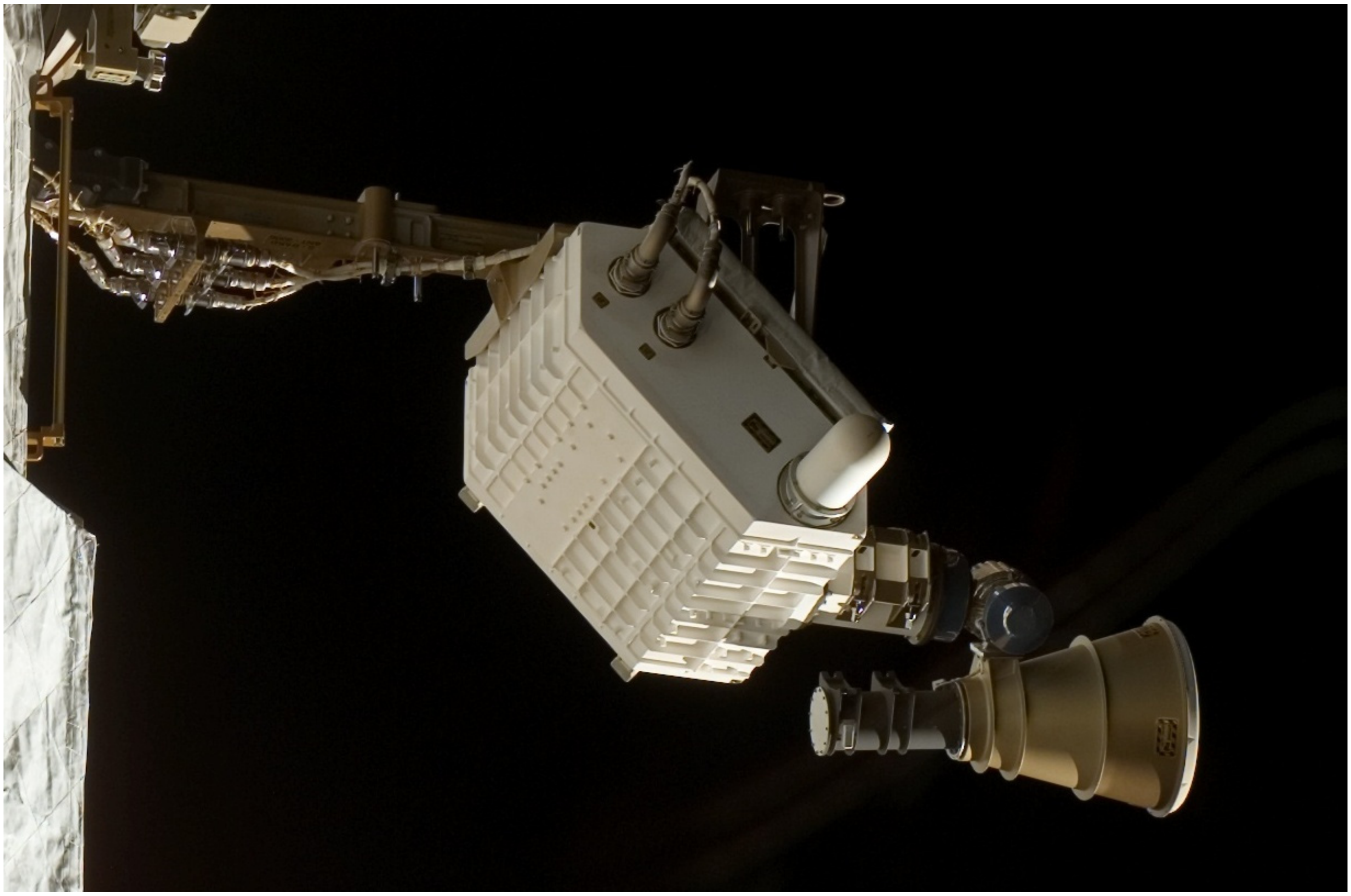


Photo of the S-Band Antenna Support Assembly

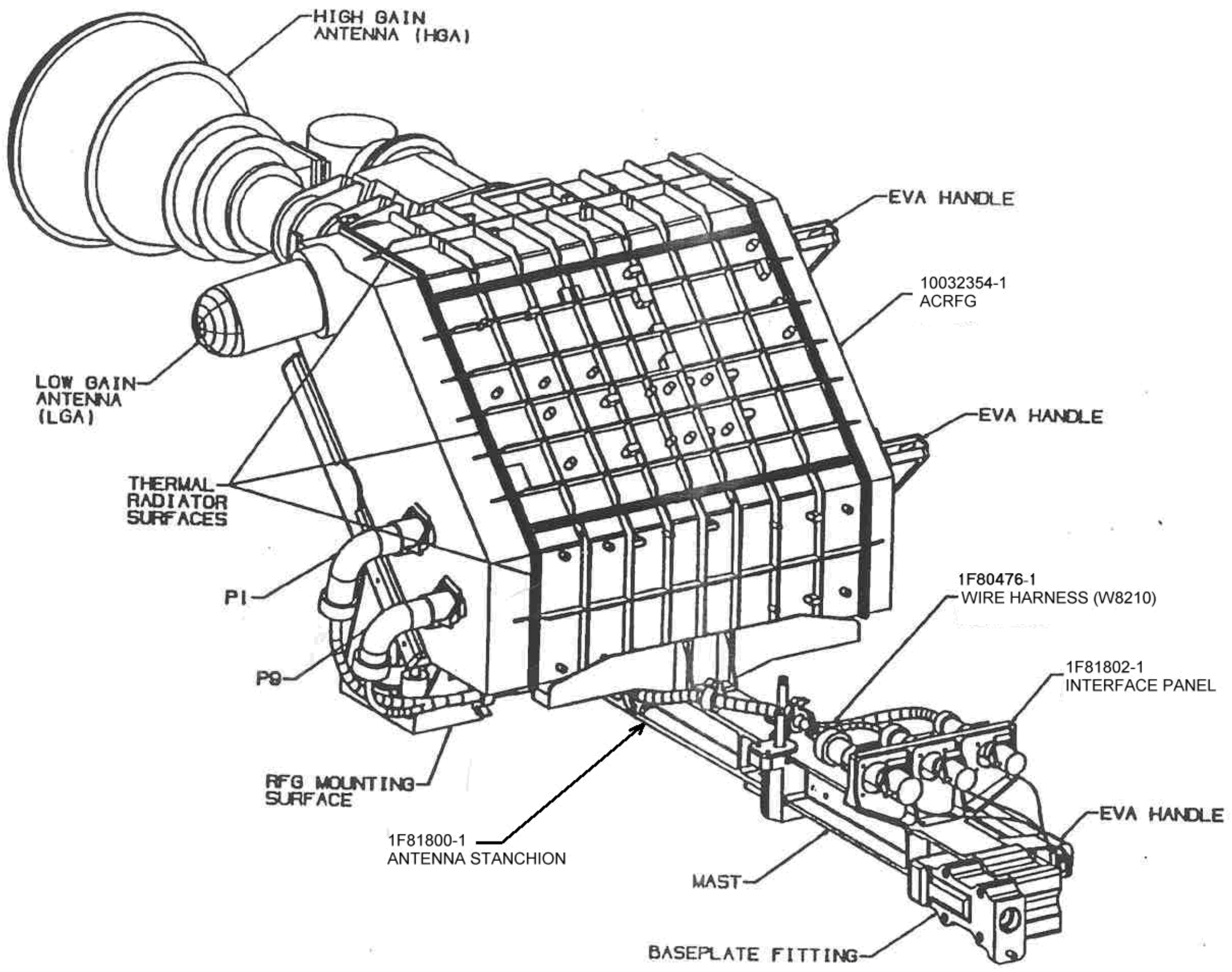


Diagram of the S-Band Antenna Support Assembly

Dextre

Dextre (also known as the Special Purpose Dexterous Manipulator), is the station's two-armed robotic "handyman," or telemanipulator.

Dextre was built by MacDonald, Dettwiler and Associates Ltd. (MDA) as part of the Canadian Space Agency's Mobile Servicing System, Canada's robotic contribution to the International Space Station. Outfitted with two highly maneuverable arms and interchangeable tools, Dextre is designed to carry out many of the tasks currently performed by astronauts. Not only does this innovation reduce the risks to human life in space, but the technology is currently being miniaturized for delicate medical procedures here on Earth.

Dextre's reach and delicate manipulation capabilities allow servicing and maintenance of user ORUs. Dextre's ORU Tool Changeout Mechanism (OTCM) can interface mechanically with user equipment or robotic tools by grasping a Standard Dexterous Grasp Fixture (SDGF) that is attached to the user equipment (ORU) or robotic tools.

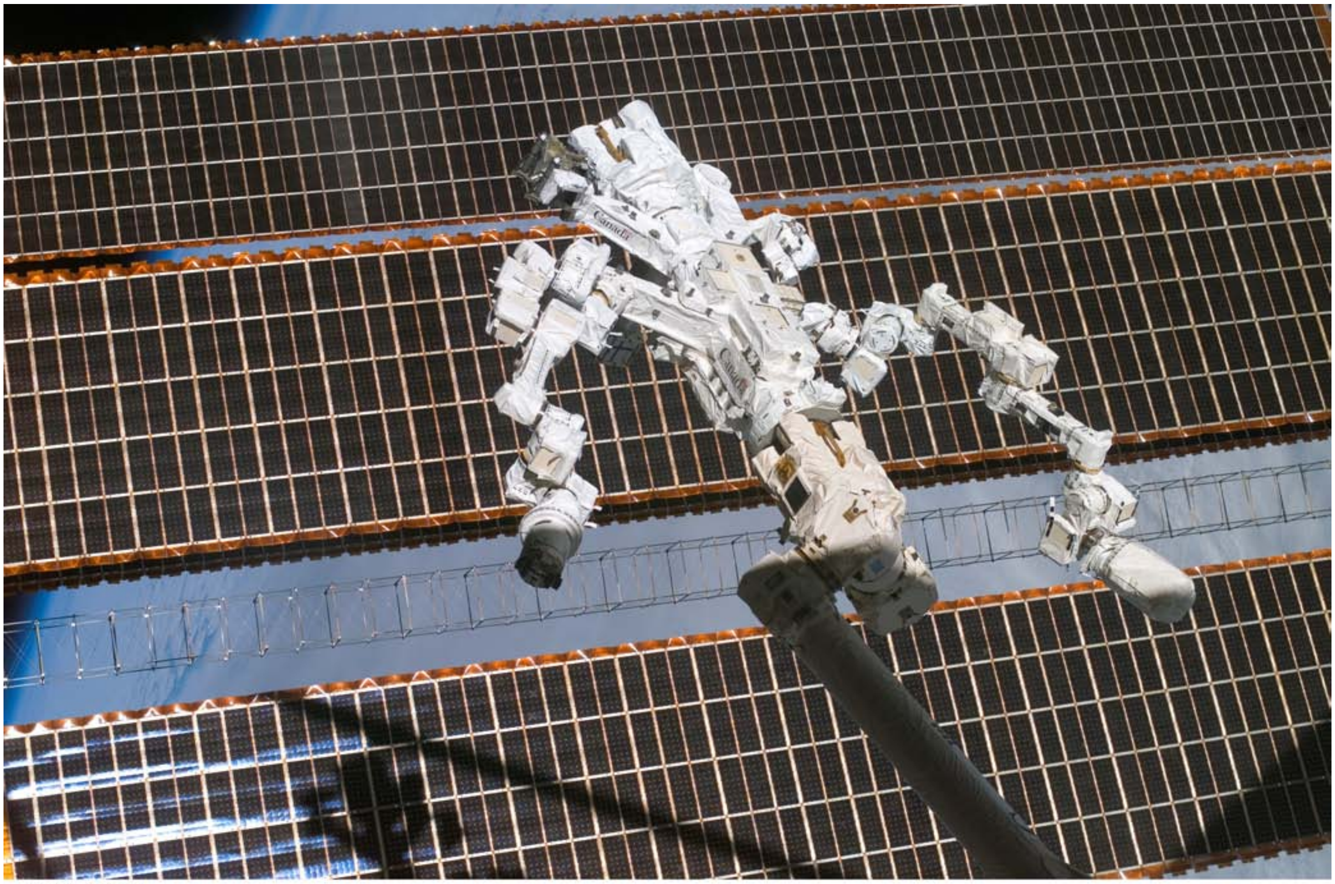


Photo of Dextre

STS-134 will deliver a spare arm for Dextre to the station. The spare is 11.5 feet (3.51 metres) long with seven joints and a load-carrying capability of 1,320 pounds (600 kg). The seven joints provide the arm with the flexibility to grasp difficult-to-reach ORUs. It is equipped with an Orbital Tool Changeout Mechanism (OTCM) at the end of the arm to hold different types of tools. It also has a camera and light that provide imagery of robotic targets. ORUs removed by Dextre are temporarily stored on a platform (Enhanced ORU Temporary Platform) attached to robot's body.

Space Test Program – Houston 3

Space Test Program – Houston 3 (STP-H3) is a complement of four individual experiments that will test concepts in low Earth orbit for long duration. The first experiment, Massive Heat Transfer Experiment (MHTEX) is sponsored by the Air Force Research Lab (AFRL). Its goal is to achieve flight qualification of an advanced capillary pumped loop system that includes multiple parallel evaporators, a dedicated starter pump and an advanced hybrid evaporator. Extended operation in the microgravity environment is to be demonstrated, and correlation of performance to ground testing for design and test purposes will be performed. The second experiment, Variable emissivity device Aerogel insulation blanket Dual zone thermal control Experiment suite for Responsive space (VADER), is also sponsored by the AFRL. It will test a robust, reconfigurable thermal control system that is focused primarily at small responsive space missions but is applicable to a wide range of missions and satellite classes. It will also test a new form of Multi-Layer Insulation (MLI) protection using Aerogel material as the thermal isolator. This material is more durable, lighter and cheaper than traditional thermal blankets. The third experiment, Digital Imaging Star Camera (DISC) is sponsored by the Naval Research Laboratory (NRL). It is a low size, weight and power sensor used for pointing knowledge of 0.02 deg or greater. The fourth experiment, Canary (not an acronym) is sponsored by the U.S. Air Force Academy. It will investigate the interaction of approaching spacecraft and the background plasma environment around the station. The STP-H3 complement is integrated and flown under the direction and management of the DoD Space Test Program Houston office.

Photo of the Space Test Program – Houston 3

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RENDEZVOUS & DOCKING

Endeavour's launch for the STS-134 mission is timed to lead to a link up with the International Space Station about 220 miles above the Earth. A series of engine firings during the first two days of the mission will bring the shuttle to a point about 50,000 feet behind the station. Once there, Endeavour will start its final approach. About 2.5 hours before docking, the shuttle's jets will be fired during what is called the terminal initiation burn. The shuttle will cover the final miles to the station during the next orbit.

As Endeavour moves closer to the station, its rendezvous radar system and trajectory control sensor will provide the crew with range and closing-rate data. Several small correction burns will place the shuttle about 1,000 feet below the station.

Commander Mark Kelly, with help from pilot Gregory H. Johnson and other crew members, will manually fly the shuttle for the remainder of the approach and docking.

Kelly will stop Endeavour about 600 feet below the station. Timing the next steps to occur with proper lighting, he will maneuver the shuttle through an approximate eight-minute back flip called the rendezvous pitch maneuver, also known as the R-bar pitch maneuver since Endeavour is in line with an imaginary vertical R-bar directly below the station. During this maneuver, station crew members Paolo Nespoli and Cady Coleman will photograph Endeavour's upper and lower surfaces through windows of the Zvezda Service Module. They will use digital cameras equipped with an 800 mm lens to provide up to one-inch resolution and a 400 mm lens providing three-inch resolution.

The photography is one of several techniques used to inspect the shuttle's thermal protection system for possible damage. Areas of special interest include the thermal protection tiles, the reinforced carbon-carbon panels along the wing leading edges and the nosecap, landing gear doors and the elevon cove. The photos will be downlinked through the station's Ku-band communications system for analysis by imagery experts in Mission Control.

When Endeavour completes its back flip, it will be back where it started with its payload bay facing the station. Kelly then will fly the shuttle through a quarter circle to a position about 400 feet directly in front of the station. From that point, he will begin the final approach to docking to the Pressurized Mating Adapter 2 at the forward end of the Harmony node.

The shuttle crew members will operate laptop computers that process the navigational data, the laser range systems and Endeavour's docking mechanism.

Using a video camera mounted in the center of the orbiter docking system, Kelly will line up the docking ports of the two spacecraft. If necessary, he will pause the shuttle 30 feet from the station to ensure the proper alignment of the docking mechanisms. He will maintain the shuttle's speed relative to the station at about one-tenth of a foot per second, while both Endeavour and the station are moving at about 17,500 mph. Kelly will keep the docking mechanisms aligned to a tolerance of three inches.

When Endeavour makes contact with the station, preliminary latches will automatically link the two spacecraft. The shuttle's steering jets will be deactivated to reduce the forces acting at the docking interface. Shock absorber springs in the docking mechanism will dampen any relative motion between the shuttle and station.

Once motion between the shuttle and the station has been stopped, the docking ring will be retracted to close a final set of latches between the two vehicles.

The Sensor Test for Orion Rel-nav Risk Mitigation, or STORRM, system is flying aboard Endeavour to examine sensor technologies that could make it easier for future space vehicles to dock to the International Space Station. It will gather data during the initial rendezvous and docking to the station, during the nominal undocking, and again during a dedicated re-rendezvous.

UNDOCKING, SEPARATION AND DEPARTURE

At undocking time, the hooks and latches will be opened and springs will push the shuttle away from the station. Endeavour's steering jets will be shut off to avoid any inadvertent firings during the initial separation.

Once the shuttle is about two feet from the station and the docking devices are clear of one another, Johnson will turn the steering jets back on and will manually control Endeavour within a tight corridor as the shuttle separates from the station.

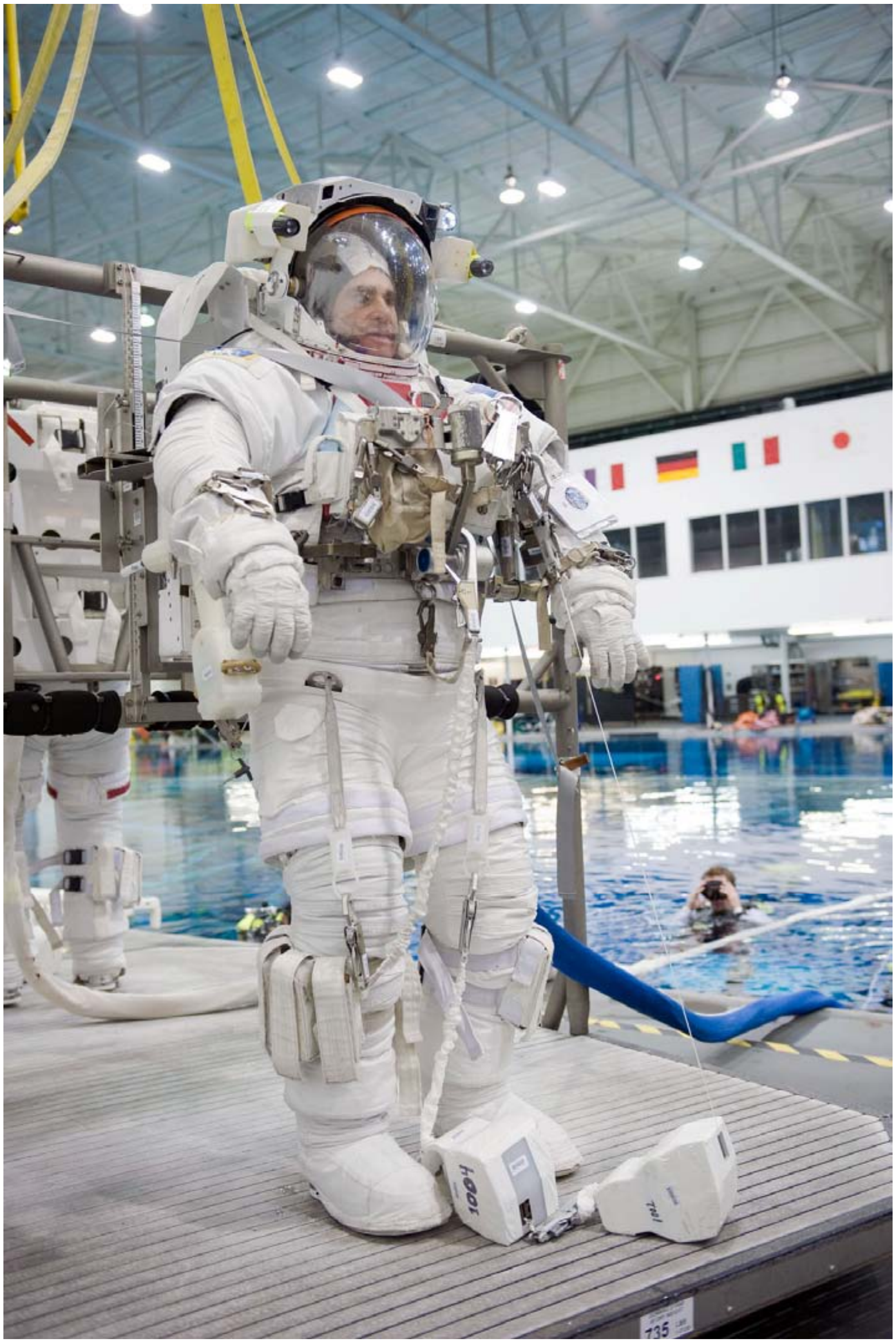
Endeavour will move to a distance of about 450 feet, where Johnson will begin to fly around the station. Endeavour will circle the shuttle around the station at a distance of about 600 feet. The shuttle crew will take detailed photographs of the external structure of the station, which serves as important documentation for the ground teams in Houston to monitor the orbiting laboratory.

Once the shuttle completes 1.5 revolutions of the complex, Johnson will fire Endeavour's jets to leave the area. Nearly two hours after undocking a second firing of the engines, which would normally take the shuttle further away, will serve as the first maneuver to bring Endeavour back toward the station for the STORRM. The test will characterize the performance of sensors in Endeavour's payload bay and acquisition of reflectors on the shuttle's docking target at the station.

The re-rendezvous will mimic the Orion vehicle's planned rendezvous trajectory and will approach no closer than 600 feet to the station. Endeavour is targeted to approach the station to a point 1,000 feet below and 300 feet behind the station at its closest point.

Nearly five hours after undocking, Endeavour's engines will fire again to depart the station's vicinity. The shuttle will begin to increase its distance behind the station with each trip around the Earth while ground teams analyze data from the late inspection of the shuttle's heat shield. However, the distance will be close enough to allow the shuttle to return to the station in the unlikely event that the heat shield is damaged, preventing the shuttle's safe re-entry.

SPACEWALKS



NASA astronaut Greg Chamitoff, STS-134 mission specialist, attired in a training version of his Extravehicular Mobility Unit (EMU) spacesuit, awaits the start of a spacewalk training session in the waters of the Neutral Buoyancy Laboratory (NBL) near NASA's Johnson Space Center.

The four spacewalks of the STS-134 mission are aimed at getting the International Space Station in the best possible shape for the retirement of the space shuttle fleet, through a variety of different tasks.

Mission Specialists Andrew Feustel, Michael Fincke and Gregory Chamitoff will spend a combined total of 26 hours outside the station on flight days 5, 7, 9 and 11.

Feustel will perform spacewalks 1, 2 and 3, wearing a spacesuit marked with solid red stripes. By the end of the mission, he will have six spacewalks on his resume – he participated in three spacewalks during the Hubble Space Telescope servicing mission in 2009. Going into the mission, he has already spent 20 hours and 58 minutes spacewalking.

Wearing an all-white spacesuit, Fincke will go outside the station for spacewalks 2, 3 and 4. He has already performed six spacewalks – four during Expedition 9 in 2004, and two during Expedition 18 in 2008 and 2009 – however, they have all been in Russian Orlan spacesuits. This will be his first spacewalk wearing a U.S. Extravehicular Mobility Unit. His current total for time spent spacewalking is 26 hours and 12 minutes.

Chamitoff, a first-time spacewalker, will wear a suit marked by broken red stripes for spacewalks 1 and 4.

When a spacewalk – also called Extravehicular Activity, or EVA for short – is going on outside, one crew member inside the International Space Station is assigned the job of Intravehicular (IV) officer, or spacewalk choreographer. In this case, whichever spacewalker is not participating outside the station, will act as the intravehicular officer for that spacewalk. Two of the spacewalks will also require astronauts inside the station to be at the controls of the station's 58-foot-long robotic arm.

Pilot Gregory H. Johnson and Expedition 27 Flight Engineer Cady Coleman will be given that responsibility for this mission. During the second spacewalk, they will carry the Special Purpose Dexterous Manipulator – or Dextre – for Feustel's work installing a camera light and lubricating its end effector. And in the final spacewalk, they will fist maneuver the shuttle's OBSS, which is to be left behind at the station when Endeavour undocks, into position for storage on the starboard side of the station's truss. Later in the spacewalk, they will also be at the controls as Chamitoff rides the arm to swap out the grapple fixtures on the boom.

Preparations will start the night before for the first and second spacewalk. For those excursions, the astronauts spend time in the station's Quest Airlock. This practice is called the campout prebreathe protocol and is used to purge nitrogen from the spacewalkers' systems and prevent decompression sickness, also known as "the bends."

During the campout, the spacewalkers will isolate themselves inside the airlock while the air pressure is lowered to 10.2 pounds per square inch, or psi. The station is kept at the near-sea-level pressure of 14.7 psi. The morning of the spacewalk, the astronauts will wear oxygen masks while the airlock's pressure is raised back to 14.7 psi for an hour and the hatch between the airlock and the rest of the station is opened. That allows the spacewalkers to perform their morning routines before returning to the airlock, where the air pressure is lowered again. Approximately 50 minutes after the spacewalkers don their spacesuits, the prebreathe protocol will be complete.

For the third spacewalk, Feustel and Fincke will try out a new procedure aimed at cutting down the amount of oxygen used in spacewalk preparations. Rather than spend the night inside the Quest, Feustel and Fincke will wait until the morning of their spacewalk to begin getting ready. They will breathe pure oxygen through air masks for an hour as the air pressure inside the Quest is lowered to 10.2 pounds per square inch. After that, they will be able to put on their spacesuits and perform light exercise (making small leg movements inside the Quest) for 50 minutes to raise their metabolic rate and purge nitrogen from their bloodstream.

The crew is scheduled to go back to the original campout procedure for the fourth spacewalk, but if the new procedure – which is called the In-Suit Light Exercise (ISLE) protocol – goes well on the third spacewalk, it may be used for the fourth as well.

EVA 1

Duration:	6 hours, 30 minutes
EVA Crew:	Feustel and Chamitoff
IV Crew:	Fincke
Robotic Arm Operators:	None

EVA Operations:

- Retrieve the Materials International Space Station Experiment (MISSE) 7A and 7B
- MISSE 8
- Install Crew and Equipment Translation Aid (CETA) cart light on S3
- Cooling loop ammonia fill set up
- Install external wireless communications antenna

The first spacewalk of the STS-134 mission has the most variety. Feustel and Chamitoff will start out by making their way to the ExPRESS Logistics Carrier 2 on the starboard side of the station's truss to retrieve two Materials International Space Station Experiments – MISSEs 7A and 7B. They were delivered to the station in November 2009 and installed during one of the STS-129 spacewalks.

To remove the experiments, Chamitoff will disconnect one power cable from each of them. He will then close the experiment and remove two pins holding MISSE 7B in place and carry it back to Endeavour's cargo bay for return home. Feustel will do the same with 7A.

Photos of the EVA 1 Spacewalkers

The two experiments returning home will be stored opposite from each other on the side of the shuttle's cargo bay and secured using two latches. When they are in place, Feustel will retrieve MISSE 8, brought up by Endeavour, and carry it back to the ExPRESS Logistics Carrier 2 for installation in 7A's place. He will install two pins to hold the experiment in place, open the experiment and hook up two power cables.

While he does so, Chamitoff will install a Crew Equipment and Translation Aid cart light on the S3 segment of the station's truss. He will use one bolt to secure the light to the cart, and hook up one power cable. Afterward, before he leaves the area, he will install a cover on one face of the S3 solar alpha rotary joint. It was removed during a November 2007 spacewalk, and will be held in place with six bolts.

Feustel and Chamitoff's next task will be to prepare for the work Feustel and Fincke will perform on the mission's second spacewalk to top off the ammonia in the station's P6 photovoltaic thermal control system cooling loop. The loop has a slow ammonia leak. They will start by installing a jumper cable that will eventually connect the cooling loops of the P4 segment of the station's truss to the P3 segment, and then venting nitrogen from the loops between P1 and P5. They will also vent nitrogen from the jumper that connects the ammonia reservoir they will use for the refill to P6.

When that is done, they will move on to the Destiny laboratory, where they will be installing antennas for the External Wireless Communication (EWC) system. Feustel will work on routing the cables it will connect to, while Chamitoff sets up the antenna. To do so, Chamitoff will first remove two handrails on Destiny and replace them with EWC handrails, which have the antennas integrated into them. Each handrail is held in place by two bolts.

Once the antenna handrails are installed, Chamitoff will connect two power cables, and Feustel will connect three more and store two additional cables for future use.

Feustel will wrap up the first spacewalk of the mission by getting tools and equipment that will be used in the second and third spacewalks ready.

EVA 2

Duration:	6 hours, 30 minutes
EVA Crew:	Feustel and Fincke
IV Crew:	Chamitoff
Robotic Arm Operators:	Johnson and Coleman

EVA Operations:

- Cooling loops ammonia fill and clean up
- Lubricate Port Solar Alpha Rotary Joint
- Install Special Purpose Dexterous Manipulator camera cover
- Lubricate Special Purpose Dexterous Manipulator latching end effector
- Install Radiator Grapple Bar Stow Beam on S1

Photos of the EVA 2 and EVA 3 Spacewalkers

Feustel and Fincke will work on two major projects during the second spacewalk of the mission: refilling one of the station's cooling loops with ammonia, and lubricating one of the station's massive Solar Alpha Rotary Joints (SARJs).

The work of the first spacewalk will mean that Feustel and Fincke have only a small amount of preparation left for the ammonia refill task. They will first finish rerouting the cables, so that there is a continuous open line from the P1 segment of the station's truss where the extra ammonia is stored in ammonia tank assemblies, to the P6 section where the leaky loop is. The flight controllers on the ground in Houston will perform a leak check of the line, and if it's good, the refill will begin. It should take about 10 minutes, during which about 5 pounds of ammonia will be added to the cooling loop.

Once the refill is complete, Feustel will vent the remaining ammonia from the jumper cables the spacewalkers installed, and then remove the cables. This will be done in two parts – the first will vent the ammonia between P1 and P5 and will last about 17 minutes. Afterward, Feustel will vent the jumper cable on P6, which will only take about four minutes.

Meanwhile, Fincke will move to the SARJ on the P3 segment of the station's truss. In 2007, its starboard-side counterpart was found to be grinding against itself, and so lubrication was added to both joints during the spacewalks of the STS-126 mission. The lubrication has been working very well, and Fincke and Feustel will be replenishing on the port side as part of the second spacewalk of the mission.

The rotary joint has 22 protective insulation covers. Fincke will start off the work by opening covers 12, 13, 16, 17, 8 and 9. He will inspect the area under one of the covers, taking photos and wiping the surface of the joint to collect samples of the remaining grease from the previous lubrication. Then, Fincke will use one grease gun with to add grease to the inner canted surface and another gun for the outer canted and datum A surfaces.

When Fincke is finished with lubricating beneath the first set of covers, he will rejoin Feustel to finish up putting the port cooling loops back into their original configuration. Once complete, flight controllers on the ground in Houston will rotate the port SARJ 200 degrees to spread the grease.

That rotation will take about an hour, giving Fincke time to install two radiator grapple bar stowage beams on the S1 segment of the station's truss. The beams will be used to store handles that would be necessary if a radiator ever needed to be replaced. Meanwhile, Feustel will get into place for his work with the Special Purpose Dexterous Manipulator, or Dextre. The station's robotic arm will bring Dextre to Feustel, so that Feustel can install a cover on one of the robot's cameras and lubricate the snares that allow the robot to grab onto equipment.

By the time those tasks are finished, the port SARJ should be in place for its second round of lubrication. Feustel and Fincke will work together on the task this time, and when they are done, they will reinstall the covers on the joint before making their way back to the Quest airlock.

EVA 3

Duration:	6 hours, 30 minutes
EVA Crew:	Feustel and Fincke
IV Crew:	Chamitoff
Robotic Arm Operators:	None

EVA Operations:

- Install and hook up Power Data and Grapple Fixture on Zarya module
- Install video signal converter on Zarya module
- Install jumper cables between the Harmony node, the Unity node and the Zarya module

The work of the third spacewalk centers around increasing redundancy in the power supply to the Russian side of the station and extending the reach of the station's robotic arm to that area. The latter will be achieved by adding a power and data grapple fixture to the exterior of the Zarya module. That will allow the arm to "walk" to Russian segment, using that grapple fixture as a base.

The spacewalk will start with Feustel and Fincke doing some setup work at the Zarya module, moving tools and equipment into place and removing caps covering the installation location. They will then return to the Quest airlock and bring out the grapple fixture and the interface equipment that it will attach to, which is called the PAMA. The size of the hardware will require both spacewalkers to carry it together.

Once they arrive back at Zarya, they will install the PAMA, which the grapple fixture will already be attached to. This requires twisting its three "feet" into place on the exterior of Zarya.

With the fixture installed, Feustel and Fincke will move on to setup work. They will start by installing a video signal converter nearby. Fincke will secure it using one bolt, while Feustel connects three cables between the converter and the grapple fixture. Fincke will then connect one final cable and install insulation on the converter.

There will then be a number of cables to connect the grapple fixture to the rest of the station. There are two power cables to connect and two data cables to install.

The majority of the rest of the spacewalk – about three hours and 15 minutes of it – will be devoted to installing jumper cables that will add an extra level of redundancy to the system that provides the Russian side of the space station with power. These cables will run from the Harmony node, to the Unity node, to the Zarya module.

While Feustel photographs their finished work, Fincke will wrap up the spacewalk by performing "get ahead" tasks as time permits.

Photos of the EVA 4 Spacewalkers

EVA 4

Duration:	6 hours, 30 minutes
EVA Crew:	Fincke and Chamitoff
IV Crew:	Feustel
Robotic Arm Operators:	Johnson and Coleman

EVA Operations:

- Stow OBSS on starboard truss
- Swap grapple fixtures on boom
- Release expandable diameter fixtures on spare Special Purpose Dexterous Manipulator arm

The bulk of the work on the final spacewalk of the STS-134 mission will focus on getting the shuttle's OBSS stored on the space station's truss system and ready for use by the station's robotic arm. The arm has proven useful in the past for providing additional reach on spacewalk tasks and could come in handy in other areas, as well, so rather than send it home on the space shuttle, it will stay behind when Endeavour leaves.

The spacewalk will start with the station's robotic arm taking the boom off the hands of the shuttle robotic arm. While Fincke and Chamitoff make their way out of the Quest airlock, Johnson and Coleman will then maneuver the boom into position for them on the starboard side of the station's truss, where stanchions will hold it in place. Fincke and Chamitoff will simply lock the boom into place. Afterward, Fincke will connect two grounding connectors, while Chamitoff installs a foot restraint on the station's robotic arm for use later in the spacewalk.

From there, both spacewalkers will move to the P6 segment of the station's truss to retrieve a power and data grapple fixture for installation on the boom. Currently, a grapple fixture in the middle of the boom is the only one that the station arm is able to use, which halves the reach of the boom when on the station's arm. To remedy this, Fincke and Chamitoff will replace an electrical flight grapple fixture currently on one end of the boom with a power and data grapple fixture that the station arm can use.

To retrieve the power and data grapple fixture, Fincke and Chamitoff will work together to release four bolts holding it in place. Chamitoff will then climb onto the station's robotic arm for a ride back to boom on the starboard side of the station's truss. There, Chamitoff, with assistance from Fincke, will release the six bolts holding the electrical flight grapple fixture to the boom and cut its cable. Then he will install an adapter assembly on the boom, using six bolts and slide the power and data grapple fixture into place on it. Four bolts will hold it in place.

Afterward, Chamitoff will climb off of the robotic arm, while Fincke stows the electrical flight grapple fixture in Endeavour's cargo bay, and the two will move onto their work on a spare arm for Dextre.

The arm will have been delivered on ExPRESS Logistics Carrier 3, where three expandable diameter fixture bolts will have held it in place for launch. Fincke and Chamitoff will release each of the bolts, making use of a specially designed pry rod, if required.

The final spacewalking task of the mission will be performed by Chamitoff. He will install insulation on the grapple fixture of the high pressure gas tank delivered by Endeavour on ExPRESS Logistics Carrier 3.

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STS-134 EXPERIMENTS

STS-134/ULF6 RESEARCH AND TECHNOLOGY DEVELOPMENT

In addition to the Alpha Magnetic Spectrometer-2, which will categorize and measure cosmic particles from its perch on the International Space Station's backbone, the STS-134 mission will deliver the most recent in a series of experiments that look at how different materials are affected by some of those cosmic particles, along with the other harsh effects of the space environment. At the end of the mission, Endeavour will return two previous batches of materials experiments that have been exposed to the space environment.

Nearly 150 experiments are continuing aboard the station as the transition from assembly work to expanded research on the international laboratory progresses. They span the basic categories of biological and biotechnology, human research, physical and materials sciences, technology development, Earth and space science and educational activities.

The STS-134 mission includes a mix of research that will be performed on Endeavour and on the station during and after the shuttle mission.

Among the new experiments flying will be several experiments flown by NASA in cooperation with the Italian Space Agency (ASI-Agenzia Spaziale Italiana), including one that looks at how the same kind of memory shape foam used in beds on Earth might be useful as a new kind of actuator, or servomechanism that supplies and transmits a measured amount of energy for mechanisms. The U.S.-Italian experiments also will look at cellular biology, radiation, plant growth and aging; how diet may affect night vision, and how an electronic device may be able used for air quality monitoring in spacecraft.

One NASA experiment known as Biology (Bio) will use, among other items, C. elegans worms that are descendants of worms that survived the STS-107 space shuttle Columbia accident. The Rapid Turn Around (RTA) engineering proof-of-concept test will use the Light Microscopy Microscope to look at three-dimensional samples of live organisms, tissue samples and fluorescent beads.

A NASA educational payload will deliver several toy Lego kits that can be assembled to form satellites, space shuttles and a scale model of the space station itself to demonstrate scientific concepts, and a Japan Aerospace Exploration Agency (JAXA) experiment called Try Zero-G that will help future JAXA astronauts show children the difference between microgravity and Earth gravity.

Research activities on the shuttle and station are integrated to maximize return during station assembly. The shuttle serves as a platform for completing short-duration research, while providing supplies and sample-return for ongoing research on station.

SHORT-DURATION EXPERIMENTS TO BE PERFORMED ON STS-134

Biology and Biotechnology

BIOKon In Space (BIOKIS) involves the investigation of seven experiments sponsored by the Italian Space Agency (ASI-Agenzia Spaziale Italiana) in the areas of cellular biology, radiation and radioprotection, aging, germination and plant growth. These experiments will aim to evaluate various biological species to determine genetic distinctions following short-duration spaceflight; also, BIOKIS will use a variety of dosimeters to monitor radiation. (NASA/ASI)

Eyespots and Macular Pigments Extracted from Algal Organisms Immobilized in Organic Matrix with the Purpose to Protect Astronaut's Retina (Night Vision) is a study on the response of microalgae strains (that contain eye spots similar to the human retina) to space radiation to obtain results applicable to future nutrition programs for astronauts. The results of the Night Vision experiment can be transferred to a food integration program that will promote the consumption of foods necessary to prevent conditions that damage the eyes (e.g., Macular Degeneration). (NASA/ASI)

National Lab Pathfinder – Vaccine (NLP-Vaccine) is a pathfinder investigation for the use of the International Space Station as a National Laboratory after space station assembly is complete. It contains several different pathogenic (disease causing) organisms. This research is investigating the use of spaceflight to develop potential vaccines for the prevention of different infections caused by these pathogens on Earth and in microgravity. (NASA)

Education Activities

The NanoRacks-CubeLabs Module-8 is a reflight of a Materials Diffusion Apparatus (MDA) for multiple crystal growth and biological experiments. The science goals for NanoRacks-CubeLabs Module-8 are proprietary. This investigation is a part of a series of investigations to be conducted on board the space station to provide the foundation for use of the space station as a National Laboratory following assembly complete. The long-term goal of this project is to enhance technological, industrial, and educational growth for the benefit of people on Earth. (NASA)

Human Research

Sleep-Wake Actigraphy and Light Exposure During Spaceflight-Short (Sleep-Short) examines the effects of spaceflight on the sleep cycles of the astronauts during space shuttle missions. Advancing state-of-the-art technology for monitoring, diagnosing and assessing treatment of sleep patterns is vital to treating insomnia on Earth and in space. (NASA)

Physical Sciences

The NanoRacks-CubeLabs Module-7 mixes samples of two or three liquids in microgravity. The science goals for NanoRacks-CubeLabs Module-7 are proprietary. The client base is international, with researchers from North America and Israel involved in using the hardware and forms the basis for future space station research. The NanoRacks-CubeLabs Platforms is a multipurpose research facility providing power and data transfer capability to the NanoRacks-CubeLabs Modules. (NASA)

Shape Memory Foam (Shape Memory Foam) experiment will evaluate the recovery of shape memory epoxy foam in microgravity obtained by solid-state foaming on ground consisting of various geometric complexities shaped on ground. This investigation is expected to study the shape memory properties required to manufacture a new concept actuator (a device that transforms energy to other forms of energy). Shape memory foam can be used as energy absorbers (panels and bumpers) and self expandable/deployable structures. Forms of shape memory foam are widely used in medical bedding and seating applications because of their unique attributes which can help aid comfort and sleep. (NASA/ASI)

Technology

Astronaut Personal Eye (APE) is a demonstration test created for the development of an autonomous microvehicle which will be used to support space station crew IVA (Intravehicular Activity) and EVA (Extravehicular Activity) operations. The microvehicle can be powered by lithium ion batteries and controlled by a microprocessor receiving inputs from IMUs (Inertial Measuring Units), based upon measurements obtained from gyroscopes (devices used for measuring or maintaining orientation). (NASA/ASI)

Electronic NOse for Space exploration (ENOS) is a study involving air quality monitoring and the search for possible anomalies in the internal on-orbit atmosphere using a network of three sensorial ENOS units. The ability to monitor the space station air quality provides the opportunity to improve the space station cabin air conditions, and to identify potential real-time anomalies that may occur in the space station's air quality. The solution developed for this experiment will be used in the ground version of the ENOS prototype. These improvements will increase the performance of these systems in terms of robustness and resolution. (NASA/ASI)

Sensor Test for Orion Relative Navigation Risk Mitigation – DTO 703 (STORRM) tests the Vision Navigation Sensor, Star Tracker, and Docking Camera planned for Orion both during shuttle approach to and departure from the space station. This test determines how well the navigation system performs during the mission. Data will be collected during rendezvous, departure, flyover and re-rendezvous with the space station. A Payload General Support Computer (PGSC) will provide experiment control, data processing, and limited data recording. Results allow for improved math models and design of future hardware. (NASA)

JAXA-Commercial consists of commercial items sponsored by JAXA sent to the station to experience the microgravity environment. (JAXA)

RESEARCH TO BE DELIVERED TO STATION ON SHUTTLE

Biology and Biotechnology

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eValuatIon And monitoring of microBiofiLms insidE International Space Station (VIABLE space station) evaluates microbial biofilm development on space materials. Microbial biofilms can exist in many different forms by a wide range of microorganisms. Most surfaces are covered with microorganisms under natural conditions. This can lead to corrosion and/or deterioration of the underlying materials. Objectives are to determine the microbial strain producing the antibiofilm product, evaluate the chemical and study innovative materials to address biological safety. (NASA/ASI)

Mycological Evaluation of Crew Exposure to space station Ambient Air (Myco) looks at how the living environment in manned spacecraft is progressively contaminated by microorganisms. Samples will be collected from the nasal cavities, the pharynx and the skin of crew members during preflight, in flight and postflight. Analysis focuses on microflora, particularly fungi sampled from subjects, which may cause opportunistic infections and allergies if their immunity is compromised. (JAXA)

Earth and Space Science

The Alpha Magnetic Spectrometer – 2 (AMS) seeks to understand fundamental issues shared by physics, astrophysics and cosmology on the origin and structure of the universe. Although the AMS is specifically looking for antimatter and dark matter, as the first magnetic spectrometer in space, AMS has and will collect information from cosmic sources emanating from stars and galaxies millions of light years beyond the Milky Way. (NASA)

Educational Activities

Commercial Generic Bioprocessing Apparatus Science Insert – 05 (CSI-05) is part of the CSI program series and provides the K-12 community opportunities to use the unique microgravity environment of the International Space Station as part of the regular classroom to encourage learning and interest in science, technology, engineering and math. This will promote education of the next generation of scientists, engineers, astronauts for the space program. (NASA)

Lego Bricks is a series of toy Lego kits that are assembled on orbit and used to demonstrate scientific concepts. Some of these models include satellites, a space shuttle orbiter, and a scale model of the International Space Station. This opportunity provides the unique learning environment of microgravity to promote student interest in Science, Technology, Engineering and Mathematics (STEM) content and careers. To accomplish this task, Lego Bricks kits are flown on board the International Space Station. Crew members perform tasks to demonstrate simple science concepts and how Lego Bricks work differently in a microgravity environment. (NASA)

Try Zero-Gravity (Try Zero-G) allows the public, especially kids, to vote for and suggest physical tasks for JAXA Astronauts to demonstrate the difference between zero-g and one-g for educational purposes. Some of tasks include putting in eye drops, performing push-ups on the ceiling, arm wrestling, and flying a magic carpet. Try Zero-G implements activities to enlighten the general public about microgravity use and human spaceflight. (JAXA)

Physical and Materials Sciences

Materials on International Space Station Experiment – 8 (MISSE-8) is a test bed for materials and computing elements outside of the International Space Station exposing them to atomic oxygen, ultraviolet, direct sunlight, radiation and extremes of heat and cold. Specimens include advanced solar cells, spacecraft materials, and lightweight computing devices and techniques, which will be tested during long-term exposure to the space environment. (NASA)

Biology (Bio) is a NASA Rapid Turn Around (RTA) engineering proof-of-concept proposal in preparation for Advanced Colloids Experiment (ACE). In Bio, crew members image three-dimensional biological sample particles, tissue samples and live organisms using the Light Microscopy Microscope. Three tests are planned. The first uses micron-size beads with different colors and one size that fluoresces. The crew excites the fluorescent beads with a blue Light-Emitting Diode (LED) using a filter to remove the excitation color of the blue LED source. In the second, the crew uses premade slides of tissue and small organisms that have been stained and fixed to check for resolution and contrast capability on biological fixed samples. In the third test, the crew grows C. elegans at ambient temperature. They will observe these organisms in real time. These worms are a commonly used model organism for cell development, behavior, genetics and radiation studies, and some are descendents of the worms flown and recovered after the STS-107 Columbia accident. (NASA)

2D-NanoTemplate fabricates large and highly oriented nano-scale two-dimensional arranged peptide arrays by suppressing convection, sedimentation, and buoyancy. Peptide particles concentrated in a sodium hydroxide solution are mixed with the sodium hydroxide solution. Approximately one week to one month is needed for the peptide to arrangement arrange themselves, after which the growth is terminated and samples are stored in the MELFI at 4° C. The research results are expected to be useful in the development of electronics on Earth. (JAXA)

Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsions – 3 (InSPACE-3) will obtain data on fluids that change their physical properties in response to magnetic fields and has promise for improving the ability to design structures, such as bridges and buildings, to better withstand earthquake forces. InSPACE-3 studies the fundamental behavior of magnetic colloidal fluids under the influence of various magnetic fields. Observations of the microscopic structures yields a better understanding of the interplay of magnetic, surface and repulsion forces between structures in magnetically responsive fluids. These fluids are classified as smart materials that transition to a solid-like state by the formation and cross-linking of microstructures in the presence of a magnetic field. On Earth, these materials are used for vibration-damping systems that can be turned on or off. (JAXA)

RESEARCH OF OPPORTUNITY

Technology

Maui Analysis of Upper Atmospheric Injections (MAUI), a DoD experiment, observes the space shuttle engine exhaust plumes from the Maui Space Surveillance Site in Hawaii when the space shuttle fires its engines at night or twilight. A telescope and all-sky imagers will take images and data while the space shuttle flies over the Maui site. The images are analyzed to better understand the interaction between the spacecraft plume and the upper atmosphere of Earth. Principal investigator: Rainer A. Dressler, Hanscom Air Force Base, Lexington, Mass. (NASA)

Ram Burn Observations – 2 (RAMBO-2) is an experiment in which the DoD uses a satellite to observe space shuttle orbital maneuvering system engine burns. Its purpose is to improve plume models, which predict the direction the plume, or rising column of exhaust, will move as the shuttle maneuvers on orbit. Understanding the direction in which the spacecraft engine plume, or exhaust flows could be significant to the safe arrival and departure of spacecraft on current and future exploration missions. (NASA)

Shuttle Exhaust Ion Turbulence Experiments (SEITE), a DoD experiment, uses space-based sensors to detect the ionospheric turbulence inferred from the radar observations from previous space shuttle Orbital Maneuvering System (OMS) burn experiments using ground-based radar. Principal investigator: Paul A. Bernhardt, Naval Research Laboratory, Washington D.C. (NASA)

Shuttle Ionospheric Modification with Pulsed Localized Exhaust Experiments (SIMPLEX), a DoD experiment, investigates plasma turbulence driven by rocket exhaust in the ionosphere using ground-based radars. Principal investigator: Paul A. Bernhardt, Naval Research Lab, Washington D.C. (NASA)

RESEARCH SAMPLES/HARDWARE TO BE RETURNED TO STATION ON SHUTTLE

Biology and Biotechnology

National Laboratory Pathfinder – Cells – 6: Jatropha-2 (NLP-Cells-6) assesses the effects of microgravity on formation, establishment and multiplication of undifferentiated cells of the Jatropha (*Jatropha curcas*), a biofuel plant, using different tissues as explant sources from different genotypes of Jatropha. Specific goals include the evaluation of changes in cell structure, growth and development, genetic changes, and differential gene expression. Postflight analysis identifies significant changes that occur in microgravity which could contribute to accelerating the breeding process for the development of new cultivars of this biofuel plant. (NASA)

Biomedical Analyses of Human Hair Exposed to a Long-term Spaceflight (Hair) examines the effect of long-duration spaceflight on gene expression and trace element metabolism in the human body. (JAXA)

Dynamism of Auxin Efflux Facilitators, CsPINs, Responsible for Gravity-regulated Growth and Development in Cucumber (CsPINs) uses cucumber seedlings to analyze the effect of gravity on the expressions of CsPINs and unravel their contributions to gravimorphogenesis (peg formation). CsPINs also differentiates hydrotropism from gravitropism in roots and compare the expression of CsPINs to figure out the interacting mechanism between the two tropisms. (JAXA)

Mycological Evaluation of Crew Exposure to space station Ambient Air (Myco) looks at how the living environment in manned spacecraft is progressively contaminated by microorganisms. Samples will be collected from the nasal cavities, the pharynx and the skin of crew members during preflight, in flight and postflight. Analysis focuses on microflora, particularly fungi sampled from subjects, which may cause opportunistic infections and allergies if their immunity is compromised. (JAXA)

Educational Activities

Asian Seed will feature a package of seeds to be stowed in the Kibo laboratory for approximately one month. During the stowed period, the package is not opened, but photos will be taken. The Asian Seed package will be recovered to the ground and forwarded to Asian Space Agencies. Then, the seeds will be used for their own programs, such as educational kits, gifts at some cultural events. (JAXA)

Human Research

Bisphosphonates as a Countermeasure to Spaceflight Induced Bone Loss (Bisphosphonates) will determine whether antiresorptive agents (help reduce bone loss), in conjunction with the routine in-flight exercise program, will protect space station crew members from the regional decreases in bone mineral density documented on previous space station missions. (NASA)

Validation of Procedures for Monitoring Crew member Immune Function (Integrated Immune) will assess the clinical risks resulting from the adverse effects of spaceflight on the human immune system and will validate a flight-compatible immune monitoring strategy. Researchers will collect and analyze blood, urine and saliva samples from crew members before, during and after spaceflight to monitor changes in the immune system. Changes in the immune system will be monitored by collecting and analyzing blood and saliva samples from crew members during flight and blood, urine, and saliva samples before and after spaceflight. (NASA)

Nutritional Status Assessment (Nutrition) is the most comprehensive in-flight study done by NASA to date of human physiologic changes during long-duration spaceflight. This study includes measures of bone metabolism, oxidative damage, nutritional assessments, and hormonal changes. This study will affect both the definition of nutritional requirements and development of food systems for future space exploration missions. This experiment will also help to understand the impact of countermeasures (exercise and pharmaceuticals) on nutritional status and nutrient requirements for astronauts. Principal investigator: Scott M. Smith, Johnson Space Center, Houston. (NASA)

The **Dietary Intake Can Predict and Protect Against Changes in Bone Metabolism during Spaceflight and Recovery (Pro K)** investigation is NASA's first evaluation of a dietary countermeasure to decrease bone loss of astronauts. Pro K proposes that a flight diet with a decreased ratio of animal protein to potassium will lead to decreased loss of bone mineral. Pro K will have an impact on the definition of nutritional requirements and development of food systems for future exploration missions, and could yield a method of counteracting bone loss that would have virtually no risk of side effects. Principal investigator: Scott M. Smith, Johnson Space Center, Houston. (NASA)

National Aeronautics and Space Administration Biological Specimen Repository (Repository) is a storage bank that is used to maintain biological specimens over extended periods of time and under well-controlled conditions. Biological samples from the space station, including blood and urine, are collected, processed and archived during the preflight, in-flight and post-flight phases of space station missions. This investigation has been developed to archive biosamples for use as a resource for future spaceflight-related research. Curator: Kathleen A. McMonigal, Johnson Space Center, Houston. (NASA)

The Spinal Elongation and its Effects on Seated Height in a Microgravity Environment (Spinal Elongation) study provides quantitative data as to the amount of change that occurs in the seated height due to spinal elongation in microgravity. Spinal elongation has been observed to occur in crew members during spaceflight, but has only previously been recorded in the standing position. The projections of seated height will provide data on the proper positioning of the seats within the vehicle, adequate clearance for seat stroke in high acceleration impacts, fit in seats, correct placements of seats with respect to each other and the vehicle and the proper orientation to displays and controls. (NASA)

Cardiovascular Health Consequences of Long-Duration Spaceflight (Vascular) studies the impact of spaceflight on the blood vessels of long-duration space explorers. Data is collected before, during and after spaceflight to assess inflammation of the artery walls, changes in blood vessel properties and cardiovascular fitness to create specific countermeasures for future long-duration space explorers beyond low-Earth orbit. (CSA)

Changes in Nutrient Contents in Space Food After Long-term Spaceflight (Space Food Nutrient) will assess changes in nutrient contents in Japanese space foods after exposure to station environment for long-duration space flight. (JAXA)

Physical and Materials Science

DEvice for the study of Critical LIquids and Crystallization – Directional Solidification Insert (DECLIC-DSI) provides a better understanding of the relationship between micro- and macrostructure formation during solidification processes. This involves investigating the birth and growth of morphological instabilities at the solid-liquid interface and the effects of coupling between the solidifying interface and the convection. By observing these phenomena in a microgravity environment, it will be possible to refine the theoretical models and numerical simulation predictions, which will ultimately result in the improvement of the industrial ground-based material development processes. (NASA)

The Materials International Space Station Experiment-7 (Mspace stationE-7) is a test bed for materials and coatings attached to the outside of the International Space Station being evaluated for the effects of atomic oxygen, ultraviolet, direct sunlight, radiation and extremes of heat and cold. This experiment allows the development and testing of new materials to better withstand the rigors of the space environment. Results will provide a better understanding of the durability of various materials when they are exposed to the space environment with applications in the design of future spacecraft. (NASA)

Smoke and Aerosol Measurement Experiment (SAME) measures smoke properties, or particle size distribution, of typical particles from spacecraft fire smokes to provide data to support requirements for smoke detection in space and identify ways to improve smoke detectors on future spacecraft. (NASA)

Marangoni analyzes the behavior of a surface-tension-driven flow in microgravity. A liquid bridge of silicone oil (5 or 10 cSt) is formed into a pair of disks. This experiment directly contributes to high quality crystal growth such as oxide materials for optical application. The outcomes will use the advance microfluid technology. The results will provide the knowledge to the high performance heat pipe with use of Marangoni convection for cooling personal computer devices and energy transport with a higher efficiency in future human space activity. (JAXA)

Production of High Performance Nanomaterials in Microgravity – 2 (Nanoskeleton-2) aims to clarify the effect of gravity on oil flotation, sedimentation and convection on crystals generated in microgravity. (JAXA)

Technology

Transport Environment Monitor Packages for ATV2 (TEM) takes temperature data aboard the European Space Agency's Automated Transfer Vehicle 2, Johannes Kepler. Temperature data will evaluate environmental conditions during transportation for biological specimen or reagents for life-science experiments aboard international partner and commercial resupply vehicles. (JAXA)

Lab-on-a-Chip Application Development-Portable Test System (LOCAD-PTS) is a handheld device for rapid detection of biological and chemical substances on surfaces aboard the space station. Currently, the technology is being used to assess fluids used in pharmaceutical processing. The technology has been used to swab the Mars Exploration Rovers (MER), for planetary protection, and to assess microbial contamination in the NEEMO (NASA Extreme Environment Mission Operations) project. This technology will provide quick medical diagnostics in clinical applications. It will also provide environmental testing capabilities that may serve homeland security. (NASA)

NanoRacks-CubeLabs-Module-3 experiments ensure that the in-orbit functionality works as planned with the ground data collection support for future NanoRacks-CubeLabs investigations. This experiment provides the foundation to successfully perform other investigations onboard the International Space Station. NanoRacks-CubeLabs Platforms is a multipurpose research facility providing power and data transfer capability to the NanoRacks-CubeLabs Modules. (NASA)

For more information on the research and technology demonstrations performed on the International Space Station, visit:

http://www.nasa.gov/mission_pages/station/science/

SPACE SHUTTLE DEVELOPMENT TEST OBJECTIVES (DTO) AND DETAILED SUPPLEMENTARY OBJECTIVES (DSO)

Development Test Objectives (DTOs) are aimed at testing, evaluating or documenting systems or hardware or proposed improvements to hardware, systems and operations.

Included in the DTOs will be the following:

DTO 854 Boundary Layer Transition Flight Experiment

The Boundary Layer Transition (BLT) flight experiment will gather information on the effect of high Mach number boundary layer transition caused by a protuberance on the space shuttle during the re-entry trajectory.

The experiment is designed to further understand the high Mach number thermal environments created by a protuberance on the lower side of the orbiter during re-entry. The protuberance was built on a BRI-18 tile originally developed as a heat shield upgrade on the orbiters. Due to the likely geometry and re-entry profile of future exploration vehicles, these vehicles will experience a high Mach number boundary layer transition during atmospheric entry. By flying this protuberance during the orbiter's re-entry, a high Mach number transition environment will be created on a small zone of the orbiter's underside, which will aid in gaining an improved understanding of the heating in high Mach number environments.

STS-134 will be the fifth phase of the flight experiment and will include data gathered on a 0.5 inch tall protuberance at speeds Mach 15, 18 and 19. This protuberance height will allow engineers to collect the highest-speed boundary layer transition data on the orbiter.

Boundary layer transition is a disruption of the smooth, laminar flow of supersonic air across the orbiter's belly and occurs normally when the orbiter's velocity has dropped to around eight to 10 times the speed of sound, starting toward the back of the heat shield and moving forward. Known as "tripping the boundary layer," this phenomenon can create eddies of turbulence that, in turn, result in higher downstream heating.

For the experiment, a heat shield tile with a “speed bump” on it was installed under Discovery's left wing to intentionally disturb the airflow in a controlled manner and make the airflow turbulent. The bump is four inches long and approximately 0.4 inch wide. Ten thermocouples are installed on several tiles, including the protuberance tile and tiles downstream of the protuberance.

Additionally, data from this experiment will expand the Aerodynamics and Aeroheating knowledge base and will be used to verify and improve design efforts for future spacecraft.

DTO 900 Solid Rocket Booster Thrust Oscillation

The Space Shuttle Program is continuing to gather data on pressure oscillation, or periodic variation, a phenomenon that regularly occurs within solid rocket motors through the remaining shuttle flights. The data obtained from previous flights designated to acquire pressure oscillation data have provided a better understanding of solid rocket motor dynamics. The collection of these additional data points will provide greater statistical significance of the data for use in dynamic analyses of the four segment motors. These analyses and computer models will be used for future propulsion system designs.

The pressure oscillation that is observed in solid rocket motors is similar to the hum made when blowing into a bottle. At 1.5 psi, or pounds per square inch, a pressure wave will move up and down the motor from the front to the rear, generating acoustic noise as well as physical loads in the structure. These data are necessary to help propulsion engineers confirm modeling techniques of pressure oscillations and the loads they create. As NASA engineers develop alternate propulsion designs for use in NASA, they will take advantage of current designs from which they can learn and measure.

In an effort to obtain data to correlate pressure oscillation with the loads it can generate, the Space Shuttle Program is continuing to use the Enhanced Data Acquisition System to gather detailed information.

DTO 805 Crosswind Landing Performance (If opportunity)

The purpose of this DTO is to demonstrate the capability to perform a manually controlled landing in the presence of a crosswind. The testing is done in two steps.

1. Pre-launch: Ensure that planning will allow selection of a runway with Microwave Scanning Beam Landing System support, which is a set of dual transmitters located beside the runway providing precision navigation vertically, horizontally and longitudinally with respect to the runway. This precision navigation subsystem helps provide a higher probability of a more precise landing with a crosswind of 10 to 15 knots as late in the flight as possible.
2. Entry: This test requires that the crew perform a manually controlled landing in the presence of a 90-degree crosswind component of 10 to 15 knots steady state. During a crosswind landing, the drag chute will be deployed after nose gear touchdown when the vehicle is stable and tracking the runway centerline.

DTO 703 Sensor Test for Orion Relative Navigation Risk Mitigation (STORRM)

STORRM is designed to demonstrate the capability of relative navigation sensors developed for automated rendezvous and docking of Orion or other future spacecraft. This DTO will test the Vision Navigation Sensor (VNS) flash lidar and high definition docking camera currently planned for the Orion vehicle. Lidar, or light detection and ranging, is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target.

Developed by the Orion Project Office at NASA's Johnson Space Center in Houston, the VNS and docking camera have the ability to advance the capability necessary for automated rendezvous and docking. The test is being performed to gain a thorough understanding of the new sensors' performance in space to validate ground simulation models and properly characterize sensor performance.

On STS-134, the new system will be tested during docking, undocking and re-rendezvous operations. Data will be collected and the astronauts will be able to monitor the information through a STORRM software application on a laptop computer inside. In addition, screen snapshots of the data will be sent to Mission Control at Johnson by slow scan video for the STORRM team to evaluate the data real-time.

During the STS-131 mission to the station, the crew installed a set of reflective elements for use during the STS-134 test. The retro-reflectors are titanium clamping mechanisms that contain a small piece of reflective tape – similar to that on stop signs – covered by Schott glass. The reflective elements, which were built at Langley Research Center in Hampton, Va., were placed in a prescribed pattern on the station's docking target and stand-off cross on the Pressurized Mating Adapter 2 (PMA 2) that is used by the shuttle to dock with the ISS. They will serve as the targets for the VNS.

The VNS is an eye-safe lidar system that provides an image of the target – in this case the space station – along with range and bearing data to precise accuracies. The docking camera is designed to provide high resolution, color images.

Having multiple reflectors in the sensor's field of vision at the same time allows the sensor to determine the relative attitude of the vehicle as well as relative position and velocity. This will provide six degrees of freedom for a future vehicle's guidance, navigation and control system.

The reflectors are designed to prevent the shuttle Trajectory Control Sensor (TCS) from tracking the reflective elements at their wavelength, preventing any confusion for the shuttle crew during docking and undocking.

The prototype VNS and docking camera are mounted in Endeavour's payload bay, in an enclosure on the orbiter docking system truss next to the shuttle's TCS.

Under direction of the Orion Project office, teams from NASA Johnson, NASA Langley, and industry partners Lockheed Martin and Ball Aerospace Technology Corporation worked together to develop and test the prototype to support the STORRM Development Test Objective.

NASA Johnson is responsible for program management, technology evaluation, flight test objectives, operational concepts, contract management and data post-processing. Engineers at Langley are responsible for engineering management, design and build of the avionics, DTO computer hardware and reflective elements. They are also responsible for the integration, testing and certification of these components.

Detailed Supplementary Objectives (DSOs) are space and life science investigations. Their purpose is to determine the extent of physiological deconditioning resulting from spaceflight, to test countermeasures to those changes and to characterize the space environment relative to crew health.

DSO-641 Risk of Orthostatic Intolerance During Re-exposure to Gravity

One of the most important physiological changes that may negatively impact crew safety is postflight orthostatic intolerance. Astronauts who have orthostatic intolerance are unable to maintain a normal systolic blood pressure during head-up tilt, have elevated heart rates and may experience presyncope or syncope with upright posture. This problem affects about 30 percent of astronauts who fly short-duration missions (4–18 days) and

83 percent of astronauts who fly long-duration missions. This condition creates a potential hazard for crew members during re-entry and after landing, especially for emergency egress contingencies.

Two countermeasures are currently employed to ameliorate post-flight orthostatic intolerance; fluid loading and an anti-gravity suit. Unfortunately, neither of these are completely effective for all phases of landing and egress; thus, continued countermeasure development is important. Preliminary evidence has shown that commercial compression hose that include abdominal compression can significantly improve orthostatic tolerance. These data are similar to clinical studies using inflatable compression garments.

Custom-fitted, commercial compression garments will be evaluated as countermeasures to immediate and longer-term post-flight orthostatic intolerance. These garments will provide a continuous, graded compression from the foot to the hip, and a static compression over the lower abdomen. These garments should provide superior fit and comfort as well as being easier to don. Tilt testing will be used as an orthostatic challenge before and after spaceflight.

For more information about this and other DSOs, visit

https://rlsda.jsc.nasa.gov/scripts/experiment/exper.cfm?exp_index=1448

and

https://rlsda.jsc.nasa.gov/docs/research/research_detail.cfm?experiment_type_code=35&researchtype=

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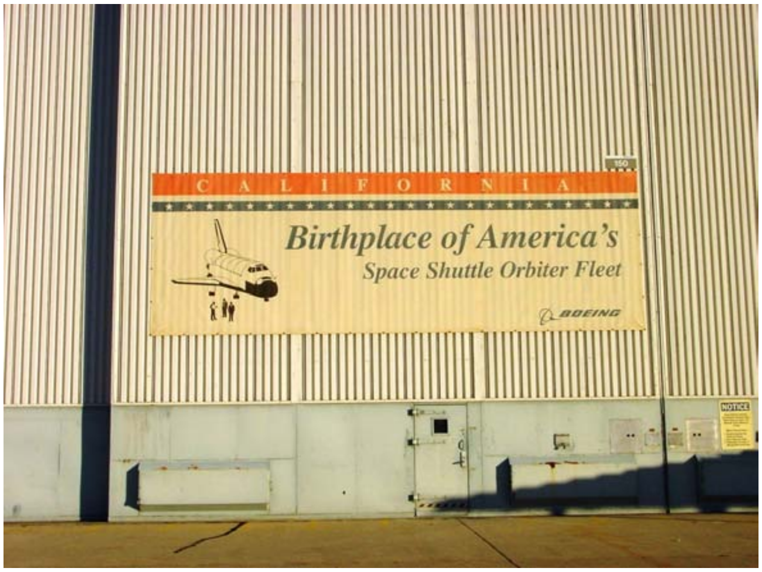
HISTORY OF SPACE SHUTTLE ENDEAVOUR (OV-105)



Later part of United Space Alliance's contract, Boeing handled orbiter maintenance at Palmdale

Born out of the tragedy of Challenger (STS 51L), NASA was officially given the go to build space shuttle Endeavour on July 31, 1987. At a one-time cost of $1.8 billion, Endeavour's engineering designation became OV-105 – the sixth shuttle and fifth and final orbital vehicle.

The contract award to Rockwell International's Space Transportation Systems Division, Downey, Calif., took advantage of the existence of structural spares already under contract. Endeavour was assembled at Rockwell's Palmdale, Calif., assembly facility – the birthplace of all the shuttles.

Construction was completed in July 1990 and Endeavour was delivered to the Kennedy Space Center, Fla., in May 1991 to begin processing for its first flight – a daring rendezvous and repair mission of an ailing Intelsat satellite that would define the commitment of the Space Shuttle Program to carry out complicated and exciting missions for another 20 years.

Endeavour is commonly referred to as OV-105 (Orbital Vehicle-105) – its airframe designation. Empty weight was 151,205 pounds at rollout and 172,000 pounds with main engines installed.

Endeavour ends it service with 25 missions, with the last being a 14-day flight to the International Space Station – designated STS-134 – to deliver the Alpha Magnetic Spectrometer, a state-of-the-art particle physics detector that will use the station's external environment as a platform to expand knowledge of the universe and lead to better understanding of the universe's origin by searching for antimatter, dark matter and measuring cosmic rays.

BACKGROUND

Authorized by Congress in August 1987 as a replacement for space shuttle Challenger, Endeavour (OV-105) arrived at Kennedy Space Center on May 7, 1991, to begin processing for its maiden flight.

The last addition to NASA's orbiter fleet, Endeavour was named after the first ship commanded by James Cook, the 18th-century British explorer, navigator and astronomer. On sailing ship Endeavour's maiden voyage in August 1768, Cook sailed to the South Pacific to observe and record the infrequent event of the planet Venus passing between Earth and the sun.

Determining the transit of Venus enabled early astronomers to find the distance of the sun from Earth, which then could be used as a unit of measurement in calculating the parameters of the universe.

Cook's voyage on the Endeavour also established the usefulness of sending scientists on voyages of exploration. While sailing with Cook, naturalist Joseph Banks and Carl Solander collected many new families and species of plants, and encountered numerous new species of animals.

HMS Endeavour and her crew reportedly made the first long-distance voyage on which no crewman died from scurvy, the dietary disease caused by lack of ascorbic acids. Cook is credited with being the first captain to use diet as a cure for scurvy, when he made his crew eat cress, sauerkraut and an orange extract.

The Endeavour measured 109 feet in length and 29 feet in width and weighed about 550 tons. Space shuttle Endeavour – its modern day namesake – is 122 feet long, 78 feet wide and weighs 75 tons (151,205 pounds).

For the first time, a national competition involving students in elementary and secondary schools produced the name of the new orbiter, which was announced by President George H. W. Bush in 1989. The space shuttle Endeavour was delivered to Kennedy Space Center on May 7, 1991, and flew its first mission, highlighted by the dramatic rescue of a stranded Intelsat communications satellite, exactly one year later on May 7, 1992.

STS-49 launched at dusk to begin what was arguably to date among the most ambitious shuttle flights – one that subsequently would provide lessons learned in the development of tools and techniques to servicing the Hubble Space Telescope and building the International Space Station.

The commitment to succeed led to the conduct of a three-man spacewalk to capture Intelsat by hand when the specially designed capture bar

could not snap in place. The spacewalk succeeded and Intelsat was affixed with a new boost motor and sent on its way. The mission set the tone for future Endeavour missions over the next 19 years, including the delivery of the first U.S. component to start assembly of the space station.

As the newest vehicle in the shuttle fleet, Endeavour also incorporated improved safety features, including a drag chute to assist with braking and control on the runway after landing. Later, all orbiters would be retrofitted with drag chutes as well.

Endeavour finishes its career with the distinction of delivering the final major component to the space station – the Alpha Magnetic Spectrometer. It is OV-105's 25th mission and the 134th in the Space Shuttle Program.

UPGRADES AND FEATURES

Spare parts from the construction of Discovery (OV-103) and Atlantis (OV-104) were used to eventually build Endeavour (OV-105). These parts were built as spares to facilitate the repair of an orbiter if needed.

Endeavour also featured new hardware designed to improve and expand orbiter capabilities. Most of this equipment was later incorporated into the other three orbiters during times of extended downtime after a certain number of flights called Orbiter Maintenance Down Period (OMDP), or Orbiter Major Modification (OMM).

Endeavour's upgrades include

- A 40-foot-diameter drag chute that reduces rollout distance by 1,000 to 2,000 feet.
- An updated avionics system that included advanced general purpose computers, improved inertial measurement units and tactical air navigation systems, enhanced master events controllers and multiplexer-demultiplexers, a solid-state star tracker. TACANs later were replaced by a state-of-the-art three-string Global Positioning System.
- Improved nose wheel steering mechanisms.
- An improved version of the Auxiliary Power Units that provide power to operate the space shuttle's hydraulic systems.
- Installation of an external airlock, making Endeavour capable of docking with the International Space Station and providing more room on the shuttle's middeck.
- Originally equipped as the first extended duration orbiter capable of stand-alone missions lasting up to 28 days. This later was removed to save weight for space station missions.
- General weight-reduction program to maximize the payload capability to the International Space Station.
- Later, 124 modifications were made during its first OMDP, including recommended return-to-flight safety modifications, bonding more than 1,000 thermal protection system tiles and inspecting more than 150 miles of wiring.
- The two most important modifications were the incorporation of the Multi-functional Electronic Display System (MEDS) known as the "glass cockpit," and the three-string global positioning system.

The glass cockpit provided full-color, flat-panel displays that improved interaction between the crew and orbiter. It provided easy-to-read graphics portraying key flight indicators like attitude display and mach speed. Endeavour was the last vehicle in the fleet to receive this system.

The three-string Global Positioning System (GPS) allowed the shuttle to make a landing at any runway long enough to handle the shuttle. The previous TACAN system only allowed for landings at military bases.

CONSTRUCTION MILESTONES

Feb. 15, 1982
Start structural assembly of Crew Module

July 31, 1987
Contract Award

Sept. 28, 1987
Start structural assembly of aft-fuselage

Dec. 22, 1987
Wings arrive at Palmdale, Calif. from Grumman

Aug. 1, 1987
Start of Final Assembly

July 6, 1990
Completed final assembly

April 25, 1991
Rollout from Palmdale

May 7, 1991
Delivery to Kennedy Space Center

April 6, 1992
Flight Readiness Firing

May 7, 1992
First Flight (STS-49)

April 19, 2011
Final Scheduled Flight (STS-134)

FLIGHT MILESTONES

1. STS-49 (May 7-16, 1992)
   3,969,019 miles
2. STS-47 (Sept. 12-20, 1992)
   3,310,922 miles
3. STS-54 (Jan. 13-19, 1993)
   2,501,277 miles
4. STS-57 (June 21 – July 1, 1993)
   4,118,037 miles
5. STS-61 (Dec. 2-12, 1993)
   4,433,772 miles
6. STS-59 (April 9-20, 1994)
   4,704,835 miles
7. STS-68 (Sept. 30 – Oct. 11, 1994)
   4,703,000 miles
8. STS-67 (March 2-18, 1995)
   1,800,000 miles
9. STS-69 (Sept. 7-18, 1995)
   4,500,000 miles
10. STS-72 (Jan. 11-20, 1996)
    3,700,000 miles
11. STS-77 (May 19-29, 1996)
    4,100,000 miles
12. STS-89 (Jan. 22-31, 1998)
    3,610,000 miles
13. STS-88 (Dec. 4-15, 1998)
    4,650,000miles
14. STS-99 (Feb. 11-22, 2000)
    4,708,821 miles
15. STS-97 (Nov. 30 – Dec. 11, 2000)
    4,476,164 miles

16. STS-100 (April 19 – May 1, 2001)
    4,910,188 miles
17. STS-108 (Dec. 5-17, 2001)
    4,817,649 miles
18. STS-111 (June 5-19, 2002)
    5,781,115 miles
19. STS-113 (Nov. 23 – Dec. 7, 2002)
    5,735,600 miles
20. STS-118 (Aug. 8-21, 2007)
    5,274,977 miles
21. STS-123 (March 11-26, 2008)
    6,577,857 miles
22. STS-126 (Nov. 14-30, 2008)
    6,615,109 miles
23. STS-127 (July 15-31, 2009)
    6,547,853 miles
24. STS-130 (Feb. 8-21, 2009)
    5,738,991 miles
25. STS-134 (April 19 – May 3, 2011)
    Approx. 5.7 million miles

Total Endeavour Miles
116,372,930 (through STS-130)

ENDEAVOUR BY THE NUMBERS

Miles traveled	116,372,930 (through STS-130)
Days in orbit	283
Orbits	4,423
Flights	24 (through STS-130)
Crew members (total seats)	166
Crew members (individual seats)	133
Russian Mir space station dockings	1 (STS-89 January 1998)
International Space Station dockings	11 (through STS-130)

SPACE SHUTTLE MILES TRAVELED 530,603,795 (133 FLIGHTS)

Columbia	121,696,993 (28 flights, including STS-107)
Challenger	23,661,290 (10 flights, including STS-51L)
Discovery	148,221,675 (39 flights, through STS-133)
Atlantis	120,650,907 (32 flights, through STS-132)
Endeavour	116,372,930 (24 flights, through STS-130)

SPACE SHUTTLE SEATS (THROUGH STS-133)

• Total Seats	835
• Individual Seats	355

STS-134 adds six more seats filled and two individual: 841/357**

**Mike Fincke and Roberto Vittori flew Soyuz, but not shuttle. Based on their MS designations, Fincke will hold the distinction of being the "last" individual to fly aboard the space shuttle. That holds true regardless of the upcoming STS-135 mission since all four crew members for Atlantis have flown previous shuttle missions.

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SHUTTLE REFERENCE DATA

SHUTTLE ABORT MODES

Redundant Set Launch Sequencer (RSLS) Aborts

These occur when the onboard shuttle computers detect a problem and command a halt in the launch sequence after taking over from the ground launch sequencer and before solid rocket booster ignition.

Ascent Aborts

Selection of an ascent abort mode may become necessary if there is a failure that affects vehicle performance, such as the failure of a space shuttle main engine or an orbital maneuvering system engine. Other failures requiring early termination of a flight, such as a cabin leak, might also require the selection of an abort mode. There are two basic types of ascent abort modes for space shuttle missions: intact aborts and contingency aborts. Intact aborts are designed to provide a safe return of the orbiter to a planned landing site. Contingency aborts are designed to permit flight crew survival following more severe failures when an intact abort is not possible. A contingency abort would generally result in a ditch operation.

Intact Aborts

There are four types of intact aborts: Abort To Orbit (ATO), Abort Once Around (AOA), Transoceanic Abort Landing (TAL) and Return To Launch Site (RTLS).

Return to Launch Site

The RTLS abort mode is designed to allow the return of the orbiter, crew and payload to the launch site, KSC, approximately 25 minutes after liftoff.

The RTLS profile is designed to accommodate the loss of thrust from one space shuttle main engine between liftoff and approximately four minutes 20 seconds, after which not enough main propulsion system propellant remains to return to the launch site. An RTLS can be considered to consist of three stages – a powered stage, during which the space shuttle main engines are still thrusting; an external tank separation phase; and the glide phase, during which the orbiter glides to a landing at the KSC. The powered RTLS phase begins with the crew selection of the RTLS abort, after solid rocket booster separation. The crew selects the abort mode by positioning the abort rotary switch to RTLS and depressing the abort push button. The time at which the RTLS is selected depends on the reason for the abort. For example, a three-engine RTLS is selected at the last moment, about 3 minutes, 34 seconds into the mission; whereas an RTLS chosen due to an engine out at liftoff is selected at the earliest time, about 2 minutes, 20 seconds into the mission (after solid rocket booster separation).

After RTLS is selected, the vehicle continues downrange to dissipate excess main propulsion system propellant. The goal is to leave only enough main propulsion system propellant to be able to turn the vehicle around, fly back toward KSC and achieve the proper main engine cutoff conditions so the vehicle can glide to KSC after external tank separation. During the downrange phase, a pitch-around maneuver is initiated (the time depends in part on the time of a space shuttle main engine failure) to orient the orbiter/external tank configuration to a heads-up attitude, pointing toward the launch site. At this time, the vehicle is still moving away from the launch site, but the space shuttle main engines are now thrusting to null the downrange velocity. In addition, excess orbital maneuvering system and reaction control system propellants are dumped by the continuous orbital maneuvering system and reaction control system engine thrustings to improve the orbiter weight and center of gravity for the glide phase and landing.

The vehicle will reach the desired main engine cutoff point with less than 2 percent excess propellant remaining in the external tank. At main engine cutoff minus 20 seconds, a pitch down maneuver (called powered pitch-down) takes the mated vehicle to the required external tank separation attitude and pitch rate. After main engine cutoff has been commanded, the external tank separation sequence begins, including a reaction control system maneuver that ensures that the orbiter does not recontact the external tank and that the orbiter has achieved the necessary pitch attitude to begin the glide phase of the RTLS.

After the reaction control system maneuver has been completed, the glide phase of the RTLS begins. From then on, the RTLS is handled similarly to a normal entry.

Transoceanic Abort Landing

The TAL abort mode was developed to improve the options available if a space shuttle main engine fails after the last RTLS opportunity but before the first time that an AOA can be accomplished with only two space shuttle main engines or when a major orbiter system failure, for example, a large cabin pressure leak or cooling system failure, occurs after the last RTLS opportunity, making it imperative to land as quickly as possible.

In a TAL abort, the vehicle continues on a ballistic trajectory across the Atlantic Ocean to land at a predetermined runway. Landing occurs about 45 minutes after launch. The landing site is selected near the normal ascent ground track of the orbiter to make the most efficient use of space shuttle main engine propellant. The landing site also must have the necessary runway length, weather conditions and U.S. State Department approval. The three landing sites that have been identified for a launch are Zaragoza, Spain; Morón, Spain; and Istres, France.

To select the TAL abort mode, the crew must place the abort rotary switch in the TAL/AOA position and depress the abort push button before main engine cutoff (depressing it after main engine cutoff selects the AOA abort mode). The TAL abort mode begins sending commands to steer the vehicle toward the plane of the landing site. It also rolls the vehicle heads up before main engine cutoff and sends commands to begin an orbital maneuvering system propellant dump (by burning the propellants through the orbital maneuvering system engines and the reaction control system engines). This dump is necessary to increase vehicle performance (by decreasing weight) to place the center of gravity in the proper place for vehicle control and to decrease the vehicle's landing weight. TAL is handled like a normal entry.

Abort to Orbit

An ATO is an abort mode used to boost the orbiter to a safe orbital altitude when performance has been lost and it is impossible to reach the planned orbital altitude. If a space shuttle main engine fails in a region that results in a main engine cutoff under speed, the MCC will determine that an abort mode is necessary and will inform the crew. The orbital maneuvering system engines would be used to place the orbiter in a circular orbit.

Abort Once Around

The AOA abort mode is used in cases in which vehicle performance has been lost to such an extent that either it is impossible to achieve a viable orbit or not enough orbital maneuvering system propellant is available to accomplish the orbital maneuvering system thrusting maneuver to place the orbiter in space. In addition, an AOA is used in cases in which a major systems problem (cabin leak, loss of cooling) makes it necessary to land quickly. In the AOA abort mode, one orbital maneuvering system thrusting sequence is made to adjust the post-main engine cutoff orbit so a second orbital maneuvering system thrusting sequence will result in the vehicle deorbiting and landing at the AOA landing site (White Sands, N.M.; Edwards Air Force Base, Calif.; or the Kennedy Space Center, Fla). Thus, an AOA results in the orbiter circling the Earth once and landing about 90 minutes after liftoff.

After the deorbit thrusting sequence has been executed, the flight crew flies to a landing at the planned site much as it would for a nominal entry.

Contingency Aborts

Contingency aborts are caused by loss of more than one main engine or failures in other systems. Loss of one main engine while another is stuck at a low thrust setting also may necessitate a contingency abort. Such an abort would maintain orbiter integrity for in-flight crew escape if a landing cannot be achieved at a suitable landing field.

Contingency aborts due to system failures other than those involving the main engines would normally result in an intact recovery of vehicle and crew. Loss of more than one main engine may, depending on engine failure times, result in a safe runway landing. However, in most three-engine-out cases during ascent, the orbiter would have to be ditched. The inflight crew escape system would be used before ditching the orbiter.

Abort Decisions

There is a definite order of preference for the various abort modes. The type of failure and the time of the failure determine which type of abort is selected. In cases where performance loss is the only factor, the preferred modes are ATO, AOA, TAL and RTLS, in that order. The mode chosen is the highest one that can be completed with the remaining vehicle performance.

In the case of some support system failures, such as cabin leaks or vehicle cooling problems, the preferred mode might be the one that will end the mission most quickly. In these cases, TAL or RTLS might be preferable to AOA or ATO. A contingency abort is never chosen if another abort option exists.

Mission Control Houston is prime for calling these aborts because it has a more precise knowledge of the orbiter's position than the crew can obtain from onboard systems. Before main engine cutoff, Mission Control makes periodic calls to the crew to identify which abort mode is (or is not) available. If ground communications are lost, the flight crew has onboard methods, such as cue cards, dedicated displays and display information, to determine the abort region. Which abort mode is selected depends on the cause and timing of the failure causing the abort and which mode is safest or improves mission success. If the problem is a space shuttle main engine failure, the flight crew and Mission Control Center select the best option available at the time a main engine fails.

If the problem is a system failure that jeopardizes the vehicle, the fastest abort mode that results in the earliest vehicle landing is chosen. RTLS and TAL are the quickest options (35 minutes), whereas an AOA requires about 90 minutes. Which of these is selected depends on the time of the failure with three good space shuttle main engines.

The flight crew selects the abort mode by positioning an abort mode switch and depressing an abort push button.

SHUTTLE ABORT HISTORY

RSLS Abort History

(STS-41 D) June 26, 1984

The countdown for the second launch attempt for Discovery's maiden flight ended at T minus (T - 4) seconds when the orbiter's computers detected a sluggish valve in main engine No. 3. The main engine was replaced and Discovery was finally launched on Aug. 30, 1984.

(STS-51 F) July 12, 1985

The countdown for Challenger's launch was halted at T - 3 seconds when onboard computers detected a problem with a coolant valve on main engine No. 2. The valve was replaced and Challenger was launched on July 29, 1985.

(STS-55) March 22, 1993

The countdown for Columbia's launch was halted by onboard computers at T - 3 seconds following a problem with purge pressure readings in the oxidizer preburner on main engine No. 2. Columbia's three main engines were replaced on the launch pad, and the flight was rescheduled behind Discovery's launch on STS-56. Columbia finally launched on April 26, 1993.

(STS-51) Aug. 12, 1993

The countdown for Discovery's third launch attempt ended at the T - 3 second mark when onboard computers detected the failure of one of four sensors in main engine No. 2 which monitor the flow of hydrogen fuel to the engine. All of Discovery's main engines were ordered replaced on the launch pad, delaying the shuttle's fourth launch attempt until Sept. 12, 1993.

(STS-68) Aug. 18, 1994

The countdown for Endeavour's first launch attempt ended 1.9 seconds before liftoff when onboard computers detected higher than acceptable readings in one channel of a sensor monitoring the discharge temperature of the high pressure oxidizer turbopump in main engine No. 3. A test firing of the engine at the Stennis Space Center in Mississippi on Sept. 2, 1994, confirmed that a slight drift in a fuel flow meter in the engine caused a slight increase in the turbopump's temperature. The test firing also confirmed a slightly slower start for main engine No. 3 during the pad abort, which could have contributed to the higher temperatures. After Endeavour was brought back to the Vehicle Assembly Building to be outfitted with three replacement engines, NASA managers set Oct. 2, 1994, as the date for Endeavour's second launch attempt.

Abort to Orbit History

(STS-51 F) July 29, 1985

After an RSLS abort on July 12, 1985, Challenger was launched on July 29, 1985. Five minutes and 45 seconds after launch, a sensor problem resulted in the shutdown of center engine No. 1, resulting in a safe "abort to orbit" and successful completion of the mission.

SPACE SHUTTLE MAIN ENGINES

Developed in the 1970s by NASA's Marshall Space Flight Center, in Huntsville, Ala., the space shuttle main engine is the most advanced liquid-fueled rocket engine ever built. Every space shuttle main engine is tested and proven flight worthy at NASA's Stennis Space Center in south Mississippi, before installation on an orbiter. Its main features include variable thrust, high performance reusability, high redundancy and a fully integrated engine controller.

The shuttle's three main engines are mounted on the orbiter aft fuselage in a triangular pattern. Spaced so that they are movable during launch, the engines are used, in conjunction with the solid rocket boosters, to steer the shuttle vehicle.

Each of these powerful main engines is 14 feet long, weighs about 7,000 pounds and is 7.5 feet in diameter at the end of its nozzle.

The engines operate for about 8.5 minutes during liftoff and ascent, burning more than 500,000 gallons of super-cold liquid hydrogen and liquid oxygen propellants stored in the external tank attached to the underside of the shuttle. The engines shut down just before the shuttle, traveling at about 17,000 miles per hour, reaches orbit.

The main engine operates at greater temperature extremes than any mechanical system in common use today. The fuel, liquefied hydrogen at -423 degrees Fahrenheit, is the second coldest liquid on Earth. When it and the liquid oxygen are combusted, the temperature in the main combustion chamber is 6,000 degrees Fahrenheit, hotter than the boiling point of iron.

The main engines use a staged combustion cycle so that all propellants entering the engines are used to produce thrust, or power, more efficiently than any previous rocket engine. In a staged combustion cycle, propellants are first burned partially at high pressure and relatively low temperature, and then burned completely at high temperature and pressure in the main combustion chamber. The rapid mixing of the propellants under these conditions is so complete that 99 percent of the fuel is burned.

At normal operating level, each engine generates 490,847 pounds of thrust, measured in a vacuum. Full power is 512,900 pounds of thrust; minimum power is 316,100 pounds of thrust.

The engine can be throttled by varying the output of the preburners, thus varying the speed of the high-pressure turbopumps and, therefore, the flow of the propellant.

At about 26 seconds into ascent, the main engines are throttled down to 316,000 pounds of thrust to keep the dynamic pressure on the vehicle below a specified level, about 580 pounds per square foot, known as max q. Then, the engines are throttled back up to normal operating level at about 60 seconds. This reduces stress on the vehicle. The main engines are throttled down again at about seven minutes, 40 seconds into the mission to maintain three g's, three times the Earth's gravitational pull, reducing stress on the crew and the vehicle. This acceleration level is about one-third the acceleration experienced on previous crewed space vehicles.

About 10 seconds before Main Engine Cutoff (MECO), the cutoff sequence begins. About three seconds later the main engines are commanded to begin throttling at 10 percent thrust per second until they achieve 65 percent thrust. This is held for about 6.7 seconds, and the engines are shut down.

The engine performance has the highest thrust for its weight of any engine yet developed. In fact, one space shuttle main engine generates sufficient thrust to maintain the flight of two and one-half Boeing 747 airplanes.

The space shuttle main engine also is the first rocket engine to use a built-in electronic digital controller, or computer. The controller accepts commands from the orbiter for engine start, change in throttle, shutdown and monitoring of engine operation.

NASA continues to increase the reliability and safety of shuttle flights through a series of enhancements to the space shuttle main engines. The engines were modified in 1988, 1995, 1998, 2001 and 2007. Modifications include new high-pressure fuel and oxidizer turbopumps that reduce maintenance and operating costs of the engine, a two-duct powerhead that reduces pressure and turbulence in the engine, and a single-coil heat exchanger that lowers the number of post flight inspections required. Another modification incorporates a large-throat main combustion chamber that improves the engine's reliability by reducing pressure and temperature in the chamber.

The most recent engine enhancement is the Advanced Health Management System (AHMS), which made its first flight in 2007. AHMS is a controller upgrade that provides new monitoring and insight into the health of the two most complex components of the space shuttle main engine – the high pressure fuel turbopump and the high pressure oxidizer turbopump. New advanced digital signal processors monitor engine vibration and have the ability to shut down an engine if vibration exceeds safe limits. AHMS was developed by engineers at Marshall.

After the orbiter lands, the engines are removed and returned to a processing facility at NASA's Kennedy Space Center, Fla., where they are rechecked and readied for the next flight. Some components are returned to the main engine's prime contractor, Pratt & Whitney Rocketdyne, West Palm Beach, Fla., for regular maintenance. The main engines are designed to operate for 7.5 accumulated hours.

SPACE SHUTTLE SOLID ROCKET BOOSTERS (SRB)

The two solid rocket boosters (SRBs) required for a space shuttle launch and first two minutes of powered flight boast the largest solid-propellant motors ever flown. They are the first large rockets designed for reuse and are the only solid rocket motors rated for human flight. The SRBs have the capacity to carry the entire weight of the External fuel Tank (ET), and orbiter, and to transmit the weight load through their structure to the Mobile Launcher Platform (MLP).

The SRBs provide 71.4 percent of the thrust required to lift the space shuttle off the launch pad and during first-stage ascent to an altitude of about 150,000 feet, or 28 miles. At launch, each booster has a sea level thrust of approximately 3.3 million pounds and is ignited after the ignition and verification of the three Space Shuttle Main Engines (SSMEs).

SRB apogee occurs at an altitude of about 230,000 feet, or 43 miles, 75 seconds after separation from the main vehicle. At booster separation, the space shuttle orbiter has reached an altitude of 24 miles and is traveling at a speed in excess of 3,000 miles per hour.

The primary elements of each booster are nose cap, housing the pilot and drogue parachute; frustum, housing the three main parachutes in a cluster; forward skirt, housing the booster flight avionics, altitude sensing, recovery avionics, parachute cameras and range safety destruct system; four motor segments, containing the solid propellant; motor nozzle; and aft skirt, housing the nozzle and thrust vector control systems required for guidance. Each SRB possesses its own redundant auxiliary power units and hydraulic pumps.

SRB impact occurs in the ocean approximately 140 miles downrange. SRB retrieval is provided after each flight by specifically designed and built ships. The frustums, drogue and main parachutes are loaded onto the ships along with the boosters and towed back to NASA's Kennedy Space Center, where they are disassembled and refurbished for reuse. Before retirement, each booster can be used as many as 20 times.

Each booster is just over 149 feet long and 12.17 feet in diameter. Both boosters have a combined weight of 1,303,314 pounds at lift-off. They are attached to the ET at the SRB aft attach ring by an upper and lower attach strut and a diagonal attach strut. The forward end of each SRB is affixed to the ET by one attach bolt and ET ball fitting on the forward skirt. While positioned on the launch pad, the space shuttle is attached to the MLP by four bolts and explosive nuts equally spaced around each SRB. After ignition of the solid rocket motors, the nuts are severed by small explosives that allow the space shuttle vehicle to perform lift off.

United Space Alliance

United Space Alliance (USA), at Kennedy facilities, is responsible for all SRB operations, except the motor and nozzle portions. In conjunction with maintaining sole responsibility for manufacturing and processing of the nonmotor hardware and vehicle integration, USA provides the service of retrieval, post flight inspection and analysis, disassembly and refurbishment of the hardware. USA also exclusively retains comprehensive responsibility for the orbiter.

The reusable solid rocket motor segments are shipped from ATK Launch Systems in Utah to Kennedy, where they are mated by USA personnel to the other structural components – the forward assembly, aft skirt, frustum and nose cap – in the Vehicle Assembly Building. Work involves the complete disassembly and refurbishment of the major SRB structures – the aft skirts, frustums, forward skirts and all ancillary hardware – required to complete an SRB stack and mate to the ET. Work then proceeds to ET/SRB mate, mate with the orbiter and finally, space shuttle close out operations. After hardware restoration concerning flight configuration is complete, automated checkout and hot fire are performed early in hardware flow to ensure that the refurbished components satisfy all flight performance requirements.

ATK Launch Systems (ATK)

ATK Launch Systems of Brigham City, Utah, manufactures space shuttle Reusable Solid Rocket Motors (RSRMs), at their Utah facility. Each RSRM – just over 126 feet long and 12 feet in diameter – consists of four rocket motor segments and an aft exit cone assembly is. From ignition to end of burn, each RSRM generates an average thrust of 2.6 million pounds and burns for approximately 123 seconds. Of the motor's total weight of 1.25 million pounds, propellant accounts for 1.1 million pounds. The four motor segments are matched by loading each from the same batches of propellant ingredients to minimize any thrust imbalance. The segmented casing design assures maximum flexibility in fabrication and ease of transportation and handling. Each segment is shipped to KSC on a heavy-duty rail car with a specialty built cover.

SRB Hardware Design Summary

Hold-Down Posts

Each SRB has four hold-down posts that fit into corresponding support posts on the MLP. Hold-down bolts secure the SRB and MLP posts together. Each bolt has a nut at each end, but the top nut is frangible, or breakable. The top nut contains two NASA Standard Detonators (NSDs), that, when ignited at solid rocket motor ignition command, split the upper nut in half.

Splitting the upper nuts allow the hold-down bolts to be released and travel downward because of NSD gas pressure, gravity and the release of tension in the bolt, which is pretensioned before launch. The bolt is stopped by the stud deceleration stand which contains sand to absorb the shock of the bolt dropping down several feet. The SRB bolt is 28 inches long, 3.5 inches in diameter and weighs approximately 90 pounds. The frangible nut is captured in a blast container on the aft skirt specifically designed to absorb the impact and prevent pieces of the nut from liberating and becoming debris that could damage the space shuttle.

Integrated Electronic Assembly

The aft Integrated Electronic Assembly (IEA), mounted in the ET/SRB attach ring, provides the electrical interface between the SRB systems and the obiter. The aft IEA receives data, commands, and electrical power from the orbiter and distributes these inputs throughout each SRB. Components located in the forward assemblies of each SRB are powered by the aft IEA through the forward IEA, except for those utilizing the recovery and range safety batteries located in the forward assemblies. The forward IEA communicates with and receives power from the orbiter through the aft IEA, but has no direct electrical connection to the orbiter.

Electrical Power Distribution

Electrical power distribution in each SRB consists of orbiter-supplied main dc bus power to each SRB via SRB buses A, B and C. Orbiter main dc buses A, B and C supply main dc bus power to corresponding SRB buses A, B and C. In addition, orbiter main dc, bus C supplies backup power to SRB buses A and B, and orbiter bus B supplies backup power to SRB bus C. This electrical power distribution arrangement allows all SRB buses to remain powered in the event one orbiter main bus fails.

The nominal dc voltage is 28 V dc, with an upper limit of 32 V dc and a lower limit of 24 V dc.

Hydraulic Power Units

There are two self-contained, independent Hydraulic Power Units (HPUs) on each SRB. Each HPU consists of an Auxiliary Power Unit (APU); Fuel Supply Module (FSM); hydraulic pump; hydraulic reservoir; and hydraulic fluid manifold assembly. The APUs are fueled by hydrazine and generate mechanical shaft power to a hydraulic pump that produces hydraulic pressure for the SRB hydraulic system. The APU controller electronics are located in the SRB aft integrated electronic assemblies on the aft ET attach rings. The two separate HPUs and two hydraulic systems are located inside the aft skirt of each SRB between the SRB nozzle and skirt. The HPU components are mounted on the aft skirt between the rock and tilt actuators. The two systems operate from T minus 28 seconds until SRB separation from the orbiter and ET. The two independent hydraulic systems are connected to the rock and tilt servoactuators.

The HPUs and their fuel systems are isolated from each other. Each fuel supply module, or tank, contains 22 pounds of hydrazine. The fuel tank is pressurized with gaseous nitrogen at 400 psi to provide the force to expel via positive expulsion the fuel from the tank to the fuel distribution line. A positive fuel supply to the APU throughout its operation is maintained.

The fuel isolation valve is opened at APU startup to allow fuel to flow to the APU fuel pump and control valves and then to the gas generator. The gas generator's catalytic action decomposes the fuel and creates a hot gas. It feeds the hot gas exhaust product to the APU two-stage gas turbine. Fuel flows primarily through the startup bypass line until the APU speed is such that the fuel pump outlet pressure is greater than the bypass line's, at which point all the fuel is supplied to the fuel pump.

The APU turbine assembly provides mechanical power to the APU gearbox, which drives the APU fuel pump, hydraulic pump and lube oil pump. The APU lube oil pump lubricates the gearbox. The turbine exhaust of each APU flows over the exterior of the gas generator, cooling it and directing it overboard through an exhaust duct.

When the APU speed reaches 100 percent, the APU primary control valve closes and the APU speed is controlled by the APU controller electronics. If the primary control valve logic fails to the open state, the secondary control valve assumes control of the APU at 112 percent speed. Each HPU on an SRB is connected to both servoactuators. One HPU serves as the primary hydraulic source for the servoactuator and the other HPU serves as the secondary hydraulics for the servoactuator. Each servoactuator has a switching valve that allows the secondary hydraulics to power the actuator if the primary hydraulic pressure drops below 2,050 psi. A switch contact on the switching valve will close when the valve is in the secondary position. When the valve is closed, a signal is sent to the APU controller that inhibits the 100 percent APU speed control logic and enables the 112 percent APU speed control logic. The 100 percent APU speed enables one APU/HPU to supply sufficient operating hydraulic pressure to both servoactuators of that SRB.

The APU 100 percent speed corresponds to 72,000 rpm, 110 percent to 79,200 rpm and 112 percent to 80,640 rpm.

The hydraulic pump speed is 3,600 rpm and supplies hydraulic pressure of 3,050, plus or minus 50 psi. A high-pressure relief valve provides overpressure protection to the hydraulic system and relieves at 3,750 psi.

The APUs/HPUs and hydraulic systems are reusable for 20 missions.

Thrust Vector Control

Each SRB has two hydraulic gimbal servoactuators: one for rock and one for tilt. The servoactuators provide the force and control to gimbal the nozzle for Thrust Vector Control (TVC). The all-axis gimbaling capability is 8 degrees. Each nozzle has a carbon cloth liner that erodes and chars during firing. The nozzle is a convergent-divergent, movable design in which an aft pivot-point flexible bearing is the gimbal mechanism.

The space shuttle ascent TVC portion of the flight control system directs the thrust of the three SSMEs and the two SRB nozzles to control shuttle attitude and trajectory during liftoff and ascent. Commands from the guidance system are transmitted to the Ascent TVC, or ATVC, drivers, which transmit signals proportional to the commands to each servoactuator of the main engines and SRBs. Four independent flight control system channels and four ATVC channels control six main engine and four SRB ATVC drivers, with each driver controlling one hydraulic port on each main and SRB servoactuator.

Each SRB servoactuator consists of four independent, two-stage servovalves that receive signals from the drivers. Each servovalve controls one power spool in each actuator, which positions an actuator ram and the nozzle to control the direction of thrust.

The four servovalves in each actuator provide a force-summed majority voting arrangement to position the power spool. With four identical commands to the four servovalves, the actuator force-sum action prevents a single erroneous command from affecting power ram motion. If the erroneous command persists for more than a predetermined time, differential pressure sensing activates a selector valve to isolate and remove the defective servovalve hydraulic pressure. This permits the remaining channels and servovalves to control the actuator ram spool.

Failure monitors are provided for each channel to indicate which channel has been bypassed. An isolation valve on each channel provides the capability of resetting a failed or bypassed channel.

Each actuator ram is equipped with transducers for position feedback to the thrust vector control system. Within each servoactuator ram is a splashdown load relief assembly to cushion the nozzle at water splashdown and prevent damage to the nozzle flexible bearing.

SRB Rate Gyro Assemblies

Each SRB contains two Rate Gyro Assemblies (RGAs) mounted in the forward skirt watertight compartment. Each RGA contains two orthogonally mounted gyroscopes – pitch and yaw axes. In conjunction with the orbiter roll rate gyros, they provide angular rate information that describes the inertial motion of the vehicle cluster to the orbiter computers and the guidance, navigation and control system during first stage ascent to SRB separation. At SRB separation, all guidance control data is handed off from the SRB RGAs to the orbiter RGAs. The RGAs are designed and qualified for 20 missions.

Propellant

The propellant mixture in each SRB motor consists of ammonium perchlorate, an oxidizer, 69.6 percent by weight; aluminum, a fuel, 16 percent by weight; iron oxide, a catalyst, 0.4 percent by weight; polymer, a binder that holds the mixture together, 12.04 percent by weight; and epoxy curing agent, 1.96 percent by weight. The propellant is an 11-point star-shaped perforation in the forward motor segment and a double truncated cone perforation in each of the aft segments and aft closure. This configuration provides high thrust at ignition and then reduces the thrust by about one-third 50 seconds after liftoff to prevent overstressing the vehicle during maximum dynamic pressure.

SRB Ignition

SRB ignition can occur only when a manual lock pin from each SRB safe and arm device has been removed by the ground crew during prelaunch activities. At T minus 5 minutes, the SRB safe and arm device is rotated to the arm position. The solid rocket motor ignition commands are issued when the three SSMEs are at or above 90 percent rated thrust; no SSME fail and/or SRB ignition Pyrotechnic Initiator Controller (PIC) low voltage is indicated; and there are no holds from the Launch Processing System (LPS).

The solid rocket motor ignition commands are sent by the orbiter computers through the Master Events Controllers (MECs) to the NSDs installed in the safe and arm device in each SRB. A PIC is a single-channel capacitor discharge device that controls the firing of each pyrotechnic device. Three signals must be present simultaneously for the PIC to generate the pyro firing output. These signals – arm, fire 1 and fire 2 – originate in the orbiter general-purpose computers and are transmitted to the MECs. The MECs reformat them to 28 V dc signals for the PICs. The arm signal charges the PIC capacitor to 40 V dc, minimum 20 V dc.

The fire 2 commands cause the redundant NSDs to fire through a thin barrier seal down a flame tunnel. This ignites a pyro booster charge, which is retained in the safe and arm device behind a perforated plate. The booster charge ignites the propellant in the igniter initiator; and combustion products of this propellant ignite the solid rocket motor igniter, which fires down the length of the solid rocket motor igniting the solid rocket motor propellant.

The General Purpose Computer (GPC) launch sequence also controls certain critical main propulsion system valves and monitors the engine-ready indications from the SSMEs. The Main Propulsion System (MPS) start commands are issued by the on-board computers at T minus 6.6 seconds. There is a staggered start – engine three, engine two, engine one – within 0.25 of a second, and the sequence monitors the thrust buildup of each engine. All three SSMEs must reach the required 90 percent thrust within three seconds; otherwise, an orderly shutdown is commanded and safing functions are initiated.

Normal thrust buildup to the required 90 percent thrust level will result in the SSMEs being commanded to the liftoff position at T - 3 seconds as well as the fire 1 command being issued to arm the SRBs. At T - 3 seconds, the vehicle base bending load modes are allowed to initialize.

At T - 0, the two SRBs are ignited by the four orbiter on-board computers; commands are sent to release the SRBs; the two T - 0 umbilicals, one on each side of the spacecraft, are retracted; the onboard master timing unit, event timer and mission event timers are started; the three SSMEs are at 100 percent; and the ground launch sequence is terminated.

SRB Separation

The SRB/ET separation subsystem provides for separation of the SRBs from the orbiter/ET without damage to or recontact of the elements – SRBs, orbiter/ET – during or after separation for nominal modes. SRB separation is initiated when the three solid rocket motor chamber pressure transducers are processed in the redundancy management middle value select and the head end chamber pressure of both SRBs is less than or equal to 50 psi. A backup cue is the time elapsed from booster ignition.

The separation sequence is initiated, commanding the thrust vector control actuators to the null position and putting the main propulsion system into a second-stage configuration 0.8 second from sequence initialization, which ensures the thrust of each SRB is less than 100,000 pounds. Orbiter yaw attitude is held for four seconds and SRB thrust drops to less than 60,000 pounds. The SRBs separate from the ET within 30 milliseconds of the ordnance firing command.

The forward attachment point consists of a ball on the SRB and socket on the ET, held together by one bolt. The bolt contains one NSD pressure cartridge at each end. The forward attachment point also carries the range safety system cross-strap wiring connecting each SRB Range Safety System (RSS), and the ET RSS with each other.

The aft attachment points consist of three separate struts: upper, diagonal, and lower. Each strut contains one bolt with an NSD pressure cartridge at each end. The upper strut also carries the umbilical interface between its SRB and the external tank and on to the orbiter.

Redesigned Booster Separation Motors (RBSM)

Eight Booster Separation Motors (BSMs), are located on each booster – four on the forward section and four on the aft skirt. BSMs provide the force required to push the SRBs away from the orbiter/ET at separation. Each BSM weighs approximately 165 pounds and is 31.1 inches long and 12.8 inches in diameter. Once the SRBs have completed their flight, the BSMs are fired to jettison the SRBs away from the orbiter and external tank, allowing the boosters to parachute to Earth and be reused. The BSMs in each cluster of four are ignited by firing redundant NSD pressure cartridges into redundant confined detonating fuse manifolds. The separation commands issued from the orbiter by the SRB separation sequence initiate the redundant NSD pressure cartridge in each bolt and ignite the BSMs to effect a clean separation.

Redesigned BSMs flew for the first time in both forward and aft locations on STS-125. As a result of vendor viability and manifest support issues, space shuttle BSMs are now being manufactured by ATK. The igniter has been redesigned and other changes include material upgrades driven by obsolescence issues and improvements to process and inspection techniques.

SRB Cameras

Each SRB flies with a complement of four cameras, three mounted for exterior views during launch, separation and descent; and one mounted internal to the forward dome for main parachute performance assessment during descent.

The ET observation camera is mounted on the SRB forward skirt and provides a wide-angle view of the ET intertank area. The camera is activated at lift off by a G-switch and records for 350 seconds, after which the recorder is switched to a similar camera in the forward skirt dome to view the deployment and performance of the main parachutes to splash down. These cameras share a digital tape recorder located within the data acquisition system.

The ET ring camera is mounted on the ET attach ring and provides a view up the stacked vehicle on the orbiter underside and the bipod strut attach point.

The forward skirt camera is mounted on the external surface of the SRB forward skirt and provides a view aft down the stacked vehicle of the orbiter underside and the wing leading edge Reinforced Carbon-Carbon (RCC) panels.

The ET attach ring camera and forward skirt camera are activated by a global positioning system command at approximately T - 1 minute 56 seconds to begin recording at approximately T - 50 seconds. The camera images are recorded through splash down. These cameras each have a dedicated recorder and are recorded in a digital format. The cameras were designed, qualified, and implemented by USA after Columbia to provide enhanced imagery capabilities to capture potential debris liberation beginning with main engine start and continuing through SRB separation.

The camera videos are available for engineering review approximately 24 hours following the arrival of the boosters at KSC.

Range Safety Systems

The RSS consists of two antenna couplers; command receivers/decoders; a dual distributor; a safe and arm device with two NSDs; two confined detonating fuse manifolds; seven Confined Detonator Fuse (CDF) assemblies; and one linear-shaped charge.

The RSS provides for destruction of a rocket or part of it with on-board explosives by remote command if the rocket is out of control, to limit danger to people on the ground from crashing pieces, explosions, fire, and poisonous substances.

The space shuttle has two RSSs, one in each SRB. Both are capable of receiving two command messages – arm and fire – which are transmitted from the ground station. The RSS is only used when the space shuttle violates a launch trajectory red line.

The antenna couplers provide the proper impedance for radio frequency and ground support equipment commands. The command receivers are tuned to RSS command frequencies and provide the input signal to the distributors when an RSS command is sent. The command decoders use a code plug to prevent any command signal other than the proper command signal from getting into the distributors. The distributors contain the logic to supply valid destruct commands to the RSS pyrotechnics.

The NSDs provide the spark to ignite the CDF that in turn ignites the linear-shaped charge for space shuttle destruction. The safe and arm device provides mechanical isolation between the NSDs and the CDF before launch and during the SRB separation sequence.

The first message, called arm, allows the onboard logic to enable a destruct and illuminates a light on the flight deck display and control panel at the commander and pilot station. The second message transmitted is the fire command. The SRB distributors in the SRBs are cross-strapped together. Thus, if one SRB received an arm or destruct signal, the signal would also be sent to the other SRB.

Electrical power from the RSS battery in each SRB is routed to RSS A. The recovery battery in each SRB is used to power RSS B as well as the recovery system in the SRB. The SRB RSS is powered down during the separation sequence, and the SRB recovery system is powered up.

Descent and Recovery

After separation and at specified altitudes, the SRB forward avionics system initiates the release of the nose cap, which houses a pilot parachute and drogue parachute; and the frustum, which houses the three main parachutes. Jettison of the nose cap at 15,700 feet deploys a small pilot parachute and begins to slow the SRB decent. At an altitude of 15,200 feet the pilot parachute pulls the drogue parachute from the frustum. The drogue parachute fully inflates in stages, and at 5,500 feet pulls the frustum away from the SRB, which initiates the deployment of the three main parachutes. The parachutes also inflate in stages and further slow the decent of the SRBs to their final velocity at splashdown. The parachutes slow each SRB from 368 mph at first deployment to 52 mph at splashdown, allowing for the recovery and reuse of the boosters.

Two 176-foot recovery ships, Freedom Star and Liberty Star, are on station at the splashdown zone to retrieve the frustums with drogue parachutes attached, the main parachutes and the SRBs. The SRB nose caps and solid rocket motor nozzle extensions are not recovered. The SRBs are dewatered using an enhanced diver operating plug to facilitate tow back. These plugs are inserted into the motor nozzle and air is pumped into the booster, causing it to lay flat in the water to allow it to be easily towed. The boosters are then towed back to the refurbishment facilities. Each booster is removed from the water and components are disassembled and washed with fresh and deionized water to limit saltwater corrosion. The motor segments, igniter and nozzle are shipped back to ATK in Utah for refurbishment. The nonmotor components and structures are disassembled by USA and are refurbished to like-new condition at both KSC and equipment manufacturers across the country.

SPACE SHUTTLE SUPER LIGHT WEIGHT TANK

The Super Lightweight External Tank (SLWT) made its first shuttle flight June 2, 1998, on mission STS-91. The SLWT is 7,500 pounds lighter than the standard external tank. The lighter weight tank allows the shuttle to deliver International Space Station elements (such as the service module) into the proper orbit.

The SLWT is the same size as the previous design. But the liquid hydrogen tank and the liquid oxygen tank are made of aluminum lithium, a lighter, stronger material than the metal alloy used for the shuttle’s current tank. The tank’s structural design has also been

improved, making it 30 percent stronger and 5 percent less dense.

The SLWT, like the standard tank, is manufactured at NASA's Michoud Assembly Facility, near New Orleans, by Lockheed Martin.

The 154-foot-long external tank is the largest single component of the space shuttle. It stands taller than a 15-story building and has a diameter of about 27 feet. The external tank holds over 530,000 gallons of liquid hydrogen and liquid oxygen in two separate tanks. The hydrogen (fuel) and liquid oxygen (oxidizer) are used as propellants for the shuttle's three main engines.

EXTERNAL TANK

The 154-foot-long external tank is the largest single component of the space shuttle. It stands taller than a 15-story building and has a diameter of about 27 feet. The external tank holds more than 530,000 gallons of liquid hydrogen and liquid oxygen in two separate tanks, the forward liquid oxygen tank and the aft liquid hydrogen tank. An unpressurized intertank unites the two propellant tanks.

Liquid hydrogen (fuel) and liquid oxygen (oxidizer) are used as propellants for the shuttle's three main engines. The external tank weighs 58,500 pounds empty and 1,668,500 pounds when filled with propellants.

The external tank is the "backbone" of the shuttle during launch, providing structural support for attachment with the solid rocket boosters and orbiter. It is the only component of the shuttle that is not reused. Approximately 8.5 minutes after reaching orbit, with its propellant used, the tank is jettisoned and falls in a preplanned trajectory. Most of the tank disintegrates in the atmosphere, and the remainder falls into the ocean.

The external tank is manufactured at NASA's Michoud Assembly Facility in New Orleans by Lockheed Martin Space Systems.

Foam Facts

The external tank is covered with spray-on foam insulation that insulates the tank before and during launch. More than 90 percent of the tank's foam is applied using an automated system, leaving less than 10 percent to be applied manually.

There are two types of foam on the external tank, known as the Thermal Protection System (TPS). One is low-density, closed-cell foam on the tank acreage and is known as Spray-On-Foam-Insulation, often referred to by its acronym, SOFI. Most of the tank is covered by either an automated or manually applied SOFI. Most areas around protuberances, such as brackets and structural elements, are applied by pouring foam ingredients into part-specific molds. The other, called ablator, is a denser composite material made of silicone resins and cork. An ablator is a material that dissipates heat by eroding. It is used on areas of the external tank subjected to extreme heat, such as the aft dome near the engine exhaust, and remaining protuberances, such as the cable trays. These areas are exposed to extreme aerodynamic heating.

Closed-cell foam used on the tank was developed to keep the propellants that fuel the shuttle's three main engines at optimum temperature. It keeps the shuttle's liquid hydrogen fuel at -423 degrees Fahrenheit and the liquid oxygen tank at near

-297 degrees Fahrenheit, even as the tank sits under the hot Florida sun. At the same time, the foam prevents a buildup of ice on the outside of the tank.

The foam insulation must be durable enough to endure a 180-day stay at the launch pad, withstand temperatures up to 115 degrees Fahrenheit, humidity as high as 100 percent, and resist sand, salt, fog, rain, solar radiation and even fungus. Then, during launch, the foam must tolerate temperatures as high as 2,200 degrees Fahrenheit generated by aerodynamic friction and radiant heating from the 3,000 degrees Fahrenheit main engine plumes. Finally, when the external tank begins reentry into the Earth's atmosphere about 30 minutes after launch, the foam maintains the tank's structural temperatures and allows it to safely disintegrate over a remote ocean location.

Though the foam insulation on the majority of the tank is only 1-inch thick, it adds 4,823 pounds to the tank's weight. In the areas of the tank subjected to the highest heating, insulation is somewhat thicker, between 1.5 to 3 inches thick. Though the foam's density varies with the type, an average density is about 2.4 pounds per cubic foot.

Application of the foam, whether automated by computer or hand-sprayed, is designed to meet NASA's requirements for finish, thickness, roughness, density, strength and adhesion. As in most assembly production situations, the foam is applied in specially designed, environmentally controlled spray cells and applied in several phases, often over a period of several weeks. Before spraying, the foam's raw material and mechanical properties are tested to ensure they meet NASA specifications. Multiple visual inspections of all foam surfaces are performed after the spraying is complete.

Most of the foam is applied at NASA's Michoud Assembly Facility in New Orleans when the tank is manufactured, including most of the "closeout" areas, or final areas applied. These closeouts are done either by hand pouring or manual spraying. Additional closeouts are completed once the tank reaches NASA's Kennedy Space Center, Fla.

The SLWT made its first shuttle flight in June 1998 on mission STS-91. The SLWT is 7,500 pounds lighter than previously flown tanks. The SLWT is the same size as the previous design, but the liquid hydrogen tank and the liquid oxygen tank are made of aluminum lithium, a lighter, stronger material than the metal alloy used previously.

Beginning with the first Return to Flight mission, STS-114 in June 2005, several improvements were made to improve safety and flight reliability.

Forward Bipod

The external tank's forward shuttle attach fitting, called the bipod, was redesigned to eliminate the large insulating foam ramps as a source of debris. Each external tank has two bipod fittings that connect the tank to the orbiter through the shuttle's two forward attachment struts. Four rod heaters were placed below each forward bipod, replacing the large insulated foam Protuberance Airload (PAL) ramps.

Liquid Hydrogen Tank & Liquid Oxygen Intertank Flange Closeouts

The liquid hydrogen tank flange located at the bottom of the intertank and the liquid oxygen tank flange located at the top of the intertank provide joining mechanisms with the intertank. After each of these three component tanks, liquid oxygen, intertank and liquid hydrogen, are joined mechanically, the flanges at both ends are insulated with foam. An enhanced closeout, or finishing, procedure was added to improve foam application to the stringer, or intertank ribbing, and to the upper and lower area of both the liquid hydrogen and liquid oxygen intertank flanges.

Liquid Oxygen Feedline Bellows

The liquid oxygen feedline bellows were reshaped to include a “drip lip” that allows condensate moisture to run off and prevent freezing. A strip heater was added to the forward bellow to further reduce the potential of high density ice or frost formation. Joints on the liquid oxygen feedline assembly allow the feedline to move during installation and during liquid hydrogen tank fill. Because it must flex, it cannot be insulated with foam like the remainder of the tank.

Other tank improvements include:

Liquid Oxygen & Liquid Hydrogen Protuberance Airload (PAL) Ramps

External tank ET-119, which flew on the second Return to Flight mission, STS-121, in July 2006, was the first tank to fly without PAL ramps along portions of the liquid oxygen and liquid hydrogen tanks. These PAL ramps were extensively studied and determined to not be necessary for their original purpose, which was to protect cable trays from aeroelastic instability during ascent. Extensive tests were conducted to verify the shuttle could fly safely without these particular PAL ramps. Extensions were added to the ice frost ramps for the pressline and cable tray brackets, where these PAL ramps were removed to make the geometry of the ramps consistent with other locations on the tank and thereby provide consistent aerodynamic flow. Nine extensions were added, six on the liquid hydrogen tank and three on the liquid oxygen tank.

Engine Cutoff Sensor Modification

Beginning with STS-122, ET-125, which launched on Feb. 7, 2008, the Engine Cutoff (ECO) sensor system feed-through connector on the liquid hydrogen tank was modified by soldering the connector’s pins and sockets to address false readings in the system. All subsequent tanks after ET-125 have the same modification.

Liquid Hydrogen Tank Ice Frost Ramps

ET-128, which flew on the STS-124 shuttle mission, May 31, 2008, was the first tank to fly with redesigned liquid hydrogen tank ice frost ramps. Design changes were incorporated at all 17 ice frost ramp locations on the liquid hydrogen tank, stations 1151 through 2057, to reduce foam loss. Although the redesigned ramps appear identical to the previous design, several changes were made. PDL* and NCFI foam have been replaced with BX* manual spray foam in the ramp’s base cutout to reduce debonding and cracking; Pressline and cable tray bracket feet corners have been rounded to reduce stresses; shear pin holes have been sealed to reduce leak paths; isolators were primed to promote adhesion; isolator corners were rounded to help reduce thermal

protection system foam stresses; BX manual spray was applied in bracket pockets to reduce geometric voids.

*BX is a type of foam used on the tank's "closeout," or final finished areas; it is applied manually or hand-sprayed. PDL is an acronym for Product Development Laboratory, the first supplier of the foam during the early days of the external tank's development. PDL is applied by pouring foam ingredients into a mold. NCFI foam is used on the aft dome, or bottom, of the liquid hydrogen tank.

Liquid Oxygen Feedline Brackets

ET-128 also was the first tank to fly with redesigned liquid oxygen feedline brackets. Titanium brackets, much less thermally conductive than aluminum, replaced aluminum brackets at four locations, XT 1129, XT 1377, Xt 1624 and Xt 1871. This change minimizes ice formation in under-insulated areas, and reduces the amount of foam required to cover the brackets and the propensity for ice development. Zero-gap/slip plane Teflon material was added to the upper outboard monoball attachment to eliminate ice adhesion. Additional foam has been added to the liquid oxygen feedline to further minimize ice formation along the length of the feedline.

LAUNCH AND LANDING

LAUNCH

As with all previous space shuttle launches, Endeavour has several options to abort its ascent, if needed, after engine failures or other systems problems. Shuttle launch abort philosophy is intended to facilitate safe recovery of the flight crew and intact recovery of the orbiter and its payload.

Abort modes include the following:

ABORT TO ORBIT

This mode is used if there is a partial loss of main engine thrust late enough to permit reaching a minimal 105 by 85 nautical mile orbit with the Orbital Maneuvering System engines. The engines boost the shuttle to a safe orbital altitude when it is impossible to reach the planned orbital altitude.

TRANSOCEANIC ABORT LANDING

The loss of one or more main engines midway through powered flight would force a landing at either Zaragoza, Spain; Morón, Spain; or Istres, France. For the launch to proceed, weather conditions must be acceptable at one of these Transoceanic Abort Landing (TAL) sites.

RETURN TO LAUNCH SITE

If one or more engines shut down early and there is not enough energy to reach Zaragoza or another TAL site, the shuttle would pitch around back toward the Kennedy Space Center (KSC) until within gliding distance of the shuttle landing facility. For the launch to proceed, weather conditions must be forecast to be acceptable for a possible landing at KSC about 20 minutes after liftoff.

ABORT ONCE AROUND

An abort once around is selected if the vehicle cannot achieve a viable orbit or will not have enough propellant to perform a deorbit burn, but has enough energy to circle the Earth once and land about 90 minutes after liftoff. The KSC shuttle landing facility is the primary landing site for an AOA, and White Sands Space Harbor, N.M., is the backup site.

LANDING

The primary landing site for Endeavour on STS-134 is Kennedy's Shuttle Landing Facility. Alternate landing sites that could be used if needed because of weather conditions or systems failures are at Edwards Air Force Base, Calif., and White Sands Space Harbor, N.M.

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ACRONYMS AND ABBREVIATIONS

A/G	Alignment Guides
A/L	Airlock
AAA	Avionics Air Assembly
ABC	Audio Bus Controller
ACBM	Active Common Berthing Mechanism
ACDU	Airlock Control and Display Unit
ACO	Assembly Checkout Officer
ACRFG	Assembly Contingency Radio Frequency Group
ACS	Atmosphere Control and Supply
ACTRA	Assembly/Contingency Transmitter/Receiver Assembly
ACU	Arm Control Unit
ADS	Audio Distribution System
AE	Approach Ellipsoid
AEP	Airlock Electronics Package
AFRL	Air Force Research Lab
AHMS	Advanced Health Management System
AI	Approach Initiation
AIS	Automatic Identification System
AJIS	Alpha Joint Interface Structure
AM	Atmosphere Monitoring
AMOS	Air Force Maui Optical and Supercomputing Site
AMS	Alpha Magnetic Spectrometer
AOA	Abort Once Around
AOH	Assembly Operations Handbook
APAS	Androgynous Peripheral Attachment
APCU	Assembly Power Converter Unit
APE	Antenna Pointing Electronics Audio Pointing Equipment
APFR	Articulating Portable Foot Restraint
APM	Antenna Pointing Mechanism
APS	Automated Payload Switch
APU	Auxillary Power Unit
APV	Automated Procedure Viewer
AR	Atmosphere Revitalization
ARCU	American-to-Russian Converter Unit
ARS	Atmosphere Revitalization System
ASW	Application Software
ATA	Ammonia Tank Assembly

ATCS	Active Thermal Control System
ATO	Abort To Orbit
ATU	Audio Terminal Unit

BAD	Broadcast Ancillary Data
BC	Bus Controller
BCDU	Battery Charge/Discharge Unit
	Berthing Mechanism Control and Display Unit
BEP	Berthing Mechanism Electronics Package
BGA	Beta Gimbal Assembly
BIC	Bus Interface Controller
BIT	Built-In Test
BM	Berthing Mechanism
BOS	BIC Operations Software
BSM	Booster Separation Motors
BSS	Basic Software
BSTS	Basic Standard Support Software

C&C	Command and Control
C&DH	Command and Data Handling
C&T	Communication and Tracking
C&W	Caution and Warning
C/L	Crew Lock
C/O	Checkout
CAM	Collision Avoidance Maneuver
CAPE	Canister for All Payload Ejections
CAPPS	Checkout, Assembly and Payload Processing Services
CAS	Common Attach System
CB	Control Bus
CBCS	Centerline Berthing Camera System
CBM	Common Berthing Mechanism
CCA	Circuit Card Assembly
CCAA	Common Cabin Air Assembly
CCHA	Crew Communication Headset Assembly
CCP	Camera Control Panel
CCT	Communication Configuration Table
CCTV	Closed-Circuit Television
CDF	Confined Detonator Fuse
CDR	Space Shuttle Commander
CDRA	Carbon Dioxide Removal Assembly
CETA	Crew Equipment Translation Aid
CHeCS	Crew Health Care System

CHX	Cabin Heat Exchanger
CISC	Complicated Instruction Set Computer
CLA	Camera Light Assembly
CLPA	Camera Light Pan Tilt Assembly
CMG	Control Moment Gyro
COTS	Commercial Off the Shelf
CPA	Control Panel Assembly
CPB	Camera Power Box
CR	Change Request
CRT	Cathode-Ray Tube
CSA	Canadian Space Agency
CSA-CP	Compound Specific Analyzer
CTC	Cargo Transport Container
CVIU	Common Video Interface Unit
CVT	Current Value Table
CZ	Communication Zone

DB	Data Book
DC	Docking Compartment
DCSU	Direct Current Switching Unit
DDCU	DC-to-DC Converter Unit
DEM	Demodulator
DFL	Decommutation Format Load
DIU	Data Interface Unit
DMS	Data Management System
DMS-R	Data Management System-Russian
DPG	Differential Pressure Gauge
DPU	Baseband Data Processing Unit
DRTS	Japanese Data Relay Satellite
DYF	Display Frame

E/L	Equipment Lock
EATCS	External Active Thermal Control System
EBCS	External Berthing Camera System
ECAL	Electromagnetic Calorimeter
ECC	Error Correction Code
ECLSS	Environmental Control and Life Support System
ECO	Engine Cutoff
ECS	Environmental Control System
ECU	Electronic Control Unit
EDSU	External Data Storage Unit
EDU	EEU Driver Unit

EE	End Effector
EETCS	Early External Thermal Control System
EEU	Experiment Exchange Unit
EF	Exposed Facility
EFBM	Exposed Facility Berthing Mechanism
EFHX	Exposed Facility Heat Exchanger
EFGF	TBD (Mission Objectives, 2nd pg)
EFU	Exposed Facility Unit
EGIL	Electrical, General Instrumentation, and Lighting
EIU	Ethernet Interface Unit
ELC	ExPRESS Logistics Carrier
ELM-ES	Japanese Experiment Logistics Module – Exposed Section
ELM-PS	Japanese Experiment Logistics Module – Pressurized Section
ELPS	Emergency Lighting Power Supply
EMGF	Electric Mechanical Grapple Fixture
EMI	Electro-Magnetic Imaging
EMU	Extravehicular Mobility Unit
E-ORU	EVA Essential ORU
EP	Exposed Pallet
EPS	Electrical Power System
ES	Exposed Section
ESA	European Space Agency
ESC	JEF System Controller
ESP	External Stowage Platform
ESW	Extended Support Software
ET	External Tank
ETCS	External Thermal Control System
ETI	Elapsed Time Indicator
ETRS	EVA Temporary Rail Stop
ETVCG	External Television Camera Group
EV	Extravehicular
EVA	Extravehicular Activity
EWC	External Wireless Communication
EXP-D	Experiment-D
EXT	External
FA	Fluid Accumulator
FAS	Flight Application Software
FCT	Flight Control Team
FD	Flight Day
FDDI	Fiber Distributed Data Interface
FDIR	Fault Detection, Isolation, and Recovery

FDS	Fire Detection System
FE	Flight Engineer
FET-SW	Field Effect Transistor Switch
FGB	Functional Cargo Block
FOR	Frame of Reference
FPMU	Floating Potential Measurement Unit
FPP	Fluid Pump Package
FR	Flight Rule
FRAM	Flight Releasable Attachment Mechanism
FRD	Flight Requirements Document
FRGF	Flight Releasable Grapple Fixture
FRM	Functional Redundancy Mode
FSE	Flight Support Equipment
FSEGF	Flight Support Equipment Grapple Fixture
FSM	Fuel Supply Module
FSW	Flight Software
GAS	Get-Away Special
GATOR	Grappling Adaptor to On-orbit Railing
GCA	Ground Control Assist
GLA	General Lighting Assemblies
	General Luminaire Assembly
GLONASS	Global Navigational Satellite System
GNC	Guidance, Navigation, and Control
GPC	General Purpose Computer
GPS	Global Positioning System
GPSR	Global Positioning System Receiver
GUI	Graphical User Interface
H&S	Health and Status
HCE	Heater Control Equipment
HCTL	Heater Controller
HD	High Definition
HEPA	High Efficiency Particulate Acquisition
HGA	High Gain Antenna
HPA	High Power Amplifier
HPGT	High Pressure Gas Tank
HPP	Hard Point Plates
HPU	Hydraulic Power Unit
HRDR	High Rate Data Recorder
HREL	Hold/Release Electronics
HRFM	High Rate Frame Multiplexer

HRM	Hold Release Mechanism
HRMS	High Rate Multiplexer and Switcher
HTV	H-II Transfer Vehicle
HTVCC	HTV Control Center
HTV Prox	HTV Proximity
HX	Heat Exchanger
I/F	Interface
IAA	Intravehicular Antenna Assembly
IAC	Internal Audio Controller
IBM	International Business Machines
ICB	Inner Capture Box
ICC	Integrated Cargo Carrier
ICS	Interorbit Communication System
ICS-EF	Interorbit Communication System – Exposed Facility
IDRD	Increment Definition and Requirements Document
IEA	Integrated Electronic Assembly
IELK	Individual Equipment Liner Kit
IFHX	Interface Heat Exchanger
IMCS	Integrated Mission Control System
IMCU	Image Compressor Unit
IMV	Intermodule Ventilation
INCO	Instrumentation and Communication Officer
IP	International Partner
IP-PCDU	ICS-PM Power Control and Distribution Unit
IP-PDB	Payload Power Distribution Box
ISLE	In-Suit Light Exercise
ISP	International Standard Payload
ISPR	International Standard Payload Rack
ISS	International Space Station
ISSSH	International Space Station Systems Handbook
ITCS	Internal Thermal Control System
ITS	Integrated Truss Segment
IVA	Intravehicular Activity
IVSU	Internal Video Switch Unit
JAXA	Japan Aerospace Exploration Agency
JCP	JEM Control Processor
JEF	JEM Exposed Facility
JEM	Japanese Experiment Module
JEMAL	JEM Airlock
JEM-EF	Japanese Experiment Module Exposed Facility

JEM-PM	Japanese Experiment Module – Pressurized Module
JEMRMS	Japanese Experiment Module Remote Manipulator System
JEUS	Joint Expedited Undocking and Separation
JFCT	Japanese Flight Control Team
JLE	Japanese Experiment Logistics Module – Exposed Section
JLP	Japanese Experiment Logistics Module – Pressurized Section
JLP-EDU	JLP-EFU Driver Unit
JLP-EFU	JLP Exposed Facility Unit
JPM	Japanese Pressurized Module
JPM WS	JEM Pressurized Module Workstation
JSC	Johnson Space Center
JTVE	JEM Television Equipment

Kbp	Kilobit per second
KOS	Keep Out Sphere
KSC	Kennedy Space Center

LB	Local Bus
LCA	LAB Cradle Assembly
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LEE	Latching End Effector
LGA	Low Gain Antenna
LMC	Lightweight MPESS Carrier
LPS	Launch Processing System
LSW	Light Switch
LTA	Launch-to-Activation
LTAB	Launch-to-Activation Box
LTL	Low Temperature Loop

MA	Main Arm
MAUI	Main Analysis of Upper-Atmospheric Injections
Mb	Megabit
Mbps	Megabit per second
MBS	Mobile Base System
MBSU	Main Bus Switching Unit
MCA	Major Constituent Analyzer
MCC	Mission Control Center
MCC-H	Mission Control Center – Houston
MCC-M	Mission Control Center – Moscow
MCDS	Multifunction Cathode-Ray Tube Display System
MCS	Mission Control System

MDA	MacDonald, Dettwiler and Associates Ltd.
MDM	Multiplexer/Demultiplexer
MDP	Management Data Processor
MEC	Master Event
MECO	Main Engine Cutoff
MEDS	Multi-functional Electronic Display System
MELFI	Minus Eighty-Degree Laboratory Freezer for ISS
MGB	Middle Grapple Box
MHTEX	Massive Heat Transfer Experiment
MIP	Mission Integration Plan
MISSE	Materials International Space Station Experiment
MKAM	Minimum Keep Alive Monitor
MLE	Middeck Locker Equivalent
MLI	Multi-layer Insulation
MLM	Multipurpose Laboratory Module
MMOD	Micrometeoroid/Orbital Debris
MOD	Modulator
MON	Television Monitor
MPC	Main Processing Controller
MPESS	Multipurpose Experiment Support Structure
MPEV	Manual Pressure Equalization Valve
MPL	Manipulator Retention Latch
MPLM	Multipurpose Logistics Module
MPM	Manipulator Positioning Mechanism
MPS	Main Propulsion System
MPV	Manual Procedure Viewer
MRM	Mini-Research Module
MSD	Mass Storage Device
MSFC	Marshall Space Flight Center
MSP	Maintenance Switch Panel
MSS	Mobile Servicing System
MT	Mobile Tracker
	Mobile Transporter
MTL	Moderate Temperature Loop
MUX	Data Multiplexer
NASA	National Aeronautics and Space Administration
NCS	Node Control Software
NET	No Earlier Than
NLT	No Less Than
n.mi.	nautical mile
NPRV	Negative Pressure Relief Valve

NSD	NASA Standard Detonator
NSV	Network Service
NTA	Nitrogen Tank Assembly
NTSC	National Television Standard Committee
OAKs	ORU Adapter Kit
OBSS	Orbiter Boom Sensor System
OCA	Orbital Communications Adapter
OCAD	Operational Control Agreement Document
OCAS	Operator Commanded Automatic Sequence
OCRA	Oxygen Recharge Compressor Assembly
ODF	Operations Data File
ODS	Orbiter Docking System
OI	Orbiter Interface
OIU	Orbiter Interface Unit
OMDP	Orbiter Maintenance Down Period
OMM	Orbiter Major Modification
OMS	Orbital Maneuvering System
OODT	Onboard Operation Data Table
ORCA	Oxygen Recharge Compressor Assembly
ORU	Orbital Replacement Unit
OS	Operating System
OSA	Orbiter-based Station Avionics
OSE	Orbital Support Equipment
OTCM	ORU and Tool Changeout Mechanism
OTP	ORU and Tool Platform
P/L	Payload
PAL	Planning and Authorization Letter Protuberance Airload
PAM	Payload Attach Mechanism
PAO	Public Affairs Office
PAS	Payload Adapter System
PBA	Portable Breathing Apparatus
PCA	Pressure Control Assembly
PCBM	Passive Common Berthing Mechanism
PCN	Page Change Notice
PCS	Portable Computer System
PCU	Power Control Unit Plasma Contactor Unit
PDA	Payload Disconnect Assembly
PDB	Power Distribution Box

PDGF	Power and Data Grapple Fixture
PDH	Payload Data Handling unit
PDL	Product Development Laboratory
PDRS	Payload Deployment Retrieval System
PDU	Power Distribution Unit
PEC	Passive Experiment Container Payload Experiment Carrier
PEHG	Payload Ethernet Hub Gateway
PFAP	PFRAM Adapter Plate Assembly
PFE	Portable Fire Extinguisher
PFRAM	Passive Flight Releasable Attachment Mechanism
PGSC	Payload General Support Computer
PIB	Power Interface Box
PIC	Pyrotechnic Initiator Controller
PIU	Payload Interface Unit
PLB	Payload Bay
PLBD	Payload Bay Door
PLC	Pressurized Logistics Carrier
PLT	Payload Laptop Terminal Space Shuttle Pilot
PM	Pressurized Module Pump Module
PMA	Pressurized Mating Adapter
PMCU	Power Management Control Unit
PMM	Pressurized Multipurpose Module
PMU	Pressurized Mating Adapter
POA	Payload ORU Accommodation
POR	Point of Resolution
PPRV	Positive Pressure Relief Valve
PRCS	Primary Reaction Control System
PREX	Procedure Executor
PRLA	Payload Retention Latch Assembly
PROX	Proximity Communications Center
psia	Pounds per Square Inch Absolute
PSP	Payload Signal Processor
PSRR	Pressurized Section Resupply Rack
PTCS	Passive Thermal Control System
PTR	Port Thermal Radiator
PTU	Pan/Tilt Unit
PVCU	Photovoltaic Controller Unit
PVM	Photovoltaic Module

PVR	Photovoltaic Radiator
PVTCS	Photovoltaic Module Thermal Control System
	Photovoltaic Thermal Control System
QD	Quick Disconnect
R&MA	Restraint and Mobility Aid
RACU	Russian-to-American Converter Unit
RAM	Read Access Memory
RBVM	Radiator Beam Valve Module
RCC	Range Control Center
	Reinforced Carbon-Carbon
RCT	Rack Configuration Table
RF	Radio Frequency
RFG	Radio Frequency Group
RGA	Rate Gyro Assemblies
RHC	Rotational Hand Controller
RICH	Ring Imaging Cherenkov
RIGEX	Rigidizable Inflatable Get-Away Special Experiment
RIP	Remote Interface Panel
RLF	Robotic Language File
RLT	Robotic Laptop Terminal
RMS	Remote Manipulator System
ROEU	Remotely Operated Electrical Umbilical
ROM	Read Only Memory
R-ORU	Robotics Compatible Orbital Replacement Unit
ROS	Russian Orbital Segment
RPC	Remote Power Controller
RPCM	Remote Power Controller Module
RPDA	Remote Power Distribution Assembly
RPM	Roll Pitch Maneuver
RS	Russian Segment
RSLS	Redundant Set Launch Sequencer
RSP	Return Stowage Platform
RSR	Resupply Stowage Rack
RSS	Range Safety System
RT	Remote Terminal
R2	Robonaut 2
RTAS	Rocketdyne Truss Attachment System
RVFS	Rendezvous Flight Software
RWS	Robotics Workstation

SAFER	Simplified Aid for EVA Rescue
SAM	SFA Airlock Attachment Mechanism
SAPA	Small Adapter Plate Assembly
SARJ	Solar Alpha Rotary Joint
SASA	S-Band Antenna Sub-Assembly
SCU	Sync and Control Unit
SD	Smoke Detector
SDS	Sample Distribution System
SEDA	Space Environment Data Acquisition equipment
SEDA-AP	Space Environment Data Acquisition equipment – Attached Payload
SELS	SpaceOps Electronic Library System
SEU	Single Event Upset
SFA	Small Fine Arm
SFAE	SFA Electronics
SI	Smoke Indicator
SLM	Structural Latch Mechanism
SLP-D	Spacelab Pallet – D
SLP-D1	Spacelab Pallet – Deployable
SLP-D2	Spacelab Pallet – D2
SLT	Station Laptop Terminal System Laptop Terminal
SLWT	Super Lightweight External Tank
SM	Service Module
SMDP	Service Module Debris Panel
SOC	System Operation Control
SODF	Space Operations Data File
SOFI	Spray-On-Foam-Insulation
SPA	Small Payload Attachment
SPB	Survival Power Distribution Box
SPDA	Secondary Power Distribution Assembly
SPDM	Special Purpose Dexterous Manipulator
SPEC	Specialist
SRAM	Static RAM
SRB	Solid Rocket Booster
SRMS	Shuttle Remote Manipulator System
SSAS	Segment-to-Segment Attach System
SSC	Station Support Computer
SSCB	Space Station Control Board
SSE	Small Fine Arm Storage Equipment
SSIPC	Space Station Integration and Promotion Center
SSME	Space Shuttle Main Engine

SSOR	Space-to-Space Orbiter Radio
SSP	Stan-dard Switch Panel
SSPTS	Station-to-Shuttle Power Transfer System
SSRMS	Space Station Remote Manipulator System
STC	Small Fire Arm Transportation Container
STORRM	Sensor Test for Orion Relative Navigation Risk Mitigation
STP-H3	Space Test Program – Houston 3
STR	Starboard Thermal Radiator
STS	Space Transfer System
STVC	SFA Television Camera
SVS	Space Vision System

TA	Thruster Assist
TAC	TCS Assembly Controller
TAC-M	TCS Assembly Controller - M
TAL	Transoceanic Abort Landing
TCA	Thermal Control System Assembly
TCB	Total Capture Box
TCCS	Trace Contaminant Control System
TCCV	Temperature Control and Check Valve
TCS	Thermal Control System
TCV	Temperature Control Valve
TDK	Transportation Device Kit
TDRS	Tracking Data and Relay Satellite
THA	Tool Holder Assembly
THC	Temperature and Humidity Control Translational Hand Controller
THCU	Temperature and Humidity Control Unit
TIU	Thermal Interface Unit
TKSC	Tsukuba Space Center (Japan)
TLM	Telemetry
TMA	Russian vehicle designation
TMR	Triple Modular Redundancy
ToF	Time-of-Flight
TPL	Transfer Priority List
TPS	Thermal Protection System
TRD	Transition Radiation Detector
TRRJ	Thermal Radiator Rotary Joint
TUS	Trailing Umbilical System
TVC	Television Camera Thrust Vector Control

UCCAS	Unpressurized Cargo Carrier Attach System
UCM	Umbilical Connect Mechanism
UCM-E	UCM – Exposed Section Half
UCM-P	UCM – Payload Half
UHF	Ultrahigh Frequency
UIL	User Interface Language
ULC	Unpressurized Logistics Carrier
UMA	Umbilical Mating Adapter
UOP	Utility Outlet Panel
UPC	Up Converter
USA	United Space Alliance
US LAB	United States Laboratory
USOS	United States On-Orbit Segment
UTA	Utility Transfer Assembly
VAJ	Vacuum Access Jumper
VBSP	Video Baseband Signal Processor
VCU	Video Control Unit
VDS	Video Distribution System
VLU	Video Light Unit
VNS	Vision Navigation Sensor
VRA	Vent Relief Assembly
VRCS	Vernier Reaction Control System
VRCV	Vent Relief Control Valve
VRIV	Vent Relief Isolation Valve
VSU	Video Switcher Unit
VSW	Video Switcher
WAICO	Waiving and Coiling
WCL	Water Cooling Loop
WETA	Wireless Video System External Transceiver Assembly
WIF	Work Interface
WRM	Water Recovery and Management
WRS	Water Recovery System
WS	Water Separator Work Site Work Station
WVA	Water Vent Assembly
ZSR	Zero-g Stowage Rack

MEDIA ASSISTANCE

NASA TELEVISION AND INTERNET

The digital NASA Television system provides higher quality images and better use of satellite bandwidth, meaning multiple channels from multiple NASA program sources at the same time.

Digital NASA TV has the following four digital channels:

1. NASA Public Channel (“Free to Air”), featuring documentaries, archival programming, and coverage of NASA missions and events.
2. NASA Education Channel (“Free to Air/Addressable”), dedicated to providing educational programming to schools, educational institutions and museums.
3. NASA Media Channel (“Addressable”), for broadcast news organizations.
4. NASA Mission Channel (Internal Only), provides high-definition imagery from science and human spaceflight missions and special events.

Digital NASA TV channels may not always have programming on every channel simultaneously.

NASA Television Now in High Definition

NASA TV now has a full-time High Definition (HD) Channel available at no cost to cable and satellite service providers. Live coverage of space shuttle missions; on-orbit video of Earth captured by astronauts aboard the International Space Station; and rocket launches of advanced scientific spacecraft are among the programming offered on NASA HD. Also available are imagery from NASA’s vast array of space satellites, as well as media briefings, presentations by expert lecturers, astronaut interviews and other special events, all in the improved detail and clarity of HD.

Getting NASA TV via satellite (AMC3 Transponder 15C)

In continental North America, Alaska and Hawaii, NASA Television’s Public, Education, Media and HD channels are MPEG-2 digital C-band signals carried by QPSK/DVB-S modulation on satellite AMC-3, transponder 15C, at 87 degrees west longitude. Downlink frequency is 4000 MHz, horizontal polarization, with a data rate of 38.86 Mhz, symbol rate of 28.1115 Ms/s, and 3/4 FEC. A Digital Video Broadcast (DVB) compliant Integrated Receiver Decoder (IRD) is needed for reception.

Effective Sept. 1, 2010, NASA TV changed the primary audio configuration for each of its four channels to AC-3, making each channel’s secondary audio MPEG 1 Layer II.

For NASA TV downlink information, schedules and links to streaming video, visit http://www.nasa.gov/ntv

Television Schedule

A schedule of key mission events and media briefings during the mission will be detailed in a NASA TV schedule posted at the link above. The schedule will be updated as necessary and will also be available at http://www.nasa.gov/multimedia/nasatv/mission_schedule.html

Status Reports

Status reports and timely updates on launch countdown, mission progress, and landing operations will be posted at: http://www.nasa.gov/shuttle

Internet Information

Information on NASA and its programs is available through the NASA Home Page and the NASA Public Affairs Home Page:
http://www.nasa.gov
or
http://www.nasa.gov/newsinfo/index.html

Information on the International Space Station is available at: http://www.nasa.gov/station

The NASA Human Space Flight Web contains an up-to-date archive of mission imagery, video and audio at: http://spaceflight.nasa.gov

Resources for educators can be found at: http://education.nasa.gov

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