The CBS News

Space Reporter's Handbook
Mission Supplement

Shuttle Mission STS-131/ISS-19A:
International Space Station Assembly and Resupply

Written and Produced By

William G. Harwood
CBS News Space Analyst
harwoodb@cbsnews.com

Revision History

Editor's Note
Mission-specific sections of the Space Reporter's Handbook are posted as flight data becomes available. Readers should check the CBS News "Space Place" web site in the weeks before a launch to download the latest edition:

http://www.cbsnews.com/network/news/space/current.html

DATE	RELEASE NOTES
04/01/10	Initial STS-131 release

Introduction

This document is an outgrowth of my original UPI Space Reporter's Handbook, prepared prior to STS-26 for United Press International and updated for several flights thereafter due to popular demand. The current version is prepared for CBS News. As with the original, the goal here is to provide useful information on U.S. and Russian space flights so reporters and producers will not be forced to rely on government or industry public affairs officers at times when it might be difficult to get timely responses. All of these data are available elsewhere, of course, but not necessarily in one place.

The STS-131 version of the CBS News Space Reporter's Handbook was compiled from NASA news releases, JSC flight plans, the Shuttle Flight Data and In-Flight Anomaly List, NASA Public Affairs and the Flight Dynamics office (abort boundaries) at the Johnson Space Center in Houston. Sections of NASA's STS-131 press kit, crew bios and the mission TV schedule are downloaded via the Internet, formatted and included in this document. Word-for-word passages (other than lists) are clearly indicated.

The SRH is a work in progress and while every effort is made to insure accuracy, errors are inevitable in a document of this nature and readers should double check critical data before publication. As always, questions, comments and suggestions for improvements are always welcome. And if you spot a mistake or a typo, please let me know!

Written, Compiled and Edited By

William G. Harwood
CBS News Space Consultant
LC-39 Press Site
Kennedy Space Center, Florida 32899

bharwood@earthlink.net

Table of Contents

NASA Media Information

NASA Television Transmission

NASA Television is now carried on an MPEG-2 digital signal accessed via satellite AMC-6, at 72 degrees west longitude, transponder 17C, 4040 MHz, vertical polarization. A Digital Video Broadcast (DVB) - compliant Integrated Receiver Decoder (IRD) with modulation of QPSK/DBV, data rate of 36.86 and FEC 3/4 is needed for reception. NASA TV Multichannel Broadcast includes: Public Services Channel (Channel 101); the Education Channel (Channel 102) and the Media Services Channel (Channel 103).

The new Digital NASA TV will have four digital channels:

1. NASA Public Service ("Free to Air"), featuring documentaries, archival programming, and coverage of NASA missions and events;
2. NASA Education Services ("Free to Air/Addressable"), dedicated to providing educational programming to schools, educational institutions and museums;
3. NASA Media Services ("Addressable"), for broadcast news organizations; and
4. NASA Mission Operations (Internal Only)

The new digital NASA Public Service Channel will be streamed on the Web. All you'll need is access to a computer. You may want to check with your local cable or satellite service provider whether it plans to continue carrying the NASA Public Service "Free to Air" Channel. If your C-Band-sized satellite dish is capable of receiving digital television signals, you'll still need a Digital Video Broadcast (DVB)-compliant MPEG-2 Integrated Receiver Decoder, or IRD, to get the new Digital NASA's Public Service "Free to Air" Channel.

An IRD that receives "Free to Air" programming like the new Digital NASA Public Service Channel can be purchased from many sources, including "off-the-shelf" at your local electronics store.

The new Digital NASA TV will be on the same satellite (AMC 6) as current analog NASA TV, but on a different transponder (17). In Alaska and Hawaii, we'll be on AMC 7, Transponder 18.

Satellite Downlink for continental North America: Uplink provider = Americom
Satellite = AMC 6
Transponder = 17C
72 Degrees West
Downlink frequency: 4040 Mhz
Polarity: Vertical
FEC = 3/4
Data Rate r= 36.860 Mhz Symbol = 26.665 Ms
Transmission = DVB

"Public" Programming: Program = 101, Video PID = 111, Audio PID = 114
"Education" Programming: Program = 102, Video PID = 121, Audio PID = 124
"Media" Programming = Program = 103, Video PID = 1031, Audio PID = 1034
"SOMD" Programming = Program = 104, Video PID = 1041, Audio PID = 1044

Home Page:	http://www.nasa.gov/multimedia/nasatv/index.html
Daily Programming:	http://www.nasa.gov/multimedia/nasatv/MM_NTV_Breaking.html
Videofile Programming:	ftp://ftp.hq.nasa.gov/pub/pao/tv-advisory/nasa-tv.txt
NTV on the Internet:	http://www.nasa.gov/multimedia/nasatv/MM_NTV_Web.html

NASA Public Affairs Contacts

Kennedy Space Center	321-867-2468 (voice) 321-867-2692 (fax) 321-867-2525 (code-a-phone)
Johnson Space Center	281-483-5811 (voice) 281-483-2000 (fax) 281-483-8600 (code-a-phone)
Marshall Space Flight Center	256-544-0034 (voice) 256-544-5852 (fax) 256-544-6397 (code-a-phone).

❑ ❑ ❑

STS-131: Internet Pages of Interest

CBS Shuttle Statistics	http://www.cbsnews.com/network/news/space/spacestats.html
CBS Current Mission Page	http://www.cbsnews.com/network/news/space/current.html
CBS Challenger/Columbia Page	http://www.cbsnews.com/network/news/space/SRH_Disasters.htm
NASA Shuttle Home Page	http://spaceflight.nasa.gov/shuttle/
NASA Station Home Page	http://spaceflight.nasa.gov/station/
NASA News Releases	http://spaceflight.nasa.gov/spacenews/index.html
KSC Status Reports	http://www-pao.ksc.nasa.gov/kscpao/status/stsstat/current.htm
JSC Status Reports	http://spaceflight.nasa.gov/spacenews/reports/index.html
STS-131 NASA Press Kit	http://www.shuttlepresskit.com/
STS-131 Imagery	http://spaceflight.nasa.gov/gallery/images/shuttle/STS-131/ndxpage1.html
STS-131 Home Page	http://www.nasa.gov/mission_pages/shuttle/main/index.html
Spaceflight Meteorology Group	http://www.srh.noaa.gov/smg/smgwx.htm
Hurricane Center	http://www.nhc.noaa.gov/index.shtml
Melbourne, Fla., Weather	http://www.srh.noaa.gov/mlb/
Entry Groundtracks	http://spaceflight.nasa.gov/realdata/index.html
KSC Video	http://science.ksc.nasa.gov/shuttle/countdown/video/
ELV Video	http://countdown.ksc.nasa.gov/elv/elv.html
Comprehensive TV/Audio Links	http://www.idb.com.au/dcottle/pages/nasatv.html

THIS PAGE INTENTIONALLY BLANK

CBS News: STS-131 Mission Preview

Shuttle Discovery poised for launch to deliver science gear and supplies to the International Space Station

By WILLIAM HARWOOD
CBS News Space Consultant

KENNEDY SPACE CENTER, Fla. -- The shuttle Discovery, carrying a crew of seven and 10 tons of supplies and equipment bound for the International Space Station, is poised for blastoff April 5 on a three-spacewalk mission to deliver ammonia coolant, experiment hardware, a darkroom, a crew hygiene station and an experiment sample freezer.

The Discovery astronauts also plan to deliver spare parts for the station's water recycling system in an ongoing effort to work the bugs out of the complex life support equipment before the shuttle's retirement later this year.

The STS-131 crew (left to right): Rick Mastracchio, Stephanie Wilson, pilot James Dutton, Dottie Metcalf-Lindenburger, commander Alan Poindexter, Naoko Yamazaki, and Clayton Anderson.

"We didn't really know how to design this hardware at the beginning," said Bill Gerstenmaier, NASA's chief of space operations. "We did as good as we could and now we're actually working those bugs out. This is important for us to have the shuttle around for these couple of flights so we can get the water systems and the life support systems up and operating."

Mission managers cleared Discovery for launch after deciding a failed helium isolation valve in the ship's right-side aft rocket pod posed no significant threat to crew safety or meeting the flight's objectives. Likewise, a review showed suspect ceramic inserts around critical bolts were unlikely to shake free and pose an impact threat during launch or re-entry.

With Discovery ready to go, spacewalker Clay Anderson, veteran of a long-duration stay aboard the station in 2007, said the crew was anxious to get on with a complex mission.

"The biggest objective is to bring the multi-purpose logistics module, the MPLM, and attach it to the station so that we can empty it," he said. "The MPLM has all sorts of cargo and supplies, experiments, racks, food, clothing. We need to get all that stuff onto the station (to make) it easier for them to sustain themselves over time.

"Then the second really big task that we have are the EVAs, the spacewalks that Rick Mastracchio and I will do. The main point of those is to replace a couple key pieces of hardware, the ammonia tank assembly on the outside of the station and then a rate gyro assembly that helps the station understand what its attitude is."

The space station is equipped with two independent coolant loops that dissipate the heat generated by the lab's electrical systems by circulating ammonia coolant through large radiator panels.

"It’s like Freon in your air conditioner at home but we use ammonia on the outside of the station," Anderson said. "So we have a huge tank, it's about (1,700) pounds. It's probably the size of a double refrigerator-freezer component and it lives on the backside toward the center of the station and there are actually two, one on the right and one on the left. The one on the left has recently been changed out by another shuttle crew. So we're going to change the one on the right."

Discovery's launching continues an extremely busy period in the life of the space station, coming three days after the planned launch of a Russian Soyuz capsule from Kazakhstan carrying three fresh crew members - cosmonauts Alexander Skvortsov, Mikhail Kornienko and NASA astronaut Tracy Caldwell Dyson.

If all goes well, the Soyuz TMA-18 spacecraft will dock with the station April 4 and its crew will join Expedition 23 commander Oleg Kotov, Japanese astronaut Soichi Noguchi and NASA flight engineer Timothy Creamer. The expanded Expedition 23 crew will, in turn, welcome the Discovery astronauts to the lab complex two days after the shuttle's launching.

"It really brings out the essence of our International Space Station and our program that we could have a shuttle and a Soyuz launching within days of each other, and how we can integrate and add to the already complex nature of what we do and the business we're in," Dyson said before launch.

With the shuttle program facing retirement later this year after a final four missions, the space station program is racing the clock to complete the outpost and stock it with supplies and spare parts before the heavy lift orbiter is grounded for good.

Kirk Shireman, deputy manager of the space station program at the Johnson Space Center in Houston, said that along with the final four shuttle missions, the program expects three more Soyuz crew launches this year, four Soyuz landings, six launches of unmanned Progress supply ships, launch of a European Space Agency Automated Transfer Vehicle resupply mission and six station-based spacewalks above and beyond the EVAs planned by visiting shuttle crews.

"So you can see, it's a busy time," he said. "The program focus is turning away from assembly. We're looking forward to fully utilizing ISS and extending the International Space Station to 2020. We'll have a very busy year and we're very much looking forward to it."

Discovery's liftoff from pad 39A at the Kennedy Space Center is targeted for 6:21:23 a.m. EDT on April 5, roughly the moment Earth's rotation carries the shuttle into the plane of the space station's orbit. The shuttle has enough power to launch five minutes to either side of that "in-plane" moment but NASA typically targets the middle of the 10-minute window to maximize ascent performance.

Joining shuttle veteran Alan Poindexter, the commander, on Discovery's flight deck will be rookie pilot James Dutton, veteran spacewalker Mastracchio and flight engineer Dorothy Metcalf-Lindenburger, a former high school teacher and astronomy enthusiast making her first flight.

Seated on the shuttle's lower deck will be shuttle veteran Stephanie Wilson, Japanese astronaut Naoko Yamazaki, making her first flight, and Anderson.

Assuming an on-time liftoff, Poindexter will guide Discovery to a docking at the space station's forward port around 3:44 a.m. on April 7. Late that evening, the Leonardo multi-purpose logistics module, loaded with 8.5 tons of supplies and equipment, will be pulled from the shuttle's cargo bay and attached to the space station's Unity module just after midnight.

The next day, Mastracchio and Anderson will stage the first of three spacewalks needed to install the ammonia coolant tank on the space station's main power truss. A spent ammonia tank will be removed and placed back in the shuttle's cargo bay for return to Earth and relaunch later this year.

Discovery is scheduled to undock from the station around 3:55 a.m. on April 16, setting up a landing back at the Kennedy Space Center around 8:29 a.m. on April 18.

The daylight landing time is the result of a recent decision to switch from a southwest-to-northeast "ascending node" re-entry trajectory, one that carries a Florida-bound shuttle over the Pacific Ocean, Central America and the Caribbean, to one that will carry Discovery from northwest to southeast over the heartland of America.

This will be only the second such "descending node" entry since the Columbia disaster. Shuttle Program Manager John Shannon said the change was ordered to give the crew more time to complete the required supply transfers and to move the landing from darkness to daylight. He said the shuttle would not fly over any population centers on its way down and that a NASA analysis showed the risk to the public was minimal.

"Post Columbia, we were very deliberate in trying to determine risks to people on the ground if we had a vehicle break up," he said. "We did some extensive modeling of what debris envelopes would be created for different vehicle breakups. It's a difficult thing to talk about, but it's important work we do.

"You take a look at the ground track of the vehicle and you look at the different debris footprints for breakups at different altitudes and then you sum all that together and you come up with a certain risk to the population. What we have done here is take a very close look and make sure the descending node opportunities, which will go over the United States, do not put any major population areas at risk and that our general population risk is below those limits that were set."

By switching to a descending node entry, "the significant advantage you get for the crew timeline really said this was the way to go," Shannon said.

The return route will be familiar to Wilson and Anderson. They were part of the STS-120 crew that flew the only other post-Columbia descending node entry in November 2007.

While only four more shuttle flights are officially on the books, scheduled for launch April 5, May 14, July 29 and Sept. 16, NASA managers are holding out hope that a fifth mission will be added to the manifest, a flight that would use the external tank and boosters set aside for an emergency rescue mission in case of problems with the last currently planned flight.

Launching a fifth mission with a crew of four, NASA could rely on the space station and Russian Soyuz ferry craft to provide emergency return capability, eliminating the need for a dedicated shuttle rescue flight.

President Barack Obama plans to visit the Kennedy Space Center during Discovery's mission to discuss the shuttle program's looming retirement, projected job losses and his administration's proposed cancellation of NASA's Constellation moon program.

If the administration ultimately supports an additional shuttle flight, as urged by Sen. Bill Nelson, D-Fla., and other lawmakers, NASA officials believe all five flights could be completed before the end of the calendar year. But a decision is needed by late April, officials say, for crew selection, training and flight planning.

A BUSY MISSION FOR DISCOVERY'S CREW

The initial stages of Discovery's mission will follow NASA's post-Columbia template, designed to make sure any damage to the shuttle's fragile heat shield is spotted and fully assessed.

Following launch, the astronauts will beam down digital pictures and video of the shuttle's external tank to help engineers determine the health of the foam insulation on the ship's external tank.

That imagery, combined with footage shot from the ground and a camera mounted on the side of the huge fuel tank will show whether any insulation or other debris fell away during launch and impacted Discovery's heat shield tiles or the reinforced carbon carbon wing leading edge panels that experience the most extreme heating during re-entry.

On the second day of the mission, the astronauts will unlimber Discovery's robot arm and attach a 50-foot-long extension equipped with a laser scanner and camera. Using the orbiter boom sensor system, or OBSS, the crew will scan the leading edge panels on both wings and the RCC nose cap to look for any signs of impact damage.

Anderson and Mastracchio, meanwhile, will test their spacesuits and the tools they plan to use during their upcoming spacewalks while Poindexter and Dutton carry out two rocket firings to fine-tune the shuttle's path to the space station.

Approaching the lab complex from behind on flight day three, Poindexter will guide Discovery to a point about 600 feet directly below the station. Once on station, he will execute a 360-degree rendezvous pitch maneuver, or RPM, rotating the shuttle through a complete back flip to expose the ship's belly to the station crew.

Using digital cameras with 400 mm and 800 mm lenses, Kotov and Creamer will photograph the underside of the orbiter to look for any signs of damage. They also will photograph the shuttle's upper surfaces and downlink the imagery to Houston for detailed analysis.

From there, Poindexter will manually guide Discovery up to a point about 400 feet directly in front of the space station with the shuttle's nose pointed toward deep space and its open payload bay facing a docking port on the forward end of the Harmony module.

"We wake up in the morning of rendezvous day and get right to work setting up our tools and making sure that we have all the equipment we need for the rendezvous," Poindexter said. "The folks on the ground have been working hard up to this point to get us to the right point to execute the rendezvous. We do a series of burns or maneuvers to bring the shuttle up underneath the space station at about 1,000 feet.

"We fly directly below the station to a distance of about 600 feet and from there we'll execute the rendezvous pitch maneuver, which allows the space station crew to image the orbiter's thermal protection system with some high-powered cameras. We'll then manually fly the shuttle up in front of the station to a distance of about 400 and then slowly back it into the space station's docking port. That's all done manually from the aft cockpit and I've got a lot of help on the flight deck with some real professional crew members who are doing most of the hard work."

After leak checks, hatches between Discovery and the station will be opened and Kotov and his crewmates will welcome Poindexter and company on board. It will be a reunion of sorts for Wilson, Anderson, Dyson and Mastracchio, who all flew together on previous shuttle/station missions.

Discovery at launch complex 39A

"I think it rocks, I'm really excited," Dyson said before launch. "These are some great friends of mine on the shuttle, I've flown with some of them, I've trained with some of them and I've shared a lot of dinners and good times with these folks. And I'm delighted for them and just ecstatic that the timing worked out for us to be in space together."

After a short safety briefing, the combined crews will get to work, transferring the spacesuits needed by Anderson and Mastracchio to the station's Quest airlock module and using the lab's robot arm to pull the OBSS out of the shuttle's cargo bay. The station arm will hand the OBSS off to the shuttle's robot arm for a possible "focused" inspection later, if any signs of heat shield damage are spotted.

The next day - flight day four - Wilson and Dutton will use the station's robot arm to pull the Leonardo MPLM out of Discovery's cargo bay so it can be attached to the Unity module's Earth-facing, or nadir, port. Loaded with cargo, the module weighs 27,274 pounds, including the 9,632-pound weight of the MPLM itself.

After a break for lunch, the astronauts will prepare the vestibule between Unity and Leonardo, open hatches and enter the cargo module for the first time. Mastracchio and Anderson, meanwhile, will close out the day by spending the night in the Quest airlock module at a reduced pressure of 10.2 pounds per square inch.

The so-called "campout" procedure helps spacewalkers purge nitrogen from their bloodstreams and prevent the bends after working in NASA's 5-psi spacesuits.

Assuming an on-time launch, the mission's first spacewalk will begin around 1:40 a.m. on April 9. It will take three excursions to move the new ammonia tank into position, remove the old tank, plumb the new assembly in its place and then move the old tank back to the shuttle.

"I think the biggest challenge of every EVA of this magnitude is the integration of the robotics and the EVA guys," Mastracchio said. "It's a real team effort. Inside, we'll have Stephanie and Jim working the arm, we'll have Dottie calling the shots as (spacewalk coordinator) and then Clay and I outside. And of course, we're working closely with the ground.

"The real challenge here is this ammonia tank that we're moving is taking three EVAs, or part of three EVAs, to get it done. Our first EVA, we'll remove the new ammonia tank from the shuttle and get it onto the station (where) we'll temp stow it. The second EVA, we'll actually swap the two ammonia tanks, the new one for the old one and then on the third EVA, we'll be moving the old tank from the space station into the space shuttle's payload bay for return. That's the biggest challenge. Between each EVA, we'll have to move the robotic arm, it has to walk off to a new work site. So there's a lot of teamwork and a lot of integration involved."

During Anderson's 2007 stay aboard the station, he participated in a spacewalk with Mastracchio during a July shuttle assembly mission.

"Rick and I are very familiar with each other," Anderson said. "We have a lot of hours of pool time together, we understand each other's strengths and weaknesses and we really enjoy working together. I think that in and of itself bodes well for what we're going to do on these three EVAs."

During the first spacewalk, Anderson and Mastracchio will disconnect ammonia and nitrogen pressurization lines from the old tank, then move to the shuttle's cargo bay where they will detach the new ammonia tank assembly from its mount and hand it off to the station's robot arm.

Wilson and Dutton, operating the space arm, will move the new ATA to a temporary mounting point on the crane's mobile base. While that is going on, the spacewalkers will install a replacement rate gyro assembly and then move to the far left end of the station's solar power truss to loosen bolts holding a massive battery pack in place. The batteries will be replaced on an upcoming shuttle flight.

"What I'll look forward to the most on these EVAs, we'll actually be crawling out to the farthest reaches of the station on the left side to do some work on some batteries out there," Anderson told CBS News. "Plus, Rick gets to go out to the Japanese Exposed Facility and do some work and then I'll be on the other side on the Columbus module doing some work and I've never seen those views.

"When I was up there and did my spacewalks before, it was a totally different configuration, so I'm really looking forward to being out on the edge, if you will, and seeing the views that we have and taking some pictures and just having a little bit of fun."

While Anderson and Mastracchio are working outside, the astronauts inside the station will be working to unload the Leonardo MPLM. Among the items scheduled for transfer during the spacewalk are the minus 80-degree experiment sample freezer, known by the acronym MELFI, and a new crew cabin, the fourth and final U.S. cabin to be moved to the station.

NASA's original plan was to equip the sleep station with a curtain-like liner to turn it into a bathing and hygiene cabinet.

"It's a space shower," Shireman said. "We don't really take showers on board the ISS, but people need to bathe and shampoo their hair and because it can release free water, we like to do it in a place that won't allow the water to float and get into avionics, electrical equipment, that can cause damage.

"So we actually put a liner in there. It's not as simple as you would think. It's not just a shower curtain, it's a little more complicated than that. But it's a station with privacy where the crew members can go and clean up. A very important thing from a health standpoint and also a psychological standpoint."

But with the arrival of the Soyuz TMA-18 spacecraft, the Expedition 23 crew will include three Russians. The Russian segment of the station only has two crew sleep stations and a third will not be available until 2012 when a new Russian lab module is launched. NASA may let the Russians use the new U.S. crew cabin as needed until then and instead use the toilet compartment in the Tranquility module as a hygiene station.

The International Space Station

Following the first spacewalk, the astronauts will spend flight day six moving supplies and equipment out of the MPLM and into the station, including an experiment rack and the Window Observational Research Facility, or WORF. The WORF rack will be installed in a bay in the U.S. Destiny lab module that features a high-quality window. Along with limiting stray light, the facility will provide attachment points for various still and video cameras, as well as other optical instruments, for enhanced Earth observations.

The next day, after another airlock campout, Anderson and Mastracchio will devote flight day seven to their second spacewalk. After unbolting the old ammonia tank assembly, Wilson and Dutton will move it to a crew equipment cart on the front side of the station's main power truss and the spacewalkers will secure it with tethers.

The arm then will move to the new ATA, grapple it and move it into position for installation in the power truss. Manually maneuvering the massive tank, the astronauts will move it into place, install four bolts and reconnect the ammonia and nitrogen pressurization lines.

"During each of the EVAS, we have to hold the ATA, this ammonia tank, up over our heads," Mastracchio said. "It's about an 1,800-pound tank, I think. Clay's going to do it on EVA 1 then I do it on EVA 2. We're going to be holding this tank over our heads, trying to control it while Jim and Stephanie come in and grapple it. So I'm a little concerned about trying to have the stability to hold that tank nice and firm and steady ... so they can come in and grapple it."

With the new tank in place, Mastracchio and Anderson will move to the front side of the truss, untether the old tank and hand it off to the robot arm. The old tank will be temporarily mounted on the mobile base station where the new tank was stowed after its initial removal from the shuttle's cargo bay.

The next day - flight day eight - the combined crews will enjoy a half day of off duty time, after which they will continue with MPLM unloading. Along with moving muscle atrophy experiment hardware into the station, they also will install a panel in the new seven-window cupola to fix a clearance problem that has prevented installation of a robotics work station.

The cupola, attached during a February shuttle mission as part of the new Tranquility module, will provide robot arm operators with panoramic, line-of-sight views to approaching cargo ships and work sites around the station.

Flight day nine will be devoted to the third spacwewalk and completing the ammonia tank transfer tasks. The robot arm will carry the depleted tank from its temporary storage point on the mobile base station to the back of Discovery's cargo bay where Mastracchio and Anderson will bolt it in place for the return to Earth.

With the old tank secure, Anderson, his feet anchored to the end of the robot arm, will be moved to the outboard side of the European Columbus module to retrieve an experiment mounting plate assembly. He and Mastracchio will mount the plate in the shuttle's cargo bay. Anderson then will move to the Canadian Special Purpose Dexterous Manipulator robot to install a second camera while Mastracchio replaces a camera light on the Destiny module.

"EVA 3 is kind of a miscellaneous EVA," Anderson said. "We have lots of different tasks we're going to do. Most notably we'll do some work with the Special Purpose Dextrous Manipulator that we like to call DEXTRE. I'll be doing some work on that one. I'll remove some thermal insulation that's been there for a while that needs to go away. I'll take that out and also I will be working on installing a camera that goes onto one of the camera locations and Rick will also be doing some camera work but he'll be doing it in a different place, on the lab module. There's a camera that needs to be fixed. It needs to be removed and replaced and Rick’s going to do that task."

The astronauts will wrap up equipment transfers from the MPLM the following day, hold a traditional in-flight news conference and take another half day off.

Flight day eleven will be devoted to completing the MPLM transfers and deactivating the cargo module. After hatches are closed, motorized bolts will be driven to detach the module from Unity's nadir port and the station's robot arm will move it back to Discovery's cargo bay for the trip home.

After that, the combined crews plan to gather in the Harmony module for one final time to bid each other farewell. Hatches between the spacecraft will be closed at the end of the day and the docking port depressurized.

The next morning, with Dutton at the controls on Discovery's flight deck, Discovery will undock and depart.

"It's the day I'm really looking forward to," Dutton said. "The pilot's big moment of glory is getting to do the fly around of the space station. So we'll undock, back away around 400 to 450 feet in front of the space station and then begin to fly a maneuver over the top in front of the space station, essentially complete a 360-degree arc around the space station.

"Then we'll continue to maneuver to essentially break out of our orbit with the station, so we'll get a real panoramic view. As big as the station is now, I can't really imagine how breathtaking that will be, getting to see it from every perspective. But it's a day I'm really looking forward to."

Leaving the station behind, the shuttle astronauts will use the ship's robot arm and the OBSS one final time to inspect the nose cap and wing leading edge panels to make sure no damage has been incurred since the flight day two inspection earlier in the mission.

Assuming no problems are found, the crew will spend the next day packing up for landing back at the Kennedy Space Center on April 18.

THIS PAGE INTENTIONALLY BLANK

STS-131 Mission Priorities[1]

As with every space shuttle flight, NASA has established a set of mission priorities and defined what is required for minimum and full mission success. The priorities, in order, are:

Category 1:

- ❑ Dock Endeavour to Pressurized Mating Adapter (PMA)-2 and perform mandator
- ❑ Dock flight 19A to pressurized mating adapter (PMA)-2 port and perform mandatory safety briefing for all crew members
- ❑ Berth MPLM to ISS Node 2 nadir
- ❑ R&R depleted S1 ATA with new ATA using SSRMS
- ❑ Transfer mandatory quantities of water from orbiter to ISS per flight 19A TPL
- ❑ Transfer and stow critical items per flight 19A TPL
- ❑ Return MPLM to the orbiter payload bay

Category 2:

- ❑ Transfer and install ISS MPLM racks to the ISS
  - -Muscle atrophy research and exercise system (MARES) to COL1F3
  - -Window observational research facility (WORF) to LAB1D3
  - -Minus eighty-degree LABoratory freezer to ISS (MELFI) - 3 to JPM 1A1
  - -Express Rack (ER) 7 to LAB1P2
  - -Crew quarters 2 to NOD2O5
  - -Zero-g stowage racks (ZSR) to LAB1P4 and JLPA1
- ❑ R&R RGA 1
- ❑ Retrieve MPAC/SEED from the JPM SEDA-AP
- ❑ Stow AGB on FHRC and FGB on P1 or S1 ATA
- ❑ Retrieve airlock mmod shields from ESP-2
- ❑ Retrieve light weight adapter plate assembly (LWAPA) from Columbus and secure to the LMC
- ❑ Perform ISS daily payload status checks as required
- ❑ Perform critical non-recoverable utilization activities.
- ❑ Return 3 ISPs
- ❑ Install STORMM DTO target reflector kit on the PMA-2 docking target
- ❑ Perform ISS high priority maintenance activities

Category 3:

- ❑ Transfer remaining cargo items to the ISS per flight 19A TPL
- ❑ Perform ISS RS preventative maintenance
- ❑ Russian satellite navigation equipment test
- ❑ Perform EVA tasks deemed to fit within the existing EVA timelines
  - -Perform P6 battery preparation tasks for ULF4
  - -Remove SPDM EP1 thermal cover
  - -Install SPDM camera light pan/tilt assembly (CLPA)
  - -CP 13 luminaire R&R
  - -Install the P1 and S1 radiator grapple fixture stowage beams
  - -Relocate WIF extender to support ULF4 EOTP installation

[1] Word for word from the NASA Mission Operations Directorate flight readiness assessment.

- ❑ Perform EVA get-ahead tasks if time permits
  - -Close P1 RBVM thermal bootie
  - -P4/P5 NH3 jumper install
  - -Remove S1 FHRC launch restraint bolts and release P clamps
- ❑ Perform daily middeck activities to support payloads
- ❑ Perform ISS payload research operations tasks
- ❑ Perform tridar SDTO 701 A

Category 4:

- ❑ Perform IVA get-ahead tasks if time permits
  - -Unpack and stow 19A cargo
  - -Install ORCA
- ❑ Shuttle reboost of ISS if mission resources allow and are consistent with ISS trajectory analysis and planning
- ❑ ISS exterior imagery survey during orbiter flyaround after undock
- ❑ Perform sdto 13005-U, ISS structural life validation and extension, during shuttle mated ISS reboost
- ❑ Perform SDTO 13005-U, ISS structural life validation and extention, during 19A orbiter docking (IWIS required)
- ❑ Perform SDTO 13005-U, ISS structural life validation and extension, during 19A orbiter undocking (IWIS highly desired).
- ❑ Perform SDTO 13005-U, ISS structural life validation and extension, during 19A MPLM berthing and unberthing (IWIS required)
- ❑ Perform payload of opportunity operations to support Maui, SEITE, RAMBO-2, and SIMPLEX

NASA STS-131 Mission Overview[2]

As the last round-trip for the Leonardo Multi-Purpose Logistics Module, Discovery's 13-day mission will provide the International Space Station with not only some 8 tons of science equipment and cargo, but also one last opportunity to send a large load of cargo back to the ground.

Leonardo serves as basically a moving van for the space station, allowing the shuttle to, first of all, deliver shipments of equipment and supplies larger than any other vehicle could accommodate, and, second, to return science experiments, unneeded hardware and trash to the ground – all other cargo transfer vehicles burn up in the Earth's atmosphere. And although Leonardo will return to the station once more on the last space shuttle mission later this year, this is scheduled to be its last round trip – Leonardo will remain permanently at the station after STS-133. So while it will deliver one more batch of goods, the cargo returning on STS-131 will be the last that it brings home.

And although there are only four shuttle missions left before the space shuttle fleet is retired, the program is still making some space "firsts" possible. With three female crew members arriving on board Discovery and one already at the station, the STS-131 mission will mark the first time that four women have been in space at one time. And as there is one Japan Aerospace Exploration Agency astronaut on each crew, the mission is also the first time for two JAXA astronauts to be in space at the same time.

Discovery, commanded by spaceflight veteran Alan G. Poindexter, is scheduled to lift off from Kennedy Space Center at 6:21 a.m. EDT on Monday, April 5, and arrive at the orbiting complex early on Wednesday, April 7.

While docked to the station, Discovery's crew will conduct three spacewalks and spend about 100 combined hours moving cargo in and out of Leonardo and the shuttle's middeck. Poindexter, 48, a U.S. Navy captain, served as pilot on STS-122 in 2008. He will be joined on the mission by pilot James P. Dutton Jr., 41, a U.S. Air Force colonel, who will be making his first trip to space. Mission specialists are Rick Mastracchio, 50, who flew on STS-106 and STS-118 in 2000 and 2007, respectively; Dorothy Metcalf-Lindenburger, 34, a former teacher who became an astronaut in 2004; Stephanie Wilson, 43, who flew on STS-121 and STS-120 in 2006 and 2007, respectively; Naoko Yamazaki, 39, a Japan Aerospace Exploration Agency astronaut; and Clayton Anderson, 51, who spent 152 days on the space station as a member of the Expedition 15 crew in 2007, traveling to the station on STS-117 and returning to Earth on STS-120.

The day after launch, Poindexter, Dutton, Metcalf-Lindenburger, Wilson and Yamazaki will take turns from Discovery's aft flight deck maneuvering its robotic arm in the traditional day-long scan of the reinforced carbon-carbon on the leading edges of the shuttle's wings and its nose cap. This initial inspection, using a 50-foot-long robotic arm extension equipped with sensors and lasers, called the Orbiter Boom Sensor System, will provide imagery experts on the ground a close-up look at the orbiter's heat shield following the dynamic liftoff. A follow-up inspection will take place after Discovery undocks from the station.

While the inspection takes place, Mastracchio and Anderson will prepare the spacesuits they will wear for their three spacewalks out of the Quest airlock at the station. Docking preparations will occupy the remainder of the crew's workday.

On the third day of the flight, Discovery will be flown by Poindexter and Dutton on its approach for docking to the station. After a series of jet firings to fine-tune Discovery's path to the complex, the shuttle will arrive at a point about 600 feet directly below the station about an hour before docking. At that time, Poindexter will execute the rendezvous pitch maneuver, a one-degree-per-second rotational "backflip" to enable station crew members to snap

---

[2] Word for word from the NASA STS-131 Press Kit, available on line at: http://www.nasa.gov/mission_pages/shuttle/main/index.html

hundreds of detailed photos of the shuttle's heat shield and other areas of potential interest – another data point for imagery analysts to pore over in determining the health of the shuttle's thermal protection system.

Once the rotation is completed, Poindexter will fly Discovery in front of the station before slowly closing in for a linkup to the forward docking port on the Harmony module. Less than two hours later, hatches will be opened between the two spacecraft and a combined crew of 13 will begin nine days of work.

Discovery's crew will be working with Expedition 23 commander, Russian cosmonaut Oleg Kotov and flight engineers T.J. Creamer and Tracy Caldwell Dyson, both of NASA; Soichi Noguchi, a Japan Aerospace Agency astronaut; and cosmonauts Alexander Skvortsov and Mikhail Kornienko. Anderson and Kotov were Expedition 15 crew members together, and Mastracchio visited during that time as part of the STS-118 mission. After a station safety briefing, Wilson and Yamazaki will operate the station's robotic arm to remove the OBSS from Discovery's cargo bay and hand it off to the shuttle robotic arm being operated by Dutton and Metcalf-Lindenburger. Wilson and Yamazaki will be back at the controls of the station's robotic arm the following day, flight day 4, as they unberth Leonardo and maneuver it into place for installation on the station's Harmony node. Anderson will then work with Noguchi to prepare Leonardo's hatch for opening near the end of the day.

That night, spacewalkers Mastracchio and Anderson will sleep in the Quest airlock as part of the overnight "campout" procedure that helps purge nitrogen from their bloodstreams, preventing decompression sickness once they move out into the vacuum of space. The campout will be repeated the night before each spacewalk.

On the fifth day of the mission, the station will be a hive of activity inside and out. Spacewalkers Mastracchio and Anderson will prepare the ammonia tank assembly brought up in Discovery's cargo bay to be removed by Dutton and Wilson at the controls of the station's robotic arm and temporarily stored on the arm's mobile base. They will also retrieve a science experiment on the Japanese Kibo Laboratory's exposed facility, replace a rate gyro assembly on the center segment of the station's truss and prepare the batteries on the station's P6 solar arrays for replacement later. Mastracchio (EV 1) will wear a suit with stripes. Anderson (EV 2) will wear a suit with no stripes. Mastracchio and Anderson each have three spacewalks under their belt, one of which they performed together during the STS-118 mission.

While that is going on outside, inside Yamazaki and Noguchi will get to work unpacking some of the larger items brought up inside Leonardo, including a new Minus Eighty-Degree Laboratory Freezer for ISS, a new crew quarters rack and the Muscle Atrophy Resistive Exercise System, a piece of exercise equipment that allows astronauts to exercise seven different joints and scientists to study the strength of the muscles they use.

The sixth day is available for focused inspection of Discovery's heat shield if mission managers deem it necessary. Dutton, Metcalf-Lindenburger and Wilson would conduct that survey in the crew's morning while Mastracchio, Yamazaki and Anderson continued unpacking Leonardo. After lunch, Mastracchio and Anderson will begin preparations for their second spacewalk, while the rest of the shuttle crew, along with Kotov and Noguchi, carry on with the transfer work.

Among the items scheduled to make their way over to the space station on flight day 6 are the Window Observational Research Facility, which provides a set of cameras, multispectral and hyperspectral scanners, camcorders and other instruments to capture imagery of the Earth and space through the Destiny laboratory's window; and EXPRESS rack 7, which will provide power, data, cooling, water and other support to a number of experiments at the station.

All Discovery crew members will participate in transfer of one form or another on flight day 7. For Mastracchio and Anderson, the work will occur over six and a half hours outside the station, as they remove a spent ammonia tank assembly from the starboard side of the station's truss and replace it with the new tank they removed from Discovery during the first spacewalk.

The following morning, the crew will have the first half of flight day 8 off to enjoy some well-earned off duty time, then it will be back to work in Leonardo and time to prepare for the third and final spacewalk of the mission on flight day 9. During that six-and-a-half-hour spacewalk, Mastracchio and Anderson will install in the shuttle's cargo bay the spent ammonia tank assembly they removed on the previous spacewalk. They'll also remove a piece of hardware used to attach equipment and experiments to the exterior of the Columbus laboratory and store it in Discovery's cargo bay; install a camera and remove an insulation blanket on the Special Purpose Dexterous Manipulator; and replace a light in a camera on the exterior of Destiny.

Crew members inside will perform more transfer work while the spacewalk is going on outside, and that work will finish up on the morning flight day 10 before the crews go off duty in the afternoon. All 13 members of the crew will also take some time out for the traditional joint crew news conference on this day.

The hatches between Harmony and Leonardo will be closed on the morning of flight day 11 in preparation for its removal from the station by Wilson and Yamazaki, who will use the space station's robotic arm to pack it back into Discovery's cargo bay for return home. With that done, Discovery's crew will say farewell to the Expedition 23 crew, and hatches will be closed between the two vehicles.

Discovery will leave the space station with more than 20,000 pounds of trash, hardware that's no longer needed and science experiments to return to Earth.

After Discovery undocks early in the morning of April 16, Dutton will guide the shuttle on a 360-degree fly-around of the station so that other crew members can document the exterior condition of the orbiting outpost. After that is complete, Poindexter, Dutton, Metcalf-Lindenburger, Wilson and Yamazaki will conduct one last inspection of Discovery's heat shield using the shuttle's robotic arm and orbiter boom sensor system.

The last full day of orbital activities by the STS-131 crew will focus on landing preparations. Poindexter, Dutton and Metcalf-Lindenburger will conduct the traditional checkout of the shuttle's flight control systems and steering jets, setting Discovery up for its supersonic return to Earth. On the 14th day of the mission, weather permitting, Poindexter and Dutton will steer Discovery to a morning landing on April 18 at the Kennedy Space Center. When the shuttle's wheels roll to a stop, it will wrap up the 38th flight for Discovery, the 131th mission in shuttle program history and the 33nd shuttle visit to the International Space Station.

THIS PAGE INTENTIONALLY BLANK

NASA STS-131 Payload Overview[3]

Space shuttle Discovery's STS-131/19A payload includes the Leonardo Multi-Purpose Logistics Module (MPLM) and the Lightweight Multi-Purpose Experiment Support Structure Carrier (LMC). The total payload weight, not counting the middeck, is 31,130 pounds. The return weight is expected to be 24,118 pounds. On the middeck of the space shuttle, it will carry GLACIER, which is a freezer designed to provide cryogenic transportation and preservation capability for samples. The unit is a double locker equivalent unit capable of transport and operation in the middeck and on-orbit operation in the EXPRESS Rack.

The space shuttle will carry on its middeck (ascent) the following items: GLACIER, MERLIN, Mouse Immunology, Space Tissue Loss, NLP-Vaccine-8, BRIC-16, APEX Cambium, ESA ECCO with WAICO2, JAXA 2D Nano Template, JAXA Myo Lab, JAXA Neuro Rad, Sleep. On its return, among the items carried on the middeck will include GLACIER, MERLIN, Mouse Immunology, Space Tissue Loss, NLP-Vaccine-8, BRIC-16, APEX-Cambium, Coldbag, JAXA Nanoskeleton, JAXA Space Seed, SWAB Return Kit, Sleep.

LEONARDO MULTI-PURPOSE LOGISTICS MODULE (MPLM) FLIGHT MODULE 1 (FM1)

The Leonardo Multi-Purpose Logistics Module (MPLM) is one of three differently named large, reusable pressurized elements, carried in the space shuttle's cargo bay, used to ferry cargo back and forth to the station. For STS-131, FM1 was modified by removing hardware to reduce the weight of the module so that more hardware could be launched for this mission. Approximately 178.1 pounds of noncritical hardware were removed from FM1.

Leonardo includes components that provide life support, fire detection and suppression, electrical distribution and computers when it is attached to the station. The cylindrical logistics module acts as a pressurized "moving van" for the space station, carrying cargo, experiments and supplies for delivery to support the six-person crew on-board the station. The module also returns spent Orbital Replacement Units (ORUs) and components that need maintenance for backup spares. Each MPLM module is 21 feet long and 15 feet in diameter – the same size as the European Space Agency's Columbus module.

On the STS-131 mission, Leonardo will carry 16 racks to the station – four experiment racks, one systems rack, seven Resupply Stowage Platforms (RSPs), and four Resupply Stowage Racks (RSRs). The MPLM will also include the fully stocked Aft Cone Stowage (first used on STS-126/Flight Utilization Logistics Flight 2 on November 14, 2008). The aft cone modification allows 12 additional cargo bags, which are similar to the size of carry-on suitcases.

The four experiment racks carried in Leonardo are: Express Rack 7, Muscle Atrophy Research and Exercise System (MARES), Minus Eighty Laboratory Freezer 3 (MELFI-3), and Window Observational Research Facility (WORF). The station system rack is Crew Quarters 4 (CQ-4). The following are more detailed descriptions on each of these racks:

1. WINDOW OBSERVATIONAL RESEARCH FACILITY (WORF)

The Window Observational Research Facility (WORF) provides new capability for scientific and commercial payloads and will be a resource for public outreach and educational opportunities for Earth Sciences (e.g., the EarthKAM, etc.). Images from space have many applications; i.e., they can be used to study global climates, land and sea formations, and crop and weather damage and health assessments. Special sensors can also provide important data regarding transient atmospheric and geologic phenomena (hurricanes and volcanic eruptions), as well as act as a test bed for collecting data for new sensor technology development.

---

[3] Word for word from the NASA STS-131 Press Kit, available on line at: http://www.nasa.gov/mission_pages/shuttle/main/index.html

The WORF is located on the nadir (Earth facing) side of the U.S. Destiny laboratory module. The Lab window, which features the highest quality optics ever flown on a human occupied spacecraft, allows viewing of 39.5 degrees forward along the axis of the station, 32.2 degrees aft and 79.1 degrees from port to starboard.

The WORF design uses the existing EXpedite the PRocessing of Experiments to Space Station (EXPRESS) Rack hardware which includes a Rack Interface Controller (RIC) box for power and data connection, Avionics Air Assembly (AAA) fan for air circulation within the rack, rack fire detection, and appropriate avionics to communicate with the station data network.

The WORF consists of a facility that provides protection for the interior of the Lab window and controls stray light exchange between the Lab interior and the external Station environment. The WORF will maximize the use of the Lab window by providing attachments for sensors (cameras, multispectral and hyperspectral scanners, camcorders and other instruments) to capture imagery of the Earth and space. It provides attachment points, power and data transfer capability for instruments to be mounted near the window.

Multiple instruments can be mounted at the same time. The rack is designed to allow rapid changes of equipment by the crew. The WORF will have available a bracket for small cameras such as 35 mm, 70 mm and camcorders. Other larger payloads, which require a nonstandard attachment, or require additional instrument isolation, must supply their own brackets or platforms which mount to the WORF using the attachment points.

2. MUSCLE ATROPHY RESEARCH AND EXERCISE SYSTEM (MARES)

The Muscle Atrophy Research and Exercise System (MARES) will be used for research on musculoskeletal, biomechanical, and neuromuscular human physiology to better understand the effects of microgravity on the muscular system.

MARES enables scientists to study the detailed effects of microgravity on the human muscle-skeletal system. It also provides a means to evaluate countermeasures designed to mitigate the negative effect, especially muscle atrophy.

The MARES hardware is made up of an adjustable chair and human restraint system, a pantograph (an articulated arm supporting the chair, used to properly position the user), a direct drive motor, associated electronics and experiment programming software, a linear adapter that translates motor rotation into linear movements, and a vibration isolation frame.

MARES is capable of supporting measurements and exercise on seven different human joints, encompassing nine different angular movements, as well as two additional linear movements (arms and legs). It is considerably more advanced than current ground-based medical dynamometers (devices used to measure force or torque) and a vast improvement over existing station muscle research facilities.

MARES is integrated into a single International Standard Payload Rack (ISPR), called the Human Research Facility (HRF) MARES Rack, where it can also be stowed when not in use. It may be used together with an associated device called the Percutaneous Electrical Muscle Stimulator (PEMS II).

3. EXPRESS RACK 7

EXpedite the PRocessing of Experiments to Space Station Rack 7 (EXPRESS rack 7) is a multipurpose payload rack system that stores and supports experiments aboard the International Space Station. The EXPRESS rack system supports science experiments in any discipline by providing structural interfaces, power, data, cooling, water, and other items needed to operate science experiments in space.

With standardized hardware interfaces and streamlined approach, the EXpedite the PRocessing of Experiments to Space Station (EXPRESS) rack enables quick, simple integration of multiple payloads aboard the space station. The system is composed of elements that remain on the station and elements that travel back and forth between the station and Earth via the space shuttle.

EXPRESS racks remain on orbit continually. Experiments are replaced in the EXPRESS racks as needed, remaining on the station for periods ranging from three months to several years, depending on the experiment's time requirements.

Payloads within an EXPRESS rack can operate independently of each other, allowing for differences in temperature, power levels, and schedules. The EXPRESS rack provides stowage, power, data, command and control, video, water cooling, air cooling, vacuum exhaust, and nitrogen supply to payloads. Each EXPRESS rack is housed in an International Standard Payload Rack (ISPR), a refrigerator-size container that serves as the rack's exterior shell.

Experiments contained within EXPRESS racks may be controlled by the station crew or remotely by the Payload Rack Officer (PRO) on duty at the Payload Operations and Integration Center at NASA's Marshall Space Flight Center in Huntsville, Ala. Linked by computer to all payload racks aboard the station, the PRO routinely checks rack integrity, temperature control, and proper working conditions for station research payloads.

4. MINUS EIGHTY-DEGREE LABORATORY FREEZER 3 (MELFI-3)

Minus Eighty-Degree Laboratory Freezer for ISS (MELFI) is a European Space Agency-built, NASA-operated freezer that allows samples to be stored on the station at temperatures as low as -80 degrees centigrade. It comprises four temperature-controlled, insulated, independent containers called "dewars," which can be set to operate at different temperatures. Each dewar is a cylindrical, vacuum-insulated 75-liter container and can accommodate samples of a variety of sizes and shapes. The total capacity of the unit is 300 liters and can range in temperatures from refrigerated to "fast frozen."

The first MELFI unit was flown to the station on STS-121 and the second MELFI unit was flown on STS-128.

5. CREW QUARTERS (CQ) 4

The crew quarters delivered on STS-131/19A will be installed in the Harmony module (Node 2). The CQ provides private crew member space with enhanced acoustic noise mitigation, integrated radiation reduction material, controllable airflow, communication equipment, redundant electrical systems, and redundant caution and warning systems. The rack-sized CQ is a system with multiple crew member restraints, adjustable lighting, controllable ventilation, and interfaces that allow each crew member to personalize their CQ workspace.

MPLM BACKGROUND INFORMATION

The Italian-built, U.S.-owned logistics modules are capable of ferrying more than 7.5 tons (15,000 pounds) of cargo, spares and supplies. This is the equivalent of a semi-truck trailer full of station gear bringing equipment to and from the space station. Equipment such as container racks with science equipment, science experiments from NASA and its international partners, assembly and spare parts and other hardware items for return, such as completed experiments, system racks, station hardware that needs repair and refuse from the approximately 220 mile-high outpost. Some of these items are for disposal on Earth while others are for analysis and data collection by hardware providers and scientists.

Leonardo was the first MPLM to fly to the station on STS-102 (March 8, 2002) and there have been nine flights total for the two modules. This will be the seventh Leonardo mission – Raffaello has flown three missions.

Of the three MPLM modules, only two remain in active service to NASA for future flights. The space shuttle flies logistic modules in its cargo bay when a large quantity of hardware has to be ferried to the orbiting habitat at one time. The modules are attached to the inside of the bay for launch and landing. When in the cargo bay, the module is independent of the shuttle cabin, and there is no passageway for shuttle crew members to travel from the shuttle cabin to the module.

After the shuttle has docked to the outpost, typically on the fourth flight day after shuttle launch, Leonardo is mated to the station using the station's robotic arm to the Node 2 NADIR port. In the event of a failure or issue which may prevent the successful latching of the MPLM to the nadir port, the zenith port can be used to mate the MPLM to the station.

Nodes are modules that connect the elements to the station, and Unity was the first element launched to the station to connect the U.S. and Russian segments of the outpost. For its return trip to Earth, Leonardo will be detached from the station and positioned back into the shuttle's cargo bay.

NASA solely owns the modules which were acquired in a bartered agreement between NASA and the Italian Space Agency for using the modules in exchange for allowing the Italians to have crew time on board station.

LEONARDO SPECIFICATIONS

Length: 21 feet
Diameter: 15 feet
Payload Mass (launch): 27,274 lbs
Payload Mass (return): 20,375 lbs
Empty Weight: 9,632 lbs

The MPLM Module Leonardo is named after the Italian inventor and scientist Leonardo da Vinci. It was the first MPLM to deliver supplies to the station. The two other modules are named Raffaello, after master painter and architect Raffaello Sanzio, and Donatello, for one of the founders of modern sculpture, Donato di Niccolo Di Betto Bardi.

Raffaello has flown three times. Leonardo has flown the most because it is equipped with programmable heater thermostats on the outside of the module that allow for more mission flexibility. Donatello is not currently on the shuttle manifest to fly because of the cost associated with getting the module up to flight status code. STS-131 is the last MPLM flight scheduled before the station is complete and space shuttle retires later this year.

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 MPLM and LMC 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 post-landing payload activities including de-stow of the module.

THE LIGHTWEIGHT MULTI-PURPOSE EXPERIMENT SUPPORT STRUCTURE CARRIER (LMC)

Located behind Leonardo in the space shuttle payload bay, is the Lightweight Multi-Purpose Experiment Support Structure Carrier (LMC), a nondeployable cross-bay carrier providing launch and landing transportation. The LMC is a light-weight Shuttle stowage platform that only weighs 1,100 pounds. The launch weight of the LMC is 3,890 pounds and the return weight will be 3,740 pounds. Goddard Space Flight Center and ATK Space provide the sustaining engineering for the LMC carriers, which have flown successfully on five previous missions.

During ascent, the LMC is carrying the Ammonia Tank Assembly (ATA), a critical spare Orbital Replacement Unit (ORU). During descent, the LMC will be carrying a spent Ammonia Tank Assembly (ATA).

NASA STS-131 Spacewalk Overview[4]

There are three spacewalks scheduled for the STS-131 mission.

EVA-1
Duration: 6 hours, 30 minutes
EVA Crew: Mastracchio and Anderson
IV CREW: Metcalf-Lindenburger
Robotic Arm Operators: Dutton and Wilson

EVA Operations
- ❑ Prepare new ammonia tank assembly for removal from the cargo bay
- ❑ Hand new ammonia tank to space station robotic arm for temporary storage
- ❑ Retrieve MPAC/SEED from Kibo exposed facility
- ❑ Replace rate gyro assembly
- ❑ Prepare P6 solar array batteries for replacement

The first leg of the ammonia tank assembly swap will start in the shuttle's cargo bay. After picking up a handle that the space station robotic arm will use to grasp the new tank, Mastracchio will move to the cargo bay and install it on the new tank then begin releasing the four bolts that hold it in place during its journey to the station.

Anderson, meanwhile, will move to the station's starboard truss segment and disconnect the old tank's four ammonia and nitrogen lines before meeting Mastracchio in the cargo bay to do the same on the new tank. Once the lines are disconnected and the bolts released, Anderson and Mastracchio will work together to lift it out of the cargo bay and into position for the robotic arm to grasp it and fly it to the external stowage platform 2 on the Quest airlock.

While it makes its way there, Anderson will clean up their work area while Mastracchio will move to the Kibo laboratory's porch – the Japanese Experiment Module's exposed facility – to retrieve the Micro-Particles Capture/ Space Environment Exposure Device experiment and temporarily stow it outside of the airlock – he will move it inside later in the spacewalk.

They will meet the robotic arm back at the external stowage platform to install another handle on the new ammonia tank assembly, while it is still in the grasp of the arm. This second handle will be used to attach the assembly to a temporary storage location on the robotic arm's mobile transporter, where it will wait for installation on the second spacewalk of the mission.

Once that handle is installed, the robotic arm will fly the tank assembly to the storage location, and the spacewalkers will move on to other tasks. The first of the tasks will be the replacement of a rate gyro assembly on the center section of the station's truss. While moving the experiment inside of the airlock, Mastracchio will retrieve a new rate gyro assembly, then move to the center of the truss, where Anderson will have removed from inside the truss, two of the four bolts holding the old assembly in place. When Mastracchio arrives at the truss segment, he will open insulation protecting the assembly, disconnect two power cables and release the final two bolts. He will then remove the old assembly and slide the new one into place, engaging the first two bolts, connecting the power cables and then engaging the last two bolts.

Meanwhile, Anderson will have moved on to their final tasks of the mission: The preparation of the batteries on the farthest port solar array for replacement on a later mission. There are two sets of batteries, and the first set was replaced on STS-127, and some of the equipment used in that work – a gap spanner and a foot restraint – is still in

[4] Word for word from the NASA STS-131 Press Kit, available on line at: http://www.nasa.gov/mission_pages/shuttle/main/index.html

place. Anderson will move it from the set of batteries replaced during STS-127 to the set of batteries he and Mastracchio will be working with. The spacewalker will be loosening the 12 bolts holding the six batteries in place before heading back inside the station.

EVA-2
Duration: 6 hours, 30 minutes
EVA Crew: Mastracchio and Anderson
IV Crew: Metcalf-Lindenburger
Robotic Arm Operators: Dutton and Wilson

EVA Operations
- ❑ Remove spent ammonia tank assembly and store temporarily
- ❑ Install new ammonia tank assembly on S1 truss segment
- ❑ Install two port radiator grapple fixture stowage beams
- ❑ Retrieve two debris covers from external stowage platform 2

Mastracchio and Anderson will begin the second spacewalk at the site of the spent ammonia tank assembly on the first segment of the station's starboard truss. Anderson will disconnect two electrical cables. Then he and Mastracchio will work together to release the four bolts holding the assembly in place, lift it off of the station's truss and hand it to the robotic arm.

Mastracchio will then move a crew and equipment translation aid cart – or CETA cart – into place to provide temporary storage for the old ammonia tank assembly. When the assembly arrives via robotic arm at the CETA cart via robotic arm, the spacewalkers will tie it to the cart with six tethers.

That frees the robotic arm up for the installation of the new ammonia tank assembly. While it is retrieving the new assembly from the mobile transporter system, Mastracchio and Anderson will take advantage of the time by installing two radiator grapple fixture stowage beams on the first port segment of the station's truss.

These beams will be used temporarily to store handles that would be necessary if a radiator ever needed to be replaced.

By the time they are done with that, the new ammonia tank assembly should be in place. Mastracchio will first remove the handle that allowed it to be stored on the mobile transporter. Then he and Anderson will work together to install it, engaging four bolts and connecting six cables. Once the robotic arm is able to release its hold, the spacewalkers will be able to remove the handle it used to grip the assembly.

The next step will be to go back to the CETA cart, where Mastracchio will untie the old ammonia tank assembly and allow the robotic arm to grasp it. Then Anderson will install another handle on it that will allow the assembly to be stored on the mobile transporter until the final spacewalk, just as the new assembly was stored between the first and second spacewalks.

The final tasks of the second spacewalk calls for Mastracchio and Anderson to return to the external stowage platform 2 by the Quest airlock and retrieve two debris shields left there during STS-129.

EVA-3
Duration: 6 hours, 30 minutes
EVA Crew: Mastracchio and Anderson
IV Crew: Metcalf-Lindenburger
Robotic Arm Operators: Dutton, Wilson and Noguchi

EVA Operations

- ❑ Install spent ammonia tank assembly in Discovery's cargo bay
- ❑ Retrieve light-weight adapter plate assembly
- ❑ Install Dextre camera
- ❑ Remove Dextre insulation cover
- ❑ Replace Destiny camera light
- ❑ Install two starboard radiator grapple fixture stowage beams
- ❑ Install worksite interface extender on mobile transporter

The ammonia tank swapout will be more than halfway done by the beginning of the final spacewalk. Before they leave the airlock, the robotic arm will have retrieved the old ammonia tank assembly from the mobile transporter. They will meet the arm at external stowage platform 2 to remove the handle that held it in place there and stow the handle on the platform.

The next stop for the assembly will be Discovery's cargo bay. The spacewalkers will tighten four bolts to hold it in place for landing and remove the remaining handle that allowed the robotic arm to carry the assembly. That will wrap up the ammonia tank assembly work for the mission.

That will take about an hour of their time, and they will fill the rest of the spacewalk with get-ahead work for future missions.

Anderson's next tasks will take him to the Columbus laboratory. He will ride the robotic arm to the end of that module to pick up a light-weight adapter plate assembly, which has been used to attach experiments to the exterior of Columbus. Anderson will store it in the shuttle's cargo bay with help from Matracchio. Then the robotic arm will fly Anderson to the Special Purpose Dexterous Manipulator, or Dextre. There he will install a second camera on the robot and remove an unnecessary insulation blanket. He will finish his work on the final spacewalk by removing the foot restraint that allowed him to ride the robotic arm.

Meanwhile Mastracchio will replace a light on a camera on the Destiny laboratory and install two more two radiator grapple fixture stowage beams, this time on the starboard side of the station's truss. His final spacewalking task of the mission will be to retrieve a worksite interface extender from the external stowage platform 2 and install it on the mobile transporter.

THIS PAGE INTENTIONALLY BLANK

STS-131: Quick-Look Mission Data

Position/Age	Astronaut/Flights	Family/TIS	DOB/Seat
Commander	Navy Capt. Alan G. Poindexter	M/2	11/05/61
48	1: STS-122	13.0 *	Up-1/Dn-1
Pilot	AF Col. James P. Dutton Jr.	M/4	11/20/68
41	0: Rookie	0.0	Up-2/Dn-2
MS1/EV1	Richard A. Mastracchio	M/3	02/11/60
50	2: STS-106,118	24.5	Up-3/Dn-7
MS2/FE	Dorothy M. Metcalf-Lindenburger	M/1	05/02/75
34	0: Rookie	0.0	Up-4/Dn-4
MS3	Stephanie D. Wilson	S/0	09/27/66
43	2: STS-121,120	28.0	Dn-5/Dn-5
MS4	Naoko Yamazaki	M/1	12/27/70
39	0: Rookie	16.0	Dn-6/Dn-6
MS5/EV2	Clayton C. Anderson	M/2	02/23/59
51	1: STS-117/ISS15	152.0	Dn-7/Up-3
ISS-23 CDR	Russian AF Col. Oleg Kotov, M.D.	M/2	10/27/65
44	1: ISS-15	296.7	TMA-17
ISS-23 FE	Soichi Noguchi	S/0	04/15/65
45	1: STS-114	114.7	TMA-17
ISS-23 FE	Army Col. Timothy J. Creamer	M/2	11/15/59
44	0: Rookie	100.7	TMA-17
ISS-23 FE	Russian AF Col. Alex. Skvortsov	M/1	05/06/66
44	0: Rookie	0	TMA-18
ISS-23 FE	Tracy Caldwell Dyson	M/0	08/14/69
41	1: STS-118	13	TMA-18
ISS-23 FE	Mikhail Kornienko	M/1	04/15/60
44	0: Rookie	0	TMA-18

Shuttle Hardware and Flight Data

STS Mission	STS-131 (flight 131
Orbiter	Discovery (38th flight)
Payload	MPLM
Launch	06:21:23 AM 04.05.10
Pad/MLP	LC-39A/MLP-3
Prime TAL	Zaragoza, Spain
Landing	08:29:23 AM 04.18.10
Landing Site	Kennedy Space Center
Duration	13 + 0 + 2
Discovery	337/01:13:19
STS Program	1262/12:30:15
MECO	135.7 X 35.7 sm
OMS Ha/Hp	141.5 X 97.8 sm
ISS docking	220 statute miles
Period	91.98
Inclination	51.6
Velocity	17,188.19
EOM Miles	5,717,974
EOM Orbits	217
SSMEs	2045 / 2060 / 2054
ET/SRB	Bi142/RSRM 110/ET-135
Software	OI-34
Left OMS	LP01/41
Right OMS	RP03/39
Forward RCS	FRC3/38
OBSS/RMS	TBD/202
Cryo/GN2	5 PRSD/5 GN2
OV/PLD Wgt	267,470 pounds

Mastracchio, Wilson, Dutton, ML, Poindexter, Yamazaki, Andersо

STS-131 Mission Patch

Flight Plan	EST
Docking	
4/7/10	03:44 AM
EVA-1	
4/9/10	01:41 AM
EVA-2	
4/11/10	02:16 AM
EVA-3	
4/13/10	03:11 AM
Undocking	
4/16/10	03:55 AM
Landing	
4/18/10	08:29 AM

Flight Control Personnel

Bryan Lunney	Ascent FD
Richard Jones	Orbit 1 FD (lead)
Mike Sarafin	Orbit 2 FD
Ginger Kerrick	Planning FD
Bryan Lunney	Entry FD
C. McMillan	ISS Orbit 1 FD
Ron Spencer	ISS Orbit 2 FD (lead)
Ed Van Cise	ISS Orbit 3 FD
Pete Nickolenko	Launch director
Steve Payne	NASA test director
Mike Moses	MMT chairman
Mike Curie	Countdown PAO
Brandi Dean	Ascent PAO

This will be the...

131st	Shuttle mission
18th	Post-Columbia mission
106th	Post-Challenger mission
38th	Flight of Discovery
35th	Night launch
22nd	Night launch off pad 39A
78th	Launch off padd 39A
TBD	51.6-degree inclination
24th	Night landing
74th	KSC landing
22nd	KSC night landing
24.20	Years since STS-51L
7.18	Years since STS-107

* Ages as of launch date *Days in space as of: 4/1/10

Compiled by William Harwood

STS-131: Quick-Look Program Statistics

Orbiter	D/H:M:S	Flights	Most Recent Flight
Challenger*	062/07:56:22	10	STS-51L: 01/28/86
Columbia*	300/17:40:22	28	STS-107: 01/16/03
Discovery	337/01:13:19	37	STS-128: 08/28/09
Atlantis	282/00:00:28	31	STS-129: 11/16/09
Endeavour	266/15:33:20	24	STS-130: 02/08/10
Total	**1262/12:30:15**	**130**	* Vehicle lost

Launches	LC-39A	LC-39B	Total	
Night	21	13	34	Daylight:
Daylight	56	40	96	SR+3 mins
Total	77	53	130	to
Most Recent	2/8/10	12/9/06		SS-3 mins

Landings	KSC	EAFB	WSSH	Total
Night	17	6	0	23
Daylight	56	48	1	105
Total	73	54	1	128
Most Recent	2/21/10	9/11/09	3/30/82	

STS Aborts	Date	Time	Abort	Mission
Discovery	6/26/84	T-00:03	RSLS-1	STS-41D
Challenger	7/12/85	T-00:03	RSLS-2	STS-51F
Challenger	7/29/85	T+05:45	ATO-1	STS-51F
Columbia	3/22/93	T-00:03	RSLS-3	STS-55
Discovery	8/12/93	T-00:03	RSLS-4	STS-51
Endeavour	8/18/94	T-00:02	RSLS-5	STS-68

Increment	Launch	Land	Duration	Crew
ISS-01	10/31/00	03/21/01	136/17:09	2
ISS-02	03/08/01	08/02/01	147:16:43	3
ISS-03	08/10/01	12/17/01	117/02:56	3
ISS-04	12/05/01	06/19/02	181/00:44	3
ISS-05	06/05/02	12/07/02	171/03:33	3
ISS-06	11/23/02	05/03/03	161/01:17	3
ISS-07	04/26/03	10/28/03	184/21:47	2
ISS-08	10/18/03	04/30/04	194/18:35	2
ISS-09	04/19/04	10/23/04	187/21:17	2
ISS-10	10/14/04	04/24/05	192/19:02	2
ISS-11	04/15/05	10/11/05	179/23:00	2
ISS-12	10/01/05	04/08/06	189/19:53	2
ISS-13	03/30/06	09/28/06	182/22:44	2/3
ISS-14	09/18/06	04/20/07	215/08:23	3
ISS-15	03/07/07	10/21/07	196/17:05	3
ISS-16	10/10/07	04/19/08	191/19:07	3
ISS-17	04/08/08	10/24/08	198/16:20	3
ISS-18	10/12/08	04/08/09	178/00:15	3
ISS-19	03/26/09	10/11/09	198/16:42	3
ISS-20/21	05/27/09	10/11/09	TBD	6
ISS-22	09/30/09	TBD	TBD	2/5

Demographics	130	TMA-18
Total Fliers	512	514
Nations	38	0
Male	460	462
Female	52	52
Total Tickets	1,127	1,130
United States	332	332
United States men	289	289
United States Women	43	43
USSR	72	72
USSR Men	70	70
USSR Women	2	2
CIS	33	35
CIS Men	30	32
CIS Women	1	1
Non US/Russian	75	75
Men	71	71
Women	6	6
Men with 7 flights	2	2
Men with 6 flights	6	6
Women/6	0	0
Men/5	15	15
Women/5	6	6
Men/4	60	60
Women/4	6	6
Men/3	70	70
Women/3	6	6
All/2	139	140
All/1	202	203

Minimum Duration STS Missions	
1. Columbia/STS-2	Fuel cell
11/21/81	MET: 2/06:13
2. Atlantis/STS-44	IMU
11/19/91	MET: 6/23:52
3. Columbia/STS-83	Fuel cell
4/4/97	MET: 3/23:13

Soyuz Aborts/Failures	
Soyuz 1 Entry Failure	04/24/67
Soyuz 11 Entry Failure	06/30/71
Soyuz 18A Launch Abort	04/05/75
Soyuz T-10A Pad Abort	09/26/83

Shuttle Failures	
1. STS-51L/Challenger	01/28/86
RH SRB at T+73s	
2. STS-107/Columbia	02/01/03
Left wing breach/re-entry	

Compiled by William Harwood

STS-131 NASA Crew Thumbnails

Position/Age	Astronaut/Flights/Education	Fam/TS	DOB/Seat	Home/BKG	Hobbies/notes
Commander Age: 48	Navy Capt. Alan G. Poindexter 1: STS-122 Master's, aeronautical engineering	M/2 13.0 *	11/05/61 Up-1/Dn-1	Rockville, MD DS/DW Iraq Navy test pilot	Motorcycles, running, weights, outdoor activity; >3,500 hours flight time
Pilot 41	AF Col. James P. Dutton Jr. 0: Rookie Master's, aeronautics and astronautics	M/4 0.0	11/20/68 Up-2/Dn-2	Eugene, Ore. Top grad AFA AF test pilot	None listed >3,300 hours flight time
MS1/EV1 50	Richard A. Mastracchio 2: STS-106,118 Master's, electrical engineering	M/3 24.5	02/11/60 Up-3/Dn-7	Waterbury, Conn. Flight controller Software	None listed 3 EVAs
MS2/FE 34	Dorothy M. Metcalf-Lindenburger 0: Rookie Teaching certification	M/1 0.0	05/02/75 Up-4/Dn-4	Fort Collins, Colo. High school science teacher	Hiking, drawing, singing, playing music, marathons
MS3 43	Stephanie D. Wilson 2: STS-121,120 Master's, aerospace engineering	S/0 28.0	09/27/66 Dn-5/Dn-5	Boston Harvard grad JPL engineer	Snow skiing, music, stamp collecting, traveling
MS4 39	Naoko Yamazaki 0: Rookie Master's, aerospace engineering	M/1 16.0	12/27/70 Dn-6/Dn-6	Matsudo, Japan JAXA engineer Soyuz qualified	Scuba diving, snow skiing, flying and music; Japanese rocket society
MS5/EV2 51	Clayton C. Anderson 1: STS-117/ISS15 Master's, aerospace engineering	M/2 152.0	02/23/59 Dn-7/Up-3	Omaha, Neb. Flight design Trajectory anal.	Coaching youth sports, flying reading, writing, music, playing piano
ISS-23 CDR 44	Russian AF Col. Oleg Kotov, M.D. 1: ISS-15 Medical doctor	M/2 296.6	10/27/65 TMA-17	Simferopol Medical officer, Star City	Diving, computers and photography; certified SCUBA diver
ISS-23 FE 45	Soichi Noguchi 1: STS-114 Master's in engineering	S/0 114.6	04/15/65 TMA-17	Chigasaki, Japan Aircraft engines Rocket scientist	Basketball, skiing, camping, flying
ISS-23 FE 44	Army Col. Timothy J. Creamer 0: Rookie Master's in physics	M/2 100.6	11/15/59 TMA-17	Up. Marlboro, Md. Army aviator Air cavalry	Tennis, running, biking, reading, scuba, German language, IT
ISS-23 FE 44	Russian AF Col. Alex. Skvortsov 0: Rookie Law degree (in progress)	M/1 0.00	05/06/66 TMA-18	Schelkovo, Russia MiG pilot >1,000 hours	Diving, soccer, fishing, badminton, hunting and tourism
ISS-23 FE 41	Tracy Caldwell Dyson 1: STS-118 Ph.D. in chemistry	M/0 13.00	08/14/69 TMA-18	Arcadia, Calif. Chem. Research Private pilot	Sports, hiking, auto repair and maintenance; college track

Current Space Demographics (post STS-130)

Post STS-130	
Total Fliers	**512**
Nations	38
Men	460
Women	52
Total Tickets	1127
United States	**332**
US Men	289
US Women	43
Soviet Union	**72**
USSR Men	70
USSR Women	2
Russia/CIS	**33**
Russian Men	30
Russian Women	1
Others	**75**
Other Men	71
Other Women	6
Men with 7 flights	2
Women with 7 flights	0
Men with 6 flights	6
Women with 6 flights	0
Men with 5 flights	15
Women with 5 flights	6
Men with 4 flights	60
Women with 4 flights	6
Men with 3 flights	70
Women with 3 flights	6
All with 2 flights	139
All with 1 flight	202
TOTAL	**512**
In-flight Fatalities	**18**
U.S. Fatalities	13
Soviet/CIS Fatalities	4
Other Nations	1

	Nation	No.
1	Afghanistan	1
2	Austria	1
3	Belgium	2
4	Brazil	1
5	Bulgaria	2
6	Canada	9
7	China	6
8	Cuba	1
9	Czech.	1
10	E. Germany	1
11	France	9
12	Germany	9
13	Hungary	1
14	India	1
15	Israel	1
16	Italy	5
17	Japan	7
18	Kazakhstan	1
19	Malaysia	1
20	Mexico	1
21	Mongolia	1
22	Netherlands	2
23	N. Vietnam	1
24	Poland	1
25	Romania	1
26	Russia	31
27	Saudi Arabia	1
28	Slovakia	1
29	South Africa	1
30	South Korea	1
31	Spain	1
32	Sweden	1
33	Switzerland	1
34	Syria	1
35	Ukraine	1
36	United King.	1
37	USA	332
38	USSR	72
	TOTAL	**512**

Rank	Space Endurance	Days/FLTs
1	**Sergei Krikalev**	**803/6**
2	Sergei Avdeyev	748/3
3	Valery Polyakov	679/2
4	Anatoly Solovyev	652/5
5	Alexander Kaleri	611/4
6	Gennady Padalka	586/3
7	Victor Afanasyev	556/4
8	Yury Usachev	553/4
9	Musa Manarov	541/2
10	Yuri Malenchenko	515/4
11	Alexander Viktorenko	489/4
12	Nikolai Budarin	446/3
13	Yuri Romanenko	430/3
14	Alexander Volkov	392/3
15	Yury Onufrienko	389/2
16	Vladimir Titov	387/4
17	Vasily Tsibliev	383/2
18	Valery Korzun	382/2
19	Pavel Vinogradov	381/2
20	**Peggy Whitson**	**377/2**
21	Leonid Kizim	375/3
22	Mike Foale	374/6
23	Alexander Serebrov	374/4
24	Valery Ryumin	372/4
25	Mike Fincke	366/2
26	Vladimir Solovyev	362/2
27	Mikhail Tyurin	344/2
28	Talgat Musabayev	342/3

Rank	Top Spacewalkers	EVAs/H:M
1	**Anatoly Solovyov**	**16/82:22**
2	**Mike Lopez-Alegria**	**10/67:40**
3	Jerry Ross	9/58:21
4	John Grunsfeld	8/58:30
5	Steven Smith	7/49:48
6	Scott Parazynski	7/47:05
7	Joe Tanner	7/46:29
8	Robert Curbeam	7/45:33
9	Niolai Budarin	8/44:25
10	James Newman	6/43:13

Projected Space Demographics (post Soyuz TMA-18)

Post Soyuz TMA-18	
Total Fliers	**514**
Nations	0
Men	462
Women	52
Total Tickets	1130
United States	**332**
US Men	289
US Women	43
Soviet Union	**72**
USSR Men	70
USSR Women	2
Russia/CIS	**35**
Russian Men	32
Russian Women	1
Others	**75**
Other Men	71
Other Women	6
Men with 7 flights	2
Women with 7 flights	0
Men with 6 flights	6
Women with 6 flights	0
Men with 5 flights	15
Women with 5 flights	6
Men with 4 flights	60
Women with 4 flights	6
Men with 3 flights	70
Women with 3 flights	6
All with 2 flights	140
All with 1 flight	203
TOTAL	**514**
In-flight Fatalities	**18**
U.S. Fatalities	13
Soviet/CIS Fatalities	4
Other Nations	1

	Nation	No.
1	Afghanistan	1
2	Austria	1
3	Belgium	2
4	Brazil	1
5	Bulgaria	2
6	Canada	9
7	China	6
8	Cuba	1
9	Czech.	1
10	E. Germany	1
11	France	9
12	Germany	9
13	Hungary	1
14	India	1
15	Israel	1
16	Italy	5
17	Japan	7
18	Kazakhstan	1
19	Malaysia	1
20	Mexico	1
21	Mongolia	1
22	Netherlands	2
23	N. Vietnam	1
24	Poland	1
25	Romania	1
26	Russia	33
27	Saudi Arabia	1
28	Slovakia	1
29	South Africa	1
30	South Korea	1
31	Spain	1
32	Sweden	1
33	Switzerland	1
34	Syria	1
35	Ukraine	1
36	United King.	1
37	USA	332
38	USSR	72
	TOTAL	**514**

Rank	Space Endurance	Days/FLTs
1	**Sergei Krikalev**	**803/6**
2	Sergei Avdeyev	748/3
3	Valery Polyakov	679/2
4	Anatoly Solovyev	652/5
5	Alexander Kaleri	611/4
6	Gennady Padalka	586/3
7	Victor Afanasyev	556/4
8	Yury Usachev	553/4
9	Musa Manarov	541/2
10	Yuri Malenchenko	515/4
11	Alexander Viktorenko	489/4
12	Nikolai Budarin	446/3
13	Yuri Romanenko	430/3
14	Alexander Volkov	392/3
15	Yury Onufrienko	389/2
16	Vladimir Titov	387/4
17	Vasily Tsibliev	383/2
18	Valery Korzun	382/2
19	Pavel Vinogradov	381/2
20	**Peggy Whitson**	**377/2**
21	Leonid Kizim	375/3
22	Mike Foale	374/6
23	Alexander Serebrov	374/4
24	Valery Ryumin	372/4
25	Mike Fincke	366/2
26	Vladimir Solovyev	362/2
27	Mikhail Tyurin	344/2
28	Talgat Musabayev	342/3

Rank	Top Spacewalkers	EVAs/H:M
1	**Anatoly Solovyov**	**16/82:22**
2	**Mike Lopez-Alegria**	**10/67:40**
3	Jerry Ross	9/58:21
4	John Grunsfeld	8/58:30
5	Steven Smith	7/49:48
6	Scott Parazynski	7/47:05
7	Joe Tanner	7/46:29
8	Robert Curbeam	7/45:33
9	Niolai Budarin	8/44:25
10	James Newman	6/43:13

Space Fatalities

Name	Nation	Date	In-flight Fatalities
Komarov, Vladimir	USSR	04/24/67	Soyuz 1 parachute failure
Dobrovolsky, Georgy	USSR	06/29/71	Soyuz 11 depressurized during entry
Patsayev, Victor	USSR	06/29/71	Soyuz 11 depressurized during entry
Volkov, Vladislav	USSR	06/29/71	Soyuz 11 depressurized during entry
Scobee, Francis	US	01/28/86	SRB failure; Challenger, STS-51L
Smith, Michael	US	01/28/86	SRB failure; Challenger, STS-51L
Resnik, Judith	US	01/28/86	SRB failure; Challenger, STS-51L
Onizuka, Ellison	US	01/28/86	SRB failure; Challenger, STS-51L
McNair, Ronald	US	01/28/86	SRB failure; Challenger, STS-51L
Jarvis, Gregory	US	01/28/86	SRB failure; Challenger, STS-51L
McAuliffe, Christa	US	01/28/86	SRB failure; Challenger, STS-51L
Husband, Rick	US	02/01/03	Entry breakup; Columbia, STS-107
McCool, William	US	02/01/03	Entry breakup; Columbia, STS-107
Chawla, Kalpana	US	02/01/03	Entry breakup; Columbia, STS-107
Anderson, Michael	US	02/01/03	Entry breakup; Columbia, STS-107
Brown, David	US	02/01/03	Entry breakup; Columbia, STS-107
Clark, Laurel	US	02/01/03	Entry breakup; Columbia, STS-107
Ramon, Ilan	Israel	02/01/03	Entry breakup; Columbia, STS-107
TOTAL:	**18**		
			Other Active-Duty Fatalities
Freeman, Theodore	US	10/31/64	T-38 jet crash in Houston
Bassett, Charles	US	02/28/66	T-38 jet crash in St Louis
See, Elliott	US	02/28/66	T-38 jet crash in St Louis
Grissom, Virgil	US	01/27/67	Apollo 1 launch pad fire
White, Edward	US	01/27/67	Apollo 1 launch pad fire
Chaffee, Roger	US	01/27/67	Apollo 1 launch pad fire
Givens, Edward	US	06/06/67	Houston car crash
Williams, Clifton	US	10/15/67	Airplane crash near Tallahassee
Robert Lawrence	US	12/08/67	F-104 crash (MOL AF astronaut)
Gagariin, Yuri	USSR	03/27/68	MiG jet trainer crash near Star City
Belyayev, Pavel	USSR	01/10/70	Died during surgery
Thorne, Stephen	US	05/24/86	Private plane crash near Houston
Levchenko, Anatoly	USSR	08/06/88	Inoperable brain tumor
Shchukin, Alexander	USSR	08/18/88	Experimental plane crash
Griggs, David	US	06/17/89	Plane crash
Carter, Manley	US	05/04/91	Commuter plane crash in Georgia
Veach, Lacy	US	10/03/95	Cancer
Robertson, Patricia	US	05/24/01	Private plane crash near Houston
			Compiled by William Harwood

STS-131/ISS-23 NASA Crew Biographies

1. STS-131 CDR: Navy Capt. Alan G. Poindexter, 48

PERSONAL DATA: Born November 5, 1961 in Pasadena, California. Considers Rockville, Maryland, to be his hometown. Married to the former Lisa A. Pfeiffer of Gulf Breeze, Florida. They have two children. Recreational interests include motorcycling, running, weight lifting, water skiing, boating, hunting, and fishing.

EDUCATION: Graduated from Coronado High School, Coronado, California in 1979. Graduated with highest honors from Georgia Institute of Technology with a bachelor of aerospace engineering degree in 1986 and a master of science in aeronautical engineering from the Naval Postgraduate School in 1995.

ORGANIZATIONS: Society of Experimental Test Pilots

AWARDS: NASA Aviation Safety Award, Navy and Marine Corps Commendation Medal with Combat V, Navy and Marine Corps Achievement Medal, various other service awards.

SPECIAL HONORS: Naval Air Warfare Center, Aircraft Division Test Pilot of the Year 1996; Top Ten Carrier Aviator, Carrier Airwing Nine.

EXPERIENCE: Poindexter was commissioned following graduation from the Georgia Institute of Technology in 1986. After a short tour of duty at the Hypervelocity Wind Tunnel Facility, Naval Surface Weapons Center, White Oak, Maryland, Poindexter reported for flight training in Pensacola, Florida. He was designated a Naval Aviator in 1988 and reported to Fighter Squadron 124, Naval Air Station Miramar, California, for transition to the F-14 Tomcat. Following his initial training, Poindexter was assigned to Fighter Squadron 211, also at Miramar, and made two deployments to the Arabian Gulf during Operations Desert Storm and Southern Watch. During his second deployment in 1993, he was selected to attend the Naval Postgraduate School/U.S. Naval Test Pilot School Cooperative Program. Following graduation in December 1995, Poindexter was assigned as a Test Pilot and Project Officer at the Naval Strike Aircraft Test Squadron (NSATS), Naval Air Station (NAS) Patuxent River, Maryland. While at NSATS, Poindexter was assigned as the lead test pilot for the F-14 Digital Flight Control System where he logged the first carrier landing and catapult launch of an F-14 with the upgraded flight controls. He also flew numerous high angle of attack/departure tests, weapons separation tests and carrier suitability trials. Following his tour at Patuxent River, Poindexter reported to Fighter Squadron 32, NAS Oceana, Virginia, where he was serving as a department head when he was selected for Astronaut training.

Poindexter has more than 3,500 hours in over 30 aircraft types and has logged over 450 carrier landings.

NASA EXPERIENCE: Selected by NASA in June 1998, he reported for training in August 1998. Initially Poindexter served in the Astronaut Office Shuttle Operations Branch performing duties as the lead support astronaut at Kennedy Space Center. In 2008 he completed his first space flight as pilot on the STS-122 and has logged over 306 hours in space. Poindexter is assigned to command the crew of STS-131, targeted for launch in April 2010.

SPACE FLIGHT EXPERIENCE: STS-122 Atlantis (February 7-20, 2008) was the 24th Shuttle mission to visit the International Space Station. Mission highlight was the delivery and installation of the European Space Agency's Columbus Laboratory. It took three spacewalks by crew members to prepare the Columbus Laboratory for its scientific work, and to replace an expended nitrogen tank on the Station's P-1 Truss. STS-122 was also a crew replacement mission, delivering Expedition-16 Flight Engineer, ESA Astronaut Léopold Eyharts, and returning home with Expedition-16 Flight Engineer, NASA Astronaut Daniel Tani. The STS-122 mission was accomplished in 12 days, 18 hours, 21 minutes and 40 seconds, and traveled 5,296,832 statute miles in 203 Earth orbits.

MARCH 2010

2. STS-131 PLT: Air Force Col. James P. Dutton, 41

PERSONAL DATA: Born in November 1968 in Eugene, Oregon. Married to the former Erin Ruhoff, also from Eugene. They have four sons—J.P., Will, Joey and Ryan. Dutton's parents, James Sr. and Nita Dutton, live in Newberg, Oregon. Erin's parents, Rod and Nancy Ruhoff, live in Eugene, Oregon.

EDUCATION:
1987, Henry D. Sheldon High School, Eugene OR
1991, B.S., Astronautical Engineering, U.S. Air Force Academy, Col. Springs CO
1994, M.S., Aeronautics & Astronautics, University of Washington, Seattle WA

ORGANIZATIONS: Society of Experimental Test Pilots, U.S. Air Force Academy Association of Graduates, Officers' Christian Fellowship, and Trinity Fellowship church.

SPECIAL HONORS: Top graduate from the United States Air Force Academy (1991), Distinguished Graduate from Euro-NATO Joint Jet Pilot Training (1992), and top graduate from F-15C student training (1995) and the U.S. Air Force Test Pilot School (2000). TIME magazine College Achievement Award recipient (1990). Bobby Bond award for top Air Force test pilot in 2003. Military decorations include a Meritorious Service Medal, Air Medal, and 10 Aerial Achievement Medals.

EXPERIENCE: Dutton has more than 3,300 flight hours in over 30 different aircraft. Prior to joining NASA, he tested the F-22 Raptor with the 411th Flight Test Squadron at Edwards Air Force Base (AFB), California. He logged more than 350 F-22 flight hours between August 2002 and June 2004 performing avionics testing and high-risk envelope expansion testing.

As a member of the U.S. Air Force Academy Class of 1991, Dutton was a member of the intercollegiate Cadet Competition Flying Team and Cadet Squadrons CS-12 "Dirty Dozen" and CS-29 "Black Panthers." After graduation, he attended undergraduate pilot training at Sheppard AFB, Texas. He went on to complete his advanced studies at the University of Washington in Seattle from 1993-1994 prior to attending F-15C training at Tyndall AFB, Florida, in 1995. Dutton flew as an operational F-15C pilot with the 493rd Fighter Squadron "Grim Reapers" at RAF Lakenheath, United Kingdom, from October 1995 to May 1998. He has flown over 100 combat hours providing air superiority in support of Operations Provide Comfort and Northern Watch over northern Iraq.

In May 1998, Dutton was reassigned to the 422nd Test & Evaluation Squadron at Nellis AFB, Nevada, where he flew operational test missions in the F-15C. He was selected to attend the U.S. Air Force Test Pilot School (TPS) and graduated with Class 00A in December 2000. After TPS, he flight tested the F-16 as a member of the 416th Flight Test Squadron until June 2002, when he joined the F-22 Combined Test Force.

NASA EXPERIENCE: Dutton was selected in May 2004 as one of 14 members of the 19th NASA astronaut class. In February 2006 he completed Astronaut Candidate Training that included scientific and technical briefings, intensive instruction in Shuttle and International Space Station systems, physiological training, T-38 flight training, and water and wilderness survival training. Dutton was initially assigned to the Exploration Branch working on the development of the Crew Exploration Vehicle (CEV) cockpit and to the Capcom Branch as a shuttle capsule communicator. He was the Ascent/Entry Capcom for STS-122 in February 2008 and STS-123 in March 2008. Dutton is assigned as pilot on the crew of STS-131, targeted for launch in April 2010.

MARCH 2010

THIS PAGE INTENTIONALLY BLANK

3. STS-131 MS-1/EV-1: Richard A. Mastracchio, 50

PERSONAL DATA: Born February 11, 1960 in Waterbury, Connecticut.

EDUCATION: Graduated from Crosby High School, Waterbury, Connecticut, in 1978; received a bachelor of science degree in electrical engineering/computer science from the University of Connecticut in 1982, a master of science of degree in electrical engineering from Rensselaer Polytechnic Institute in 1987, and a master of science degree in physical science from the University of Houston-Clear Lake in 1991.

ORGANIZATIONS: Member, Institute of Electrical and Electronics Engineers.

EXPERIENCE: Rick Mastracchio worked for Hamilton Standard in Connecticut as an engineer in the system design group from 1982 until 1987. During that time, he participated in the development of high performance, strapped-down inertial measurement units and flight control computers.

NASA EXPERIENCE: In 1987, Mastracchio moved to Houston, Texas, to work for the Rockwell Shuttle Operations Company at the Johnson Space Center. In 1990, he joined NASA as an engineer in the Flight Crew Operations Directorate. His duties included the development of space shuttle flight software requirements, the verification of space shuttle flight software in the Shuttle Avionics Integration Laboratory, and the development of ascent and abort crew procedures for the Astronaut Office. From 1993 until 1996, he worked as an ascent/entry Guidance and Procedures Officer (GPO) in Mission Control. An ascent/entry GPO has both pre-mission and real time Space Shuttle support responsibilities in the areas of onboard guidance, navigation, and targeting. During that time, he supported seventeen missions as a flight controller.

In April 1996, Mastracchio was selected as an Astronaut Candidate and started training in August 1996. Mastracchio has worked technical issues for the Astronaut Office Computer Support Branch, for Space Station Operations, and the EVA Branch, and also served as lead for cockpit avionics upgrades. Mastracchio flew as a mission specialist on STS-106 and STS-118 and has logged over 588 hours in space, including 3 EVAs totaling 18 hours and 13 minutes. He is assigned to the crew of STS-131, targeted for launch in April 2010.

SPACE FLIGHT EXPERIENCE: STS-106 Atlantis (September 8-20, 2000). During the 12-day mission, the crew successfully prepared the International Space Station for the arrival of the first permanent crew. The five astronauts and two cosmonauts delivered more than 6,600 pounds of supplies and installed batteries, power converters, a toilet and a treadmill on the Space Station. Two crewmembers performed a space walk in order to connect power, data and communications cables to the newly arrived Zvezda Service Module and the Space Station. Mastracchio was the ascent/entry flight engineer, the primary robotic arm operator, and responsible for the transfer of items from the Space Shuttle to the Space Station. STS-106 orbited the Earth 185 times, and covered 4.9 million miles in 11 days, 19 hours, and 10 minutes.

STS-118 (August 8-21, 2007) was the 119th space shuttle flight, the 22nd flight to the station, and the 20th flight for Endeavour. During the mission Endeavour's crew successfully added another truss segment, a new gyroscope and external spare parts platform to the International Space Station. Mastracchio was the ascent/entry flight engineer and participated in three of the four spacewalks (EVAs). Traveling 5.3 million miles in space, the STS-118 mission was completed in 12 days, 17 hours, 55 minutes and 34 seconds.

MARCH 2010

THIS PAGE INTENTIONALLY BLANK

4. STS-131 MS-2/FE: Dorothy Metcalf-Lindenburger, 34

PERSONAL DATA: Born on May 2, 1975 in Colorado Springs, Colorado, but considers Fort Collins, Colorado her hometown. Married Jason Metcalf-Lindenburger of Pendelton, Oregon, in 2000. They have one child. Her parents are Joyce and Keith Metcalf, who reside in Fort Collins, Colorado. Dorothy enjoys running (has completed over 10 marathons including Boston in 2004), hiking, drawing, singing, and playing music.

EDUCATION:
Fort Collins High School, Fort Collins, Colorado.
B.A., Geology, Whitman College, Washington, 1997 (graduated with honors in her major and cum laude).
Teaching Certification, Central Washington University, Washington, 1999.

ORGANIZATIONS: Phi Beta Kappa, Geological Society of America, National Science Teachers Association, International Technology Education Association, National Council of Teachers of Mathematics.

SPECIAL HONORS: 2004 VIP for the Vancouver School District, 1999 Outstanding Teacher Preparation Candidate at Central Washington University, 1996 GSA Field Camp Award, Whitman College Awards: Leed's Geology Award and Order of the Waiilaptu, 1995-1996 NAIA Academic All-American in Cross Country and Track, 1996 NAIA Conference Champion in the 10K.

EXPERIENCE: Five years of teaching earth science and astronomy at Hudson's Bay High School in Vancouver, Washington. Three years of coaching cross-country at the high school level, and two years of coaching Science Olympiad. Undergraduate research with the KECK Consortium for two summers: 1995 in Wyoming mapping the last glaciations of Russell Creek, and 1996 mapping and determining the petrology of the rocks in the Wet Mountain region of Colorado. Both research positions led to publications.

NASA EXPERIENCE: Selected by NASA as a Mission Specialist in May 2004. In February 2006 she completed Astronaut Candidate Training that included scientific and technical briefings, intensive instruction in Shuttle and International Space Station systems, physiological training, T-38 flight training, and water and wilderness survival training. Completion of this initial training qualified her for technical assignments within the Astronaut Office and future flight assignment. Most recently she served as the Astronaut Office Station Branch lead for systems and crew interfaces. Currently, she is assigned to the crew of STS-131, targeted for launch in April 2010.

MARCH 2010

THIS PAGE INTENTIONALLY BLANK

5. STS-131 MS-3/EV-2: Stephanie D. Wilson, 43

PERSONAL DATA: Born in 1966 in Boston Massachusetts. Enjoys snow skiing, music, stamp collecting, and traveling.

EDUCATION: Graduated from Taconic High School, Pittsfield, Massachusetts, in 1984; received a bachelor of science degree in engineering science from Harvard University in 1988, and a master of science degree in aerospace engineering from the University of Texas, in 1992.

ORGANIZATIONS: American Institute of Aeronautics and Astronautics.

EXPERIENCE: After graduating from Harvard in 1988, Wilson worked for 2 years for the former Martin Marietta Astronautics Group in Denver, Colorado. As a Loads and Dynamics engineer for Titan IV, Wilson was responsible for performing coupled loads analyses for the launch vehicle and payloads during flight events. Wilson left Martin Marietta in 1990 to attend graduate school at the University of Texas. Her research focused on the control and modeling of large, flexible space structures. Following the completion of her graduate work, she began working for the Jet Propulsion Laboratory in Pasadena, California, in 1992. As a member of the Attitude and Articulation Control Subsystem for the Galileo spacecraft, Wilson was responsible for assessing attitude controller performance, science platform pointing accuracy, antenna pointing accuracy and spin rate accuracy. She worked in the areas of sequence development and testing as well. While at the Jet Propulsion Laboratory, Wilson also supported the Interferometery Technology Program as a member of the Integrated Modeling Team, which was responsible for finite element modeling, controller design, and software development.

NASA EXPERIENCE: Selected by NASA in April 1996, Wilson reported to the Johnson Space Center in August 1996. Having completed two years of training and evaluation, she is qualified for flight assignment as a mission specialist. She was initially assigned technical duties in the Astronaut Office Space Station Operations Branch to work with Space Station payload displays and procedures. She then served in the Astronaut Office CAPCOM Branch, working in Mission Control as a prime communicator with on-orbit crews. Following her work in Mission Control, Wilson was assigned technical duties in the Astronaut Office Shuttle Operations Branch involving the Space Shuttle Main Engines, External Tank and Solid Rocket Boosters. A veteran of two space flights, STS-121 in 2006, and STS-120 in 2007, Wilson has logged over 28 days in space. Wilson is assigned to the crew of STS-131, targeted for launch in April 2010.

SPACE FLIGHT EXPERIENCE: STS-121 (July 4-17, 2006), was a return-to-flight test mission and assembly flight to the International Space Station. During the 13-day flight the crew of Space Shuttle Discovery tested new equipment and procedures that increase the safety of space shuttles, repaired a rail car on the International Space Station and produced never-before-seen, high-resolution images of the Shuttle during and after its July 4th launch. Wilson supported robotic arm operations for vehicle inspection, multi-purpose logistics module installation and EVAs and was responsible for the transfer of more than 15,000 pounds of supplies and equipment to the ISS. The crew also performed maintenance on the space station and delivered a new Expedition 13 crew member to the station. The mission was accomplished in 306 hours, 37 minutes and 54 seconds.

STS-120 Discovery (October 23-November 7, 2007) launched from and returned to land at the Kennedy Space Center, Florida. Designated as flight 10A in the ISS assembly sequence, it was also a crew rotation flight, delivering an Expedition 16 crew member and returning with an Expedition-15 crew member. During the STS-120 mission, the Node 2 module named “Harmony” was delivered to the International Space Station. This element opened up the capability for future international laboratories to be added to the station. In addition, the P6 Solar Array was re-located from the Z1 Truss to the end of the port side of the Integrated Truss Structure. During the re-deploy of the array, the array panels snagged and were damaged. An unplanned spacewalk was successfully performed to repair the array. The mission was accomplished in 238 orbits, traveling 6.2 million miles in 15 days, 2 hours, and 23 minutes.

MARCH 2010

6. STS-131 MS-4: Naoko Yamazaki, 39

PERSONAL DATA: Born in 1970 in Matsudo, Chiba Prefecture, Japan. Married to Taichi Yamazaki. They have one child, Yuki. She enjoys scuba diving, snow skiing, flying and music. Her parents, Akito and Kimie Sumino reside in Matsudo.

EDUCATION: Graduated from Ochanomizu University Senior High School in 1989; Received a Bachelor's degree in Aerospace Engineering from the University of Tokyo in 1993 and a Master's degree in Aerospace Engineering from the University of Tokyo in 1996.

ORGANIZATIONS: The Japan Society for Aeronautical and Space Sciences; Japanese Rocket Society.

EXPERIENCE: Yamazaki joined the National Space Development Agency of Japan (NASDA) in 1996 and was involved in the Japanese Experiment Module (JEM) system integration, and specifically assigned developmental tasks. She also conducted failure analysis and assembly/initial operation procedure development in the JEM Project Team. From June 1998 to March 2000, she was involved in the development of the ISS Centrifuge (life science experiment facility) and conducted conceptual framework and preliminary design in the Centrifuge Project Team.

In February 1999, Yamazaki was selected by NASDA (currently JAXA) as one of three Japanese astronaut candidates for the International Space Station (ISS). She attended the ISS Astronaut Basic Training program starting in April 1999 and was certified as an astronaut in September 2001. Since 2001, she has participated in ISS Advanced Training, in addition to supporting the development of the hardware and operation of the Japanese Experiment Module "Kibo" and the Centrifuge.

On October 1, 2003, NASDA merged with ISAS (Institute of Space & Astronautic Science) and NAL (National Aerospace Laboratory of Japan) and was renamed JAXA (Japan Aerospace Exploration Agency).

In May 2004, she completed Soyuz-TMA Flight Engineer-1 training at the Yuri Gagarin Cosmonaut Training Center (GCTC), Star City, Russia.

NASA EXPERIENCE: Yamazaki arrived at the Johnson Space Center in June, 2004. In February 2006 she completed Astronaut Candidate Training that included scientific and technical briefings, intensive instruction in Shuttle and International Space Station systems, physiological training, T-38 flight training, and water and wilderness survival training. Completion of this initial training qualified her for various technical assignments within the Astronaut Office and future flight assignment as a mission specialist. She initially served in the Astronaut Office Robotics Branch. Currently, she is assigned to the crew of STS-131, targeted for launch in April 2010.

MARCH 2010

THIS PAGE INTENTIONALLY BLANK

7. STS-131 MS-5/EV-2: Clayton C. Anderson, 51

DATA: Born February 23, 1959 in Omaha, Nebraska. He considers Ashland, Nebraska to be his hometown. Married to the former Susan Jane Harreld of Elkhart, Indiana. They have two children; a son, Clayton "Cole" and a daughter, Sutton Marie. Clay's mother, Alice J. Anderson, and father, John T. Anderson, are deceased. Susan's parents are Jack and Mary Harreld of Bella Vista, Arkansas. Recreational interests include: officiating College and High School basketball; participation in all sports; coaching youth sports; flying; reading; writing music; playing the piano/organ and vocal performance. As an undergraduate he competed on the football, basketball and track teams.

EDUCATION: Graduated from Ashland-Greenwood High School, Ashland, Nebraska, 1977; received a bachelor of science degree (Cum Laude) in Physics from Hastings College, Nebraska in 1981 and a master of science degree in Aerospace Engineering from Iowa State University in 1983.

ORGANIZATIONS: Southwest Basketball Officials Association; Former Men's College Basketball Official: Red River Athletic, Southern Collegiate Athletic, Heart of Texas, Lone Star, and Texas/New Mexico Junior College Athletic Conferences; Aircraft Owners and Pilots Association (AOPA); Johnson Space Center Employee Activities Association: Vice President of Athletics (1987-1992); Clear Lake Optimist Club Past President and Vice President. Alpha Chi National Scholastic Honor Society, Hastings College, Hastings Nebraska (1980-1981).

SPECIAL HONORS: Honorary Doctorate Degree from Hastings College, 2004; Distinguished Alumnus Award, National Council of Alpha Chi 2001; NASA Quality and Safety Achievement Recognition (QASAR) Award 1998; NCAA National Christian College Basketball Championships Official (1997, 1998); JSC Certificate of Commendation (1993); Outstanding Young Man of America (1981, 1985, 1987); Bronco Award Winner, Hastings College (1981).

NASA EXPERIENCE: Anderson joined the Johnson Space Center in 1983 in the Mission Planning and Analysis Division where he performed rendezvous and proximity operations trajectory designs for early Space Shuttle and Space Station missions. In 1988 he moved to the Mission Operations Directorate (MOD) as a Flight Design Manager leading the trajectory design team for the Galileo planetary mission (STS-34) while serving as the backup for the Magellan planetary mission (STS-31). In 1989, Anderson was chosen supervisor of the MOD Ascent Flight Design Section and following reorganization, the Flight Design Engineering Office of the Flight Design and Dynamics Division. In 1993 he was named the Chief of the Flight Design Branch. From 1996 until his selection Anderson held the post of Manager, Emergency Operations Center, NASA Johnson Space Center.

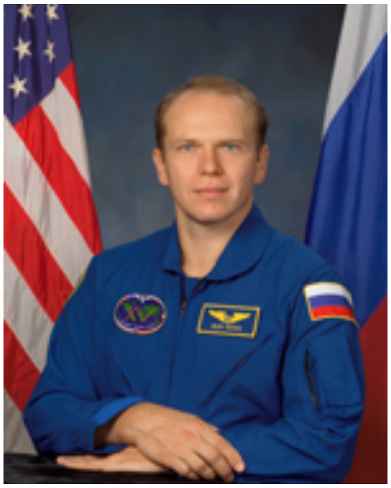
Selected as a mission specialist by NASA in June 1998, he reported for training in August of that year. Training included orientation briefings and tours, numerous scientific and technical briefings, intensive instruction in Shuttle and International Space Station (ISS) systems, physiological training, ground school to prepare for T-38 flight training, as well as learning water and wilderness survival techniques.

Prior to being assigned to a space flight Anderson served as the lead for the Enhanced Caution and Warning (ECW) System development effort within the Space Shuttle Cockpit Avionics Upgrade (CAU) Project. Previously, he was the Crew Support Astronaut for ISS Expedition 4, providing ground support on technical issues in addition to supporting the crew families. Anderson also served as an ISS Capsule Communicator (CAPCOM) and as the Astronaut Office crew representative for the Station's electrical power system. In November of 2002, Anderson completed training in the Extravehicular Activity (EVA) Skills program. He also served as back-up Flight Engineer for Expeditions 12, 13 and 14 to the Station. He completed his first space flight in 2007 and has logged 152 days in space and over 18 EVA hours in 3 spacewalks. Anderson is assigned to the crew of STS-131, targeted for launch in April 2010.

SPACE FLIGHT EXPERIENCE: In 2007, Clay Anderson spent a five month tour of duty working aboard the International Space Station. He launched to the Station on June 8, 2007 aboard Shuttle Atlantis with the crew of STS-117. Docking with the Station on flight day 3, he replaced Suni Williams as the Expedition 15 Flight Engineer and also assumed the role of Science Officer for the Expedition. During his 152 day tour of duty aboard the ISS, Anderson performed 3 spacewalks, two with crewmembers of STS-118, totaling 18 hours, 01 minutes. During his 'stage' EVA, Anderson jettisoned (disposed of) two pieces of space hardware, including the Early Ammonia Servicer (EAS) weighing in at over 1400 lbs. and a piece of "onboard support equipment" creating space satellites "Nebraska 1 and Nebraska 2." In addition, Anderson operated the Robotic Manipulator Canadarm2 to move the Station's Pressurized Mating Adapter (PMA) 3 to the Node 1 nadir (earth pointing) docking port in preparation for the arrival of Node 2 "Harmony" delivered by the crew of STS-120. Anderson returned home aboard Shuttle Discovery as a member of the STS-120 crew, landing at KSC on November 7, 2007.

MARCH 2010

1. ISS-23 CDR: Oleg Kotov, M.D., 44 (colonel, Russian Air Force)



PERSONAL DATA: Born October 27, 1965, in Simferopol. His parents, Valeri Efimovich and Elena Ivanovna Kotov, reside in Moscow. Married to Svetlana Nikolayevna Kotova (previously, Bunyakina). They have two children. He enjoys diving, computers, and photography.

EDUCATION: In 1982 Dr. Kotov finished high school in Moscow and entered the Kirov Military Medical Academy, from which he graduated in 1988.

EXPERIENCE: After graduation from the Academy in 1988, Dr. Kotov served at the Gagarin Cosmonaut Training Center, where he held the positions of Deputy lead test-doctor and Lead test doctor.

During his service he dealt with problems of altitude physiology and space flight effects on a human body. He gained experience in practical training and medical support of EVAs on the Mir station, and was a crew surgeon and instructor for biomedical training and science program training. He is a certified SCUBA diver.

He was selected as a cosmonaut candidate by GCTC in 1996. From June 1996 to March 1998, he completed a course of basic training for spaceflight. In March 1998, he received a test-cosmonaut qualification.

Since July 1998, Dr. Kotov has been a cosmonaut-researcher and test-cosmonaut of the GCTC Cosmonaut Office. From May-August 1998, Dr. Kotov trained for a flight on the Soyuz and the Mir station as a backup crewmember to the Mir-26 mission.

Since October 1998, he has been undergoing advanced training for ISS flights. He served as a flight engineer and Soyuz commander on the ISS-6 and ISS-13 backup crews.

From February-October 1999 he served as a Representative of GCTC (DOH) at JSC. During 2001-2002 he worked as a CAPCOM for Expedition-3 and 4 in MCC-M and Moscow Support Group in MCC-H. In 2004 he became Chief of the CAPCOM Branch in the Cosmonaut Office.

Dr. Kotov is currently serving a six month tour of duty as a flight engineer and Soyuz commander on the Expedition-15 mission to the International Space Station. Expedition-15 launched on April 7 aboard a Soyuz TMA-10 spacecraft arriving at the ISS complex on April 9, 2007.

APRIL 2007

THIS PAGE INTENTIONALLY BLANK

2. ISS-23 FE: Soichi Noguchi, 45

PERSONAL DATA: Born in 1965 in Yokohama, Kanagawa, Japan. Considers Chigasaki, Kanagawa, Japan, to be his hometown. Enjoys basketball, skiing, camping, and flying. Holds flight instructor certificate as CFII and MEI.

EDUCATION: Graduated from Chigasaki-Hokuryo High School, Chigasaki, in 1984; received a bachelor of engineering degree in aeronautical engineering from the University of Tokyo in 1989, and a master of engineering degree in aeronautical engineering from the University of Tokyo in 1991.

ORGANIZATIONS: Member of the Japan Society for Aeronautical and Space Sciences.

EXPERIENCE: Noguchi joined Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) in April 1991. He completed a training course in the Manufacturing Department, and then he was assigned to the Aerodynamics Group, Research and Development Department, Aero-Engine and Space Operations, IHI. He was involved in the aerodynamic design of commercial aero-engines, planning and successful completion of the component tests of aero-engines, and the research of compressor aerodynamic performance. He was selected by the National Space Development Agency of Japan (NASDA) in June 1996. Effective October 1, 2003, NASDA merged with ISAS (Institute of Space & Astronautic Science) and NAL (National Aerospace Laboratory of Japan) and was renamed JAXA (Japan Aerospace Exploration Agency).

NASA EXPERIENCE: Noguchi reported to the Johnson Space Center in August 1996. Having completed two years of training and evaluation, he is qualified for flight assignment as a mission specialist. He participated in the basic training course for Russian manned space systems at Gagarin Cosmonaut Training Center in Russia in 1998. He then continued MS advanced training at JSC and was also assigned technical duties to support the Japanese Experiment Module (Kibo) development tests. In April 2001, he was assigned to the crew of STS-114. He flew on STS-114 Discovery (July 26-August 9, 2005) and has logged over 333 hours in space, including over 20 EVA hours. Noguchi is assigned to the Expedition 20 International Space Station mission, scheduled to launch on a Soyuz spacecraft in November 2009. He will join the Expedition 20 mission in progress and will serve a 6-month tour of duty as a flight engineer. He currently serves as a back-up Expedition 18 crew member.

SPACE FLIGHT EXPERIENCE: STS-114 Discovery (July 26-August 9, 2005) was the Return to Flight mission during which the Shuttle docked with the International Space Station and the crew tested and evaluated new procedures for flight safety and Shuttle inspection and repair techniques. Noguchi served as MS-1 and EV-1 and performed 3 EVAs (spacewalks) totaling 20 hours and 5 minutes. After a 2-week, 5.8 million mile journey in space, the orbiter and its crew of seven astronauts returned to land at Edwards Air Force Base, California.

MAY 2008

THIS PAGE INTENTIONALLY BLANK

3. ISS-23 FE: Army Col. Timothy J. Creamer, 50

PERSONAL DATA: Born November 15, 1959 in Ft. Huachuca, Arizona, but considers Upper Marlboro, Maryland, to be his hometown. Married to the former Margaret E. Hammer. They have two children. His interests also include tennis, running, biking, reading, SCUBA, German language, and information technologies. Both his mother, Mary E. Creamer, and his father, Edmund J. Creamer, Jr., are deceased.

EDUCATION:
Bishop McNamara High School, Forestville, Maryland, 1978.
B.S., Chemistry, Loyola College, Baltimore, Maryland, 1982.
M.S., Physics, Massachusetts Institute of Technology, 1992.

ORGANIZATIONS: Member of Alpha Sigma Nu, Phi Kappa Phi, Sigma Pi Sigma, Army Aviation Association of America, Association of the United States Army, and the British-American Project.

SPECIAL HONORS: Meritorious Service Medal (2nd Oak Leaf Cluster); Army Achievement Medal (1st Oak Leaf Cluster); The Air Force's Space and Missile Badge; National Defense Service Medal; Senior Army Aviator; Senior Parachutist; Distinguished Graduate of the U.S. Army Aviation School. Recipient of the Russian Federation of Astronautics Yuri Gagarin medal.

EXPERIENCE: Creamer graduated from Loyola College in May 1982 with a Bachelor of Science degree in chemistry, and was commissioned through the ROTC program as a Second Lieutenant in the U.S. Army. He entered the U.S. Army Aviation School in December 1982, and was designated as an Army Aviator in August 1983, graduating as the Distinguished Graduate from his class. He was subsequently assigned to the 1st Armored Division as a section leader, platoon leader, flight operations officer, and as a personnel staff officer for the 501st Attack Helicopter Battalion. In 1987, he was assigned to the 82nd Airborne Division as a commander of an air cavalry troop in the 17th Cavalry, and later as the personnel officer of the 82nd Aviation Brigade. Following this assignment, he completed a Master of Science degree in physics at MIT in 1992, and was subsequently assigned to the Department of Physics at the United States Military Academy as an Assistant Professor. Other military schools include Army Parachutist Course, Army Jumpmaster Course, the Combined Arms Services Staff School, and the Command and General Staff College. Prior to his astronaut selection in 1998, he had been working as a Space Operations Officer, with the Army Space Command, stationed in Houston, Texas. He is now the Army's NASA Detachment commander.

NASA EXPERIENCE: Creamer was assigned to NASA at the Johnson Space Center in July 1995 as a Space Shuttle vehicle integration test engineer. His duties primarily involved engineering liaison for launch and landing operations of the Space Shuttle. He was actively involved in the integrated tests of the systems for each Orbiter for its preparations for its next flight, and directly supported eight Shuttle missions as a vehicle integration test team lead. Additionally, he focused his efforts in coordinating the information technologies for the Astronaut Office to aid personnel in their electronic communications both on JSC as well as through their travels to other Centers.

Selected by NASA in June 1998, Creamer reported for Astronaut Candidate Training in August 1998. Having completed the initial two years of intensive Space Shuttle and Space Station training, he was assigned technical duties in the Space Station Branch of the Astronaut Office, where his primary focus involved the command and control computers on Space Station, as well as the office automation support computers, and the operational Local Area Network encompassing all international partners and modules.

Beginning November 2000, Creamer became the Crew Support Astronaut for the Expedition 3 Crew, which was on orbit from August 2001 to December 2001. He was the primary contact for all the crew needs, coordination, planning and interactions, and was the primary representative of the crew while they were on orbit.

Starting March 2002, Creamer headed the Hardware Integration Section of the Space Station Branch, responsible for ensuring all hardware configurations were properly integrated, and that all operational aspects of the future ISS hardware are accounted for. In October 2004, he was assigned to be the astronaut office representative and coordinator for all things relating to on-orbit Information Technologies.

He was next assigned to the Robotics Branch, dealing with the International Partners on all computer aspects of Robotics operations, as well as all of the Command and Control software and user interfaces. Additionally, he was the real-time support lead for Expedition-12 for all things involving the Robotics operations on the International Space Station.

He is assigned to International Space Station Expeditions 22 & 23, scheduled to launch on a Soyuz spacecraft in December 2009. He will join the remaining members of the Expedition 21 mission in progress and will serve a 6-month tour of duty as a flight engineer and NASA science officer. He currently serves as a back-up Expedition 19 crew member.

APRIL 2009

4. ISS-23 FE: Alexander Skvortsov (colonel, Russian Air Force), 43

PERSONAL DATA: Born May 6, 1966, in Schelkovo, Moscow Region. Married to Skvortsova (nee Krasnikova) Elena Georgievna. They have one daughter, Anna. Hobbies include diving, soccer, badminton, fishing, hunting, tourism.

EDUCATION: Graduated from the Stavropol Air Force Pilot and Navigator School as pilot-engineer in 1987, and in 1997 from the Military Red Banner Air Defense Academy. Currently works on a law degree at the Russian Academy of Civil Service.

EXPERIENCE: Skvortsov flew L-39, MiG-23 and Su-27 aircraft. Skvortsov has logged around 1000 hours of flight time. He is a Class 1 Air Force pilot, a qualified diver and paraborne instructor. From January 1998 to November 1999 Skvortsov completed basic space training. He was qualified as a test-cosmonaut in November, 1999. Starting January 2000 he was in ISS advanced training. In March 2008 Skvortsov was assigned to the ISS 21/22 backup crew as a flight engineer and Soyuz TMA commander.

AUGUST 2009

THIS PAGE INTENTIONALLY BLANK

5. ISS-23 FE: Tracy Caldwell Dyson, Ph.D., 40

PERSONAL DATA: Born in Arcadia, California. Married to George Dyson. Tracy enjoys sports, hiking, and auto repair/maintenance. She competed in intercollegiate Track & Field at CSUF as both a sprinter and long jumper.

EDUCATION: Received B.S. in Chemistry from the California State University at Fullerton (1993) and Ph.D. in Chemistry from the University of California at Davis (1997).

SPECIAL HONORS: NASA Go the Extra Mile (GEM) Award (2001), NASA Superior Accomplishment Award (2000), Outstanding Doctoral Student Award in Chemistry from UC Davis (1997), Patricia Roberts Harris Graduate Fellowship in Chemistry (1993-1997). Lyle Wallace Award for Service to the Department of Chemistry, CSU Fullerton (1993). National Science Foundation Research Experience for Undergraduates Award, (1992). Council of Building & Construction Trades Scholarship (1991 & 1992). Big West Scholar Athlete (1989-1991).

EXPERIENCE: As an undergraduate researcher at CSU Fullerton, Caldwell designed, constructed and implemented electronics and hardware associated with a laser-ionization, time-of-flight mass spectrometer for studying atmospherically-relevant gas-phase chemistry. During that time she also worked as an electrician/inside wireman for her father's electrical contracting company doing commercial and light industrial type construction. At UC Davis, Caldwell taught general chemistry laboratory and began her graduate research. Her dissertation work focused on investigating molecular-level surface reactivity and kinetics of metal surfaces using electron spectroscopy, laser desorption, and Fourier transform mass spectrometry techniques. She also designed and built peripheral components for a variable temperature, ultra-high vacuum scanning tunneling microscopy system. In 1997, she received the Camille and Henry Drefus Postdoctoral Fellowship in Environmental Science to study atmospheric chemistry at the University of California, Irvine. There she investigated reactivity and kinetics of atmospherically relevant systems using atmospheric pressure ionization mass spectrometry, Fourier transform infrared and ultraviolet absorption spectroscopies. In addition, she developed methods of chemical ionization for spectral interpretation of trace compounds. Dr. Caldwell has published and presented her work in numerous papers at technical conferences and in scientific journals. She is a private pilot and conversational in American Sign Language (ASL) and Russian.

NASA EXPERIENCE: Selected by NASA in June 1998, Caldwell reported for training in August 1998. In 1999, she was first assigned to the Astronaut Office ISS Operations Branch as a Russian Crusader, participating in the testing and integration of Russian hardware and software products developed for ISS. In 2000, she was assigned prime Crew Support Astronaut for the 5th ISS Expedition crew, serving as their representative on technical and operational issues throughout the training and on-orbit phase of their mission. Caldwell has worked inside Mission Control as spacecraft communicator (CAPCOM) for both Space Shuttle and ISS operations, serving also as the lead CAPCOM for ISS Increment 11. Other technical assignments have included flight software verification in the Shuttle Avionics Integration Laboratory (SAIL) and supporting Shuttle launch and landing operations at Kennedy Space Center, Florida. She has logged over 305 hours in space having completed her first space flight on STS-118 in 2007.

SPACE FLIGHT EXPERIENCE: STS-118 (August 8-21, 2007) was the 119th space shuttle flight, the 22nd flight to the International Space Station (ISS), and the 20th flight for Endeavour. During the mission Endeavour's crew successfully added truss segment S5 and a new gyroscope to the ISS. As MS-1, Caldwell assisted in flight deck operations on ascent and also aided in rendezvous/docking operations with the ISS. Caldwell operated Endeavour's robotic arm to maneuver the Orbiter Boom Sensor System (OBSS) and handover the S5 truss segment to the ISS, and also served as the intravehicular or 'IV' crewmember, directing the four spacewalks. Traveling 5.3 million miles in space, the STS-118 mission was completed in 12 days, 17 hours, 55 minutes and 34 seconds.

NOVEMBER 2009

6. ISS-23 FE: Mikhail Kornienko, 50

PERSONAL DATA: Born April 15, 1960, in Syzran, Kuibyshev region, Russia. Married to Irina Kornienko, a medical doctor. They have a grown daughter. His father, Boris G. Kornienko (1928-1965), a military pilot, perished in an airplane crash. His mother, Faina M. Kornienko is retired.

EDUCATION: Graduated from secondary school # 15, Chelyabinsk, Russia, in 1977. From 1981-1987 he studied at the Moscow Aviation Institute named after S. Ordzhonikidze.

EXPERIENCE : Upon graduation from school in 1977, he worked at a radio equipment plant in Chelyabinsk, Russia. In May 1978, Mikhail was called to service in the Soviet Army. He served in the paratrooper forces in Kirovobad, Azerbaidzhan, the USSR. In May 1980, he completed his military service with the rank of a junior sergeant. From 1980-1986 Kornienko worked for the Moscow Militia. At the same time he attended the evening Department of Moscow Aviation Institute. Upon graduation from the Moscow Aviation Institute in 1987, he was qualified as a liquid propellant rocket engines mechanical engineer. In 1986, he resigned from the Militia and entered a mechanical engineering design bureau. During 1986 to 1991 he worked in the Baikonur Launch Facility as a launch equipment specialist.

October 1991 to April 1995 he worked for commercial companies. In October 1995, Kornienko started working at the Energia Rocket/Space Corporation (RSC) as an engineer. He was assigned with developing technical documentation for cosmonaut primary and backup crew tests and training. He took part in EVA tests in simulated zero-gravity at the hydrolab and at the Selen dynamic stand. In the process of this work he acquired experience in organizing extravehicular repair/ refurbishment and assembly activities on the Mir orbital station. He also directly participated in testing the Energia RSC production on the testing ground.

In 1998, Kornienko was selected as a test cosmonaut candidate and, in 1991, following basic training at the Yu. Gagarin Cosmonaut Training Center, was qualified as a test cosmonaut. Since 1999, he has trained in the ISS group. He served on the ISS-8 backup crew as a flight engineer.

In 2005, Kornienko was assigned to the Expedition-15 backup crew.

DECEMBER 2006

THIS PAGE INTENTIONALLY BLANK

STS-131 Crew Photographs


CDR Alan Poindexter


PLT James Dutton


MS1/EV1 Richard Mastracchio

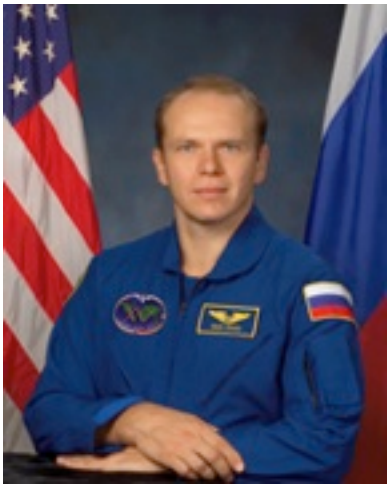

MS2/FE Dorothy M-Lindenburger


MS3 Stephanie Wilson


MS4 Naoko Yamazaki


MS5/EV2 Clayton Anderson

ISS-23 Crew Photographs


ISS-23 CDR Oleg Kotov


ISS-23 FE Soichi Noguchi


ISS-32 FE Timothy Creamer


ISS-23 FE Alexander Skvortsov


ISS-23 FE Tracy Caldwell Dyson


ISS-23 FE Mikhail Kornienko

STS-131 Launch Windows

The launch window for STS-131 is defined by a requirement to launch within about five minutes of the moment Earth's rotation carries the launch pad into the plane of the International Space Station's orbit. To optimize ascent performance, NASA targets the middle of the 10-minute launch window.

Date	Window Open	Launch	Window Close	Space Station Docking
04/05/10	06:16:23 AM	06:21:23 AM	06:26:23 AM	Flight Day 3
			06:29:36 AM	FD 4
04/06/10	05:53:52 AM	05:58:52 AM	06:03:52 AM	FD 3
04/07/10	05:28:09 AM	05:33:09 AM	05:38:09 AM	FD 3
			05:41:23 AM	FD 4
04/08/10	05:05:37 AM	05:10:37 AM	05:15:37 AM	FD 3
04/09/10	04:39:55 AM	04:44:55 AM	04:49:55 AM	FD 3
			04:53:09 AM	FD 4
04/10/10	04:17:24 AM	04:22:24 AM	04:27:24 AM	FD 3
04/11/10	03:52:39 AM	03:56:42 AM	04:01:42 AM	FD 3
			04:04:55 AM	FD 4
04/12/10	03:29:10 AM	03:34:10 AM	03:39:10 AM	FD 3
04/13/10	03:05:46 AM	03:08:28 AM	03:13:28 AM	FD 3
			03:16:41 AM	FD 4
04/14/10	02:40:56 AM	02:45:56 AM	02:50:56 AM	FD 3

STS-131 Launch and Flight Control Personnel

KSC/LCC	Launch Ops	LCC PAO	Fueling PAO
STS-131 LD	Pete Nickolenko	Mike Curie	N/A
STS-131 NTD	Steve Payne		
STS-131 OTC	Lori Sally		

JSC/MCC	Flight Ops	MCC PAO	STS CAPCOM
Space Shuttle			
Ascent FD	Bryan Lunney	Brandi Dean	Rick Sturckow
Weather			George Zamka
Orbit 1 FD (ld)	Richard Jones	Brandi Dean	Rick Sturckow
Orbit 2 FD	Mike Sarafin	Josh Byerly	Aki Hoshide
Planning FD	Ginger Kerrick	Lynnette Madison	Megan McArthur
	Chris Cassidy		
Entry FD	Bryan Lunney	Brandi Dean	Rick Sturckow
Weather			George Zamka
Team 4	Gary Horlacher		
ISS			
Orbit 1	C. McMillan	N/A	Mike Jenson
Orbit 2 (ld)	Ron Spencer	N/A	Stan Love
Orbit 3	Ed van Cise	N/A	Marcus Reagan
Team 4	Brian Smith		

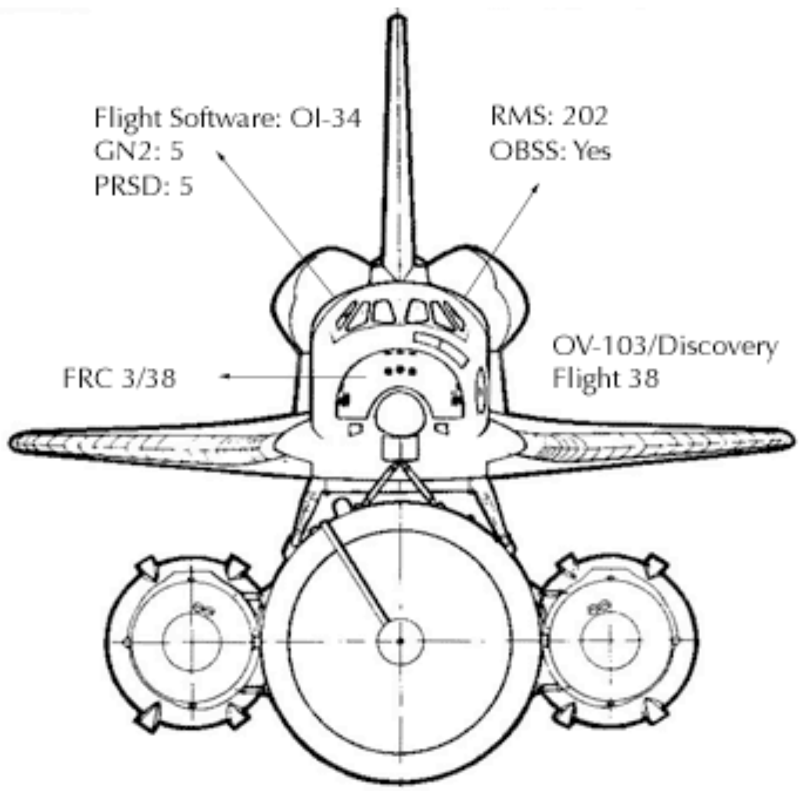
Flight Support	Prime	Backup	Backup
STS manager	John Shannon		
MMT (JSC)	LeRoy Cain		
MMT (KSC)	Mike Moses		
Weather Coord.	John Casper		
Launch STA	Chris Ferguson		
Entry STA (KSC)	Chris Ferguson		
Entry STA (EAFB)	Dom Gorie		
TAL Zaragoza	Rex Walheim		
TAL Istres	Barry Wilmore		
TAL Moron	Dom Gorie		
JSC PAO at KSC	Jenny Knotts		
HQ PAO at KSC	Bob Jacobs	Mike Curie	
Astro Support	Chris Cassidy	Mike Foreman	
Family Support	Steve Frick	Bobby Satcher	Aki Hoshide

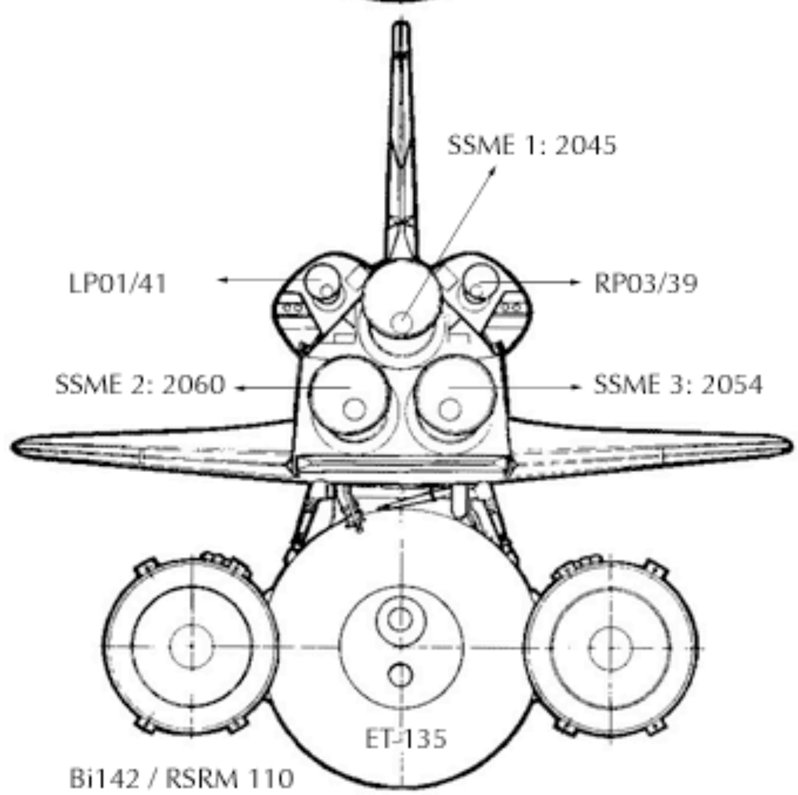
STS-131 Crew	Name	Launch Seating	Entry Seating
Commander	Alan Poindexter	Up-1	Up-1
Pilot	James Dutton	Up-2	Up-2
MS1/EV1	R Mastracchio0	Up-3	Down-7
MS2/FE	Dorothy Metcalf	Up-4	Up-4
MS3	Stephanie Wilson	Down-5	Down-5
MS4	Naoko Yamazaki	Down-6	Down-6
MS5/EV2	Clay Anderson	Down-7	Up-3

Ascent bailout sequence	MS3,MS4,MS5,MS2,MS1,PLT,CDR
Entry bailout sequence	MS3,MS4,MS1,MS2,MS5,PLT,CDR

EVAs	Crew	Suit Markings	IV
EVA-1	Mastracchio	Red stripes	D. Metcalf-L.
	Anderson	Unmarked	
EVA-2	Mastracchio	Red stripes	D. Metcalf-L.
	Anderson	Unmarked	
EVA-3	Mastracchio	Red stripes	D. Metcalf-L.
	Anderson	Unmarked	

STS-131 Flight Hardware/Software





Discovery Flight History

Source: NASA

Discovery (OV-103), the third of NASA's fleet of reusable, winged spaceships, arrived at Kennedy Space Center in November 1983. It was launched on its first mission, flight 41-D, on August 30, 1984. Discovery is named for two famous sailing ships; one sailed by Henry Hudson in 1610-11 to search for a northwest passage between the Atlantic and Pacific Oceans, and the other by James Cook on a voyage during which he discovered the Hawaiian Islands.

FLT	#	STS#	DD	HH	MM	SS	Launch	Mission Notes
N/A		41D	00	00	00	00	06/02/84	Flight readiness firing
N/A		41D	00	00	00	00	06/26/84	RSLS abort: SSME-3 MFV
01	12	41D	06	00	56	04	08/30/84	SBS, Syncom, Telstar
02	14	51A	07	23	44	56	11/07/84	Westar, Palapa retrieval
03	15	51C	03	01	33	23	01/24/85	DOD (Magnum?)
04	16	51D	06	23	55	23	04/12/85	Telesat, Syncom; EVA
05	18	51G	07	01	38	52	06/17/85	Morelos, Arabsat, Telstar
06	20	51I	07	02	17	42	08/27/85	ASC, Aussat, Syncom
N/A		26	00	00	00	00	08/10/88	FRF
07	26	26	04	01	00	11	09/29/88	TDRS-3 (return to flight)
08	28	29	04	23	38	50	03/13/89	TDRS-4
09	32	33	05	00	06	48	11/22/89	DOD
10	35	31	05	01	16	06	04/24/90	Hubble Space Telescope
11	36	41	04	02	10	04	10/06/90	Ulysses solar probe
12	40	39	08	07	22	23	04/28/91	DOD/SDI (unclassified)
13	43	48	05	08	27	38	09/12/91	UARS
14	45	42	08	01	14	44	01/22/92	IML-1
15	52	53	07	07	19	47	12/02/92	DOD-1 (payload classified)
16	54	56	09	06	08	24	04/08/93	ATLAS-2
N/A		51	00	00	00	00	08/12/93	RSLS abort
17	57	51	09	20	11	11	09/12/93	ACTS, SPAS
18	60	60	08	07	09	22	02/03/94	WSF-1, Russian MS
19	64	64	10	22	49	57	09/09/94	LITE, SAFER, SPIFEX; EVA
20	67	63	08	06	28	15	02/03/95	Mir-1, Spartan, EVA
21	70	70	08	22	20	07	07/13/95	TDRS-G
22	82	82	09	23	37	09	02/11/97	HST Servicing Mission
23	86	85	11	20	26	59	08/07/97	CRISTA-SPAS
24	91	91	09	19	53	57	06/02/98	Mir Docking No. 9
25	92	95	08	21	43	57	10/29/98	Spartan-201R; John Glenn
26	94	96	09	19	13	01	05/27/99	ISS 2A.1
27	96	103	07	23	10	47	12/19/99	HST SM-3A
28	100	92	12	22	21	41	10/11/00	ISS 3A
29	103	102	12	19	49	32	03/08/01	ISS 5A.1
30	106	105	11	21	12	44	08/10/01	ISS 7A.1
31	114	114	13	21	32	48	07/26/05	ISS ULF-1
32	115	121	12	18	36	48	07/04/06	ISS ULF-1.1
33	117	116	12	20	44	24	12/09/06	ISS 12A.1
34	120	120	15	02	23	00	10/23/07	ISS 10A
35	123	124	13	18	13	07	05/31/08	ISS 1J
36	125	119	12	19	29	33	03/15/09	ISS 15A
37	128	128	13	20	53	45	08/28/09	ISS-17A
	Vehicle Total		**337**	**01**	**13**	**19**		

THIS PAGE INTENTIONALLY BLANK

STS-131 Countdown Timeline

Editor's Note…
All times up to and including the start of the final hold at T-minus nine minutes are targeted for the opening of the planar window. By convention, NASA rounds these times down in all cases.

EDT	EVENT
Fri 04/02/10	
02:30 AM	Call to stations
03:00 AM	Countdown begins
12:00 PM	Crew sleep begins
01:00 PM	Fuel cell reactant load preps
06:30 PM	MEC/SRB power up
07:00 PM	Clear crew module
07:00 PM	Begin 4-hour built-in hold
07:00 PM	Clear blast danger area
07:45 PM	Orbiter pyro-initiator controller test
07:55 PM	SRB PIC test
08:00 PM	Crew wakeup
08:55 PM	Master events controller pre-flight BITE test
11:00 PM	Resume countdown
Sat 04/03/10	
12:30 AM	Fuel cell oxygen loading begins
03:00 AM	Fuel cell oxygen load complete
03:00 AM	Fuel cell hydrogen loading begins
05:30 AM	Fuel cell hydrogen loading complete
06:30 AM	Pad open; ingress white room
07:00 AM	Begin 9-hour built-in hold
07:00 AM	PRSD offload
09:00 AM	Crew module clean and vacuum
12:00 PM	Crew sleep begins
12:30 PM	OMBUU demate
01:00 PM	Remove APU vent covers
01:30 PM	MPS 2000 psi GSE
04:00 PM	Countdown resumes
04:00 PM	Main engine preps
04:00 PM	MECs 1 and 2 on; avionics system checkout
06:00 PM	FRCS Tyvek cover remova/inspect
08:00 PM	Crew wakeup
10:30 PM	Deflate RSS dock seals; tile inspection
11:00 PM	Tile inspection
11:00 PM	TSM prepped for fueling

EDT	EVENT
Sun 04/04/10	
12:00 AM	Begin 13-hour 56-minute hold
12:00 AM	L-1 engineering briefing
12:15 AM	Crew weather briefing
12:30 AM	Crew orbiter/payload briefings
01:00 AM	NASA TV coverage of Soyuz TMA-18 docking
01:28 AM	Soyuz TMA-18 docking with ISS
01:30 AM	ASP crew module inspection
01:30 AM	OIS communications check
03:20 AM	JSC flight control team on station
03:30 AM	Comm activation
04:00 AM	Crew module voice checks
04:30 AM	Soyuz TMA-18/ISS hatch opening
05:00 AM	Flight crew equipment late stow
09:30 AM	RSS to park position
10:30 AM	Final TPS, debris inspection
11:00 AM	Ascent switch list
12:00 PM	Crew sleep begins
01:56 PM	Resume countdown
02:16 PM	Pad clear of non-essential personnel
02:16 PM	APU bite test
03:06 PM	Fuel cell activation
03:56 PM	Booster joint heater activation
04:26 PM	MEC pre-flight bite test
04:41 PM	Tanking weather update
05:26 PM	Final fueling preps; launch area clear
05:56 PM	Red crew assembled
06:41 PM	Fuel cell integrity checks complete
06:56 PM	Begin 2-hour built-in hold (T-minus 6 hours)
07:06 PM	Safe-and-arm PIC test
07:56 PM	External tank ready for loading
08:00 PM	Crew wakeup
08:19 PM	Mission management team tanking meeting
08:45 PM	NASA TV fueling coverage begins
08:56 PM	Resume countdown (T-minus 6 hours)
08:56 PM	LO2, LH2 transfer line chilldown
09:00 PM	Final crew medical checks
09:06 PM	Main propulsion system chill down
09:06 PM	LH2 slow fill
09:36 PM	LO2 slow fill
09:41 PM	Hydrogen ECO sensors go wet
09:46 PM	LO2 fast fill
09:49 PM	Crew medical checks
09:56 PM	LH2 fast fill
11:51 PM	LH2 topping
11:56 PM	LH2 replenish
11:56 PM	LO2 replenish

EDT	EVENT
11:56 PM	Begin 2-hour 30-minute built-in hold (T-minus 3 hours)
11:56 PM	Closeout crew to white room
11:56 PM	External tank in stable replenish mode
Mon 04/05/10	
12:11 AM	Astronaut support personnel comm checks
12:41 AM	Pre-ingress switch reconfig
01:15 AM	NASA TV launch coverage begins
01:56 AM	Final crew weather briefing
02:01 AM	Crew suit up begins
02:26 AM	Resume countdown (T-minus 3 hours)
02:31 AM	Crew departs O&C building
03:01 AM	Crew ingress
03:51 AM	Astronaut comm checks
04:16 AM	Hatch closure
04:46 AM	White room closeout
05:06 AM	Begin 10-minute built-in hold (T-minus 20m)
05:16 AM	NASA test director countdown briefing
05:16 AM	Resume countdown (T-minus 20m)
05:17 AM	Backup flight computer to OPS 1
05:21 AM	KSC area clear to launch
05:27 AM	Begin final built-in hold (T-minus 9m)
05:57:23 AM	NTD launch status verification
06:12:23 AM	Resume countdown (T-minus 9m)
06:16:23 AM	Orbiter access arm retraction
06:16:23 AM	Launch window opens
06:16:23 AM	Hydraulic power system (APU) start
06:16:28 AM	Terminate LO2 replenish
06:17:23 AM	Purge sequence 4 hydraulic test
06:17:23 AM	IMUs to inertial
06:17:28 AM	Aerosurface profile
06:17:53 AM	Main engine steering test
06:18:28 AM	LO2 tank pressurization
06:18:48 AM	Fuel cells to internal reactants
06:18:53 AM	Clear caution-and-warning memory
06:19:23 AM	Crew closes visors
06:19:26 AM	LH2 tank pressurization
06:20:33 AM	SRB joint heater deactivation
06:20:52 AM	Shuttle GPCs take control of countdown
06:21:02 AM	SRB steering test
06:21:16 AM	Main engine start (T-6.6 seconds)
06:21:23 AM	**SRB ignition (LAUNCH)**

THIS PAGE INTENTIONALLY BLANK

STS-131 Weather Guidelines[5]

Landing Weather Flight Rules
All criteria refer to observed and forecast weather conditions except for the first day PLS, which is forecast weather only. Weather Flight Rules become more conservative for on-board or ground equipment problems. To launch, the RTLS forecast must be GO and at least one of the TAL sites must be GO.

RTLS / TAL / AOA / PLS Criteria
For RTLS (Return To Launch Site) with redundant MLS (Microwave Landing System) capability and a weather reconnaissance aircraft: The RTLS forecast must be GO to launch.

Cloud coverage 4/8 or less below 5,000 feet and a visibility of 4 statute miles or greater are required.

Wind (Peak): Crosswind component may not exceed 15 knots. Headwind may not exceed 25 knots. Tailwind may not exceed 15 knots. Peak winds must not be greater than 10 knots over the average wind.

Turbulence must not be greater than moderate intensity.

No thunderstorms, lightning, or precipitation within 20 nautical miles of the runway, or within 10 nautical miles of the final approach path extending outward to 30 nautical miles from the end of the runway. The 20 nautical mile standoff from the runway approximates the 10 nautical mile standoff to approaches at both ends of the runway. Under specific conditions, light rain showers are permitted within the 20 nautical mile radius providing they meet explicit criteria.

No detached opaque thunderstorm anvils less than three hours old within 15 nautical miles of the runway, or within 5 nautical miles of the final approach path extending outward to 30 nautical miles from the end of the runway.

For TAL (Trans-oceanic Abort Landing) sites with redundant MLS (Microwave Landing System) capability and a weather reconnaissance aircraft: To launch, at least one of the TAL sites must be GO.

Cloud coverage 4/8 or less below 5,000 feet and a visibility of 5 statute miles or greater are required.

Wind (Peak): Crosswind component may not exceed 15 knots. Headwind may not exceed 25 knots. Tailwind may not exceed 15 knots. Peak winds must not be greater than 10 knots over the average wind.

Turbulence must not be greater than moderate intensity.

No thunderstorms, lightning, or precipitation within 20 nautical miles of the runway, or within 10 nautical miles of the final approach path extending outward to 30 nautical miles from the end of the runway. The 20 nautical mile standoff from the runway approximates the 10 nautical mile standoff along the approaches to both ends of the runway. Under specific conditions, light rain showers are permitted within the 20 nautical mile radius providing they meet explicit criteria.

No detached opaque thunderstorm anvils less than three hours old within 15 nautical miles of the runway, or within 5 nautical miles of the final approach path extending outward to 30 nautical miles from the end of the runway.

---

[5] Source: Spaceflight Meteorology Group, Johnson Space Center

For AOA (Abort Once Around) sites:

Cloud coverage 4/8 or less below 8,000 feet and a visibility of 5 statute miles or greater is required.

Wind (Peak): Crosswind component may not exceed 15 knots (PLS night landing crosswind may not exceed 12 knots). Headwind may not exceed 25 knots. Tailwind may not exceed 15 knots. Peak winds must not be greater than 10 knots over the average wind.

Turbulence must not be greater than moderate intensity.

No thunderstorms, lightning, or precipitation within 30 nautical miles of the runway. The 30 nautical mile standoff from the runway approximates the 20 nautical mile standoff along the approaches to both ends of the runway.

No detached opaque thunderstorm anvil cloud less than 3 hours old within 20 nautical miles of the runway or within 10 nautical miles of the final approach path extending to 30 nautical miles from the end of the runway.

For first day PLS (Primary Landing Sites):

Cloud coverage 4/8 or less below 8,000 feet and a visibility of 5 statute miles or greater is required.

Wind (Peak): Crosswind component may not exceed 15 knots (PLS night landing crosswind may not exceed 12 knots). Headwind may not exceed 25 knots. Tailwind may not exceed 15 knots. Peak winds must not be greater than 10 knots over the average wind.

Turbulence must not be greater than moderate intensity.

No thunderstorms, lightning, or precipitation within 30 nautical miles of the runway. The 30 nautical mile standoff from the runway approximates the 20 nautical mile standoff along the approaches to both ends of the runway.

No detached opaque thunderstorm anvil cloud less than 3 hours old within 20 nautical miles of the runway or within 10 nautical miles of the final approach path extending to 30 nautical miles from the end of the runway.

End-of-Mission Landing Weather Flight Rules:

Cloud coverage of 4/8 or less below 8,000 feet and a visibility of 5 miles or greater required.

Wind (Peak): Daylight crosswind component may not exceed 15 knots (12 knots at night). Headwind may not exceed 25 knots. Tailwind may not exceed 15 knots. Peak winds must not be greater than 10 knots over the average wind. Turbulence must not be greater than moderate intensity.

No thunderstorms, lightning, or precipitation within 30 nautical miles of the runway. The 30 nautical mile standoff from the runway approximates the 20 nautical mile standoff along the approaches to both ends of the runway.

Detached opaque thunderstorm anvils less than three hours old must not be within 20 nautical miles of the runway or within 10 nautical miles of the flight path when the orbiter is within 30 nautical miles of the runway.

Consideration may be given for landing with a "no go" observation and a "go" forecast if at decision time analysis clearly indicates a continuing trend of improving weather conditions, and the forecast states that all weather criteria will be met at\ landing time.

Weather Terms (Abbreviated Listing)

Cloud Coverage:

SKC	Sky Clear	(No clouds)
FEW	Few	
SCT	Scattered	(3/8 or 4/8 cloud coverage)
BKN*	Broken	(5/8 through 7/8 cloud coverage)
OVC*	Overcast	(8/8 cloud coverage)

* BKN and OVC are considered cloud ceilings

Cloud Height: Heights in hundreds of feet above ground level (e.g. 025 = 2,500 ft; 250 = 25,000 ft.)
Visibility: Distance in statute miles

The speed is in knots (1 knot = 1.15 MPH), typically given in average and peak (e.g. 10P16)

THIS PAGE INTENTIONALLY BLANK

STS-131 Ascent Events Summary

Flight Data	EST	L-MM:SS	Terminal Countdown			Realtime
STS-130	5:27:23 AM	Variable	**T-9 hold begins**			-44:01:14
5-Apr-10	6:12:23 AM	L-09:00	Resume countdown			-44:46:14
05:21:23 AM	6:16:23 AM	L-07:30	Orbiter access arm retraction			-44:50:14
Win Close	6:16:23 AM	L-05:00	Auxilliary power unit start			-44:50:14
05:26:23 AM	6:16:28 AM	L-04:55	Liquid oxygen drainback begins			-44:50:19
-44:00:14	6:17:23 AM	L-04:00	Purge sequence 4 hydraulic test			-44:51:14
	6:17:23 AM	L-04:00	IMUs to inertial			-44:51:14
SLF Max Wind:	6:18:28 AM	L-02:55	Oxygen tank at flight pressure			-44:52:19
TBD	6:18:48 AM	L-02:35	Fuel cells to internal			-44:52:39
Wind Direction:	6:18:53 AM	L-02:30	Clear caution-and-warning			-44:52:44
TBD	6:19:26 AM	L-01:57	Hydrogen tank at flight pressure			-44:53:17
SLF Crosswind:	6:20:52 AM	L-00:31	Shuttle computers control countdown			-44:54:43
TBD	6:21:02 AM	L-00:21	Booster steering test			-44:54:53
TBD	6:21:16 AM	L-00:06.6	Main engine ignition			-44:55:07
Abort Data		**L+MM:SS**	**Ascent Events Timeline**	**MPH**	**FPS**	
0:02:35	**5:21:23 AM**	**T+00:00**	**LAUNCH**			-43:55:14
RTLS	5:21:33 AM	T+00:10	START ROLL MANEUVER	921	1,350	-43:55:24
ONLY	5:21:41 AM	T+00:18	END ROLL MANEUVER	1,016	1,490	-43:55:32
	5:22:01 AM	T+00:38	START THROTTLE DOWN (72%)	1,316	1,930	-43:55:52
	5:22:15 AM	T+00:52	START THROTTLE UP (104.5%)	1,493	2,190	-43:56:06
	5:22:22 AM	T+00:59	MAX Q (695 psf)	1,602	2,350	-43:56:13
	5:23:28 AM	T+02:05	SRB STAGING	3,648	5,350	-43:57:19
	5:23:38 AM	T+02:15	START OMS ASSIST (1:44 duration)	3,771	5,530	-43:57:29
0:02:36	5:23:58 AM	T+02:35	2E TAL MORON (104.5%, 2s)	4,023	5,900	-43:57:49
TAL	5:24:04 AM	T+02:41	2E TAL ZARAGOZA (104.5%, 2s)	4,091	6,000	-43:57:55
	5:24:15 AM	T+02:52	2E TAL ISTRES (104.5%, 2s)	4,296	6,300	-43:58:06
	5:25:10 AM	T+03:47	NEGATIVE RETURN (KSC) (104.5%, 3s)	5,455	8,000	-43:59:01
0:01:04	5:26:34 AM	T+05:11	PRESS TO ATO (104.5%, 2s, 160 u/s)	7,705	11,300	-44:00:25
ATO	5:26:47 AM	T+05:24	DROOP ZARAGOZA (109%,0s)	8,114	11,900	-44:00:38
	5:27:10 AM	T+05:47	ROLL TO HEADS UP	9,014	13,220	-44:01:01
	5:27:24 AM	T+06:01	1E OPS-3 ZARAGOZA (109%,0s,2EO SIMO)	9,546	14,000	-44:01:15
	5:27:27 AM	T+06:04	1E TAL ZARAGOZA (104.5%,2s,2EO SIMO)	9,751	14,300	-44:01:18
	5:27:38 AM	T+06:15	PRESS TO MECO (104.5%, 2s, 160 u/s)	10,160	14,900	-44:01:29
MECO Ha/Hp	5:27:38 AM	T+06:15	1E TAL MORON (109%,0s,2EO SEQ,1st EO @ VI)	11,046	16,200	-44:01:29
	5:27:38 AM	T+06:15	1E TAL ISTRES (109%,0s,2EO SEQ,1st EO @ VI)	11,456	16,800	-44:01:29
136 X 36 sm	5:28:19 AM	T+06:56	1E PRESS-TO-MECO (104.5%, 2s, 592 u/s)	12,137	17,800	-44:02:10
	5:28:43 AM	T+07:20	NEGATIVE MORON (2@67%)	13,501	19,800	-44:02:34
OMS-2 Ha/Hp	5:29:05 AM	T+07:42	LAST 2E PRE-MECO TAL ZARAGOZA (2@67%)	14,865	21,800	-44:02:56
142 X 98 sm	5:29:05 AM	T+07:42	NEGATIVE ISTRES (2@67%)	14,865	21,800	-44:02:56
	5:29:11 AM	T+07:48	LAST 1E PRE-MECO TAL ZARAGOZA (104.5%)	15,342	22,500	-44:03:02
	5:29:17 AM	T+07:54	23K	15,683	23,000	-44:03:08
	5:29:17 AM	T+07:54	LAST 3E PRE-MECO TAL ZARAGOZA (3@67%)	15,683	23,000	-44:03:08
	5:29:41 AM	T+08:18	LAST TAL DIEGO GARCIA	17,252	25,300	-44:03:32
	5:29:47 AM	T+08:24	MECO COMMANDED	17,592	25,800	-44:03:38
	5:29:53 AM	T+08:30	ZERO THRUST	17,606	25,820	-44:03:44
			Compiled by William Harwood	**Inertial Velocity**		

STS-131 Trajectory Data[6]

T+ MM:SS	Thrust (%)	Altitude FT	Mach Number	Vrelative MPH	Vinertial MPH	Gs	Range (sm)
00:00	100.0	-23	0.0	0.0	914.4	0.3	0.0
00:10	104.5	937	0.2	136.4	926.0	1.7	0.0
00:20	104.5	4,280	0.4	319.8	1,056.9	1.9	0.1
00:30	104.5	9,518	0.6	502.5	1,199.4	1.8	0.5
00:40	82.0	17,528	0.9	689.4	1,356.3	1.7	1.2
00:50	72.0	26,431	1.1	825.8	1,481.7	1.7	2.2
01:00	104.5	36,709	1.4	998.3	1,635.8	2.0	3.4
01:10	104.5	50,396	1.9	1,264.2	1,879.9	2.3	5.1
01:20	104.5	65,336	2.4	1,581.3	2,195.7	2.5	7.2
01:30	104.5	84,273	2.9	1,972.7	2,598.0	2.5	10.4
01:40	104.5	103,355	3.3	2,348.4	2,983.9	2.5	14.2
01:50	104.5	125,992	3.8	2,760.2	3,405.3	2.2	19.4
02:00	104.5	147,150	4.0	2,953.9	3,609.9	1.0	25.0
02:10	104.5	168,718	4.1	3,052.1	3,720.3	1.0	31.4
02:20	104.5	187,826	4.2	3,166.6	3,847.2	1.0	37.8
02:30	104.5	207,545	4.5	3,309.2	4,000.6	1.0	45.3
02:40	104.5	224,288	5.0	3,451.7	4,151.3	1.1	52.5
02:50	104.5	239,915	5.4	3,605.8	4,311.5	1.1	60.1
03:00	104.5	255,838	5.9	3,787.8	4,499.7	1.1	69.0
03:10	104.5	269,182	6.3	3,965.1	4,680.4	1.1	77.5
03:20	104.5	282,640	6.7	4,172.4	4,890.4	1.2	87.5
03:30	104.5	293,790	7.2	4,371.5	5,091.6	1.2	97.0
03:40	104.5	303,930	7.4	4,580.9	5,301.6	1.2	107.1
03:50	104.5	313,944	7.6	4,822.9	5,543.7	1.3	118.7
04:00	104.5	322,034	7.8	5,051.4	5,772.1	1.3	129.8
04:10	104.5	329,865	8.1	5,313.9	6,033.3	1.3	142.7
04:20	104.5	336,044	8.3	5,563.5	6,282.2	1.4	155.0
04:30	104.5	341,843	8.5	5,850.5	6,567.2	1.4	169.2
04:40	104.5	346,238	8.8	6,122.6	6,837.2	1.5	182.8
04:50	104.5	349,830	9.1	6,406.3	7,118.8	1.5	197.0
05:00	104.5	352,897	9.5	6,731.5	7,442.0	1.6	213.4
05:10	104.5	354,925	9.9	7,040.4	7,748.2	1.6	229.0
05:20	104.5	356,368	10.3	7,395.0	8,100.0	1.7	247.0
05:30	104.5	357,010	10.8	7,731.1	8,433.5	1.7	264.1
05:40	104.5	357,061	11.3	8,082.3	8,781.9	1.8	282.1
05:50	104.5	356,492	11.8	8,486.7	9,182.9	1.9	302.7
06:00	104.5	355,483	12.4	8,870.6	9,564.0	2.0	322.4
06:10	104.5	353,998	13.1	9,311.1	10,001.8	2.0	345.1
06:20	104.5	352,431	13.7	9,731.8	10,419.1	2.1	366.7
06:30	104.5	350,454	14.5	10,222.7	10,906.7	2.2	391.5
06:40	104.5	348,393	15.3	10,693.9	11,374.4	2.4	415.3
06:50	104.5	346,175	16.1	11,190.3	11,867.4	2.5	440.1
07:00	104.5	343,687	17.0	11,767.9	12,441.6	2.6	468.7
07:10	104.5	341,521	18.0	12,325.6	12,995.9	2.8	496.0
07:20	104.5	339,403	19.1	12,979.6	13,646.4	3.0	527.5
07:30	98.0	337,884	20.1	13,590.5	14,254.0	3.0	557.7
07:40	92.0	336,868	21.0	14,203.5	14,863.6	3.0	589.2

[6] Predicted data. Inertial velocity includes Earth's rotation.

T+ MM:SS	Thrust (%)	Altitude FT	Mach Number	Vrelative MPH	Vinertial MPH	Gs	Range (sm)
07:50	86.0	336,431	22.1	14,878.6	15,534.6	3.0	625.5
08:00	80.0	336,780	23.0	15,492.3	16,145.5	3.0	659.9
08:10	75.0	338,149	23.9	16,166.0	16,816.5	3.0	699.4
08:20	67.0	340,490	24.6	16,782.4	17,430.2	2.8	738.0
08:30	67.0	343,640	24.7	16,958.3	17,605.4	0.0	777.8
08:31	67.0	343,951	24.7	16,958.3	17,605.4	0.0	781.7
08:32	67.0	344,261	24.7	16,958.3	17,605.4	0.0	785.5
08:33	67.0	344,573	24.6	16,958.3	17,605.4	0.0	789.4
08:34	67.0	344,650	24.6	16,958.3	17,605.4	0.0	793.3

THIS PAGE INTENTIONALLY BLANK

STS-131 Flight Plan

Editor's Note…
Current as of 04/01/10

ACRONYMS: OMS: orbital maneuvering system rockets; RMS: shuttle robot arm; SSRMS: station robot arm; EMU: shuttle spacesuits; group B: backup computer powerdown/powerup; SAFER: spacewalk jet backpack; EVA: spacewalk; PMA: pressurized mating adaptor; FGB: Zarya core module; SM: Zvezda command module; PAO: public affairs office; FCS: flight control system; RCS: reaction control system rockets

DATE/ET	DD	HH	MM	SS	EVENT
Flight Day 1					
04/05					
Mon 06:21 AM	00	00	00	00	Launch
Mon 06:58 AM	00	00	37	03	OMS-2 rocket firing
Mon 07:11 AM	00	00	50	00	Post insertion timeline begins
Mon 08:51 AM	00	02	30	00	Laptop computer setup (part 1)
Mon 08:51 AM	00	02	30	00	GIRA installation
Mon 09:07 AM	00	02	46	35	NC-1 rendezvous rocket firing
Mon 09:51 AM	00	03	30	00	SEE setup
Mon 10:16 AM	00	03	55	00	Group B computer powerdown
Mon 10:21 AM	00	04	00	00	Wing leading edge sensors activated
Mon 10:31 AM	00	04	10	00	ET umbilical downlink
Mon 10:41 AM	00	04	20	00	ET photo
Mon 10:56 AM	00	04	35	00	ET video downlink
Mon 12:21 PM	00	06	00	00	Crew sleep begins
Flight Day 2					
Mon 08:21 PM	00	14	00	00	Crew wakeup
Mon 09:56 PM	00	15	35	17	NC-2 rendezvous rocket firing
Mon 10:51 PM	00	16	30	00	SRMS powerup
Mon 11:06 PM	00	16	45	00	SRMS checkout
Mon 11:21 PM	00	17	00	00	Ergometer setup
Mon 11:51 PM	00	17	30	00	SRMS unberths OBSS
Mon 11:51 PM	00	17	30	00	Spacesuit checkout preps
04/06					
Tue 12:21 AM	00	18	00	00	Spacesuit checkout
Tue 01:06 AM	00	18	45	00	OBSS starboard wing survey
Tue 01:51 AM	00	19	30	00	Spacesuit prepped for transfer to station
Tue 03:01 AM	00	20	40	00	Crew meals begin
Tue 03:11 AM	00	20	50	00	OBSS nose cap survey
Tue 04:01 AM	00	21	40	00	OBSS port wing survey
Tue 05:01 AM	00	22	40	00	Middeck transfer preps
Tue 06:16 AM	00	23	55	00	SRMS berths OBSS
Tue 07:21 AM	01	01	00	00	Rendezvous tools checkout
Tue 07:36 AM	01	01	15	00	LDRI downlink
Tue 08:36 AM	01	02	15	00	Centerline camera setup
Tue 09:20 AM	01	02	58	37	NC-3 rendezvous rocket firing
Tue 09:36 AM	01	03	15	00	Orbiter docking system ring extension

DATE/ET	DD	HH	MM	SS	EVENT
Tue 12:21 PM	01	06	00	00	Crew sleep begins
Flight Day 3					
Tue 08:21 PM	01	14	00	00	STS/ISS crew wakeup
Tue 09:36 PM	01	15	15	00	ISS daily planning conference
Tue 09:51 PM	01	15	30	00	Group B computer powerup
Tue 10:06 PM	01	15	45	00	Rendezvous timeline begins
Tue 11:31 PM	01	17	10	00	Spacesuit removal from airlock
Tue 11:34 PM	01	17	13	26	NC-4 rendezvous rocket firing
04/07					
Wed 01:06 AM	01	18	45	02	TI burn
Wed 02:26 AM	01	20	05	00	Approach timeline begins
Wed 02:41 AM	01	20	20	00	RPM photography starts
Wed 03:44 AM	01	21	23	00	DOCKING
Wed 04:11 AM	01	21	50	00	Leak checks
Wed 04:46 AM	01	22	25	00	Orbiter docking system prepped for ingress
Wed 04:41 AM	01	22	20	00	Group B computer powerdown
Wed 05:11 AM	01	22	50	00	Hatch open
Wed 05:41 AM	01	23	20	00	Welcome aboard!
Wed 05:56 AM	01	23	35	00	Safety briefing
Wed 06:26 AM	02	00	05	00	Spacesuits moved to ISS
Wed 06:26 AM	02	00	05	00	SRMS OBSS handoff
Wed 07:51 AM	02	01	30	00	REBA checkout
Wed 09:26 AM	02	03	05	00	Video playback ops
Wed 09:31 AM	02	03	10	00	ISS evening planning conference
Wed 11:51 AM	02	05	30	00	ISS crew sleep begins
Wed 12:21 PM	02	06	00	00	STS crew sleep begins
Flight Day 4					
Wed 08:21 PM	02	14	00	00	Crew wakeup
Wed 09:56 PM	02	15	35	00	ISS daily planning conference
Wed 10:21 PM	02	16	00	00	SSRMS grapples MPLM
Wed 10:51 PM	02	16	30	00	SSRMS unberths MPLM
04/08					
Thu 12:11 AM	02	17	50	00	SSRMS installs MPLM
Thu 12:36 AM	02	18	15	00	MPLM first stage bolts
Thu 12:56 AM	02	18	35	00	MPLM second stage bolts
Thu 01:11 AM	02	18	50	00	EVA-1: Equipment lock preps
Thu 02:16 AM	02	19	55	00	SSRMS ungrapples MPLM
Thu 02:46 AM	02	20	25	00	Crew meals begin
Thu 03:01 AM	02	20	40	00	MPLM vestibule pressurization
Thu 03:46 AM	02	21	25	00	Middeck transfers
Thu 04:16 AM	02	21	55	00	MPLM vestibule config for ingress
Thu 05:46 AM	02	23	25	00	MPLM activation (part 1)
Thu 07:41 AM	03	01	20	00	MPLM activation (part 2)
Thu 08:01 AM	03	01	40	00	MPLM ingress
Thu 08:16 AM	03	01	55	00	PAO event

DATE/ET	DD	HH	MM	SS	EVENT
Thu 08:46 AM	03	02	25	00	EVA-1: Procedures review
Thu 10:06 AM	03	03	45	00	ISS daily planning conference
Thu 11:16 AM	03	04	55	00	EVA-1: Mask pre-breathe
Thu 12:01 PM	03	05	40	00	EVA-1: Airlock depress to 10.2 psi
Thu 12:21 PM	03	06	00	00	ISS crew sleep begins
Thu 12:51 PM	03	06	30	00	STS crew sleep begins
Flight Day 5					
Thu 08:51 PM	03	14	30	00	Crew wakeup
Thu 09:26 PM	03	15	05	00	EVA-1: Airlock repress/hygiene break
Thu 10:16 PM	03	15	55	00	EVA-1: Airlock depress to 10.2 psi
Thu 10:36 PM	03	16	15	00	ISS daily planning conference
Thu 11:31 PM	03	17	10	00	MPLM transfers
04/09					
Fri 12:06 AM	03	17	45	00	EVA-1: Spacesuit purge
Fri 12:21 AM	03	18	00	00	EVA-1: Spacesuit prebreathe
Fri 01:11 AM	03	18	50	00	EVA-1: Crew lock depressurization
Fri 01:41 AM	03	19	20	00	ZSR transfer
Fri 01:41 AM	03	19	20	00	EVA-1: Spacesuits to battery power
Fri 01:56 AM	03	19	35	00	EVA-1/EV-1: FBG retrieve
Fri 01:56 AM	03	19	35	00	EVA-1/EV-2: S1 ATA FQD release
Fri 02:06 AM	03	19	45	00	ZSR deploy
Fri 02:11 AM	03	19	50	00	EVA-1/EV-1: Payload bay ATA preps
Fri 02:41 AM	03	20	20	00	EVA-1/EV-2: Payload bay ATA preps
Fri 03:11 AM	03	20	50	00	EVA-1: ATA release and handoff
Fri 03:36 AM	03	21	15	00	MELFI transfer
Fri 03:56 AM	03	21	35	00	EVA-1/EV-1: JEM seed retrieval
Fri 03:56 AM	03	21	35	00	EVA-1/EV-2: Payload bay cleanup
Fri 04:36 AM	03	22	15	00	CQ2 transfer
Fri 04:41 AM	03	22	20	00	EVA-1: ABG retrieve and install
Fri 05:26 AM	03	23	05	00	EVA-1: S0 RGA R&R
Fri 05:56 AM	03	23	35	00	EVA-1/EV-2: P6 battery preps
Fri 06:41 AM	04	00	20	00	EVA-1/EV-1: P6 battery preps
Fri 07:26 AM	04	01	05	00	EVA-1: Cleanup
Fri 07:56 AM	04	01	35	00	EVA-1: Airlock ingress
Fri 08:11 AM	04	01	50	25	EVA-1: Airlock repressurization
Fri 08:26 AM	04	02	05	00	Post-EVA servicing
Fri 10:21 AM	04	04	00	00	ISS crew sleep begins
Fri 12:51 PM	04	06	30	00	ISS daily planning conference
Fri 01:21 PM	04	07	00	00	STS crew sleep begins
Flight Day 6					
Fri 09:21 PM	04	15	00	00	Crew wakeup
Fri 10:46 PM	04	16	25	00	ISS daily planning conference
04/10					
Sat 12:21 AM	04	18	00	00	F1 DOUG review
Sat 12:51 AM	04	18	30	00	Focused inspection (if needed)

DATE/ET	DD	HH	MM	SS	EVENT
Sat 12:51 AM	04	18	30	00	MPLM transfers
Sat 12:51 AM	04	18	30	00	WORF transfer
Sat 02:21 AM	04	20	00	00	ZSR transfer
Sat 02:46 AM	04	20	25	00	ZSR Deploy
Sat 03:16 AM	04	20	55	00	ER-7 transfer
Sat 03:46 AM	04	21	25	00	Crew meals begin
Sat 03:46 AM	04	21	25	00	EVA-2: SSRMS maneuver
Sat 04:46 AM	04	22	25	00	PAO event
Sat 05:16 AM	04	22	55	00	ISP install
Sat 05:56 AM	04	23	35	00	EVA-2: Tools configured
Sat 06:16 AM	04	23	55	00	ISP install
Sat 07:16 AM	05	00	55	00	ISP install
Sat 07:16 AM	05	00	55	00	EVA-2: Equipment lock preps
Sat 07:16 AM	05	00	55	00	MPLM pivot install
Sat 08:56 AM	05	02	35	00	PAO educational event
Sat 09:16 AM	05	02	55	00	EVA-2: Procedures review
Sat 10:21 AM	05	04	00	00	ISS evening planning conference
Sat 11:46 AM	05	05	25	00	EVA-2: Mask pre-breathe
Sat 12:31 PM	05	06	10	00	EVA-2: Airlock depress to 10.2 psi
Sat 12:51 PM	05	06	30	00	ISS crew sleep begins
Sat 01:21 PM	05	07	00	00	STS crew sleep begins
Flight Day 7					
Sat 09:21 PM	05	15	00	00	Crew wakeup
Sat 10:01 PM	05	15	40	00	EVA-1: Airlock repress/hygiene break
Sat 10:51 PM	05	16	30	00	EVA-1: Airlock depress to 10.2 psi
Sat 11:21 PM	05	17	00	00	ISS daily planning conference
04/11					
Sun 12:41 AM	05	18	20	00	EVA-2: Spacesuit purge
Sun 12:56 AM	05	18	35	00	EVA-2: Spacesuit prebreathe
Sun 01:46 AM	05	19	25	00	EVA-2: Crew lock depressurization
Sun 02:16 AM	05	19	55	00	EVA-2: Spacesuits to battery power
Sun 02:21 AM	05	20	00	00	EVA-2: Airlock egress
Sun 02:31 AM	05	20	10	00	EVA-2: S1 ATA removal and handoff
Sun 03:31 AM	05	21	10	00	EVA-2: ATA tiedown CETA
Sun 04:16 AM	05	21	55	00	EVA-2: P1 radiator GF beam
Sun 04:46 AM	05	22	25	00	EVA-2: AGB release
Sun 05:16 AM	05	22	55	00	EVA-2: ATA install on S1
Sun 06:01 AM	05	23	40	00	EVA-2/EV-1: S1 ATA connectors
Sun 06:16 AM	05	23	55	00	EVA-2/EV-2: APFR relocate
Sun 06:46 AM	06	00	25	00	EVA-2: CETA ATA release
Sun 07:46 AM	06	01	25	00	EVA-2: Airlock MMOD install
Sun 08:31 AM	06	02	10	00	EVA-2: Cleanup and ingress
Sun 08:46 AM	06	02	25	00	EVA-2: Airlock repressurization
Sun 09:01 AM	06	02	40	00	Spacesuit servicing
Sun 10:46 AM	06	04	25	00	ISS daily planning conference
Sun 01:21 PM	06	07	00	00	ISS crew sleep begins
Sun 01:51 PM	06	07	30	00	STS crew sleep begins

DATE/ET	DD	HH	MM	SS	EVENT
Flight Day 8					
Sun 09:51 PM	06	15	30	00	Crew wakeup
Sun 11:51 PM	06	17	30	00	ISS daily planning conference
04/12					
Mon 12:31 AM	06	18	10	00	SSRMS maneuver
Mon 12:51 AM	06	18	30	00	Crew off duty
Mon 05:21 AM	06	23	00	00	Joint crew meal
Mon 06:26 AM	07	00	05	00	MPLM transfers
Mon 06:51 AM	07	00	30	00	ERCA swap
Mon 07:16 AM	07	00	55	00	MARES stowage configuration
Mon 07:21 AM	07	01	00	00	EVA-3: Tools configured
Mon 08:36 AM	07	02	15	00	Cupola panel install
Mon 08:46 AM	07	02	25	00	EVA-3: Equipment lock preps
Mon 10:16 AM	07	03	55	00	EVA-3: Procedures review
Mon 11:16 AM	07	04	55	00	PAO event
Mon 11:36 AM	07	05	15	00	ISS daily planning conference
Mon 12:46 PM	07	06	25	00	EVA-3: Mask pre-breathe
Mon 01:31 PM	07	07	10	00	EVA-3: Airlock depress to 10.2 psi
Mon 01:51 PM	07	07	30	00	ISS crew sleep begins
Mon 02:21 PM	07	08	00	00	STS crew sleep begins
Flight Day 9					
Mon 10:21 PM	07	16	00	00	STS/ISS crew wakeup
Mon 10:56 PM	07	16	35	00	EVA-3: 14.7 psi repress/hygiene break
Mon 11:46 PM	07	17	25	00	EVA-3: Airlock depress to 10.2 psi
04/13					
Tue 12:21 AM	07	18	00	00	ISS daily planning conference
Tue 01:36 AM	07	19	15	00	EVA-3: Spacesuit purge
Tue 01:51 AM	07	19	30	00	EVA-3: Spacesuit prebreathe
Tue 02:41 AM	07	20	20	00	EVA-3: Crew lock depressurization
Tue 03:11 AM	07	20	50	00	EVA-3: Spacesuits to battery power
Tue 03:16 AM	07	20	55	00	EVA-3: Airlock egress/setup
Tue 03:26 AM	07	21	05	00	EVA-3: AGB stow
Tue 03:56 AM	07	21	35	00	EVA-3: Payload bay setup
Tue 04:26 AM	07	22	05	00	EVA-3: ATA install on LMC
Tue 05:11 AM	07	22	50	00	EVA-3/EV-1: FGB removal and PLB cleanup
Tue 05:11 AM	07	22	50	00	EVA-3/EV-2: SSRMS setup
Tue 05:41 AM	07	23	20	00	EVA-3/EV-2: LWAPA retrieval
Tue 06:11 AM	07	23	50	00	EVA-3/EV-1: LWAPA retrieval
Tue 06:41 AM	08	00	20	00	EVA-3/EV-1: CP13 ETVCG light
Tue 06:41 AM	08	00	20	00	EVA-3/EV-2: SPDM CLPA1 install
Tue 07:41 AM	08	01	20	00	EVA-3/EV-2: SPDN EP1 cover removal
Tue 07:41 AM	08	01	20	00	EVA-3/EV-1: S1 radiator GF beam
Tue 08:11 AM	08	01	50	00	EVA-3/EV-2: SSRMS cleanup
Tue 08:41 AM	08	02	20	00	EVA-3/EV-1: WIFEX release
Tue 08:41 AM	08	02	20	00	EVA-3/EV-2: Get aheads
Tue 09:11 AM	08	02	50	00	EVA-3: Cleanup and ingress

DATE/ET	DD	HH	MM	SS	EVENT
Tue 09:41 AM	08	03	20	00	EVA-3: Airlock repressurization
Tue 09:56 AM	08	03	35	00	Spacesuit servicing
Tue 12:21 PM	08	06	00	00	ISS daily planning conference
Tue 02:51 PM	08	08	30	00	ISS crew sleep begins
Tue 03:21 PM	08	09	00	00	STS crew sleep begins
Flight Day 10					
Tue 11:21 PM	08	17	00	00	Crew wakeup
04/14					
Wed 01:21 AM	08	19	00	00	ISS daily planning conference
Wed 02:11 AM	08	19	50	00	MPLM transfers
Wed 03:51 AM	08	21	30	00	N2N CBM CPA install
Wed 04:56 AM	08	22	35	00	EVA tool restow
Wed 05:36 AM	08	23	15	00	MPLM rack config
Wed 06:11 AM	08	23	50	00	Joint crew meal
Wed 07:11 AM	09	00	50	00	Crew photo
Wed 07:31 AM	09	01	10	00	Crew news conference
Wed 08:21 AM	09	02	00	00	Crew off duty
Wed 12:56 PM	09	06	35	00	ISS daily planning conference
Wed 01:11 PM	09	06	50	00	PAO educational event
Wed 03:51 PM	09	09	30	00	ISS crew sleep begins
Wed 04:21 PM	09	10	00	00	STS crew sleep begins
Flight Day 11					
04/15					
Thu 12:21 AM	09	18	00	00	Crew wakeup
Thu 02:21 AM	09	20	00	00	ISS daily planning conference
Thu 02:36 AM	09	20	15	00	Middeck transfers
Thu 02:51 AM	09	20	30	00	MPLM egress
Thu 03:06 AM	09	20	45	00	MPLM deactivation
Thu 03:26 AM	09	21	05	00	MPLM vestibule demate
Thu 04:56 AM	09	22	35	00	MPLM vestibule depress
Thu 05:21 AM	09	23	00	00	EPO SRMS
Thu 05:51 AM	09	23	30	00	EPO SSRMS
Thu 07:26 AM	10	01	05	00	SSRMS grapples MPLM
Thu 08:41 AM	10	02	20	00	MPLM uninstall
Thu 09:56 AM	10	03	35	00	MPLM install in PLB
Thu 10:11 AM	10	03	50	00	SSRMS ungrapples MPLM
Thu 11:56 AM	10	05	35	00	Farewell ceremony
Thu 12:11 PM	10	05	50	00	Rendezvous tools checkout
Thu 12:11 PM	10	05	50	00	Hatches closed
Thu 12:41 PM	10	06	20	00	ODS leak checks
Thu 12:51 PM	10	06	30	00	Centerline camera install
Thu 01:41 PM	10	07	20	00	Evening planning conference
Thu 03:51 PM	10	09	30	00	ISS crew sleep begins
Thu 04:21 PM	10	10	00	00	STS crew sleep begins

DATE/ET	DD	HH	MM	SS	EVENT
Flight Day 12					
04/16					
Fri 12:21 AM	10	18	00	00	Crew wakeup
Fri 02:21 AM	10	20	00	00	ISS daily planning conference
Fri 02:26 AM	10	20	05	00	Group B computer powerup
Fri 03:16 AM	10	20	55	00	Undocking timeline begins
Fri 03:55 AM	10	21	34	00	Undocking
Fri 05:10 AM	10	22	49	00	Sep 1 burn
Fri 05:38 AM	10	23	17	00	Sep 2 burn
Fri 05:41 AM	10	23	20	00	Crew meals begin
Fri 07:01 AM	11	00	40	00	Group B computer powerdown
Fri 07:11 AM	11	00	50	00	Playback ops
Fri 07:16 AM	11	00	55	00	EVA unpack and stow
Fri 07:41 AM	11	01	20	00	Starboard wing survey
Fri 09:21 AM	11	03	00	00	Nose cap survey
Fri 10:11 AM	11	03	50	00	Port wing survey
Fri 11:56 AM	11	05	35	00	OBSS berthing
Fri 11:56 AM	11	05	35	00	LDRI downlink
Fri 04:21 PM	11	10	00	00	STS crew sleep begins
Flight Day 13					
04/17					
Sat 12:21 AM	11	18	00	00	STS crew wakeup
Sat 03:21 AM	11	21	00	00	Cabin stow begins
Sat 03:41 AM	11	21	20	00	FCS checkout
Sat 04:51 AM	11	22	30	00	RCS hotfire
Sat 05:06 AM	11	22	45	00	PILOT operations
Sat 06:06 AM	11	23	45	00	Deorbit review
Sat 06:36 AM	12	00	15	00	Crew meal
Sat 07:36 AM	12	01	15	00	PAO event
Sat 07:56 AM	12	01	35	00	Cabin stow resumes
Sat 09:16 AM	12	02	55	00	L-1 comm check
Sat 12:46 PM	12	06	25	00	Wing leading edge sensor deact
Sat 12:51 PM	12	06	30	00	Ergometer stow
Sat 01:01 PM	12	06	40	00	PGSC stow (part 1)
Sat 01:11 PM	12	06	50	00	KU antenna stow
Sat 04:21 PM	12	10	00	00	Crew sleep begins
Flight Day 14					
04/18					
Sun 12:21 AM	12	18	00	00	Crew wakeup
Sun 03:25 AM	12	21	04	00	Deorbit timeline begins
Sun 07:27 AM	13	01	06	00	Deorbit ignition (rev. 206)
Sun 08:29 AM	13	02	08	00	Landing at KSC

THIS PAGE INTENTIONALLY BLANK

STS-131 Television Schedule

Editor's note:
NASA's daily video highlights reel will be replayed on the hour during crew sleep periods. The timeing of actual events is subject to change and some events may or may not be carried live on NASA television.

NASA Note: NASA Television is now carried on an MPEG-2 digital signal accessed via satellite AMC-6, at 72 degrees west longitude, transponder 17C, 4040 MHz, vertical polarization. A Digital Video Broadcast (DVB) - compliant Integrated Receiver Decoder (IRD) with modulation of QPSK/DBV, data rate of 36.86 and FEC 3/4 will be needed for reception. NASA mission coverage will be simulcast digitally on the Public Services Channel (Channel #101); the Education Channel (Channel #102) and the Media Services Channel (Channel #103). Further information is available at: http://www1.nasa.gov/multimedia/nasatv/digital.html. Mission Audio can be accessed on AMC-6, Transponder 13, 3971.3 MHz, horizontal polarization.

ORBIT EVENT MET EDT GMT

```
MONDAY, APRIL 5 - FD 1/FD 2
...STS-131 LAUNCH COVERAGE BEGINS......................01:15 AM...06:15
...DISCOVERY LAUNCH.........................00/00:00...06:21 AM...10:21
...MECO.....................................00/00:08...06:29 AM...10:29
1...LAUNCH REPLAYS..........................00/00:13...06:34 AM...10:34
1...ADDITIONAL LAUNCH REPLAYS FROM KSC.......00/00:45...07:06 AM...11:06
1...POST LAUNCH NEWS CONFERENCE.............00/01:09...07:30 AM...11:30
2...PAYLOAD BAY DOOR OPENING................00/01:25...07:46 AM...11:46
3...ASCENT FLIGHT CONTROL TEAM VIDEO REPLAY..00/04:09...10:30 AM...14:30
4...EXTERNAL TANK HANDHELD VIDEO DOWNLINK....00/04:35...10:56 AM...14:56
5...DISCOVERY CREW SLEEP BEGINS.............00/06:00...12:21 PM...16:21
5...FLIGHT DAY 1 HIGHLIGHTS.................00/06:39...01:00 PM...17:00
6...VIDEO FILE..............................00/08:39...03:00 PM...19:00
10...DISCOVERY CREW WAKE UP (FD 2)..........00/14:00...08:21 PM...00:21
12...RMS CHECKOUT...........................00/16:45...11:06 PM...03:06
12...OBSS UNBERTH...........................00/17:30...11:51 PM...03:51

TUESDAY, APRIL 6 - FD 2/FD 3
13...RMS/OBSS SURVEY OF TPS BEGINS..........00/18:45...01:06 AM...05:06
16...MISSION STATUS BRIEFING................00/23:39...06:00 AM...10:00
16...OBSS BERTH.............................00/23:55...06:16 AM...10:16
17...RENDEZVOUS TOOL CHECKOUT...............01/01:00...07:21 AM...11:21
18...ODS RING EXTENSION.....................01/03:10...09:31 AM...13:31
20...DISCOVERY CREW SLEEP BEGINS............01/06:00...12:21 PM...16:21
21...FLIGHT DAY 2 HIGHLIGHTS................01/06:39...01:00 PM...17:00
22...VIDEO FILE.............................01/08:39...03:00 PM...19:00
23...MMT BRIEFING...........................01/10:39...05:00 PM...21:00
26...DISCOVERY CREW WAKE UP (FD 3)..........01/14:00...08:21 PM...00:21
27...RENDEZVOUS OPERATIONS BEGIN............01/15:45...10:06 PM...02:06

WEDNESDAY,  APRIL 7 - FD 3/FD 4
29...TI BURN...01/18:47...01:08 AM...05:08
30...DISCOVERY RPM DOCUMENTATION BEGINS......01/20:21...02:42 AM...06:42
31...DISCOVERY/ISS DOCKING..................01/21:23...03:44 AM...07:44
32...DISCOVERY/ISS CREW HATCH OPENING.......01/23:20...05:41 AM...09:41
```

ORBIT	EVENT	MET	EDT	GMT
32	MISSION STATUS BRIEFING	02/00:09	06:30 AM	10:30
32	SSRMS GRAPPLE & UNBERTH OBSS	02/00:15	06:36 AM	10:36
33	SSRMS HANDOFF OBSS TO SRMS	02/01:00	07:21 AM	11:21
34	SHUTTLE VTR PLAYBACK OF DOCKING	02/03:10	09:31 AM	13:31
36	ISS CREW SLEEP BEGINS	02/05:30	11:51 AM	15:51
36	DISCOVERY CREW SLEEP BEGINS	02/06:00	12:21 PM	16:21
37	FLIGHT DAY 3 HIGHLIGHTS	02/06:39	01:00 PM	17:00
38	VIDEO FILE	02/08:39	03:00 PM	19:00
39	HD FLIGHT DAY 3 CREW HIGHLIGHTS	02/09:39	04:00 PM	20:00
39	MMT BRIEFING	02/09:39	04:00 PM	20:00
40	ISS FLIGHT DIRECTOR UPDATE	02/11:39	06:00 PM	22:00
41	ISS FLIGHT DIRECTOR UPDATE REPLAY	02/13:39	08:00 PM	00:00
41	DISCOVERY/ISS CREW WAKE UP (FD 4)	02/14:00	08:21 PM	00:21
43	SSRMS GRAPPLE & UNBERTH MPLM	02/16:00	10:21 PM	02:21
44	DISCOVERY/ISS TRANSFERS BEGIN	02/17:15	11:36 PM	03:36
44	SSRMS INSTALLS MPLM ON UNITY	02/17:50	12:11 AM	04:11
	THURSDAY, APRIL 8 - FD 4/FD 5			
45	MISSION STATUS BRIEFING	02/19:39	02:00 AM	06:00
48	MPLM ACTIVATION BEGINS	02/23:25	05:46 AM	09:46
49	MPLM INGRESS	03/01:40	08:01 AM	12:01
49	U.S. PAO EVENT	03/01:55	08:16 AM	12:16
49	EVA # 1 CREW PROCEDURE REVIEW	03/02:15	08:36 AM	12:36
51	EVA # 1 CAMPOUT BEGINS	03/04:55	11:16 AM	15:16
52	ISS CREW SLEEP BEGINS	03/06:00	12:21 PM	16:21
52	DISCOVERY CREW SLEEP BEGINS	03/06:30	12:51 PM	16:51
52	FLIGHT DAY 4 HIGHLIGHTS	03/06:39	01:00 PM	17:00
54	VIDEO FILE	03/08:39	03:00 PM	19:00
54	HD FLIGHT DAY 4 CREW HIGHLIGHTS	03/09:39	04:00 PM	20:00
54	MMT BRIEFING	03/09:39	04:00 PM	20:00
56	ISS FLIGHT DIRECTOR UPDATE	03/11:39	06:00 PM	22:00
57	ISS FLIGHT DIRECTOR UPDATE REPLAY	03/14:09	08:30 PM	00:30
57	DISCOVERY/ISS CREW WAKE UP (FD 5)	03/14:30	08:51 PM	00:51
58	EVA # 1 PREPARATIONS RESUME	03/15:05	09:26 PM	01:26
60	DISCOVERY/ISS TRANSFERS RESUME	03/17:45	12:06 AM	04:06
	FRIDAY, APRIL 9 - FD 5/FD 6			
61	EVA # 1 BEGINS	03/19:20	01:41 AM	05:41
61	S1 OLD ATA FGB RETRIEVAL	03/19:35	01:56 AM	05:56
61	ATA REMOVAL PREPARATIONS IN PAYLOAD BAY	03/19:50	02:11 AM	06:11
62	HANDOFF NEW ATA TO SSRMS	03/20:50	03:11 AM	07:11
62	MPAC/SEED EXPERIMENT REMOVAL FROM JEF	03/21:35	03:56 AM	07:56
63	AGB RETRIEVAL FROM ESP-2	03/22:20	04:41 AM	08:41
63	S0 RGA #1 REMOVAL/REPLACEMENT	03/23:05	05:26 AM	09:26
64	P6 BATTERY REMOVAL PREPS	04/00:20	06:41 AM	10:41
65	EVA # 1 ENDS	04/01:50	08:11 AM	12:11
66	MISSION STATUS BRIEFING	04/04:09	10:30 AM	14:30
68	ISS CREW SLEEP BEGINS	04/06:30	12:51 PM	16:51
68	DISCOVERY CREW SLEEP BEGINS	04/07:00	01:21 PM	17:21
69	FLIGHT DAY 5 HIGHLIGHTS	04/07:39	02:00 PM	18:00
69	VIDEO FILE	04/08:39	03:00 PM	19:00
70	HD FLIGHT DAY 5 CREW HIGHLIGHTS	04/09:39	04:00 PM	20:00

ORBIT EVENT MET EDT GMT

72...ISS FLIGHT DIRECTOR UPDATE.............04/12:09...06:30 PM...22:30
73...ISS FLIGHT DIRECTOR UPDATE REPLAY.......04/14:39...09:00 PM...01:00
74...DISCOVERY/ISS CREW WAKE UP (FD 6).......04/15:00...09:21 PM...01:21
76...WORF TRANSFER..........................04/18:05...12:26 AM...04:26
76...OBSS FOCUSED INSPECTION (If required)...04/18:30...12:51 AM...04:51

SATURDAY, APRIL 10 - FD 6/FD 7
77...ZSR TRANSFER...........................04/19:30...01:51 AM...05:51
79...U.S. PAO EVENT.........................04/22:45...05:06 AM...09:06
81...EVA # 2 PROCEDURE REVIEW...............05/02:55...09:16 AM...13:16
82...U.S. PAO EDUCATION EVENT...............05/04:15...10:36 AM...14:36
83...MISSION STATUS BRIEFING................05/04:39...11:00 AM...15:00
83...EVA # 2 CAMPOUT BEGINS.................05/05:25...11:46 AM...15:46
84...ISS CREW SLEEP BEGINS..................05/06:30...12:51 PM...16:51
84...DISCOVERY CREW SLEEP BEGINS............05/07:00...01:21 PM...17:21
85...FLIGHT DAY 6 HIGHLIGHTS................05/07:39...02:00 PM...18:00
86...HD FLIGHT DAY 6 CREW HIGHLIGHTS........05/09:39...04:00 PM...20:00
87...ISS FLIGHT DIRECTOR UPDATE.............05/12:09...06:30 PM...22:30
89...ISS FLIGHT DIRECTOR UPDATE REPLAY.......05/14:39...09:00 PM...01:00
89...DISCOVERY/ISS CREW WAKE UP (FD 7).......05/15:00...09:21 PM...01:21
90...EVA # 2 PREPARATIONS RESUME............05/15:40...10:01 PM...02:01
91...DISCOVERY/ISS TRANSFERS RESUME.........05/17:40...12:01 AM...04:01

SUNDAY, APRIL 11 - FD 7/FD 8
93...EVA # 2 BEGINS.........................05/19:55...02:16 AM...06:16
93...RELEASE S1 OLD ATA & HANDOFF TO SSRMS...05/20:10...02:31 AM...06:31
93...OLD S1 ATA TIEDOWN TO PORT CETA CART....05/21:10...03:31 AM...07:31
94...P1 GRAPPLE FIXTURE STOWAGE BEAM INSTALL.05/21:55...04:16 AM...08:16
94...AGB REMOVAL FROM NEW ATA...............05/22:25...04:46 AM...08:46
94...INSTALL NEW ATA ON S1 TRUSS............05/22:55...05:16 AM...09:16
95...NEW ATA ELECTRICAL CONNECTIONS.........05/23:40...06:01 AM...10:01
96...RELEASE OLD ATA FROM CETA CART.........06/00:25...06:46 AM...10:46
96...AIRLOCK MMOD SHIELD RETRIEVAL..........06/01:25...07:46 AM...11:46
97...EVA # 2 ENDS...........................06/02:25...08:46 AM...12:46
98...MISSION STATUS BRIEFING................06/04:39...11:00 AM...15:00
100...ISS CREW SLEEP BEGINS.................06/07:00...01:21 PM...17:21
100...DISCOVERY CREW SLEEP BEGINS...........06/07:30...01:51 PM...17:51
100...FLIGHT DAY 7 HIGHLIGHTS...............06/07:39...02:00 PM...18:00
102...HD FLIGHT DAY 7 CREW HIGHLIGHTS.......06/10:39...05:00 PM...21:00
104...ISS FLIGHT DIRECTOR UPDATE............06/12:39...07:00 PM...23:00
105...ISS FLIGHT DIRECTOR UPDATE REPLAY......06/15:09...09:30 PM...01:30
105...DISCOVERY/ISS CREW WAKE UP (FD 8)......06/15:30...09:51 PM...01:51
107...CREW OFF DUTY PERIOD BEGINS...........06/18:30...12:51 AM...04:51

MONDAY, APRIL 12 - FD 8/FD 9
109...MISSION STATUS BRIEFING...............06/20:39...03:00 AM...07:00
111...JAXA PAO EVENT........................07/00:20...06:41 AM...10:41
111...MPLM TRANSFERS RESUME.................07/00:30...06:51 AM...10:51
112...INTERPRETED REPLAY OF JAXA PAO EVENT...07/01:39...08:00 AM...12:00
113...EVA #3 PROCEDURE REVIEW...............07/03:25...09:46 AM...13:46
114...U.S. PAO EVENT........................07/04:25...10:46 AM...14:46
115...EVA # 3 CAMPOUT BEGINS................07/06:25...12:46 PM...16:46

ORBIT	EVENT	MET	EDT	GMT

```
116...ISS CREW SLEEP BEGINS..................07/07:30...01:51 PM...17:51
116...DISCOVERY CREW SLEEP BEGINS............07/08:00...02:21 PM...18:21
117...FLIGHT DAY 8 HIGHLIGHTS................07/08:39...03:00 PM...19:00
117...VIDEO FILE.............................07/09:39...04:00 PM...20:00
119...HD FLIGHT DAY 8 CREW HIGHLIGHTS........07/11:39...06:00 PM...22:00
119...ISS FLIGHT DIRECTOR UPDATE.............07/12:39...07:00 PM...23:00
121...ISS FLIGHT DIRECTOR UPDATE REPLAY......07/15:39...10:00 PM...02:00
121...DISCOVERY/ISS CREW WAKE UP (FD 9)......07/16:00...10:21 PM...02:21
122...EVA #3 PREPARATIONS RESUME.............07/16:35...10:56 PM...02:56
123...DISCOVERY/ISS TRANSFERS RESUME.........07/18:35...12:56 AM...04:56

TUESDAY, APRIL 13 - FD 9/FD 10
124...SSRMS REMOVES OLD ATA FROM MBS.........07/19:55...02:16 AM...06:16
125...EVA #3 BEGINS..........................07/20:50...03:11 AM...07:11
125...AGB REMOVAL FROM OLD ATA...............07/21:05...03:26 AM...07:26
126...SSRMS INSTALLS OLD ATA IN PAYLOAD BAY..07/22:05...04:26 AM...08:26
127...LWAPA RETRIEVAL FROM COLUMBUS..........07/23:50...06:11 AM...10:11
127...CLPA #1 INSTALL ON SPDM................08/00:20...06:41 AM...10:41
129...EVA #3 ENDS............................08/03:20...09:41 AM...13:41
131...MISSION STATUS BRIEFING................08/05:39...12:00 PM...16:00
132...ISS CREW SLEEP BEGINS..................08/08:30...02:51 PM...18:51
133...DISCOVERY CREW SLEEP BEGINS............08/09:00...03:21 PM...19:21
133...FLIGHT DAY 9 HIGHLIGHTS................08/09:39...04:00 PM...20:00
134...VIDEO FILE.............................08/10:39...05:00 PM...21:00
135...HD FLIGHT DAY 10 CREW HIGHLIGHTS.......08/12:39...07:00 PM...23:00
136...ISS FLIGHT DIRECTOR UPDATE.............08/14:39...09:00 PM...01:00
138...ISS FLIGHT DIRECTOR UPDATE REPLAY......08/16:39...11:00 PM...03:00
138...DISCOVERY/ISS CREW WAKE UP (FD 10).....08/17:00...11:21 PM...03:21

WEDNESDAY, APRIL 14 - FD 10/FD 11
140...DISCOVERY/ISS TRANSFERS RESUME.........08/20:00...02:21 AM...06:21
141...HARMONY CBM CONTROL PANEL INSTALL......08/21:30...03:51 AM...07:51
143...JOINT CREW NEWS CONFERENCE.............09/01:10...07:31 AM...11:31
144...CREW OFF DUTY PERIOD...................09/01:50...08:11 AM...12:11
146...INTERPRETED REPLAY OF CREW CONFERENCE..09/04:39...11:00 AM...15:00
147...U.S. PAO EDUCATION EVENT...............09/06:50...01:11 PM...17:11
147...MISSION STATUS BRIEFING................09/07:24...01:45 PM...17:45
149...ISS CREW SLEEP BEGINS..................09/09:30...03:51 PM...19:51
149...DISCOVERY CREW SLEEP BEGINS............09/10:00...04:21 PM...20:21
150...FLIGHT DAY 10 HIGHLIGHTS...............09/10:39...05:00 PM...21:00
150...VIDEO FILE.............................09/11:39...06:00 PM...22:00
151...HD FLIGHT DAY 10 CREW HIGHLIGHTS.......09/12:39...07:00 PM...23:00
153...ISS FLIGHT DIRECTOR UPDATE.............09/15:39...10:00 PM...02:00
154...ISS FLIGHT DIRECTOR UPDATE REPLAY......09/17:39...12:00 AM...04:00
154...DISCOVERY/ISS CREW WAKE UP (FD 11).....09/18:00...12:21 AM...04:21

THURSDAY, APRIL 15 - FD 11/FD 12
156...MPLM EGRESS............................09/20:30...02:51 AM...06:51
159...SSRMS GRAPPLES MPLM....................10/01:05...07:26 AM...11:26
160...SSRMS UNINSTALLS MPLM..................10/02:20...08:41 AM...12:41
161...MISSION STATUS BRIEFING................10/03:39...10:00 AM...14:00
162...DISCOVERY/ISS FAREWELL & HATCH CLOSURE.10/05:35...11:56 AM...15:56
```

ORBIT EVENT MET EDT GMT

```
162...RENDEZVOUS TOOL CHECKOUT..............10/05:50...12:11 PM...16:11
163...CENTERLINE CAMERA INSTALLATION........10/06:30...12:51 PM...16:51
164...ISS CREW SLEEP BEGINS.................10/09:30...03:51 PM...19:51
165...DISCOVERY CREW SLEEP BEGINS...........10/10:00...04:21 PM...20:21
165...FLIGHT DAY 11 HIGHLIGHTS..............10/10:39...05:00 PM...21:00
166...VIDEO FILE............................10/11:39...06:00 PM...22:00
167...HD FLIGHT DAY 11 CREW HIGHLIGHTS......10/12:39...07:00 PM...23:00
170...DISCOVERY/ISS CREW WAKE UP (FD 12)....10/18:00...12:21 AM...04:21

FRIDAY, APRIL 16 - FD 12/FD 13
172...DISCOVERY UNDOCKS FROM ISS............10/21:34...03:55 AM...07:55
173...DISCOVERY FLYAROUND OF ISS BEGINS.....10/21:59...04:20 AM...08:20
174...DISCOVERY FINAL SEPARATION FROM ISS...10/23:17...05:38 AM...09:38
174...SHUTTLE VTR PLAYBACK OF UNDOCKING.....11/00:30...06:51 AM...10:51
175...RMS/OBSS LATE INSPECTION..............11/01:20...07:41 AM...11:41
176...MISSION STATUS BRIEFING...............11/03:39...10:00 AM...14:00
178...OBSS BERTH............................11/05:35...11:56 AM...15:56
181...DISCOVERY CREW SLEEP BEGINS...........11/10:00...04:21 PM...20:21
181...FLIGHT DAY 12 HIGHLIGHTS..............11/10:39...05:00 PM...21:00
182...VIDEO FILE............................11/11:39...06:00 PM...22:00
182...HD FLIGHT DAY 12 CREW HIGHLIGHTS......11/12:39...07:00 PM...23:00
186...DISCOVERY CREW WAKE UP (FD 13)........11/18:00...12:21 AM...04:21

SATURDAY, APRIL 17 - FD 13/FD 14
188...CABIN STOWAGE BEGINS..................11/21:00...03:21 AM...07:21
188...FCS CHECKOUT..........................11/21:20...03:41 AM...07:41
189...RCS HOT-FIRE TEST.....................11/22:30...04:51 AM...08:51
191...DISCOVERY U.S. PAO EVENT..............12/01:15...07:36 AM...11:36
192...MISSION STATUS BRIEFING...............12/04:09...10:30 AM...14:30
194...KU-BAND ANTENNA STOWAGE...............12/06:50...01:11 PM...17:11
196...DISCOVERY CREW SLEEP BEGINS...........12/10:00...04:21 PM...20:21
197...FLIGHT DAY 13 HIGHLIGHTS..............12/10:39...05:00 PM...21:00
198...HD FLIGHT DAY 13 CREW HIGHLIGHTS......12/12:39...07:00 PM...23:00
202...DISCOVERY CREW WAKE UP (FD 14)........12/18:00...12:21 AM...04:21

SUNDAY, APRIL 18
204...DEORBIT PREPARATIONS BEGIN............12/21:10...03:31 AM...07:31
205...PAYLOAD BAY DOOR CLOSING..............12/22:26...04:47 AM...08:47
206...DISCOVERY DEORBIT BURN................13/01:06...07:27 AM...11:27
207...MILA C-BAND RADAR ACQUISITION.........13/01:55...08:16 AM...12:16
207...DISCOVERY LANDING.....................13/02:08...08:29 AM...12:29
```

THIS PAGE INTENTIONALLY BLANK

Appendix 1: Space Shuttle Flight and Abort Scenarios

The shuttle weighs 4.5 million pounds at launch and it hits 140 mph - going straight up - in about 10 seconds. The shuttle burns its fuel so fast that in less than 100 seconds it weighs half what it did at launch. In eight-and-a-half minutes, the vehicle is traveling some 17,000 mph, or five miles per second. That's about eight times faster than a rifle bullet, fast enough to fly from Los Angeles to New York in 10 minutes. Calling a shuttle launch "routine" misses the mark. The margin for error is very slim indeed and the astronauts face a limited number of survivable abort options.

The shuttle makes the climb to orbit using two solid-fuel boosters and three hydrogen-fueled main engines. Contrary to popular myth, the shuttle pilots do little more than monitor their instruments and computer displays during ascent; the shuttle's four flight computers do all the piloting barring a malfunction of some sort that might force the crew to take manual control.

NASA puts the overall odds of a catastrophic failure at about 1-in-80.

The main engines generate a combined 37 million horsepower, which is equivalent to the output of 23 Hoover Dams. They are ignited at 120 millisecond intervals starting 6.6 seconds prior to launch. Computers bolted to each powerplant monitor engine performance 50 times per second and, after all three are running smoothly, the boosters are ignited. Pressure inside the hollow boosters jumps from sea level to more than 900 pounds per square inch in a quarter of a second as the propellant ignites. Liftoff is virtually instantaneous.

The boosters burn for about two minutes and five seconds. They are far more powerful than the three main engines and provide all the shuttle's steering during the initial minutes of flight using hydraulic pistons that move the nozzles at the base of each rocket. After the boosters are jettisoned, the shuttle's three liquid-fueled engines provide steering and flight control.

The engines are throttled down to 65 percent power about 40 seconds into flight to lower the stress on the shuttle as it accelerates through the region of maximum aerodynamic pressure (715 pounds per square foot at 48 seconds). After that, the engines are throttled back up to 104 percent. All three engines shut down about eight and a half minutes after takeoff, putting the shuttle in a preliminary orbit. The empty external fuel tank is then jettisoned and breaks up in the atmosphere over the Indian or Pacific oceans. The initial orbit is highly elliptical and the shuttle's two orbital maneuvering rockets are fired about 43 minutes after launch to put the craft in a circular orbit.

There are no survivable booster failures like the one that destroyed Challenger 73 seconds after liftoff in 1986. Like a holiday bottle rocket, the boosters cannot be shut down once they are ignited. They are rigged with plastic explosives to blow open their cases and eliminate forward thrust should a catastrophic failure send a shuttle veering out of control toward populated areas or sea lanes. In that case, the crew is considered expendable. There is no survivable way to separate from the boosters while they are operating. They simply have to work.

But the shuttle system was designed to safely handle a single main engine failure at any point after startup. In all cases, such "intact" aborts begin after the solid-fuel boosters have been jettisoned. In other words, if an abort is declared 10 seconds after liftoff, it will not actually go into effect until 2 minutes and 30 seconds after launch.

An engine failure during the startup sequence will trigger a "redundant set launch sequencer abort," or RSLS abort. If one or more engine experiences problems during startup, the shuttle's flight computers will issue immediate shut-down commands and stop the countdown before booster ignition. This has happened five times in shuttle history (the most recent RSLS abort occurred in August 1994).

An RSLS abort does not necessarily threaten the safety of the shuttle crew, but hydrogen gas can be released through the engine nozzles during shutdown. Hydrogen burns without visible sign of flame and it's possible a brief pad fire can follow the engine cutoff. But the launch pad is equipped with a sophisticated fire extinguishing system and other improvements implemented in the wake of the 1986 Challenger accident that will automatically start spraying the orbiter with water if a fire is detected. Fire detection sensors are located all over the pad.

While in-flight abort regimes overlap to a degree, a return to the launch site (RTLS) is only possible during the first four minutes of flight. Beyond that point, a shuttle has flown too far to make it back to Florida with its remaining fuel. But in practice, an RTLS is only a threat in the first 2.5 minutes or so of flight. After that, a crew can press on to an emergency landing in Spain or Africa, the preferred option if there's a choice because it puts less stress on the shuttle.

A trans-Atlantic abort (TAL) is an option throughout ascent but after about five minutes, the shuttle is going fast enough to attempt an abort to a lower-than-planned orbit, depending on the shuttle's altitude and velocity at the time of the failure. If the shuttle crew has a choice between an RTLS and a TAL, they will select the TAL option. If the choice is between TAL and ATO, they will select the abort to orbit.

Here are the actual numbers for a recent shuttle flight (velocity includes a contribution from Earth's rotation at 28.5 degrees north latitude):

TIME	EVENT	MPH
0:10	THE SHUTTLE ROLLS TO "HEADS DOWN" ORIENTATION	920
0:40	START THROTTLE DOWN	1,405
0:48	MAXIMUM AERODYNAMIC PRESSURE	1,520
0:53	START THROTTLE UP TO 104%	1,589
2:04	SOLID-FUEL BOOSTERS ARE JETTISONED	3,818
2:10	THE SHUTTLE CAN NOW ABORT TO SPAIN OR FRANCE	3,955
3:45	THE SHUTTLE CAN NO LONGER RETURN TO KSC	5,591
4:12	THE SHUTTLE CAN NOW ABORT TO ORBIT	6,273
5:13	SHUTTLE CAN REACH NORMAL ORBIT WITH TWO ENGINES	8,045
5:48	THE SHUTTLE ROLLS TO "HEADS UP" ORIENTATION	9,205
6:32	SHUTTLE CAN REACH ORBIT WITH ONE ENGINE	11,114
7:24	ENGINES THROTTLE DOWN TO LIMIT G LOADS ON CREW	13,977
8:24	MAIN ENGINE CUTOFF	17,727

An RTLS abort is considered the riskiest of the abort procedures because the shuttle crew must reverse course to head back for Florida, which puts severe stresses on the vehicle. TAL is the preferred abort mode for early engine failures. A second engine failure during an RTLS makes the chances of a success slim while a TAL abort can be flown in many instances with two failures.

Normal Flight Details[7]

In the launch configuration, the orbiter and two solid rocket boosters are attached to the external tank in a vertical (nose-up) position on the launch pad. Each solid rocket booster is attached at its aft skirt to the mobile launcher platform by four bolts.

Emergency exit for the flight crew on the launch pad up to 30 seconds before lift-off is by slidewire. There are seven 1,200-foot- long slidewires, each with one basket. Each basket is designed to carry three persons. The baskets, 5 feet in diameter and 42 inches deep, are suspended beneath the slide mechanism by four cables. The slidewires carry the baskets to ground level. Upon departing the basket at ground level, the flight crew progresses to a bunker that is designed to protect it from an explosion on the launch pad.

At launch, the three space shuttle main engines-fed liquid hydrogen fuel and liquid oxygen oxidizer from the external tank-are ignited first. When it has been verified that the engines are operating at the proper thrust level, a signal is sent to ignite the solid rocket boosters. At the proper thrust-to-weight ratio, initiators (small explosives) at eight hold-down bolts on the solid rocket boosters are fired to release the space shuttle for lift-off. All this takes only a few seconds.

Maximum dynamic pressure is reached early in the ascent, nominally approximately 60 seconds after lift-off.

Approximately a minute later (two minutes into the ascent phase), the two solid rocket boosters have consumed their propellant and are jettisoned from the external tank. This is triggered by a separation signal from the orbiter. The boosters briefly continue to ascend, while small motors fire to carry them away from the space shuttle. The boosters then turn and descend, and at a predetermined altitude, parachutes are deployed to decelerate them for a safe splashdown in the ocean. Splashdown occurs approximately 141 nautical miles (162 statute miles) from the launch site. The boosters are recovered and reused.

Meanwhile, the orbiter and external tank continue to ascend, using the thrust of the three space shuttle main engines. Approximately eight minutes after launch and just short of orbital velocity, the three space shuttle engines are shut down (main engine cutoff), and the external tank is jettisoned on command from the orbiter.

The forward and aft reaction control system engines provide attitude (pitch, yaw and roll) and the translation of the orbiter away from the external tank at separation and return to attitude hold prior to the orbital maneuvering system thrusting maneuver.

The external tank continues on a ballistic trajectory and enters the atmosphere, where it disintegrates. Its projected impact is in the Indian Ocean (except for 57-degree inclinations) in the case of equatorial orbits (Kennedy Space Center launch) and in the extreme southern Pacific Ocean in the case of a Vandenberg Air Force Base launch.

Normally, two thrusting maneuvers using the two orbital maneuvering system engines at the aft end of the orbiter are used in a two-step thrusting sequence: to complete insertion into Earth orbit and to circularize the spacecraft's orbit. The orbital maneuvering system engines are also used on orbit for any major velocity changes. In the event of a direct-insertion mission, only one orbital maneuvering system thrusting sequence is used.

The orbital altitude of a mission is dependent upon that mission. The nominal altitude can vary between 100 to 217 nautical miles (115 to 250 statute miles).

The forward and aft reaction control system thrusters (engines) provide attitude control of the orbiter as well as any minor translation maneuvers along a given axis on orbit.

[7] The remainder of this appendix, with clearly noted exceptions, is taken directly from shuttle-builder Rockwell International's Shuttle Reference book.

At the completion of orbital operations, the orbiter is oriented in a tailfirst attitude by the reaction control system. The two orbital maneuvering system engines are commanded to slow the orbiter for deorbit. The reaction control system turns the orbiter's nose forward for entry. The reaction control system controls the orbiter until atmospheric density is sufficient for the pitch and roll aerodynamic control surfaces to become effective.

Entry interface is considered to occur at 400,000 feet altitude approximately 4,400 nautical miles (5,063 statute miles) from the landing site and at approximately 25,000 feet per second velocity. At 400,000 feet altitude, the orbiter is maneuvered to zero degrees roll and yaw (wings level) and at a predetermined angle of attack for entry. The angle of attack is 40 degrees. The flight control system issues the commands to roll, pitch and yaw reaction control system jets for rate damping.

The forward reaction control system engines are inhibited prior to entry interface, and the aft reaction control system engines maneuver the spacecraft until a dynamic pressure of 10 pounds per square foot is sensed, which is when the orbiter's ailerons become effective. The aft reaction control system roll engines are then deactivated. At a dynamic pressure of 20 pounds per square foot, the orbiter's elevators become active, and the aft reaction control system pitch engines are deactivated. The orbiter's speed brake is used below Mach 10 to induce a more positive downward elevator trim deflection. At approximately Mach 3.5, the rudder becomes activated, and the aft reaction control system yaw engines are deactivated at 45,000 feet.

Entry guidance must dissipate the tremendous amount of energy the orbiter possesses when it enters the Earth's atmosphere to assure that the orbiter does not either burn up (entry angle too steep) or skip out of the atmosphere (entry angle too shallow) and that the orbiter is properly positioned to reach the desired touchdown point.

During entry, energy is dissipated by the atmospheric drag on the orbiter's surface. Higher atmospheric drag levels enable faster energy dissipation with a steeper trajectory. Normally, the angle of attack and roll angle enable the atmospheric drag of any flight vehicle to be controlled. However, for the orbiter, angle of attack was rejected because it creates surface temperatures above the design specification. The angle of attack scheduled during entry is loaded into the orbiter computers as a function of relative velocity, leaving roll angle for energy control. Increasing the roll angle decreases the vertical component of lift, causing a higher sink rate and energy dissipation rate. Increasing the roll rate does raise the surface temperature of the orbiter, but not nearly as drastically as an equal angle of attack command.

If the orbiter is low on energy (current range-to-go much greater than nominal at current velocity), entry guidance will command lower than nominal drag levels. If the orbiter has too much energy (current range-to-go much less than nominal at the current velocity), entry guidance will command higher-than-nominal drag levels to dissipate the extra energy.

Roll angle is used to control cross range. Azimuth error is the angle between the plane containing the orbiter's position vector and the heading alignment cylinder tangency point and the plane containing the orbiter's position vector and velocity vector. When the azimuth error exceeds a computer-loaded number, the orbiter's roll angle is reversed.

Thus, descent rate and downranging are controlled by bank angle. The steeper the bank angle, the greater the descent rate and the greater the drag. Conversely, the minimum drag attitude is wings level. Cross range is controlled by bank reversals.

The entry thermal control phase is designed to keep the backface temperatures within the design limits. A constant heating rate is established until below 19,000 feet per second.

The equilibrium glide phase shifts the orbiter from the rapidly increasing drag levels of the temperature control phase to the constant drag level of the constant drag phase. The equilibrium glide flight is defined as flight in which the flight path angle, the angle between the local horizontal and the local velocity vector, remains constant. Equilibrium glide flight provides the maximum downrange capability. It lasts until the drag acceleration reaches 33 feet per second squared.

The constant drag phase begins at that point. The angle of attack is initially 40 degrees, but it begins to ramp down in this phase to approximately 36 degrees by the end of this phase.

In the transition phase, the angle of attack continues to ramp down, reaching the approximately 14-degree angle of attack at the entry terminal area energy management interface, at approximately 83,000 feet altitude, 2,500 feet per second, Mach 2.5 and 52 nautical miles (59 statute miles) from the landing runway. Control is then transferred to TAEM guidance.

During the entry phases described, the orbiter's roll commands keep the orbiter on the drag profile and control cross range.

TAEM guidance steers the orbiter to the nearest of two heading alignment cylinders, whose radii are approximately 18,000 feet and which are located tangent to and on either side of the runway centerline on the approach end. In TAEM guidance, excess energy is dissipated with an S-turn; and the speed brake can be utilized to modify drag, lift-to-drag ratio and flight path angle in high-energy conditions. This increases the ground track range as the orbiter turns away from the nearest HAC until sufficient energy is dissipated to allow a normal approach and landing guidance phase capture, which begins at 10,000 feet altitude. The orbiter also can be flown near the velocity for maximum lift over drag or wings level for the range stretch case. The spacecraft slows to subsonic velocity at approximately 49,000 feet altitude, about 22 nautical miles (25.3 statute miles) from the landing site.

At TAEM acquisition, the orbiter is turned until it is aimed at a point tangent to the nearest HAC and continues until it reaches way point 1. At WP-1, the TAEM heading alignment phase begins. The HAC is followed until landing runway alignment, plus or minus 20 degrees, has been achieved. In the TAEM prefinal phase, the orbiter leaves the HAC; pitches down to acquire the steep glide slope; increases airspeed; banks to acquire the runway centerline; and continues until on the runway centerline, on the outer glide slope and on airspeed. The approach and landing guidance phase begins with the completion of the TAEM prefinal phase and ends when the spacecraft comes to a complete stop on the runway.

The approach and landing trajectory capture phase begins at the TAEM interface and continues to guidance lock-on to the steep outer glide slope. The approach and landing phase begins at about 10,000 feet altitude at an equivalent airspeed of 290, plus or minus 12, knots 6.9 nautical miles (7.9 statute miles) from touchdown. Autoland guidance is initiated at this point to guide the orbiter to the minus 19- to 17-degree glide slope (which is over seven times that of a commercial airliner's approach) aimed at a target 0.86 nautical mile (1 statute mile) in front of the runway. The spacecraft's speed brake is positioned to hold the proper velocity. The descent rate in the later portion of TAEM and approach and landing is greater than 10,000 feet per minute (a rate of descent approximately 20 times higher than a commercial airliner's standard 3-degree instrument approach angle).

At 1,750 feet above ground level, a preflare maneuver is started to position the spacecraft for a 1.5-degree glide slope in preparation for landing with the speed brake positioned as required. The flight crew deploys the landing gear at this point.

The final phase reduces the sink rate of the spacecraft to less than 9 feet per second. Touchdown occurs approximately 2,500 feet past the runway threshold at a speed of 184 to 196 knots (213 to 226 mph).

Intact 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. Other failures requiring early termination of a flight, such as a cabin leak, might 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.

There are four types of intact aborts: abort to orbit, abort once around, transatlantic landing and return to launch site.

The ATO mode is designed to allow the vehicle to achieve a temporary orbit that is lower than the nominal orbit. This mode requires less performance and allows time to evaluate problems and then choose either an early deorbit maneuver or an orbital maneuvering system thrusting maneuver to raise the orbit and continue the mission.

The AOA is designed to allow the vehicle to fly once around the Earth and make a normal entry and landing. This mode generally involves two orbital maneuvering system thrusting sequences, with the second sequence being a deorbit maneuver. The entry sequence would be similar to a normal entry.

The TAL mode is designed to permit an intact landing on the other side of the Atlantic Ocean. This mode results in a ballistic trajectory, which does not require an orbital maneuvering system maneuver.

The RTLS mode involves flying downrange to dissipate propellant and then turning around under power to return directly to a landing at or near the launch site.

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 would be 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.

The Mission Control Center-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 tell them 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 current 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 space shuttle main engine fails.

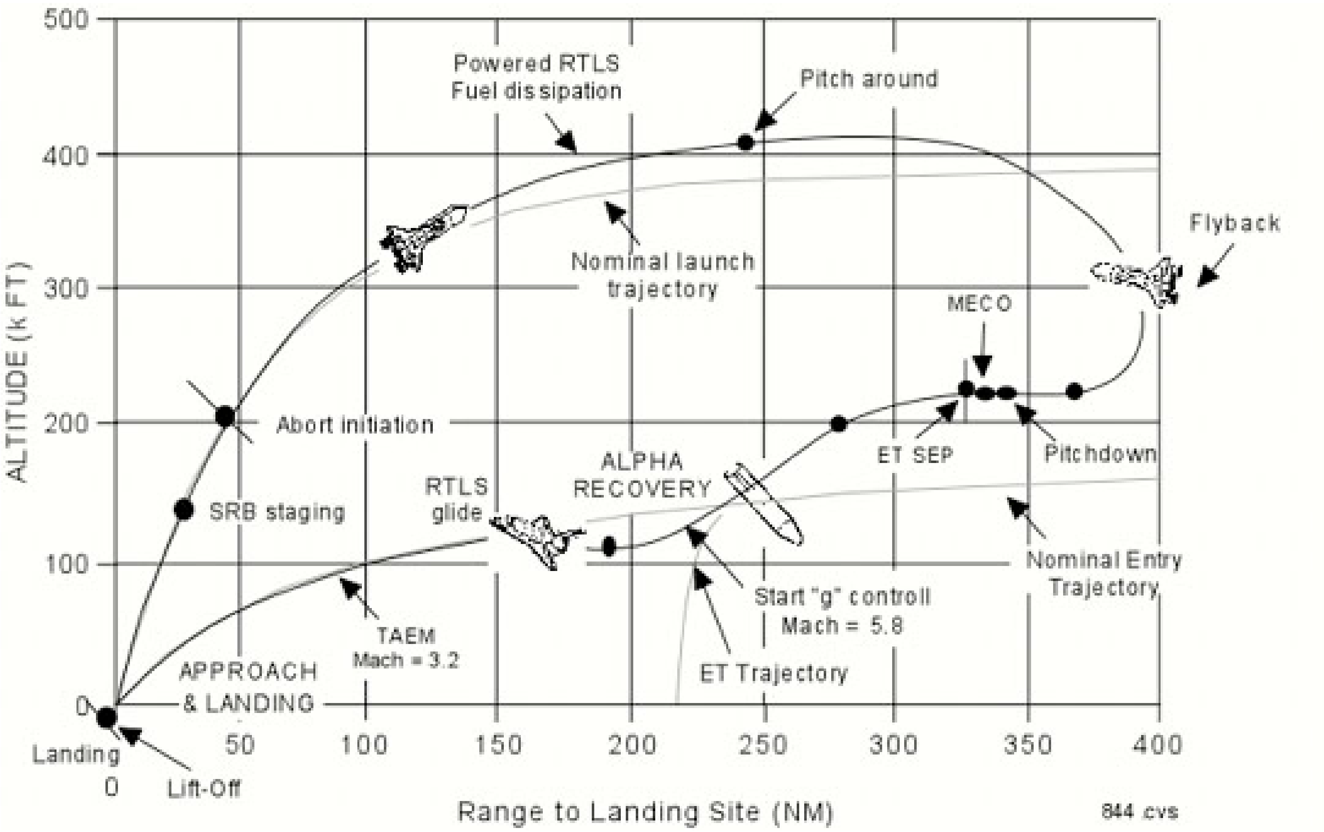
If the problem is a system failure that jeopardizes the vehicle, the fastest abort mode that results in the earliest vehicle landing is chosen. RTLS and TAL are the quickest options (35 minutes), whereas an AOA requires approximately 90 minutes. Which of these is selected depends on the time of the failure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

1. Return to Launch Site (RTLS) Abort

The RTLS abort mode is designed to allow the return of the orbiter, crew, and payload to the launch site, Kennedy Space Center, approximately 25 minutes after lift-off. The RTLS profile is designed to accommodate the loss of thrust from one space shuttle main engine between lift-off and approximately four minutes 20 seconds, at which time 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 ET separation phase; and the glide phase, during which the orbiter glides to a landing at the Kennedy Space Center. The powered RTLS phase begins with the crew selection of the RTLS abort, which is done 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, approximately three minutes 34 seconds into the mission; whereas an RTLS chosen due to an engine out at lift-off is selected at the earliest time, approximately two 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 towards the Kennedy Space Center and achieve the proper main engine cutoff conditions so the vehicle can glide to the Kennedy Space Center 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 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 translation 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 translation maneuver has been completed, the glide phase of the RTLS begins. From then on, the RTLS is handled similarly to a normal entry.

2. Trans-Atlantic Landing (TAL) Abort

The TAL abort mode was developed to improve the options available when 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 approximately 45 minutes after launch. The landing site is selected near the nominal ascent ground track of the orbiter in order 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. Currently, the three landing sites that have been identified for a due east launch are Moron,, Spain; Zaragoza, Spain; and Istres LaTube, 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 nominal entry.

3. East-Coast Abort and Landing (ECAL)[8] Abort

When the shuttle was originally designed, multiple main engine failures early in flight meant a ditching somewhere in the Atlantic Ocean. After Challenger, the shuttle was rigged with a bailout system to give the crew a better chance of survival. In the space station era, an additional option was implemented to give of a shuttle with multiple engine failures a chance to reach an East Coast runway.

To reach the space station, the shuttle must launch into to the plane of its orbit. That plane is tilted 51.6 degrees to the equator. As a result, shuttles bound for the station take off on a northeasterly trajectory that parallels the East Coast of the United States. Should two or three engines fail before the shuttle is going fast enough to reach Europe or to turn around and return to Florida, the crew would attempt a landing at one of 15 designated East Coast runways, 10 in the United States and five in Canada.

First, the shuttle's flight computers would pitch the nose up to 60 degrees to burn off fuel and yaw the ship 45 degrees to the left of its ground track to begin moving it closer to the coast. The shuttle also would roll about its vertical axis to put the crew in a "heads up" orientation on top of the external fuel tank. Based on velocity, fuel remaining and other factors, the shuttle eventually would pitch down and jettison the external tank. From there, the flight computers would attempt to steer the ship to the designated runway using angle of attack as the primary means of bleeding off energy.

---

[8] ECALs were not included in the original Rockwell Shuttle Reference. This information is provided by the author.

An ECAL abort is a high-risk, last-resort option and would only be implemented if the only other alternative was to ditch in the ocean.

4. Abort to Orbit (ATO)[9] Abort

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 Mission Control Center 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.

5. Abort Once Around (AOA) Abort

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 on orbit and the deorbit thrusting maneuver. 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; or the Kennedy Space Center). Thus, an AOA results in the orbiter circling the Earth once and landing approximately 90 minutes after lift-off.

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.

6. 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 may also 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 in-flight crew escape system would be used before ditching the orbiter.

Editor's Note… Here is a bit of background on the crew's bailout system from an earlier edition of the Space Reporter's Handbook:

> During the early phases of flight, two or more engine failures, depending on when they happened, could leave the shuttle without enough power to make it to a runway. In that case, the crew would have to "ditch" the orbiter somewhere in the ocean. Given that shuttles land at more than 200 mph, ditching is not considered a survivable option.

---

[9] Aside from the Jan. 28, 1986, Challenger disaster, the only other in-flight engine shutdown in the history of the shuttle program occurred July 29, 1985, when Challenger's No. 1 engine shut down five minutes and 45 seconds after liftoff because of a faulty temperature sensor on the engine's high-pressure fuel turbopump. In that case, Challenger was able to abort to a lower-than-planned orbit and, after extensive replanning, complete its Spacelab mission.

In the wake of the Challenger disaster, NASA examined several possible escape systems ranging from ejection seats to simply jumping out the side hatch for a parachute descent. The agency ultimately settled on a bail out system that required modifications to let a crew blow the side hatch safely away from the shuttle during descent.

In the current system, a 248-pound, 8.75-foot telescoping pole is mounted along the ceiling of the crew cabin's lower deck. In a bailout, the pole extends through the open hatch. An astronaut then hooks his or her parachute harness to the pole and slides down it for a safe descent (without the pole, an astronaut probably would be blown into the left wing or the aft rocket pod).

To go along with the system, shuttle crews now take off and land wearing bulky, bright orange spacesuits capable of keeping them alive at altitudes up to 100,000 feet. The 70-pound suits feature a built-in life preserver and air supply with backpacks housing a parachute and a small, collapsible life raft.

To operate the system, an astronaut seated on the shuttle's lower deck pulls a handle that opens a vent at an altitude of about 40,000 feet to let cabin air pressure equalize at around 30,000 feet. The commander then orients the shuttle so that its rate of descent is just right to maintain the proper airspeed of between 185 knots and 195 knots. He then puts the shuttle on autopilot and climbs down to the lower deck.

At that point, the side hatch is jettisoned and the crew begins to bail out. As soon as the astronaut hits the water, the parachute is automatically cut free, a life preserver inflates and the life raft automatically fills with air. Assuming bail out started at 20,000 feet or so, all crew members would be clear of the shuttle by the time it had descended to an altitude of 10,000 feet. Each astronaut would hit the water about a mile apart from each other along the line following the shuttle's flight path.

Orbiter Ground Turnaround

Spacecraft recovery operations at the nominal end-of-mission landing site are supported by approximately 160 space shuttle Launch Operations team members. Ground team members wearing self-contained atmospheric protective ensemble suits that protect them from toxic chemicals approach the spacecraft as soon as it stops rolling. The ground team members take sensor measurements to ensure the atmosphere in the vicinity of the spacecraft is not explosive. In the event of propellant leaks, a wind machine truck carrying a large fan will be moved into the area to create a turbulent airflow that will break up gas concentrations and reduce the potential for an explosion.

A ground support equipment air-conditioning purge unit is attached to the right-hand orbiter T-0 umbilical so cool air can be directed through the orbiter's aft fuselage, payload bay, forward fuselage, wings, vertical stabilizer, and orbital maneuvering system/reaction control system pods to dissipate the heat of entry.

A second ground support equipment ground cooling unit is connected to the left-hand orbiter T-0 umbilical spacecraft Freon coolant loops to provide cooling for the flight crew and avionics during the postlanding and system checks. The spacecraft fuel cells remain powered up at this time. The flight crew will then exit the spacecraft, and a ground crew will power down the spacecraft.

At the Kennedy Space Center, the orbiter and ground support equipment convoy move from the runway to the Orbiter Processing Facility.

If the spacecraft lands at Edwards Air Force Base, the same procedures and ground support equipment are used as at the Kennedy Space Center after the orbiter has stopped on the runway. The orbiter and ground support equipment convoy move from the runway to the orbiter mate and demate facility at Edwards Air Force Base. After detailed inspection, the spacecraft is prepared to be ferried atop the shuttle carrier aircraft from Edwards Air Force Base to the Kennedy Space Center. For ferrying, a tail cone is installed over the aft section of the orbiter.

In the event of a landing at an alternate site, a crew of about eight team members will move to the landing site to assist the astronaut crew in preparing the orbiter for loading aboard the shuttle carrier aircraft for transport back to the Kennedy Space Center. For landings outside the U.S., personnel at the contingency landing sites will be provided minimum training on safe handling of the orbiter with emphasis on crash rescue training, how to tow the orbiter to a safe area, and prevention of propellant conflagration.

Upon its return to the Orbiter Processing Facility at the Kennedy Space Center, the orbiter is safed (ordnance devices safed), the payload (if any) is removed, and the orbiter payload bay is reconfigured from the previous mission for the next mission. Any required maintenance and inspections are also performed while the orbiter is in the OPF. A payload for the orbiter's next mission may be installed in the orbiter's payload bay in the OPF or may be installed in the payload bay when the orbiter is at the launch pad.

The spacecraft is then towed to the Vehicle Assembly Building and mated to the external tank. The external tank and solid rocket boosters are stacked and mated on the mobile launcher platform while the orbiter is being refurbished. Space shuttle orbiter connections are made and the integrated vehicle is checked and ordnance is installed.

The mobile launcher platform moves the entire space shuttle system on four crawlers to the launch pad, where connections are made and servicing and checkout activities begin. If the payload was not installed in the OPF, it will be installed at the launch pad followed by prelaunch activities.

The solid rocket boosters start the on-the-launch-pad buildup followed by the external tank. The orbiter is then mated to the external tank on the launch pad.

The launch processing system at the launch pad is similar to the one used at the Kennedy Space Center.

Kennedy Space Center Launch Operations has responsibility for all mating, prelaunch testing and launch control ground activities until the space shuttle vehicle clears the launch pad tower. Responsibility is then turned over to NASA's Johnson Space Center Mission Control Center-Houston. The Mission Control Center's responsibility includes ascent, on-orbit operations, entry, approach and landing until landing runout completion, at which time the orbiter is handed over to the postlanding operations at the landing site for turnaround and relaunch. At the launch site the solid rocket boosters and external tank are processed for launch and the solid rocket boosters are recycled for reuse.

THIS PAGE INTENTIONALLY BLANK

Appendix 2: STS-51L and STS-107 Remembering Challenger and Columbia[10]

An impromptu memorial to the crew of STS-107 at the main entrance to the Johnson Space Center

STS-51L: Challenger's Final Flight

The shuttle Challenger, NASA's second manned orbiter, blasted off on its final mission at 11:38 a.m. EST on Jan. 28, 1986. The initial moments of the 25th shuttle flight appeared normal, but just over a minute into flight, Challenger exploded in a terrifying fireball. Here is part of one of the many stories the author wrote that day as Cape Canaveral bureau manager for United Press International (note: breaking news wire service stories are written "on the fly" in real time and readers familiar with Challenger's destruction will spot several inadvertent errors):

> **NASA says astronauts apparently dead**
> **By WILLIAM HARWOOD**
> CAPE CANAVERAL, Fla. (UPI) – The space shuttle Challenger exploded shortly after blastoff today and hurtled into the Atlantic Ocean. The seven crew members, including teacher Christa McAuliffe, apparently were killed in the worst disaster in space history.

10 For additional information, including detailed timelines, please see the CBS News "Space Place" website at: **http://www.cbsnews.com/network/news/space/SRH_Disasters.htm**

"It is a national tragedy," said Jesse Moore, director of the Johnson Space Center. "I regret that I have to report … that searches … did not reveal any evidence that the crew members are alive."

He said data from instruments, launch pad systems and other sources would be impounded for an investigation.

The explosion occurred while two powerful booster rockets were still attached to the shuttle. There was no way for the crew to escape the out-of-control spacecraft, which fell into the ocean 18 miles off the coast. Burning debris falling from the sky kept rescuers from reaching the scene immediately.

"We have a report that the vehicle has exploded," said NASA spokesman Steve Nesbitt. "We are now looking at all the contingency operations awaiting word from any recovery forces downrange."

On board the Challenger were commander Francis "Dick" Scobee, co-pilot Michael Smith, Judith Resnik, Ellison Onizuka, Ronald McNair, satellite engineer Gregory Jarvis and McAuliffe, the Concord, N.H. social studies teacher who was chosen from 11,000 candidates to be the first private citizen to fly on a shuttle.

Blow by: In this photo, black smoke can be seen billowing from an O-ring joint at the base of Challenger's right-side solid-fuel booster moments after ignition. The joint resealed itself but eventually reopened, triggering the shuttle's destruction 73 seconds after liftoff.

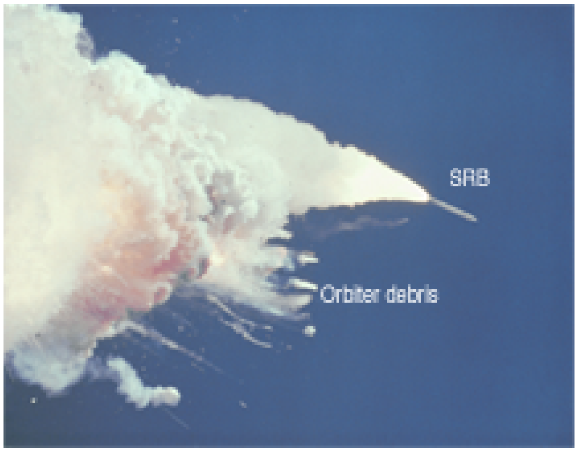
Unlike the shuttle Columbia during its first flights at the dawn of the shuttle era, Challenger was not equipped with ejection seats or other ways for the crew to get out of the spacecraft. McAuliffe's parents, Edward and Grace Corrigan, watching from the VIP site three miles from the launch pad, hugged each other and sobbed as the fireball erupted in the sky. Students at her school, assembled to watch their teacher's launch, watched in stunned silence.

Other students, friends and fellow teachers in Concord cheered the blastoff and then fell into stony silence as the disaster was brought home to them on television. Mark Letalien, a junior at the Concord high school, said "I didn't believe it happened. They made such a big thing about it. Everyone's watching her and she gets killed."

It was the 25th shuttle flight, the 10th for Challenger and the worst disaster in the nation's space program. It came exactly 19 years and a day from the only previous accident - aboard the first Apollo moon capsule on its launch pad Jan. 27, 1967. Astronauts Virgil "Gus" Grissom, Edward White and Roger Chaffee died in that fire.

NASA said Challenger's launch appeared entirely normal until one minute and 15 seconds after liftoff, when the shuttle had accelerated to a speed of 1,977 mph, three times the speed of sound. It was 4.9 miles up and 18 miles out over the ocean.

"Challenger, go at throttle up," mission control told the spacecraft 52 seconds after launch. Scobee's final words to mission control were: "Roger, go at throttle up." Television replays showed close-ups of the speeding ship suddenly enveloped in a ball of fire. Its engines continued firing, raising it out of the flames, but it was out of control.



Multiple contrails could be seen streaking through the sky as the $1.1 billion shuttle arced out over the Atlantic and debris fell into the sea.

In Washington, President Reagan was in an Oval Office meeting when aides brought him the grim news. He rushed into a study in time to see a television replay of the explosion. His face was creased with horror and anxiety. The House of Representatives recessed in the face of the national tragedy.

❑ ❑ ❑

A panel of outside experts led by former Secretary of State William Rogers concluded Challenger was destroyed by the rupture of an O-ring joint in the shuttle's right-side solid-fuel booster. The resulting "burn through" created a jet of flame that ultimately ate through Challenger's external tank, triggering its collapse 73 seconds after blastoff. Almost simultaneously, Challenger, traveling faster than sound, broke apart after being subjected to aerodynamic forces it was not designed to withstand. The ship's crew cabin broke away from the rest of the shuttle and crashed into the Atlantic Ocean at more than 200 mph (see photo at left).

The Rogers Commission report was delivered on June 6 to Camp David, Md., where President Reagan was spending the weekend. A formal presentation with the members of the commission was hgeld in the Rose Garden at the White House. The 256-page report was divided into nine chapters. The first two chapters presented a brief history of the shuttle program and past flights and detailed the events leading up to Challenger's launching on Jan. 28. The commission also presented a detailed timeline of the disaster before getting down to business in Chapter 4.

The Cause of the Accident

The Rogers Commission listed 16 findings on the primary cause of the accident before stating the following conclusion:

"The commission concluded that the cause of the Challenger accident was the failure of the pressure seal in the aft field joint of the right Solid Rocket Motor. The failure was due to a faulty design unacceptably sensitive to a number of factors. These factors were the effects of temperature, physical dimensions, the character of materials, the effects of reusability, processing and the reaction of the joint to dynamic loading."

A thorough analysis of all available evidence showed no abnormalities with the external fuel tank, Challenger and its three main engines or the shuttle's payload and records showed all the hardware used in flight 51-L met NASA specifications. Launch processing, from the initial stacking of the rocket boosters to work done at the launch pad was normal, but during assembly of the right-side booster, engineers ran into snags. One of the fuel segments that mated at the aft field joint was severely out of round and had to be forced into the proper shape with a high-power hydraulic tool. In addition, measurements showed that because of previous use, the two fuel segments in question had slightly larger diameters than normal but they still were within specifications.

Recall for a moment the construction of the joint. The upper rim of the bottom fuel segment, called a clevis, is an upward-facing U-shaped groove. The lower rim of the fuel segment above, called a tang, slides into the clevis and the resulting interlocking joint is bolted together with 177 high-strength steel pins. Running around the interior of the inner leg of the clevis are the two rubber O-ring seals. Because of the larger than normal joint diameters, at the moment of ignition, the tang and clevis had an average gap of .004 inches, which would have compressed the O-rings severely. Because the fuel segments were slightly out of round, the smallest gap was in the area where the rupture occurred during flight, although it is not known if the high compression on the O-ring was present at liftoff.

It was a record 36 degrees when Challenger took off and infrared measurements taken at the launch pad showed the temperature around the circumference of the aft field joint was in the neighborhood of 28 degrees in the area where the rupture occurred, the coldest spot on the booster. To understand the significance of the temperature factor, consider again the operation of the rocket motor at ignition when internal pressure shoots from zero to nearly 1,000 pounds per square inch. This tremendous force pushes outward and causes the joints to bulge slightly, a phenomenon known as joint rotation. During the ignition transient, the tang and clevis typically separate as much as .017 and .029 inches where the primary and secondary O-rings are located. The gap opening reaches maximum about 600 milliseconds after ignition when the motor reaches full pressure. To keep the joint sealed as the tang-clevis separation increases during ignition, the O-rings must seat properly and the commission said cold O-rings take longer to reach the proper position.

"At the cold launch temperature experienced, the O-ring would be very slow in returning to its normal rounded shape. It would not follow the opening of the tang-to-clevis gap. It would remain in its compressed position in the O-ring channel and not provide a space between itself and the upstream channel wall. Thus, it is probable the O-ring would not be pressure actuated to seal the gap in time to preclude joint failure due to blow-by and erosion from hot combustion gases," the report said.

Further, the commission found that experimental evidence showed other factors, such as humidity and the performance of the heat-shielding putty in the joint "can delay pressure application to the joint by 500 milliseconds or more." Records showed that in each shuttle launch in temperature below 61 degrees, one or more booster O-rings showed signs of erosion or the effects of heat. Complicating the picture, there was the possibility of ice in the suspect joint because Challenger had been exposed to seven inches of rainfall during its month on the launch pad prior to blastoff. Research showed ice could have prevented proper sealing by the secondary O-ring.

Launch pad cameras showed puffs of black smoke shooting from the region of the aft field joint beginning about the same time the motor reached full pressure. The commission said two overall failure scenarios were possible: a small leak could have developed at ignition that slowly grew to the point that flame erupted through the joint as photographs indicated some 58 seconds after blastoff. More likely, however, the gap between the burned O-rings and the clevis probably was sealed up by "deposition of a fragile buildup of aluminum oxide and other combustion debris. The resealed section of the joint could have been disturbed by thrust vectoring (steering), space shuttle motion and flight loads induced by changing winds aloft." NASA revealed after the accident that wind shear was higher for Challenger's mission than for any previous shuttle flight.

That the shuttle booster joints were faulty and overly dependent on a variety of factors was clear. The commission's findings on the secondary causes of the disaster were more subtle but just as damning to the space agency.

The Contributing Cause of the Accident

"The decision to launch the Challenger was flawed," the Rogers Commission said. "Those who made that decision were unaware of the recent history of problems concerning the O-rings and the joint and were unaware of the initial written recommendation of the contractor advising against the launch at temperatures below 53 degrees Fahrenheit and the continuing opposition of the engineers at Thiokol after the management reversed its position.

They did not have a clear understanding of Rockwell's concern that it was not safe to launch because of ice on the pad. If the decision makers had known all of the facts, it is highly unlikely that they would have decided to launch 51-L on January 28, 1986."

Before shuttles are cleared for flight, a formal "flight readiness review" is held by top NASA managers to discuss any open items that might affect a launch. Previous flights are reviewed to make sure any problems had been addressed before commiting the next shuttle for launch. Mulloy testified NASA management was well aware of the O-ring issue and cited the flight readiness review record as proof. He was correct in that during several preceding flight readiness reviews, the O-ring problem was mentioned. But it was only mentioned in the context that it was an acceptable risk and that the boosters had plenty of margin. It was not mentioned at all during the 51-L readiness review.

"It is disturbing to the commission that contrary to the testimony of the solid rocket booster project manager, the seriousness of concern was not conveyed in Flight Readiness Review to Level 1 and the 51-L readiness review was silent."

Keel said later the real turning point in the commission investigation came on Feb. 10 during a closed hearing in Washington. It was there the commission learned of the launch-eve debate over clearing Challenger for launch. Boisjoly would later recall the events of Jan. 27 in this manner:

Boisjoly: "I felt personally that management was under a lot of pressure to launch and that they made a very tough decision, but I didn't agree with it. One of my colleagues that was in the meeting summed it up best. This was a meeting where the determination was to launch and it was up to us to prove beyond a shadow of a doubt that it was not safe to do so. This is in total reverse to what the position usually is in a preflight conversation or a flight readiness review. It is usually exactly opposite that."

Commission member Arthur B.C. Walker: "Do you know the source of the pressure on management that you alluded to?"

Boisjoly: "Well, the comments made over the [teleconference network] is what I felt, I can't speak for them, but I felt it, I felt the tone of the meeting exactly as I summed up, that we were being put in a position to prove that we should not launch rather then being put in the position and prove that we had enough data for launch. And I felt that very real."

The Rogers Commission concluded that a "well structured" management system with the emphasis on flight safety would have elevated the booster O-ring issue to the status it deserved and that NASA's decision-making process was clearly faulty. One can only wonder how many other launch-eve debates occurred during the previous 24 missions that were never mentioned because the flight turned out to be a success.

"Had these matters been clearly stated and emphasized in the flight readiness process in terms reflecting the views of most of the Thiokol engineers and at least some of the Marshall engineers, it seems likely that the launch of 51-L might not have occurred when it did," the commission said.

The commission also determined that the waiving of launch constraints based on previous success came at the expense of flight safety because the waivers did not necessarily reach top-level management for a decision. Finally, the commission charged engineers at the Marshall Space Flight Center where the booster program was managed had a "propensity" for keeping knowledge of potentially serious problems away from other field centers in a bid to address them internally.

An Accident Rooted in History

"The Space Shuttle's Solid Rocket Booster problem began with the faulty design of its joint and increased as both NASA and contractor management first failed to recognize it as a problem, then failed to fix it and finally treated it as an acceptable flight risk," the Rogers Commission said.

Morton Thiokol won the contract to build shuttle boosters in 1973. Of the four competitors, Thiokol ranked at the bottom for design and development but came in first in the management category. NASA later said Thiokol was selected because "cost advantages were substantial and consistent throughout all areas evaluated." The result was an $800 million cost-plus-award-fee contract.

Morton Thiokol hoped to keep costs down by borrowing heavily from the design of the Titan 3 solid rocket motors. Both systems, for example, used tang and clevis joints but the shuttle design had major differences as well. Unlike in the Titan, which relied on a single O-ring seal, two rubber O-rings were employed in the shuttle booster and both faced heavy pressure loads at launch. The way the seals worked in the shuttle boosters was elegant in its simplicity. Before fuel joints were to be mated, an asbestos-filled putty would be used to fill in the gap between the two propellant faces of the fuel segments. The putty, then, would serve as a barrier to prevent hot gas from reaching the O-ring seals. But the putty was plastic so when the rocket was ignited, internal pressure would force the putty to flow toward the outside of the joint. In doing so, air between the putty and the O-ring would become pressurized, forcing the O-ring to "extrude" into the minute gap between the clevis and tang. In this manner, the joint would be sealed and even if the primary O-ring failed to operate, the secondary seal would fill in the gap, so to speak. To make sure the O-rings were, in fact, able to seal the joints prior to ignition, Thiokol included a "leak test port" in each booster joint. Once assembled, the space between the two O-rings could be pressurized with 50 psi air. If the pressure stayed steady, engineers would know the joint was airtight and that no path from the propellant to the primary O-ring existed for hot gas or flame.

So much for theory. When testing began, results were not what Thiokol engineers expected.

The design of the joint had led engineers to believe that once pressurized, the gap between the tang and clevis actually would decrease slightly, thereby improving the sealing action of the O-rings. To test the booster's structural integrity, Thiokol conducted "hydroburst" tests in 1977. In these tests, water was pumped inside a booster case and pressurized to 1.5 times actual operating pressure. Careful measurements were made and to their surprise, engineers realized that the tang and clevis joint actually bulged outward, widening the gap between the joint members. While Thiokol tended to downplay the significance of the finding at the time, engineers at Marshall were dismayed by the results. John Q. Miller, a chief booster engineer at the Alabama rocket center, wrote a memo on Jan. 9, 1978, to his superiors, saying, "We see no valid reason for not designing to accepted standards" and that improvements were mandatory "to prevent hot gas leaks and resulting catastrophic failure." This memo and another along the same lines actually were authored by Leon Ray, a Marshall engineer, with Miller's agreement. Other memos followed but the Rogers Commission said Thiokol officials never received copies. In any case, the Thiokol booster design passed its Phase 1 certification review in March 1979. Meanwhile, ground test firings confirmed the clevis-tang gap opening. An independent oversight committee also said pressurization through the leak test port pushed the primary O-ring the wrong way so that when the motor was ignited, the compression from burning propellant had to push the O-ring over its groove in order for it to extrude into the clevis-tang gap. Still, NASA engineers at Marshall concluded "safety factors to be adequate for the current design" and that the secondary O-ring would serve as a redundant backup throughout flight.

On Sept. 15, 1980, the solid rocket booster joints were classified as criticality 1R, meaning the system was redundant because of the secondary O-ring. Even so, the wording of the critical items list left much room for doubt: "Redundancy of the secondary field joint seal cannot be verified after motor case pressure reaches approximately 40 percent of maximum expected operating pressure." The joint was classified as criticality 1R until December 1982 when it was changed to criticality 1. Two events prompted the change: the switch to a non-asbestos insulating putty - the original manufacturer had discontinued production - and the results of tests in May 1982 that finally convinced Marshall management that the secondary O-ring would not function after motor pressurization. Criticality 1 systems are defined as those in which a single failure results in loss of mission, vehicle and crew. Even though the classification was changed, NASA engineers and their counterparts at Morton Thiokol still considered the joint redundant through the ignition transient. The Rogers Commission found this to be a fatal flaw in judgment.

Criticality 1 systems must receive a formal "waiver" to allow flight. On March 28, 1983, Michael Weeks, associate administrator for space flight (technical) signed the document that allowed continued shuttle missions despite the joint concerns.

"We felt at the time, all of the people in the program I think felt that this solid rocket motor in particular was probably one of the least worrisome things we had in the program," Weeks said.

Then came the flight of mission 41-B, the 10th shuttle mission, launched Feb. 3, 1984. Prior to that time, only two flights had experienced O-ring damage: the second shuttle mission and the sixth. In both cases, only a single joint was involved. But after 41-B, inspectors found damage to a field joint and a nozzle joint. Marshall engineers were concerned about the unexpected damage, but a problem assessment report concluded: "This is not a constraint to future launches." For the next shuttle flight, 41-C, NASA managers were advised launch should be approved but that there was a possibility of some O-ring erosion. Meanwhile, to make absolutely sure the O-rings were seated properly prior to launch, the leak test pressure was increased to 100 psi and later to 200 psi, even though Marshall engineers realized that increased the possibility of creating blow holes through the insulating putty. Such blow holes, in turn, could provide paths for hot gas to reach the O-rings. In any case, the statistics are simple: of the first nine shuttle flights, when joints were tested with 50 psi or 100 psi pressure, only one field joint problem was noticed. With the 200 psi tests, more than 50 percent of the shuttle missions exhibited some field joint O-ring erosion.

So even though research was underway to improve the joint design, shuttles continued flying. On Jan. 24, 1985, Atlantis took off on the first classified military shuttle mission, flight 51-C. The temperature at launch time was a record 53 degrees and O-ring erosion was noted in both boosters after recovery. Damage was extensive: both booster nozzle primary O-rings showed signs of blow by during ignition and both the primary and secondary seals in the right booster's center segment field joint were affected by heat. Thiokol engineers would later say temperature apparently increased the chances for O-ring damage or erosion by reducing resiliency. Concern mounted after the flight of mission 51-B in April 1985 when engineers discovered a nozzle primary O-ring had been damaged and failed to seat at all and that the secondary seal also was eroded. This was serious and more studies were ordered. Mulloy then instituted a launch constraint, meaning a waiver was required before every succeeding mission. Mulloy signed such waivers six flights in a row before Challenger took off for the last time.

On Aug. 19, 1985, NASA managers in Washington were briefed on the O-ring issue and the next day, Morton Thiokol established an O-ring task force because "the result of a leak at any of the joints would be catastrophic." But company engineers told the commission the task force ran into red tape and a lack of cooperation.

"The genesis of the Challenger accident - the failure of the joint of the right solid rocket motor - began with decisions made in the design of the joint and in the failure by both Thiokol and NASA's solid rocket booster project office to understand and respond to facts obtained during testing," the Rogers Commission concluded.

The panel said NASA's testing program was inadequate, that engineers never had a good understanding of the mechanics of joint sealing and that the material presented to NASA management in August 1985 "was sufficiently detailed to require corrective action prior to the next flight."

Pressures on the System

"With the 1982 completion of the orbital test flight series, NASA began a planned acceleration of the Space Shuttle launch schedule," the Rogers Commission said. "One early plan contemplated an eventual rate of a mission a week, but realism forced several downward revisions. In 1985, NASA published a projection calling for an annual rate of 24 flights by 1990. Long before the Challenger accident, however, it was becoming obvious that even the modified goal of two flights a month was overambitious."

When the shuttle program was conceived, it was hailed as the answer to the high cost of space flight. By building a reusable space vehicle, the United States would be able to lower the cost of placing a payload into orbit while at the same time, increase its operational capability on the high frontier. The nation's space policy then focused on the shuttle as the premier launcher in the American inventory and expendable rockets were phased out. Once shuttle flights began, NASA quickly fell under pressure to meet a heavy schedule of satellite launches for commercial, military and scientific endeavors. And as the flight rate increased, the space agency's resources became stretched to the limit. Indeed, the Rogers Commission said evidence indicated even if the 51-L disaster had been avoided, NASA would have been unable to meet the 16-launch schedule planned for 1986.

But NASA's can-do attitude refused to let the agency admit its own limitations as it struggled along against increasingly significant odds and diminishing resources. The Rogers Commission found that astronaut training time was being cut back, that frequent and late payload changes disrupted flight planning and that a lack of spare parts was beginning to manifest itself in flight impacts at the time of the Challenger accident.

The Rogers Commission concluded:

1. "The capabilities of the system were stretched to the limit to support the flight rate in winter 1985/1986," the commission wrote. "Projections into the spring and summer of 1986 showed a clear trend; the system, as it existed, would have been unable to deliver crew training software for scheduled flights by the designated dates. The result would have been an unacceptable compression of the time available for the crews to accomplish their required training.

2. "Spare parts are in short supply. The shuttle program made a conscious decision to postpone spare parts procurements in favor of budget items of perceived higher priority. Lack of spare parts would likely have limited flight operations in 1986.

3. "Stated manifesting policies [rules governing payload assignments] are not enforced. Numerous late manifest changes (after the cargo integration review) have been made to both major payloads and minor payloads throughout the shuttle program.

4. "The scheduled flight rate did not accurately reflect the capabilities and resources.

5. "Training simulators may be the limiting factor on the flight rate; the two current simulators cannot train crews for more than 12-15 flights per year.

6. "When flights come in rapid succession, current requirements do not ensure that critical anomalies occurring during one flight are identified and addressed appropriately before the next flight."

Other Safety Considerations

The Rogers Commission also identified a number of safety considerations to be addressed by NASA before the resumption of shuttle flights. The realization that Challenger's crew had no survivable abort options during solid rocket flight prompted the commission to recommend a re-evaluation of all possible abort schemes and escape options.

Two types of shuttle aborts were possible at the time of the Challenger accident: the four intact aborts, in which the shuttle crew attempts an emergency landing on a runway, and contingency aborts, in which the shuttle is not able to make it to a runway and instead "ditches" in the ocean. But the commission said tests at NASA's Langely Research Center showed an impact in the ocean probably would cause major structural damage to the orbiter's crew cabin. In addition, "payloads in the cargo bay are not designed to withstand decelerations as high as those expected and would very possibly break free and travel forward into the crew cabin." Not a pleasant prospect.

"My feeling is so strong that the orbiter will not survive a ditching, and that includes land, water or any unprepared surface," astronaut Weitz told the commission. "I think if we put the crew in a position where they're going to be asked to do a contingency abort, then they need some means to get out of the vehicle before it contacts earth."

If there was a clear "winner" in the Rogers Commission report is was the astronauts. Nearly every concern raised by Young and his colleagues was addressed and NASA managers privately grumbled that with the re-emergence of "astronaut power," the agency would become so conservative it would be next to impossible to get a shuttle off the ground.

Recommendations:

The Rogers Commission made nine recommendations to conclude its investigation of the worst disaster in space history.

1. A complete redesign of the solid rocket booster segment joints was required with the emphasis on gaining a complete understanding of the mechanics of seal operation; the joints should be as structurally stiff as the walls of the rockets and thus less susceptible to rotation; and NASA should consider vertical test firings to ensure duplication of the loads experienced during a shuttle launch. In addition, the panel recommended that NASA ask the National Research Council to set up an independent review committee to oversee the redesign of the booster joints.

2. NASA's shuttle program management system should be reviewed and restructured, with the program manger given more direct control over operations, and NASA should "encourage the transition of qualified astronauts into agency management positions" to utilize their flight experience and to ensure proper attention is paid to flight safety. In addition, the commission said NASA should establish a shuttle safety advisory panel.

3. The commission recommended a complete review of all criticality 1, 1R, 2 and 2R systems before resumption of shuttle flights.

4. NASA was told to set up an office of Safety, Reliability and Quality Control under an associate administrator reporting to the administrator of the space agency. This office would operate autonomously and have oversight responsibilities for all NASA programs.

5. Communications should be improved to make sure critical information about shuttle systems makes it from the lowest level engineer to the top managers in the program. "The commission found that Marshall Space Flight Center project managers, because of a tendency at Marshall to management isolation, failed to provide full and timely information bearing on the safety of flight 51-L to other vital elements of shuttle program management," the panel said. Astronauts should participate in flight readiness reviews, which should be recorded, and new policies should be developed to "govern the imposition and removal of shuttle launch constraints."

6. NASA should take action to improve safety during shuttle landings by improving the shuttle's brakes, tires and steering system and terminating missions at Edwards Air Force Base, Calif., until weather forecasting improvements are made at the Kennedy Space Center.

7. "The commission recommends that NASA make all efforts to provide a crew escape system for use during controlled gliding flight." In addition, NASA was told to "make every effort" to develop software modifications that would allow an intact landing even in the event of multiple engine failures early in flight.

8. Pressure to maintain an overly ambitious flight rate played a role in the Challenger disaster and the Rogers Commission recommended development of new expendable rockets to augment the shuttle fleet.

9. "Installation, test and maintenance procedures must be especially rigorous for space shuttle items designated criticality 1. NASA should establish a system of analyzing and reporting performance trends in such items." In addition, the commission told NASA to end its practice of cannibalizing parts from one orbiter to keep another flying and instead to restore a healthy spare parts program despite the cost.

❑ ❑ ❑

Along with redesigning the O-ring booster joints, the agency reviewed the status of the overall shuttle program and ordered hundreds of modifications and improvements to beef up the safety of the shuttle itself. The shuttle "critical items list," which ranks systems and components according to the results of a failure, underwent a thorough review with far-reaching results. Criticality 1 components are those in which a failure leads to loss of vehicle and crew while criticality 1R systems are those in which a redundant backup is in place. Before the Challenger disaster, NASA listed 617 criticality 1 and 787 criticality 1R systems, a total of 1,404. As a result of the post-Challenger review, 1,514 criticality 1 systems were identified along with 2,113 criticality 1R components, a total of 3,627.

The numbers increased because NASA took a much harder look at the shuttle and its systems in the wake of Challenger and while at first glance they would appear to imply the shuttle is more dangerous than before, in reality they mean NASA simply has a better, more realistic understanding of the ship.

In the shuttle itself, more than 210 changes were ordered for first flight along with about 30 to widen safety margins in the powerful hydrogen-fueled main engines by improving welds and reducing bearing wear and turbine blade cracks, a source of concern in the past. Among the shuttle modifications were landing gear brake improvements and a redesign of the 17-inch valves in the main engine propellant feed lines to prevent premature closure and inadvertent engine shutdown.

Other major changes include installation of ribs to strengthen the structure of the shuttle's airframe, an automatic cutoff system to prevent maneuvering rocket problems and modifications to improve the ability of the nose section of the shuttle to withstand the tremendous heat of atmospheric re-entry. About 100 changes were made in the computer programs that actually fly the shuttle to take into account the performance of modified hardware and to improve safety margins.

NASA re-emphasized safety in mission design, implementing stricter weather criteria, new launch commit criteria and a revamped management structure that gave the final responsibility for clearing a shuttle for launch to an astronaut.

Shuttle flights resumed Sept. 29, 1988, and NASA launched 87 successful flights in a row before Columbia returned to Earth on Feb. 1, 2003.

Challenger's crew: Back row, left to right: Ellison Onizuka, Christa McAuliffe, Greg Jarvis, Judy Resnik; Front row, left to right: Mike Smith, Dick Scobee, Ron McNair

The Fate of Challenger's Crew

"NASA is unable to determine positively the cause of death of the Challenger astronauts but has established that it is possible, but not certain, that loss of consciousness did occur in the seconds following the orbiter breakup." NASA Press Release

"We have now turned our full efforts to the future, but will never forget our seven friends who gave their lives to America's space frontier." - Rear Adm. Richard Truly, Associate Administrator for Space Flight

The Rogers Commission did not discuss the fate of the crew or provide much detail about the crew cabin wreckage. Indeed, all references to "contact 67," the crash site of the crew compartment, were deleted from the official record, including charts that mapped various debris areas. This was done, perhaps, to preclude the possibility that anyone could find out the latitude and longitude of the cabin wreck site for diving and personal salvage. But ultimately, it was simply an extension of NASA's policy of no comment when it came to the astronauts. After all, hundreds of reporters knew the exact coordinates by eavesdropping on Navy radio. In any case, while the astronauts were not discussed in the commission report, the crew module was.

Analysis of crew cabin wreckage indicates the shuttle's windows may have survived the explosion. It is thus possible the crew did not experience high altitude decompression. If so, some or all of the astronauts may have been alive and conscious all the way to impact in the Atlantic some 18 miles northeast of the launch pad. The cabin hit the water at better than 200 mph on Scobee's side. The metal posts of the two forward flight deck seats, for example, were bent sharply to the right by force of impact when the cabin disintegrated.

"The internal crew module components recovered were crushed and distorted, but showed no evidence of heat or fire," the commission report said. "A general consistency among the components was a shear deformation from the top of the components toward the +Y (to the right) direction from a force acting from the left. Components crushed or sheared in the above manner included avionics boxes from all three avionics bays, crew lockers, instrument panels and the seat frames from the commander and the pilot. The more extensive and heavier crush damage appeared on components nearer the upper left side of the crew module. The magnitude and direction of the crush damage indicates that the module was in a nose down and steep left bank attitude when it hit the water.

"The fact that pieces of forward fuselage upper shell were recovered with the crew module indicates that the upper shell remained attached to the crew module until water impact. Pieces of upper forward fuselage shell recovered or found with the crew module included cockpit window frames, the ingress/egress hatch, structure around the hatch frame and pieces of the left and right sides. The window glass from all of the windows, including the hatch window, was fractured with only fragments of glass remaining in the frames."

Several large objects were tracked by radar after the shuttle disintegrated. One such object, classified as "Object D," hit the water 207 seconds after launch about 18 nautical miles east of launch pad 39B. This apparently was the crew cabin. "It left no trail and had a bright white appearance (black and white recording) until about T+175 seconds," an appendix to the Rogers Commission report said. "The image then showed flashes of both white and black until T+187 seconds, after which time it was consistently black. The physical extent of the object was estimated from the TV recording to be about 5 meters." This description is consistent with a slowly spinning crew module, which had black heat-shield tiles on its bottom with white tiles on its side and top.

The largest piece of crew cabin wreckage recovered was a huge chunk of the aft bulkhead containing the airlock hatch that led into the payload bay and one of the two flight deck windows that looked out over the cargo hold. The bulkhead wreckage measured 12 feet by 17 feet.

Here is a chronology of the crew cabin recovery operation and the efforts to determine the fate of the astronauts:

Mid-March Four astronaut "personal egress air packs," called PEAPs, are recovered along with other cabin wreckage.

April 18 NASA announced the crew cabin recovery operation was complete and that identifiable remains of all seven astronauts were on shore undergoing analysis.

April 25 The Armed Forces Institute of Pathology notified NASA it had been unable to determine a cause of death from analysis of remains. Joseph Kerwin, director of life sciences at the Johnson Space Center, began an in-depth analysis of the wreckage in a search for the answer.

May 20 Johnson Space Center crew systems personnel began analysis of the four PEAPs, emergency air packs designed for use if a shuttle crew must attempt an emergency exit on the ground when dangerous vapors might be in the area.

May 21 Investigators found evidence some of the PEAPs had been activated.

June 4 Investigators determined PEAP activation was not caused by crew cabin impact in the ocean.

June 9 Smith's PEAP was identified by serial number.

June 25 The PEAPs were sent to th Army Depot in Corpus Christi, Texas, for further analysis.

June 27 Scobee's PEAP was identified by serial number; Army investigators determined that three of the four air packs had been activated.

July 18 Truly received Kerwin's preliminary report on the fate of the astronauts. On July 24, NASA began informing the astronauts' families about what the investigation had found.

Some of the first wreckage recovered included four flight computers and both the cabin's operational flight recorders, used to record data about various shuttle systems and also used for the cabin's intercom system. It was on this tape that NASA heard Smith say "Uh oh" an instant before the shuttle broke apart, showing that at least some of the astronauts had a brief moment of awareness before the explosion that would claim their lives. On July 28, six months to the day after the disaster, NASA staged a news conference in Washington to discuss the investigation. Kerwin said the cause and time of death remained unknown.

"The findings are inconclusive," he wrote in a letter to Truly. "The impact of the crew compartment with the ocean surface was so violent that evidence of damage occurring in the seconds which followed the explosion was masked. Our final conclusions are:

> The cause of death of the Challenger astronauts cannot be positively determined;
>
> The forces to which the crew were exposed during orbiter breakup were probably not sufficient to cause death or serious injury; and
>
> The crew possibly, but not certainly, lost consciousness in the seconds following orbiter breakup due to in-flight loss of crew module pressure."

Accelerometers, instruments that measure the magnitude and direction of forces acting on the shuttle during flight, lost power when the nose section ripped away two tenths of a second after structural break up began. Independent analysis of all recovered data and wreckage concluded the nose pitched down as soon as it broke away and then slowed rapidly from aerodynamic forces. Calculations and analysis of launch photography indicate the acceleration forces the astronauts felt were between 12 and 20 times the force of gravity in a vertical direction, that is, as the cabin broke away, the astronauts were violently pushed down in their seats.

"These accelerations were quite brief," Kerwin wrote. "In two seconds, they were below four G's; in less than 10 seconds, the crew compartment was essentially in free fall. Medical analysis indicates that these accelerations are survivable, and that the probability of major injury to crew members is low."

When Challenger broke up, it was traveling at 1.9 times the speed of sound at an altitude of 48,000 feet. The crew module continued flying upward for some 25 seconds to an altitude of about 65,000 feet before beginning the long fall to the ocean. From breakup to impact took two minutes and 45 seconds. Impact velocity was 207 mph, subjecting the module to a braking force of approximately 200 times the force of gravity. Any astronaut still alive at that moment was killed instantly.

When the cabin ripped away from the fuselage, the crew's oxygen supplies were left behind in the payload bay, "except for a few seconds supply in the lines," Kerwin said. But each astronaut's airtight flight helmet also was connected to a PEAP that contained about six minutes of breathing air. Kerwin said because of the design of the activation switch, it was highly unlikely the PEAPs were turned on by impact. But unlike the oxygen system, the PEAPs did not provide pressurized air and if the cabin lost pressure, they would not have allowed the crew to remain conscious.

"It is possible, but not certain, that the crew lost consciousness due to an in-flight loss of crew module pressure," Kerwin wrote. "Data to support this is:

> The accident happened at 48,000 feet and the crew cabin was at that altitude or higher for almost a minute. At that altitude, without an oxygen supply, loss of cabin pressure would have caused rapid loss of consciousness and it would not have been regained before water impact.
>
> PEAP activation could have been an instinctive response to unexpected loss of cabin pressure.
>
> If a leak developed in the crew compartment as a result of structural damage during or after breakup (even if the PEAPs had been activated), the breathing air available would not have prevented rapid loss of consciousness.
>
> The crew seats and restraint harnesses showed patterns of failure which demonstrates that all the seats were in place and occupied at water impact with all harnesses locked. This would likely be the case had rapid loss of consciousness occurred, but it does not constitute proof."

Challenger's crew departs the Kennedy Space Center

Despite NASA's best efforts, engineers were never able to determine if cabin pressure was lost. Astronaut Crippen said later he was convinced it did, however, because had the cabin maintained pressure there would have been no need to activate the PEAPs. He said in his view, the astronauts made a "desperate" attempt to survive by activating the PEAPs when pressure was suddenly lost.

Of the four PEAPs recovered, the one that belonged to Scobee had not been activated. Of the other three, one was identified as Smith's and because of the location of the activation switch on the back of his seat, Truly said he believed Resnik or Onizuka turned the pilot's emergency air supply on in a heroic bid to save his life. The exact sequence of events will never be known.

STS-107: Columbia's Final Voyage

The shuttle Columbia blasted off on mission STS-107 at 10:39 a.m. on Jan. 16, 2003. At the controls were commander Rick Husband, pilot William "Willie" McCool, flight engineer Kalpana Chawla, physician Laurel Clark, payload commander Michael Anderson, physician David Brown and Israeli astronaut Ilan Ramon. STS-107 was one of only two flights left on the shuttle manifest that were not bound for the international space station (the other was a Hubble Space Telescope servicing mission).

Columbia breaks up above Texas. Photographed by Jim Dietz at his home near Dallas.

The goal of the 16-day mission was to carry out space station-class research in a variety of disciplines, ranging from biology to medicine, from materials science to pure physics and technology development, research that, for a variety of reasons, had never made it to the international space station.

Columbia's launching appeared normal, but analysis of tracking camera footage later that day showed a large chunk of foam insulation broke away from the shuttle's external tank about 81 seconds after liftoff. The foam appeared to come from a the left bipod ramp, an aerodynamically shaped ramp of foam built up around one of the two struts holding the nose of the shuttle to the tank. The foam fell along the tank and disappeared under Columbia's left wing. A shower of whitish debris was seen an instant later exiting from under the wing. The foam had obviously struck the wing, but where? And what sort of damage, if any, did it cause?

Engineers ultimately would conclude the impact likely caused no entry-critical damage. Husband and his crew were only informed about the strike in passing, in an email from mission managers who were concerned the astronauts might hear about the strike from reporters during upcoming on-orbit interviews. As it turned out, only a few reporters even knew about the foam strike and no one asked the crew about it. For their part, Husband and company chalked up a near perfect science mission before packing up for the trip back to Earth.

The day before re-entry, flight director LeRoy Cain downplayed the foam strike, saying engineers "took a very thorough look at the situation with the tile on the left wing and we have no concerns whatsoever. We haven't changed anything with respect to our trajectory design. It will be a nominal, standard trajectory."

He was wrong.

Shuttle Columbia destroyed in entry mishap
By WILLIAM HARWOOD
CBS News

The shuttle Columbia suffered a catastrophic failure returning to Earth Saturday, breaking apart 207,135 feet above Texas en route to a landing at the Kennedy Space Center to close out a 16-day science mission. The shuttle's seven-member crew - two women and five men, including the first Israeli space flier - perished in the disaster, the first loss of life on the high frontier since the 1986 Challenger disaster.

The initial phases of the descent went normally and Columbia crossed above the coast of California just north of San Francisco around 5:51 a.m. local time, or 8:51 a.m. EST, on track for a landing on runway 33 at the Kennedy Space Center just 25 minutes later at 9:16 a.m.

The first sign of anything unusual came at 8:53 a.m., when the shuttle was flying high above the heartland of America.

Telemetry showed a sudden loss of hydraulic system data from the inboard and outboard wing flaps, or elevons, on Columbia's left wing. Three minutes later, sensors in the brake lines and tires of the shuttle's left-side main landing gear suddenly stopped providing data.

The shuttle continued to fly in a normal manner with no hint that a catastrophic failure was imminent.

Then at 8:58 a.m., sensors that monitor temperatures where the shuttle's protective thermal tiles are glued or bonded to the airframe suddenly dropped out followed one minute later by loss of data from landing gear pressure sensors on the left side tires. Columbia's flight computers alerted the astronauts to the pressure indication and one of the crew members acknowledged the alert in a brief call to mission control.

That was the final transmission from the space shuttle. Moments later, all data were lost and the vehicle broke up while traveling 18.3 times the speed of sound. Mission duration to that point was 15 days 22 hours 20 minutes and 22 seconds, translating to 8:59:22 a.m. EST (Editor's note: This time was later amended; see the detailed timeline below for exact timing). Wreckage was soon found strewn over a debris "footprint" stretching across eastern Texas and into Louisiana. There was no immediate word on where Columbia's reinforced crew module might have crashed to Earth.

In a brief address to the nation, President Bush said "this day has brought terrible news and great sadness to our country. Columbia is lost. There are no survivors."

"The same creator who names the stars also knows the names of the seven souls we mourn today," he said. "The crew of the shuttle Columbia did not return safely to Earth. Yet we can pray they are all safely home."

Said NASA Administrator Sean O'Keefe: "The loss of this valiant crew is something we will never be able to get over."

Family members were standing by at the shuttle runway to welcome their loved ones back to Earth. William Readdy, NASA's associate administrator for space flight and a veteran shuttle commander, praised the astronauts' families for showing an "incredible amount of dignity considering their loss."

"They knew the crew was absolutely dedicated to the mission they were performing," he said, barely able to control his emotions. "They believed in what they were doing and in the conversations with the families, they said we must find what happened, fix it and move on. We can't let their sacrifice be in vain.

"Today was a very stark reminder this is a very risky endevour, pushing back the frontiers in outer space. Unfortunately, people have a tendency to look at it as something that is more or less routine. I can assure you, it is not.

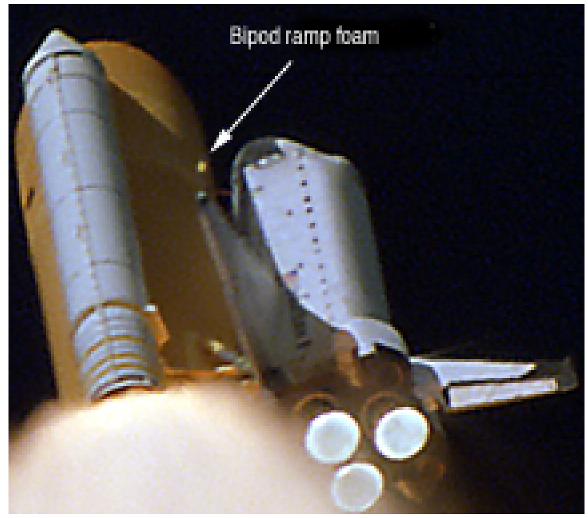
"I have to say as the one responsible for shuttle and (space) station within NASA, I know the people in NASA did everything possible preparing for this flight to make it as perfect as possible," Readdy said. "My promise to the crew and the crew families is the investigation we just launched will find the cause. We'll fix it. And then we'll move on."

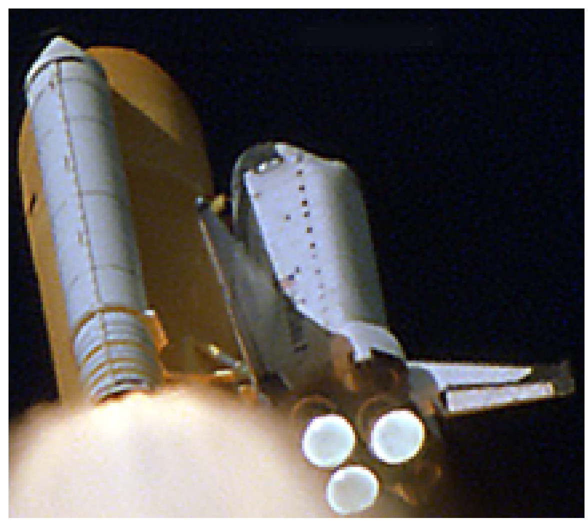
The goal of mission STS-107 was to carry out space station-class research in a variety of disciplines, ranging from biology to medicine, from materials science to pure physics and technology development, research that cannot yet be accommodated on the still-unfinished international space station.

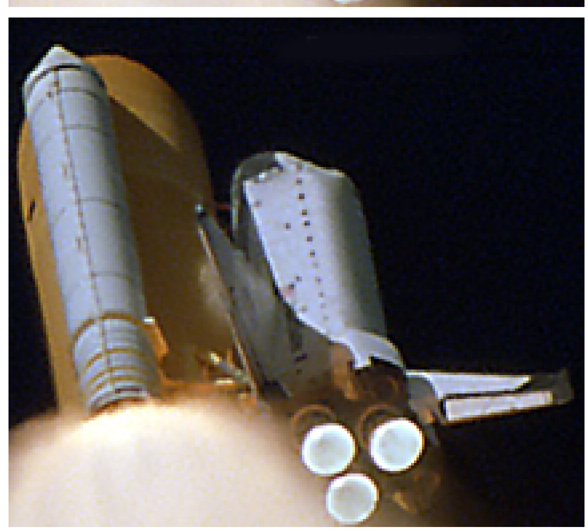
More than 80 experiments were on board, most of them in a Spacehab research module in Columbia's cargo bay. To collect as much data as possible, the astronauts worked around the clock in two 12-hour shifts. By all accounts, the crew accomplished all of their major objectives.

At an afternoon news conference, shuttle program manager Ronald Dittemore and senior flight director Milt Heflin reviewed the telemetry from the shuttle and answered as many questions as possible. NASA's openness during the immediate aftermath of a devastating day was in stark contrast to the strict "no comment" policy implemented in the wake of the 1986 Challenger disaster that frustrated the public and tarnished the agency's reputation for openness.

10:40:22 a.m., Jan. 16, 2003: A briefcase-size chunk of foam breaks away from the left bi-pod ramp of Columbia's external fuel tank 81.7 seconds after liftoff as seen in these enhanced video frames from a NASA tracking camera. The shuttle's velocity is 1,568 mph and the foam breaks into several pieces as it tumbles in the airstream. In two-tenths of a second, the largest piece of debris slows to 1,022 mph as it disappears behind Columbia's left wing (photo 3). It emerges in a powdery looking shower of debris after hitting the wing at a relative velocity of about 545 mph.







"We're devastated because of the events that unfolded this morning," Dittemore said. "There's a certain amount of shock in our system because we have suffered the loss of seven family members. And we're learning to deal with that. Certainly, a somber mood in our teams as we continue to try to understand the events that occurred, but our thoughts and our prayers go out to the families.

"As difficult as this is for us, we wanted to meet with you and be as fair and open with you (as possible), given the facts as we understand them today," he said. "We will certainly be learning more as we go through the coming hours, days and weeks. We'll tell you as much as we know, we'll be as honest as we can with you and certainly we'll try to fill in the blanks over the coming days and weeks."

An internal NASA team of senior managers was named to handle the initial investigation into the disaster. An independent team of experts also was named to ensure objectivity. All flight control data and shuttle telemetry was impounded and "tiger teams" were formed to begin the painful tasks of sifting the data and coordinating the recovery of debris.

Dittemore said the shuttle fleet will remain grounded until engineers pinpoint what went wrong with Columbia and determine what corrections might be necessary.

Columbia's flight was one of only two remaining on NASA's long term launch schedule that does not involve the international space station. NASA had planned to launch the shuttle Atlantis around March 6 to ferry a fresh crew to the station and to bring the lab's current occupants back to Earth after 114 days in space.

Around 9:30 a.m. Saturday, flight controllers informed Expedition 6 commander Kenneth Bowersox, flight engineer Nikolai Budarin and science officer Donald Pettit that

Columbia had been lost during re-entry.

Bowersox and his crewmates have enough on-board supplies to remain aloft aboard the station through June. In fact, an unmanned Russian Progress supply ship is scheduled for launch Sunday from the Baikonur Cosmodrome in Kazakstan. That launch will proceed as planned, officials said.

If the shuttle fleet remains grounded through June, the station crew could be forced to abandon the station and return to Earth aboard a Russian Soyuz lifeboat. Fresh lifeboats are delivered to the station every six months to ensure the crew has a way to bail out in case of problems with the shuttle fleet or some other in-flight emergency.

With enough supplies on board to last Bowersox and his crewmates until late June, "there's some time for us to work through this," Dittemore said. "Right now, certainly there is a hold on future flights until we get ourselves established and understand the root cause of this disaster."

Astronaut Kalpana Chawla, working in Columbia’s Spacehab research module, looks back toward the photographer through a tunnel connecting the lab to the shuttle’s crew module.

Dittemore provided a sense of the loss felt by NASA and its contractors when he said "it's an emotional event, when we work together, we work together as family member and we treat each other that way. It's a sad loss for us.

"We understand the risks that are involved in human spaceflight and we know these risks are manageable and we also know they're serious and can have deadly consequences," he said. "So we are bound together with the threat of disaster all the time. We all rely on each other to make each spaceflight successful. So when we have an event like today, when we lose seven family members, it's just devastating to us."

Columbia blasted off on the 113th shuttle mission Jan. 16. The climb to space appeared uneventful, but about one minute and 20 seconds after liftoff, long-range tracking cameras showed a piece of foam insulation from the shuttle's external tank breaking away and hitting Columbia's left wing. The foam came from near the area where a forward bipod assembly attaches the nose of the shuttle to the tank. The debris hit the left wing near its leading edge.

Entry flight director Leroy Cain said Friday a detailed analysis of the debris impact led engineers to believe there was no serious damage. Columbia was not equipped with a robot arm for this Spacehab research mission and the impact area was not visible from the shuttle's crew cabin.

Whether the debris caused enough damage to compromise the integrity of the wing's thermal protection system is not yet known. But when the failure occurred, the shuttle was experiencing maximum heat loads of nearly 3,000 degrees Fahrenheit.

"If we did have a structural problem or a thermal problem, you would expect to get it at the peak heating," he said. "The most extreme thermal environment was right at mach 18 and that's where we lost the vehicle."

The shuttle Challenger was destroyed in 1986 by the failure of an O-ring seal in one of the ship's two solid-fuel boosters. All seven crew members perished, including New Hampshire social studies teacher Christa McAuliffe. McAuliffe's backup, Idaho teacher Barbara Morgan, witnessed the disaster from the NASA press site 4.2 miles from Challenger's launch pad.

In a painful footnote to Saturday tragedy, Morgan was once again at the Kennedy Space Center, this time as a full-time astronaut awaiting launch in November on Columbia's next mission. Morgan is the first member of a new class of educator astronauts, part of a program initiated by O'Keefe to help generate more student interest in science and technology.

Since the educator-astronaut program was announced last month, more than 1,000 teachers have expressed interest or been nominated as potential candidates by students, family members or friends. The status of that program, and the impact of Columbia's loss on Morgan's flight, is not yet known.

But as President Bush promised family members and the nation Saturday, "the cause for which they died will continue. Our journey into space will go on."

❏ ❏ ❏

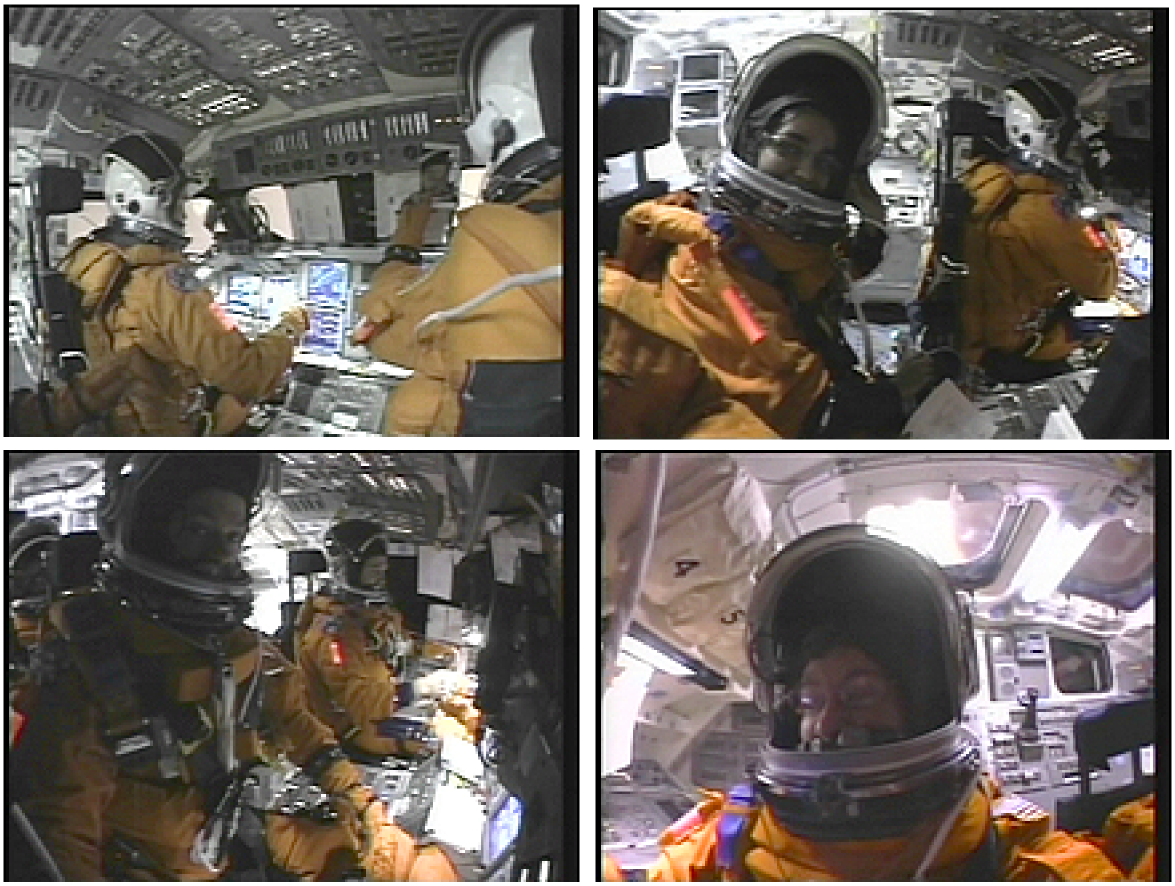
In the days, weeks and months ahead, an investigation of the disaster revealed echoes of Challenger: a long history of foam insulation problems that represented an unrecognized risk; bureaucratic inertia; slipshod internal communications and ineffective management at the top levels of NASA. The Columbia Accident Investigation Board, lead by retired Navy Adm. Harold Gehman, issued its report Aug. 28, 2005, concluding the so-called "NASA culture" was deeply flawed and in need of major modifications to prevent a repeat of the Columbia disaster in the years ahead.

"Based on NASA's history of ignoring external recommendations, or making improvements that atrophy with time, the Board has no confidence that the space shuttle can be safely operated for more than a few years based solely on renewed post-accident vigilance," the report stated.

Photographer Gene Blevins captured this shot of Columbia streaking high above California minutes before its destruction. By this point, Columbia's left wing was in the process of melting from the inside out.

Continuing, the report said that unless NASA took strong action to change its management culture to enhance safety margins in shuttle operations, "we have no confidence that other 'corrective actions' will improve the safety of shuttle operations. The changes we recommend will be difficult to accomplish - and they will be internally resisted."

For an agency with such a proud tradition - sending 12 men to the surface of the moon, establishing a permanent presence in low Earth orbit, exploring the solar system with unmanned robots and launching scientific sentinels to probe the depths of space and time - the criticism levied by the accident board seemed extreme in its harshness.



Columbia's flight deck, as captured by a videocamera operated by Laurel Clark, 15 minutes before the shuttle's destruction Feb. 1, 2003. In the top left frame, the heat of re-entry is evident out the windows in front of commander Rick Husband and pilot Willie McCool. In the top right frame, Chawla smiles for the camera. Bottom right: Clark turns the camera on herself.

But the accident investigation board members and their investigators clearly believed the sharp tone was appropriate, in their view essential to ensuring that wide-ranging corrective actions would be actually implemented. The board's investigation found that "management decisions made during Columbia's final flight reflect missed opportunities, blocked or ineffective communications channels, flawed analysis and ineffective leadership."

In the end, the report concluded, NASA managers never really understood the lessons of the 1986 Challenger disaster and "echoes of Challenger" abounded in the miscues that led to Columbia's destruction.

"Connecting the parts of NASA's organizational system and drawing the parallels with Challenger demonstrate three things," the board found. "First, despite all the post-Challenger changes at NASA and the agency's notable achievements since, the causes of the institutional failure responsible for Challenger have not been fixed.

"Second, the Board strongly believes that if these persistent, systemic flaws are not resolved, the scene is set for another accident. Therefore, the recommendations for change are not only for fixing the shuttle's technical system, but also for fixing each part of the organizational system that produced Columbia's failure.

"Third, the Board's focus on the context in which decision making occurred does not mean that individuals are not responsible and accountable. To the contrary, individuals always must assume responsibility for their actions. What it does mean is that NASA's problems cannot be solved simply by retirements, resignations, or transferring personnel."

The 13-member Columbia Accident Investigation Board spent seven months investigating the Feb. 1 Columbia disaster, reviewing more than 30,000 documents, conducting more than 200 formal interviews and collecting testimony from expert witnesses. The board also oversaw debris recovery efforts in Texas and Louisiana that involved more than 25,000 searchers. The investigation was expected to cost $19.8 million when all was said and done.

The board's 248-page report was released at the National Transportation and Safety Board in Washington. Reporters were allowed to review the report ahead of time, surrendering cell phones and wireless laptop network cards before entering a closed off "reading room" at 6 a.m. Gehman and other members of the panel discussed the report during a news conference.

"The people of NASA have accomplished great things," Dana Rohrabacher, D-Calif., chairman of a key House space committee, told CBS News. "They've put a man on the moon within a very short period of time, the people of NASA have been a source of great pride for the people of the United States.

"But for far too long, they've been resting on their laurels and bathing in past glories, nostalgic about the glory days," he continued. "It's time to look to the future and it's time to recapture a tough, hard-working body of people who have new challenges and are not just looking at the past but looking to the future. And that means Congress and the president have got to act on the Gehman report."

The CAIB report focused on two broad themes: The direct cause of the disaster - falling external fuel tank foam insulation that blasted a deadly hole in the leading edge of Columbia's left wing 82 seconds after liftoff - and the management system that failed to recognize frequent foam shedding as a potentially lethal defect before Columbia even took off.

The report also focuses on how NASA's mission management team, a panel of senior agency managers responsible for the day-to-day conduct of Columbia's mission, failed to recognize the severity of the foam strike that actually occurred, virtually eliminating any chance to save the shuttle's crew, either by attempting repairs in orbit or launching a rescue mission.

The report made 29 recommendations, 15 of which were to be implemented before shuttle flights resumed. Five of those were released earlier, requiring NASA to eliminate foam shedding to the maximum extent possible; to obtain better imagery from the ground and in orbit to identify any problems with the shuttle's thermal protection system; and development of tools and procedures to repair any such damage in space.

The more difficult recommendations addressed management changes and the establishment of an independent Technical Engineering Authority to verify launch readiness, oversee and coordinate requests for waivers and to "decide what is and is not an anomalous event." The TEA "should have no connection to or responsibility for schedule and program cost." In addition, the report concluded, NASA's Office of Safety and Mission Assurance should have direct authority over all shuttle safety programs and be independently funded.

"It is the Board's opinion that good leadership can direct a culture to adapt to new realities," the panel wrote. "NASA's culture must change, and the Board intends (its) recommendations to be steps toward effecting this change."

The foam strike that doomed Columbia was not seen until the day after launch when engineers began reviewing tracking camera footage as they do after every launching. A film camera in Cocoa Beach that could have photographed the impact on the underside of the left wing was out of focus. A video camera at the same site was

properly focused, but it lacked the resolution, or clarity, to show exactly where the foam hit or whether it caused any damage. A third camera at a different site showed the foam disappearing under the left wing and emerging as a cloud of debris after striking the underside. Again, the exact impact point could not be seen.
Stunned engineers immediately began analyzing the available film and video and ultimately determined the foam had struck heat shield tiles on the underside of the wing, perhaps near the left main landing gear door. No one ever seriously considered a direct heat on the reinforced carbon carbon panels making up the wing leading edge because no trace of foam debris was ever seen crossing the top of the wing. As the board ultimately concluded, however, the foam did, in fact, strike the leading edge on the lower side of RCC panel No. 8.

Senior shuttle managers inspect Columbia's wreckage. Left to right: Wayne Hale; Mission Management team Chairman Linda Ham; shuttle program manager Ron Dittemore; shuttle engineering chief Ralph Roe.

In hindsight, it's difficult to understand why the possibility of a leading edge impact didn't receive more attention. The board concluded that was due at least in part to the influential role of Calvin Schomburg, a senior engineer at the Johnson Space Center with expertise in the shuttle's heat-shield tiles.

"Shuttle program managers regarded Schomburg as an expert on the thermal protection system," the board wrote. "However, the board notes that Schomburg as not an expert on reinforced carbon carbon (RCC), which initial debris analysis indicated the foam may have struck. Because neither Schomburg nor shuttle management rigorously differentiated between tiles and RCC panels, the bounds of Schomburg's expertise were never properly qualified or questioned."

In any case, a team of Boeing engineers at the Johnson Space Center, under direction of NASA's mission management team, ultimately concluded the foam strike did not pose a safety of flight issue. Their analysis, using a computer program called CRATER, predicted areas of localized, possibly severe damage to the underside of the left wing, but no catastrophic breach. The concern, rather, was that any damage likely would require extensive repairs before Columbia could fly again.

While the damage assessment was getting under way, at least three different attempts were made to obtain spy satellite photography of the impact site to resolve the matter one way or the other. But in a series of communications miscues, the efforts ultimately were quashed by the MMT, under the direction of former flight director Linda Ham.

Ham said she was never able to find out who wanted such photographs and, without a formal requirement, had no reason to proceed. As for the debris assessment, Ham and other members of the MMT never challenged the hurried analysis or questioned the conclusion Columbia could safely return to Earth as is.

Many mid-level engineers said later they had serious misgivings about the debris assessment and heavy email traffic indicated fairly widespread concern about potentially serious problems if the foam strike had compromised Columbia's left main landing gear. Yet those concerns never percolated up the Ham, Dittemore or other members of the mission management team.

Ham and Dittemore both have said they were always open for questions or comments from lower-level engineers and that everyone on the team was encouraged, even duty bound, to bring any serious concerns to the attention of senior management.

But the CAIB disagreed.

"Communication did not flow effectively up to or down from program managers," the board wrote. "After the accident, program managers stated privately and publicly that if engineers had a safety concern, they were obligated to communicate their concerns to management. Managers did not seem to understand that as leaders they had a corresponding and perhaps greater obligation to create viable routes for the engineering community to express their views and receive information. This barrier to communications not only blocked the flow of information to managers but it also prevented the downstream flow of information from managers to engineers, leaving Debris Assessment Team members no basis for understanding the reasoning behind Mission Management Team decisions."

An impromptu memorial to one of Columbia's fallen astronauts in the Texas countryside.

As for not hearing any dissent, the board wrote, "managers' claims that they didn't hear the engineers' concerns were due in part to their not asking or listening."

"Management decisions made during Columbia's final flight reflect missed opportunities, blocked or ineffective communications channels, flawed analysis and ineffective leadership," the board wrote. "Perhaps most striking is the fact that management - including Shuttle Program, Mission Management Team, Mission Evaluation Room (personnel) and flight director and mission control - displayed no interest in understanding a problem and its implications.

"Because managers failed to avail themselves of the wide range of expertise and opinion necessary to achieve the best answer to the debris strike question - 'Was this a safety-of-flight concern?' - some space shuttle program managers failed to fulfill the implicit contract to do whatever is possible to ensure the safety of the crew. In fact, their management techniques unknowingly imposed barriers that kept at bay both engineering concerns and dissenting views and ultimately helped create 'blind spots' that prevented them from seeing the danger the foam strike posed."

Shuttle program manager Dittemore and members of the mission management team "had, over the course of the space shuttle program, gradually become inured to external tank foam losses and on a fundamental level did not believe foam striking the vehicle posed a critical threat to the orbiter," the board wrote.

In the end, it was a moot point. Once the foam breached the leading edge of Columbia's left wing, the crew was doomed. The astronauts had no way to repair the breach - no robot arm and no tile repair equipment - and there was no realistic chance another shuttle could be readied in time for a rescue mission.

Maybe so. But NASA's flawed management system never gave the agency a chance to prove it still had the "right stuff." And it was that institutional system, or "culture," at NASA that must be changed, the board said, to prevent another accident.

"An organization system failure calls for corrective measures that address all relevant levels of the organization, but the Board's investigation shows that for all its cutting-edge technologies, 'diving-catch' rescues and imaginative plans for the technology and the future of space exploration, NASA has shown very little understanding of the inner workings of its own organization," the report states.

"NASA's bureaucratic structure kept important information from reaching engineers and managers alike. The same NASA whose engineers showed initiative and a solid working knowledge of how to get things done fast had a managerial culture with an allegiance to bureaucracy and cost-efficiency that squelched the engineers' efforts.

"When it came to managers' own actions, however, a different set of rules prevailed. The Board found that Mission Management Team decision-making operated outside the rules even as it held its engineers to a stifling protocol. Management was not able to recognize that in unprecedented conditions, when lives are on the line, flexibility and democratic process should take priority over bureaucratic response."

NASA Administrator Sean O'Keefe said the space agency would use the Columbia Accident Investigation Board's final report as a blueprint for correcting the problems that led to Columbia's demise.

"We have accepted the findings and will comply with the recommendations to the best of our ability," O'Keefe said in a statement. "The board has provided NASA with an important road map as we determine when we will be 'fit to fly' again.

"Due to the comprehensive, timely and open public communication displayed by the Board throughout the investigative process, we already have begun to take action on the earlier issued recommendations, and we intend to comply with the full range of recommendations released today."

Retired Navy Adm. Harold Gehman, chairman of the Columbia Accident Investigation Board.

Gehman told CBS News after the CAIB report was released that NASA had little choice. In the panel's view, he said, NASA could not safely operate the space shuttle program without major changes in its management system.

"I think there's a little bit of denial that NASA, at least in the shuttle program, that NASA has modified its organizational structure over the years into one that no longer contains the attributes that they built their reputations on," Gehman said. "There may be some people who deny that, but the board is absolutely convinced, we think there's no room for any doubt whatsoever, the management system they have right now is not capable of safely operating the shuttle over the long term. That's the bottom line."

Gehman also said Congress and the White House must share blame for the Columbia disaster with NASA. Asked what he might tell President Bush about NASA and the agency's second in-flight tragedy, Gehman said he would point out that "NASA is a great organization that he and the country can have a lot of pride in. And that they are operating under and unrealistic set of rules and guidelines."

"Exploring space on a fixed cost basis is not realistic," the retired admiral said. "Launching shuttles on a calendar basis instead of an event-driven basis is not realistic. Demanding that you save money and run this thing in an efficient and effective way and that you get graded on schedule and things like that is not realistic. That the whole nation and Congress and the White House has an unrealistic view of how we do space exploration."

In addition, the board's report "clearly specifies that there is responsibility at both ends of Pennsylvania Avenue for this that are shared with NASA," Gehman said. "Now in some cases, NASA over markets what they can do. They promise more than they can deliver and they promise they can deliver it at a price that is less than it's really going to cost. But in some cases, it is demanded of them, in order to get a program approved, that they agree to unrealistic schedules and unrealistic price tags. So there's blame at both ends here."

The CAIB report focused heavily on decisions made by NASA's mission management team. But Gehman told CBS News the space agency's management system was so dysfunctional it hardly mattered who was in charge.

"We believe very, very strongly that you could substitute almost anybody in those positions and operate under the guidelines and rules and precedents that were being used in NASA and they would make the same errors," he said.

"Let me give you a specific case in point. Much has been made of the fact that the MMT didn't meet every day. NASA regulations require that they meet every day. So I had my board go back and see what were the meetings scheduled for the previous two shuttle missions? Guess what? They met every third day.

"So Linda Ham was doing her job according to the standards and precedents that were set by the establishment," he continued. "Even though the rules say you have to meet every day, you don't really have to. So that's an organizational flaw and she was performing her duties in that respect in accordance with the standards and precedents that had been previously established by her predecessors. And her predecessor's bosses had let that go on.

"So we feel very, very strongly that just moving the people around won't fix that problem. Unfortunately, we live in a town here in Washington, DC, in which they frequently demand someone pay. But we on the board were not influenced by that" and the board did not assign personal blame for any real or perceived errors in judgment.

Could a more experienced or proactive program manager or MMT chairman have made a different in Columbia's case?

"We feel there's some part of this, maybe even a lot of these problems, could have been mitigated by a stronger, a more suspicious, nervous kind of a person," Gehman said of the MMT and its chairman. "But our conclusion, our very, very strong conclusion is even if you had really brilliant people, really spectacular people, if you had the very, very best person you could get, that it would be a low probability bet that you could count on them to overcome the flaws in the organization. That is a low probability course of action."

Asked if NASA was "in denial" about serious management flaws and defects, Gehman said "in a lot of cases, they will deny that they have a basic organizational flaw which is dangerous. I think they'll deny that, some of them. Others will applaud it. It kind of depends on where you sit."

The CAIB's criticism of NASA drew an unusual response from Stephen Feldman, president of The Astronauts Memorial Foundation.

"One of the great risks of the Columbia tragedy and the subsequent report and commentary is that outstanding scientists and engineers may feel so criticized and unappreciated that they will leave NASA and the space program for higher paying and often less stressful jobs in the private sector," he said in a statement. "The outstanding safety record that NASA has compiled over the years shouldn't be forgotten because of one terrible accident on February 1, 2003."

But O'Keefe's promise to full implement the CAIB recommendations drew praise from the National Space Society, a nonprofit advocacy group founded by German rocket scientist Wernher von Braun.

"The National Space Society urges NASA to embrace the recommendations of the CAIB and work diligently to fundamentally reform its decision-making processes and safety organizations so that we can safely return the Space Shuttle fleet to service," said Executive Director Brian Chase. "However, in order for NASA to fully implement the CAIB recommendations and continue the exploration of space, the agency will need appropriate funding to accomplish those tasks.

"The White House and the U.S. Congress must accept their share of responsibility for the future of our nation's space exploration efforts and provide the necessary leadership.

"Perhaps most importantly, NASA and our nation's leaders need to take this opportunity to foster development of new space transportation systems and renew a long-term commitment to human space exploration."

Four and a half months after the CAIB report was released, President Bush gave a speech at NASA Headquarters in Washington in which he called for retirement of the shuttle by 2010; development of a new manned "crew exploration vehicle; the establishment of a permanent base on the moon by 2020 and eventual manned flights to Mars.

Recommendations of the Columbia Accident Investigation Board

PART ONE – THE ACCIDENT

Thermal Protection System

1 Initiate an aggressive program to eliminate all External Tank Thermal Protection System debris-shedding at the source with particular emphasis on the region where the bipod struts attach to the External Tank. [RTF]

2 Initiate a program designed to increase the Orbiter's ability to sustain minor debris damage by measures such as improved impact-resistant Reinforced Carbon-Carbon and acreage tiles. This program should determine the actual impact resistance of current materials and the effect of likely debris strikes. [RTF]

3 Develop and implement a comprehensive inspection plan to determine the structural integrity of all Reinforced Carbon-Carbon system components. This inspection plan should take advantage of advanced non-destructive inspection technology. [RTF]

4 For missions to the International Space Station, develop a practicable capability to inspect and effect emergency repairs to the widest possible range of damage to the Thermal Protection System, including both tile and Reinforced Carbon-Carbon, taking advantage of the additional capabilities available when near to or docked at the International Space Station.

For non-Station missions, develop a comprehensive autonomous (independent of Station) inspection and repair capability to cover the widest possible range of damage scenarios.

Accomplish an on-orbit Thermal Protection System inspection, using appropriate assets and capabilities, early in all missions.

The ultimate objective should be a fully autonomous capability for all missions to address the possibility that an International Space Station mission fails to achieve the correct orbit, fails to dock successfully, or is damaged during or after undocking. [RTF]

5 To the extent possible, increase the Orbiter's ability to successfully re-enter Earth's atmosphere with minor leading edge structural sub-system damage.

6 In order to understand the true material characteristics of Reinforced Carbon-Carbon components, develop a comprehensive database of flown Rein-forced Carbon-Carbon material characteristics by destructive testing and evaluation.

7 Improve the maintenance of launch pad structures to minimize the leaching of zinc primer onto Reinforced Carbon-Carbon components.

8 Obtain sufficient spare Reinforced Carbon-Car-bon panel assemblies and associated support components to ensure that decisions on Rein-forced Carbon-Carbon maintenance are made on the basis of component specifications, free of external pressures relating to schedules, costs, or other considerations.

9 Develop, validate, and maintain physics-based computer models to evaluate Thermal Protection System damage from debris impacts. These tools should provide realistic and timely estimates of any impact damage from possible debris from any source that may ultimately impact the Orbiter. Establish impact damage thresholds that trigger responsive corrective action, such as on-orbit inspection and repair, when indicated.

Imaging

10 Upgrade the imaging system to be capable of providing a minimum of three useful views of the Space Shuttle from liftoff to at least Solid Rocket Booster separation, along any expected ascent azimuth. The operational status of these assets should be included in the Launch Commit Criteria for future launches. Consider using ships or aircraft to provide additional views of the Shuttle during ascent. [RTF]

11 Provide a capability to obtain and downlink high-resolution images of the External Tank after it separates. [RTF]

12 Provide a capability to obtain and downlink high-resolution images of the underside of the Orbiter wing leading edge and forward section of both wings' Thermal Protection System. [RTF]

13 Modify the Memorandum of Agreement with the National Imagery and Mapping Agency to make the imaging of each Shuttle flight while on orbit a standard requirement. [RTF]

Orbiter Sensor Data

14 The Modular Auxiliary Data System instrumentation and sensor suite on each Orbiter should be maintained and updated to include current sensor and data acquisition technologies.

15 The Modular Auxiliary Data System should be redesigned to include engineering performance and vehicle health information, and have the ability to be reconfigured during flight in order to allow certain data to be recorded, telemetered, or both as needs change.

Wiring

16 As part of the Shuttle Service Life Extension Program and potential 40-year service life, develop a state-of-the-art means to inspect all Orbiter wiring, including that which is inaccessible

Bolt Catchers

17 Test and qualify the flight hardware bolt catchers. [RTF]

Closeouts

18 Require that at least two employees attend all final closeouts and intertank area hand-spraying procedures. [RTF]

Micrometeoroid and Orbital Debris

19 Require the Space Shuttle to be operated with the same degree of safety for micrometeoroid and orbital debris as the degree of safety calculated for the International Space Station. Change the micrometeoroid and orbital debris safety criteria from guidelines to requirements.

Foreign Object Debris

20 Kennedy Space Center Quality Assurance and United Space Alliance must return to the straightforward, industry-standard definition of “Foreign Object Debris” and eliminate any al-ternate or statistically deceptive definitions like “processing debris.” [RTF]

PART TWO – WHY THE ACCIDENT OCCURRED

Scheduling

21 Adopt and maintain a Shuttle flight schedule that is consistent with available resources. Although schedule deadlines are an important management tool, those deadlines must be regularly evaluated to ensure that any additional risk incurred to meet the schedule is recognized, understood, and acceptable. [RTF]

Training

22 Implement an expanded training program in which the Mission Management Team faces potential crew and vehicle safety contingencies beyond launch and ascent. These contingencies should involve potential loss of Shuttle or crew, contain numerous uncertainties and unknowns, and require the Mission Management Team to assemble and interact with support organizations across NASA/Contractor lines and in various locations. [RTF]

Organization

23 Establish an independent Technical Engineering Authority that is responsible for technical requirements and all waivers to them, and will build a disciplined, systematic approach to identifying, analyzing, and controlling hazards throughout the life cycle of the Shuttle System. The independent technical authority does the following as a minimum:

- Develop and maintain technical standards for all Space Shuttle Program projects and elements
- Be the sole waiver-granting authority for all technical standards
- Conduct trend and risk analysis at the sub-system, system, and enterprise levels
- Own the failure mode, effects analysis and hazard reporting systems
- Conduct integrated hazard analysis
- Decide what is and is not an anomalous event
- Independently verify launch readiness
- Approve the provisions of the recertification program called for in Recommendation R9.1-1. The Technical Engineering Authority should be funded directly from NASA Headquarters, and should have no connection to or responsibility for schedule or program cost.

24 NASA Headquarters Office of Safety and Mission Assurance should have direct line authority over the entire Space Shuttle Program safety organization and should be independently re-sourced.

25 Reorganize the Space Shuttle Integration Office to make it capable of integrating all elements of the Space Shuttle Program, including the Or-biter.

PART THREE – A LOOK AHEAD

Organization

26 Prepare a detailed plan for defining, establishing, transitioning, and implementing an independent Technical Engineering Authority, independent safety program, and a reorganized Space Shuttle Integration Office as described in R7.5-1, R7.5-2, and R7.5-3. In addition, NASA should submit annual reports to Congress, as part of the budget review process, on its implementation activities. [RTF]

Recertification

27 Prior to operating the Shuttle beyond 2010, develop and conduct a vehicle recertification at the material, component, subsystem, and system levels. Recertification requirements should be included in the Service Life Extension Program.

Closeout Photos/Drawing System

28 Develop an interim program of closeout photographs for all critical sub-systems that differ from engineering drawings. Digitize the close-out photograph system so that images are immediately available for on-orbit troubleshooting. [RTF]

29 Provide adequate resources for a long-term pro-gram to upgrade the Shuttle engineering draw-ing system including:

- Reviewing drawings for accuracy
- Converting all drawings to a computer-aided drafting system
- Incorporating engineering changes

❏ ❏ ❏

The Fate of Columbia's Crew

NASA released a detailed engineering study Dec. 30, 2008, outlining lessons learned about astronaut survival based on an analysis of the 2003 Columbia disaster. The study does not provide any significant new details about the fate of Columbia's crew - investigators earlier concluded the seven astronauts died of sudden oxygen loss and blunt force trauma as the crew module broke up - but a new timeline provides a wealth of data showing the pilots attempted to troubleshoot a cascade of problems in the final moments before the spacecraft's computers lost control.

The timeline also shows, in grim detail, the forces acting on the shuttle's crew module in the final seconds before it broke apart, subjecting the astronauts to a sudden loss of air pressure that occurred so rapidly they did not have time to close their helmet visors.

The study, the most detailed astronaut survival analysis ever conducted, includes 30 recommendations for improving crew safety on future flights based on a review of the safety equipment and procedures used during Columbia's mission.

"I call on spacecraft designers from all the other nations of the world, as well as the commercial and personal spacecraft designers here at home to read this report and apply these hard lessons, which have been paid for so dearly," said former shuttle Program Manager Wayne Hale, now serving as a NASA associate administrator. "This report confirms that although the valiant Columbia crew tried every possible way to maintain control of their vehicle, the accident was not ultimately survivable."

As part of its support for the Columbia Accident Investigation Board, NASA set up a Crew Survival Working Group in the wake of the Feb. 1, 2003, disaster that later evolved into the Spacecraft Crew Survival Integrated Investigation Team. The crew survival team began its study in October 2004 with the goals of expanding the earlier working group analysis and making recommendations to improve safety on future vehicles.

The Columbia breakup was not survivable, but the new report sheds light on how various shuttle safety systems performed and what sort of changes may be needed to improve safety in future spacecraft like the Orion capsules that will replace the shuttle after the fleet is retired in 2010.

The report was completed in December 2008, but its release was delayed "out of respect for the Columbia crew families," said veteran shuttle commander Pam Melroy, deputy project manager of the investigation. "At their request, we released it after Christmas but while the children were still out of school and home with their family members so they could discuss the findings and the elements of the report with some privacy. That's what drove the timing of today."

Columbia was destroyed by a breach in the leading edge of the shuttle's left wing that was caused by the impact of foam insulation from the ship's external tank during launch 16 days earlier. The wing melted from the inside out and eventually failed, either folding over or breaking away. The shuttle's flight computers then lost control and the crippled spacecraft went into a catastrophic spin. The nose section housing the crew module ripped away from the fuselage relatively intact, but the module broke apart within a few moments due to thermal stress and aerodynamic forces.

The analysis of Columbia's breakup identified five "lethal events:"

1. Depressurization: Shortly after Columbia's flight computers lost control due to the failure of the shuttle's heat-damaged left wing, the crew module broke away from the fuselage. The astronauts are believed to have survived the initial breakup. But within a few moments, the crew module lost pressure "so rapidly that the crew members were incapacitated within seconds, before they could configure the (pressure) suit for full protection from loss of cabin pressure," the new study concluded. "Although circulatory systems functioned for a brief time, the effects of the depressurization were severe enough that the crew could not have regained consciousness. This event was lethal to the crew."

Recommendations: Improve crew training to increase emphasis on the transition between problem solving and survival operations; future spacecraft must integrate pressure suit operations into the design of the vehicle.

2. Exposure of the unconscious or deceased astronauts to unexpected rotating forces without sufficient upper body restraints and helmets: When Columbia lost control, the resulting motion was not violent enough, in and of itself, to be lethal. The crew module separated from the fuselage "and continued to rotate," the study concluded. "After the crew lost consciousness due to the loss of cabin pressure, the seat inertial reel mechanisms on the crews' shoulder harnesses did not lock. As a result, the unconscious or deceased crew was exposed to cyclical rotational motion while restrained only at the lower body. Crew helmets do not conform to the head. Consequently, lethal trauma occurred to the unconscious or deceased crew due to the lack of upper body support and restraint."

Recommendations: Re-evaluate crew procedures; future seats and suits should be "integrated to ensure proper restraint of the crew in off-nominal situations."

3. Separation of the crew from the crew module and the seat: "The breakup of the crew module and the crew's subsequent exposure to hypersonic entry conditions was not survivable by any currently existing capability," the study says. "The lethal-type consequences of exposure to entry conditions included traumatic injury due to seat restraints, high loads associated with deceleration due to a change in ballistic number, aerodynamic loads, and thermal events. Crew circulatory functions ceased shortly before or during this event."

Recommendation: Optimize future spacecraft design for "the most graceful degradation of vehicle systems and structure to enhance chances for crew survival."

4. Exposure to near vacuum, aerodynamic acceleration and low temperatures: Shuttle pressure suits are certified to a maximum altitude of 100,000 feet and a velocity of about 560 knots. "It is uncertain whether it can protect a crew member at higher altitudes and air speeds," the study says.

Recommendation: Pressure suits should be evaluated to determine weak points; improvements should be made as warranted.

5. Ground impact: The current parachute system requires manual action by the astronauts.

Recommendation: "Future spacecraft crew survival systems should not rely on manual activation to protect the crew."

The new study also made recommendations to improve future crew survival investigations.

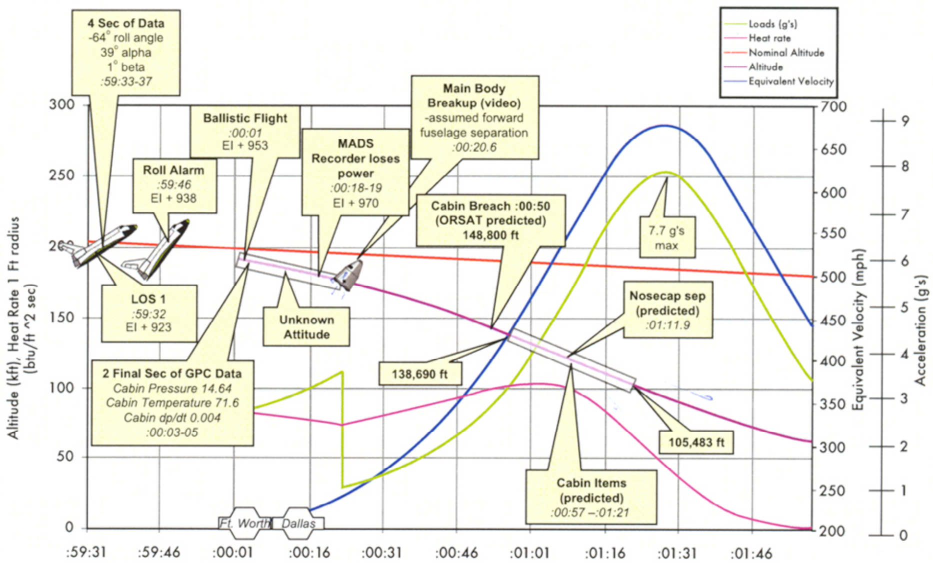
"The SCSIIT investigation was performed with the belief that a comprehensive, respectful investigation could provide knowledge that would improve the safety of future space flight crews and explorers," the group wrote. "By learning these lessons and ensuring that we continue the journey begun by the crews of Apollo 1, Challenger and Columbia, we help to give meaning to their sacrifice and the sacrifice of their families. it is for them, and for the future generations of explorers, that we strive to be better and go farther."

The 400-page report is posted on line at: http://www.nasa.gov/reports

One striking aspect of the initial 2003 accident board study was similarities between how the shuttle Challenger broke up during launch in 1986 and how Columbia met its fate during re-entry in 2003. In both cases, the reinforced crew modules broke away from the shuttle fuselage relatively intact. And in both cases, the astronauts are believed to have survived the initial breakup.

In an appendix to the Columbia accident board report, investigators concluded "acceleration levels seen by the crew module prior to its catastrophic failure were not lethal. LOS (loss of signal) occurred at 8:59:32 (a.m. EST). The death of the crew members was due to blunt force trauma and hypoxia. The exact time of death - sometime after 9:00:19 a.m. Eastern Standard Time - cannot be determined because of the lack of direct physical or recorded evidence."

"Failure of crew module was precipitated by thermal degradation of structural properties that resulted in a catastrophic sequential structural failure that happened very rapidly as opposed to a catastrophic instantaneous 'explosive' failure," the report said. "Crew module separation from the forward fuselage is not an anomalous condition in the case of a vehicle loss of control as has been the case in both 51-L (Challenger) and STS-107 (Columbia)."



Columbia Accident Investigation Board summary of critical events

But the shuttle crew module, on its own, has no power and no systems were present that could have saved either crew after breakup occurred.

Even so, "it is irrefutable, as conclusively demonstrated by items that were recovered in pristine condition whose locations were within close proximity to some crew members, that it was possible to attenuate the potentially hostile environment that was present during CM (crew module) break-up to the point where physically and thermally induced harmful effects were virtually eliminated," the CAIB concluded.

"This physical evidence makes a compelling argument that crew survival under environmental circumstances seen in this mishap could be possible given the appropriate level of physiological and environmental protection."

The CAIB went on to recommend that NASA "investigate techniques that will prevent the structural failure of the CM due to thermal degradation of structural properties to determine the feasibility for application. Future crewed vehicles should incorporate the knowledge gained from the (Challenger) and (Columbia) mishaps in assessing the feasibility of designing vehicles that will provide for crew survival even in the face of a mishap that results in the loss of the vehicle."

Columbia blasted off on mission STS-107 on Jan. 16, 2003. On board were commander Rick Husband, pilot William "Willie" McCool, Michael Anderson, David Brown, Kalpana Chawla, Laurel Clark and Ilan Ramon, the first Israeli to fly in space.

Some 81.7 seconds after liftoff, a briefcase-size chunk of foam insulation broke away from Columbia's external tank. Long-range tracking cameras showed the foam disappearing under the left wing and a cloud of debris emerging an instant later.

No one knew it at the time, but the foam had hit the underside of the left wing's reinforced carbon carbon leading edge, punching a ragged hole four to six inches across. During re-entry 16 days later, superheated air entered the breach and melted the wing from the inside out.

In the moments leading up the catastrophic failure, telemetry from the damaged shuttle indicated problems with the left wing, including loss of data from hydraulic line sensors and temperature probes and left main landing gear pressure readings. The astronauts - Husband, McCool, Chawla and Clark strapped in on the upper flight deck, Anderson, Brown and Ramon seated on the lower deck - presumably were unaware of anything unusual until just before the left wing either folded over or broke away and the vehicle's flight computers lost control.

The final words from Columbia's crew came at 8:59:32 a.m. when Husband, presumably responding to a tire alarm acknowledgement from mission control, said "Roger, uh, buh " At that point, the shuttle was nearly 38 miles above Central Texas and traveling at 18 times the speed of sound. No more voice transmissions were received. But telemetry, some of it garbled, continued to flow for a few more moments.

That data, combined with stored telemetry on a data recorder that was found in the shuttle's wreckage and analysis of recovered debris, eventually allowed engineers to develop a rough timeline of events after the initial loss of signal.

In the new study, data show the crew received multiple indications of problems in the minute prior to loss of control, which probably occurred right around the time of Husband's last transmission. Fifty-eight seconds before that event, the first of four tire pressure alert messages was displayed. Thirty-one seconds before loss of control, the left main landing gear indicator changed state. Seven seconds before LOC, a pulsing yaw thruster light came on as the jets began firing continuously to keep the shuttle properly oriented. Less than one second before LOC, aileron trim exceeded 3 degrees.

"For the crew, the first strong indications of the LOC would be lighting and horizon changes seen through the windows and changes on the vehicle attitude displays," the report says. "Additionally, the forces experienced by the crew changed significantly and began to differ from the nominal, expected accelerations. The accelerations were translational (due to aerodynamic drag) and angular (due to rotation of the orbiter). The translational acceleration due to drag was dominant, and the direction was changing as the orbiter attitude changed relative to the velocity vector (along the direction of flight).

"Results of a shuttle LOC simulation show that the motion of the orbiter in this timeframe is best described as a highly oscillatory slow (30 to 40 degrees per second) flat spin, with the orbiter's belly generally facing into the velocity vector. It is important to note that the velocity vector was still nearly parallel to the ground as the vehicle was moving along its trajectory in excess of Mach 15. The crew experienced a swaying motion to the left and right (Y-axis) combined with a pull forward (X-axis) away from the seatback. The Z-axis accelerations pushed the crew members down into their seats. These motions might induce nausea, dizziness, and disorientation in crew members, but they were not incapacitating. The total acceleration experienced by the crew increased from approximately 0.8 G at LOC to slightly more than 3 G by the CE (catastrophic event).

"The onset of this highly oscillatory flat spin likely resulted in the need for crew members to brace as they attempted to diagnose and correct the orbiter systems. One middeck crew member had not completed seat ingress and strap-in at the beginning of this phase. Seat debris and medical analyses indicate that this crew member was not fully restrained before loss of consciousness. Only the shoulder and crotch straps appear to have been connected. The normal sequence for strap-in is to attach the lap belts to the crotch strap first, followed by the shoulder straps. Analysis of the seven recovered helmets indicated that this same crew member was the only one not wearing a helmet. Additionally, this crew member was tasked with post-deorbit burn duties. This suggests that this crew member was preparing to become seated and restrained when the LOC dynamics began. During a dynamic flight condition, the lap belts hanging down between the closely space seats would be difficult to grasp due to the motion of the orbiter, which may be why only the shoulder straps were connected."

Recovered cockpit switch panels indicate McCool attempted to troubleshoot hydraulic system problems. Either Husband or McCool also returned the shuttle's autopilot to the automatic setting at 9:00:03 a.m. after one of the two hand controllers apparently was inadvertently bumped. "These actions indicate that the CDR or the PLT was still mentally and physically capable of processing display information and executing commands and that the orbiter dynamics were still within human performance limitations," the study concludes.

"It was a very short time," Hale said. "We know it was very disorienting motion that was going on. There were a number of alarms that went off simultaneously. And the crews, of course, are trained to maintain or regain control in a number of different ways and we have evidence from (recovered debris that they) were trying very hard to regain control. We're talking about a very brief time, in a crisis situation, and I'd hate to go any further than that."

Said Melroy: "I'd just like to add we found that those actions really showed the crew was relying on their training in problem solving and problem resolution and that they were focused on attempting to recover the vehicle when they did detect there was something off nominal. They showed remarkable systems knowledge and problem resolution techniques. Unfortunately, of course, there was no way for them to know with the information they had that that was going to be impossible. But we were impressed with the training, certainly, and the crew."

From the point the crew cabin broke away from the fuselage to the point where depressurization occurred "can be narrowed to a range of 17 seconds, from between GMT 14:00:18 (9:00:18 a.m.) to GMT 14:00:35," the report states. "Crew module debris items recovered west of the main crew module debris field were 8 inches in diameter or smaller, were not comprised of crew module primary structure, and originated from areas above and below the middeck floor. This indicates that the crew module depressurization was due to multiple breaches (above and below the floor), and that these breaches were initially small.

"When the forebody separated from the midbody, the crew members experienced three dramatic changes in their environment: 1. all power was lost, 2. the motion and acceleration environment changed; and 3. crew cabin depressurization began within 0 to 17 seconds. With the loss of power, all of the lights and displays went dark (although each astronaut already had individual chem-lights activated). The intercom system was no longer functional and the orbiter O2 system was no longer available for use, although individual, crew worn Emergency Oxygen System (EOS) bottles were still available.

"As the forebody broke free from the rest of the orbiter, its ballistic number underwent a sharp change from an average ballistic number of 41.7 pounds per square foot (psf) (out of control intact orbiter) to 122 psf (free-flying forebody). The aerodynamic drag of the forebody instantaneously decreased, resulting in a reduction in the translational deceleration from approximately 3.5 G to about 1 G."

As experienced by the astronauts, the change from a normal re-entry to loss of control and separation of the crew module from the fuselage "all occurred in approximately 40 seconds. Experience shows that this is not sufficient time to don gloves and helmets."

"Histological (tissue) examination of all crew member remains showed the effects of depressurization. Neither the effects of CE nor the accelerations immediately post-CE would preclude the crew members who were wearing helmets from closing and locking their visors at the first indication of a cabin depressurization. This action can be accomplished in seconds. This strongly suggests that the depressurization rate was rapid enough to be nearly immediately incapacitating. The exact rate of cabin depressurization could not be determined, but based on video evidence complete loss of pressure was reached no later than (NLT) GMT 14:00:59 (9:00:59 a.m.), and was likely much earlier. The medical findings show that the crew could not have regained consciousness after this event. Additionally, respiration ceased after the depressurization, but circulatory functions could still have existed for a short period of time for at least some crew members."

For background, here are the results of the original Crew Survival Working Group's assessment, as reported in "Comm Check: The Final Flight of Shuttle Columbia" by Michael Cabbage and William Harwood (Free Press, 2004; some of the conclusions may change based on the new study):

> At the CAIB's request, NASA formed a Crew Survivability Working Group to determine, if possible, the cause of crew death. Here is what the group concluded (taken from page 77 of the Columbia Accident Investigation Report):

Medical and Life Sciences

The Working Group found no irregularities in its extensive review of all applicable medical records and crew health data. The Armed Forces Institute of Pathology and the Federal Bureau of Investigation conducted forensic analyses on the remains of the crew of Columbia after they were recovered. It was determined that the acceleration levels the crew module experienced prior to its catastrophic failure were not lethal. The death of the crew members was due to blunt trauma and hypoxia. The exact time of death sometime after 9:00:19 a.m. Eastern Standard Time cannot be determined because of the lack of direct physical or recorded evidence.

Failure of the Crew Module

The forensic evaluation of all recovered crew module/forward fuselage components did not show any evidence of over-pressurization or explosion. This conclusion is supported by both the lack of forensic evidence and a credible source for either sort of event. The failure of the crew module resulted from the thermal degradation of structural properties, which resulted in a rapid catastrophic sequential structural breakdown rather than an instantaneous "explosive" failure.

Separation of the crew module/forward fuselage assembly from the rest of the Orbiter likely occurred immediately in front of the payload bay (between Xo576 and Xo582 bulkheads). Subsequent breakup of the assembly was a result of ballistic heating and dynamic loading. Evaluations of fractures on both primary and secondary structure elements suggest that structural failures occurred at high temperatures and in some cases at high strain rates. An extensive trajectory reconstruction established the most likely breakup sequence, shown below (page 77 of the CAIB report).

The load and heat rate calculations are shown for the crew module along its reconstructed trajectory. The band superimposed on the trajectory (starting about 9:00:58 a.m. EST) represents the window where all the evaluated debris originated. It appears that the destruction of the crew module took place over a period of 24 seconds beginning at an altitude of approximately 140,000 feet and ending at 105,000 feet. These figures are consistent with the results of independent thermal re-entry and aerodynamic models. The debris footprint proved consistent with the results of these trajectory analyses and models. Approximately 40 to 50 percent, by weight, of the crew module was recovered.

The Working Group's results significantly add to the knowledge gained from the loss of Challenger in 1986. Such knowledge is critical to efforts to improve crew survivability when designing new vehicles and identifying feasible improvements to the existing Orbiters.

Crew Worn Equipment

Videos of the crew during re-entry that have been made public demonstrate that prescribed procedures for use of equipment such as full-pressure suits, gloves, and helmets were not strictly followed. This is confirmed by the Working Group's conclusions that three crew members were not wearing gloves, and one was not wearing a helmet. However, under these circumstances, this did not affect their chances of survival.

Columbia's crew
Blue shirts (left to right): David Brown, Willie McCool, Michael Anderson
Red shirts (left to right): Kalpana Chawla, Rick Husband, Laurel Clark, Ilan Ramon

Appendix 3: NASA Acronyms[11]

Acronym	Meaning
A/D	Analog-to-Digital
ac	Alternating Current
ACP	Astronaut Control Panel
ACS	Advanced Camera for Surveys
ACTR 5	Actuator 5
AFD	Aft Flight Deck
AID	Analog Input Differential
AKA	Active Keel Actuator
ALC	Automatic Light Control
AMSB	Advanced Mechanism Selection Box
APE	Auxiliary PFR Extender
ASIPE	Axial Science Instrument Protective Enclosure
ASLR	Aft Shroud Latch Repair
ATM	Auxiliary Transport Module
BAPS	Berthing and Positioning System
BAR	Berthing Assist and Restraint
BITE	Built-In Test Equipment
BOT	Beginning of Travel
BSP	BAPS Support Post
BSR	BITE Status Register
BTU	Bus Terminal Unit
CAB	Cabin
CASH	Cross Aft Shroud Harness
CAT	Crew Aids and Tools
CCTV	Closed Circuit Television
CDU	Common Drive Unit
CEP	Containment Environmental Package
CNTL	Control
COPE	Contingency ORU Protective Enclosure
COS	Cosmic Origins Spectrograph
CPC	Cyro Port Cover
CPT	Comprehensive Performance Test
CPUA	Clamp Pickup Assembly
CRES	Corrosion-Resistant Steel
CSM	Cargo Systems Manual
CSS	Center Support Structure
D/R	Deploy/Return
DBA	Diode Box Assembly
DBC	Diode Box Controller
DBC	Data Bus Coupler
dc	Direct Current
DI/DO	Discrete Input/Discrete Output
DIH	Discrete Input High
DIL	Discrete Input Low
DOF	Degree of Freedom
DOH	Discrete Output High
DOL	Discrete Output Low
DPC	Direct Power Converter
DPST	Double Pole, Single throw
ECU	Electronic Control Unit

[11] From the NASA STS-131 Press Kit: (http://www.nasa.gov/mission_pages/shuttle/shuttlemissions/hst_sm4/index.html)

Acronym	Meaning
EGSE	Electrical Ground Support Equipment
EMU	Extravehicular Mobility Unit
ENA	Enable
EOT	End of Travel
EPDSU	Enhanced Power Distribution and Switching Unit
EPDU	Electrical Power Distribution Unit
ESM	Electronic Support Module
ESS	Essential
ET	External Tank
EURM	Emergency Umbilical Retract Mechanism
EVA	Extravehicular Activity
EXT	External
FD	Flight Day
FDA	Failure Detection/Annunciation
FGS	Fine Guidance Sensor
FHST	Fixed Head Star Tracker
FMDM	Flexible Multiplexer/Demultiplexer
FOC	Faint Object Camera
FSS	Flight Support System
FWD	Forward
FXC	Forward X-Constraint
GPC	General Purpose Computer
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HOST	Hubble-On-Orbit Space Test
HPGSCA	HST Payload General Support Computer Assembly
HRD	Harness Restraint Device
HST	Hubble Space Telescope
HTR	Heater
I/F	Interface
I/O	Input/Output
ICD	Interface Control Document
IND	indicator
IOM	Input/Output Module
IPCU	Interface Power Control Unit
IVA	Intravehicular Activity
J-BOX	Junction Box
JSC	Johnson Space Center
L/A	Latch Assist
LAT	Latch
LIS	Load Isolation System
LOPE	Large ORU Protective Enclosure
LPS	Light and Particle Shield
LRU	Line Replaceable Unit
MCA	Motor Control Assembly
MCC	Mission Control Center
MDI	Magnetically Damped Isolator
MDM	Multiplexer/Demultiplexer
MET	Mission Elapsed Time
MGSE	Mechanical Ground Support Equipment
MIA	Multiplexer Interface Adapter
MLI	Multilayer Insulation
MMC	Mid-Motor Controller
MMCA	Mid-Motor Control Assembly

Acronym	Meaning
MNA	Main A
MNB	Main B
MOD	Mission Operations Directorate
MOPE	Multi-Mission ORU Protective Enclosure
MSID	Measurement Stimulus Identification
M-STRUT	Magnetic Strut
MULE	Multi-Use Lightweight Equipment
NBL	Neutral Buoyancy Lab
NCC	NICMOS CryoCooler
NCS	NICMOS Cooling System
NICMOS	Near Infrared Camera and Multi-Object Spectrometer
NOBL	New Outer Blanket Layer
NRZ-L	Non-Return-to-Zero Level
NT	NOBL Transporter
OPA	ORU Plate Assembly
ORB	Orbiter
ORU	Orbital Replacement Unit
ORUC	Orbital Replacement Unit Carrier
PA	Pallet Assembly
PBM	Payload Bay Mechanical
PCM	Pulse-Code Modulation
PCN	Page Change Notice
PCU	Power Control Unit
PCU	Power Conditioning Unit
PDI	Payload Data Interleaver
PDIP	Payload Data Interface Panel
PDRS	Payload Deployment and Retrieval System
PDSU	Power Distribution and Switching Unit
PE	Protective Enclosure
PFR	Portable Foot Restraint
PGT	Pistol Grip Tool
PI	Payload Interrogator
PL	Payload
PLB	Payload Bay
PLBD	Payload Bay Door
POH	Pulse Output High
PPCU	Port Power Conditioning Unit
PRB	Preload Release Bracket
PRCS	Primary Reaction Control System
PRLA	Payload Retention Latch Actuator
PROM	Programmable Read-Only Memory
PRT	Power Ratchet Tool
PSP	Payload Signal Processor
PWR	Power
RAC	Rigid Array Carrier
REL	Released
RF	Radio Frequency
RL	Retention Latch
RMS	Remote Manipulator System
RNS	Relative Navigation System
RSIPE	Radial Science Instrument Protective Enclosure
RSU	Rate Sensing Unit
RWA	Reaction Wheel Assembly
SA	Solar Array
SAC	Second Axial Carrier
SADA	Solar Array Drive Adapter

Acronym	Meaning
SADM	Solar Array Drive Mechanism
SAP	SAC Adapter Plate
SCM	Soft Capture Mechanism
SCRS	Soft Capture and Rendezvous System
SCU	Sequence Control Unit
SI	Science Instrument
SI C&DH	Science Instrument Command and Data Handling
SIP	Standard Interface Panel
SLIC	Super Lightweight Interchangeable Carrier
SLP	SpaceLab Pallet
SM	Servicing Mission
SM	Systems Management
SMEL	Servicing Mission Equipment List
SOPE	Small ORU Protective Enclosure
SORU	Small Orbital Replaceable Unit
SPCU	Starboard Power Conditioning Unit
SSE	Space Support Equipment
SSME	Space Shuttle Main Engine
SSP	Standard Switch Panel
SSPC	Solid State Power Controller
SSSH	Space Shuttle Systems Handbook
STBD	Starboard
STIS	Space Telescope Imaging Spectrograph
STOCC	Space Telescope Operations Control Center
STS	Space Transportation System
SURV	Survival
TA	Translation Aid
tb	Talkback
TM	Transport Module
TVAC	Thermal Vacuum
UA	Umbilical Actuator
UARS	Upper Atmospheric Research Satellite
UASE	UARS Airborne Structure Equipment
UDM	Umbilical Disconnect Mechanism
UPS	Under Pallet Storage
USA	United Space Alliance
VCU	Video Control Unit
VIK	Voltage Improvement Kit
WFC	Wide Field Camera
WFPC	Wide Field Planetary Camera
WRKLT	Worklight