The CBS News

Space Reporter's Handbook Mission Supplement

Shuttle Mission STS-129/ISS-ULF 3:
Spares for the International Space Station

Written and Produced By

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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
11/12/09	Initial STS-129 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-129 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-129 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!

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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).

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STS-129: 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-129 NASA Press Kit	http://www.shuttlepresskit.com/
STS-129 Imagery	http://spaceflight.nasa.gov/gallery/images/shuttle/STS-129/ndxpage1.html
STS-129 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

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CBS News STS-129 Mission Preview

Shuttle Atlantis poised for launch to deliver critical spares to the International Space Station

By WILLIAM HARWOOD
CBS News Space Consultant

KENNEDY SPACE CENTER, Fla. -- With the shuttle program entering its final year of operation, engineers are readying Atlantis for launch Monday on a three-spacewalk mission to deliver 15 tons of spare parts and equipment to the International Space Station as a hedge against failures when the shuttle is no longer available for service calls.

"In terms of being the flight that brings up all the spares for station, this is really full," said Bill Gerstenmaier, NASA's director of space operations. "They've done a tremendous job of really outfitting station with all the spares that are going to be needed, essentially through its lifetime. This flight, and a couple of the other shuttle flights that come later, really set us up very well for kind of the end of the shuttle servicing era."

The crew of shuttle Atlantis (left to right): Leland Melvin, Randolph Bresnik, pilot Barry "Butch" Wilmore, commander Charles Hobaugh, Michael Foreman and Robert Satcher (NASA)

Awaiting a decision by the Obama administration on what sort of spacecraft will replace the shuttle and whether the moon or some other target will be NASA's next objective, the agency is pressing ahead with the Bush administration's directive to complete the space station and end shuttle flights by the end of 2010.

The International Space Station currently is only funded through 2015, but there appears to be widespread political support to extend operations through 2020. That would mean operating the lab complex for 10 years without the shuttle and its cavernous cargo bay to deliver large spares and other components.

With just six missions left on NASA's shuttle manifest between now and the end of fiscal 2010, Atlantis' mission is one of two devoted primarily to delivering critical spare parts and equipment - orbital replacement units, or ORUs - that are too large to be delivered by European, Russian or Japanese cargo ships.

"We're looking for the long-term outfitting of station, making sure the ISS is ready for the long haul and has the longest life capability possible," shuttle commander Charles Hobaugh said. "Our flight is one of the first flights that externally will provide a lot of those spare parts and long-lead type replacement items that are required to keep it healthy and running for quite some time."

Along with delivering spare parts and components, Atlantis also will bring astronaut Nicole Stott back to Earth after a three-month stay in space. It is the final planned use of a shuttle for crew rotation. From this point forward, U.S. astronauts will ride Russian Soyuz capsules to and from the station, at $50 million a seat.

But stockpiling spare parts is the core mission for Atlantis' crew and space station utilization flight No. 3, or ULF-3.

Mounted on pallets in Atlantis' payload bay are two spare control moment gyroscopes, used to control the station's orientation in space; a high pressure oxygen tank for the station's airlock; and a spare pump module, nitrogen tank and an ammonia reservoir for the lab's cooling system.

The pallets also carry a replacement robot arm latching end effector, or mechanical hand; a spare power cable spool used by the arm's mobile transporter; a solar array battery charge-discharge unit; and a device used to prevent potentially dangerous electrical arcs between the station and the electrically charged extreme upper atmosphere.

A box housing spare circuit breakers that can be installed by the station's robot arm and a Canadian robot known as DEXTRE is mounted on one of the pallets and a materials exposure experiment carried aloft in the shuttle's cargo bay will be mounted on ELC-2 during the crew's final spacewalk.

Atlantis also is carrying a spare S-band antenna assembly, along with supplies for the lab's six-member crew, gear for an amateur radio experiment and a system that can be used to track ships at sea.

The two cargo pallets will be mounted on the left and right sides of the station's main solar power truss and plugged into the lab's electrical grid to power heaters and provide telemetry. The new oxygen tank will be attached to the station's airlock during a spacewalk. The rest of the hardware will simply sit, waiting for the day it might be needed.

"It is establishing critical spares on board the International Space Station," said lead shuttle Flight Director Mike Sarafin. "We're going to warehouse parts that only the shuttle can deliver in large volume to the International Space Station for the pending retirement of the space shuttle, roughly a year from now.

"We're going to deliver two large external logistics carriers full of spares and position those outside the International Space Station so that when and if some of the hardware that's required to sustain the power production and thermal environment on board the space station eventually fails, we've got that hardware there and available and we don't need another vehicle to bring it to the space station."

After the shuttle is retired, supplies and equipment will be delivered to the International Space Station by unmanned Russian Progress spacecraft, the European Space Agency's Automated Transfer Vehicle, or ATV, Japan's new HTV cargo carrier and commercial providers now in the process of designing future vehicles.

On Nov. 12, a new Russian docking module called Poisk automatically locked itself to an upward facing port on the Zvezda command module, providing a fourth docking port for the Russian segment of the station - a necessity for long-term support of up to six full-time crew members.

But none of the unmanned cargo ships is capable of delivering the components routinely carried by the space shuttle that are too big to pass through the station's hatches. Most of the spares being launched aboard Atlantis have no other way of getting to the station.

"This is why these need to fly now on the shuttle," said station Flight Director Brian Smith. "There's no other way to get these ORUs ... to the ISS. And these are all critical spares. You can tell by what their function is we have to have these pre-positioned because they all serve vital roles on the space station."

The good news, he said, is that "we don't have an immediate need for any of them. We're leaving them on the decks.

The International Space Station (NASA)

"To say which one is more critical, you kind of need a crystal ball to see which system is more likely to fail," he said. "They all serve a critical purpose. Losing CMGs, control moment gyros, is a big deal, because if you lose your non-propulsive capability to maintain attitude, the only thing you've got left is the propulsive control and the prop(ellant) is a consumable. When you start looking at the retirement of the shuttle and what it costs to fly prop, that becomes a big deal. So prop conservation has been a big theme for the last year or so. Which means the CMGs are that much more important.

"You can also talk about the external thermal control system. We've got two of those, loop A and loop B outside. Each one has a pump module, the NTA (nitrogen tank assembly) and ATA (ammonia tank assembly). Losing one of those loops is very significant. We'd lose cooling capability to half of the electronics on the U.S., European and Japanese part of the space station. So that could become very critical very quickly.

"So it's just a matter of what the next failure is going to be," he said. "I would say at this point in time, they have equal criticality, which is why they're on this flight."

Atlantis is scheduled for liftoff from launch complex 39A at the Kennedy Space Center at 2:28 p.m. EST, roughly the moment Earth's rotation carries the pad into the plane of the space station's orbit. The shuttle launch window closes Nov. 20 because of temperature constraints related to the station's orbit. The next shuttle launch window opens Dec. 6.

Atlantis' processing has been routine, but engineers have spent a fair amount of time evaluating a potential issue with the acoustic shock of main engine ignition.

The issue first came to light after the October 1998 shuttle flight that launched former Sen. John Glenn back into orbit. During liftoff, the door covering the shuttle's braking parachute fell off, prompting an investigation that ultimately led to liftoff acoustics.

Additional instrumentation was added to subsequent flights and the data seemed to show sound levels were in the expected range. But in a subsequent analysis, engineers realized the way the sensors were being calibrated did not adequately take into account how the vibration of the pressure transducers themselves interacted with the sound they were supposed to measure.

More accurate calibration showed the acoustic environment at engine startup "was a lot more severe than we thought," said Mike Moses, the shuttle integration manager at Kennedy. "It was definitely above what our design limit was."

Engineers then began analyzing shuttle structures to make sure they could safely withstand the unexpected acoustic environment. One area of concern involved bolts that hold maneuvering jet extensions, called "stingers," on the back of the shuttle's orbital maneuvering system rocket pods.

Boroscope inspections of the bolt in question showed no cracks, at least to the limits of the instrument's resolution. Engineers also examined qualification hardware built in the early days of the shuttle program that was subjected to vibrations simulating 100 missions to look for any signs of undue stress. No major problems were found and engineers believe Atlantis can be safely launched as is. But additional instrumentation was ordered to collect more data during launch.

Joining Hobaugh on the shuttle's flight deck for the 129th shuttle mission will be pilot Barry "Butch" Wilmore, Leland Melvin and Randolph Bresnik. Strapped in on Atlantis' lower deck will be Michael Foreman and Robert Satcher, an orthopedic surgeon-turned-astronaut. Hobaugh, Foreman and Melvin, a former pro football draft pick, are shuttle veterans while their crewmates are making their first space flight.

Assuming an on-time launch, Bresnik will miss the birth of his second child, a girl, scheduled for delivery Nov. 20, two weeks ahead of her December due date.

"She's a pretty amazing woman," Bresnik said of his wife, Rebecca, in an interview with CBS News. "She's actually the lead for international law here at the Johnson Space Center. ... Her sister's coming down if I'm not here to help out. We're very fortunate for that, and the NASA family here.

"While I'm sad, I'm disappointed, to miss the birth, I'm hoping she'll forgive me later on when I tell her why I wasn't there when she was born. Miracles happen and miracle childbirth is certainly something we've been astounded by the past nine months and we're not going to complain about the timing of it. It's just unfortunate these two amazing life events happen all at the same time.

"I just look forward to getting the call that mother and baby are safe and healthy," Bresnik said. "If we're still docked to the ISS, depending on when the launch date is, we ought to be able to see a video conference with them and talk to them afterwards. That'll be great."

Assuming an on-time launch, the astronauts will be in orbit on Thanksgiving, preparing Atlantis for a landing at the Kennedy Space Center around 9:47 a.m. on Nov. 27.

Asked if the crew planned anything special for the holiday, Hobaugh said "the season is whatever the season is. It could be Christmas, it could be Thanksgiving, who knows? We're just always pleased to be in space and I don't care what they give us, it could be beef brisket, it could be tofu, it doesn't matter to me. We're going to enjoy ourselves no matter what we do."

The first two days of Atlantis' mission will follow the standard post-Columbia template, with the astronauts focused on setting up computers and other gear, testing their spacesuits and rendezvous aids and inspecting the ship's reinforced carbon carbon nose cap and wing leading edge panels for any signs of damage during ascent.

On flight day three, Hobaugh and Wilmore will oversee a carefully choreographed rendezvous with the space station, approaching from behind and maneuvering to a point about 600 feet directly below the outpost. Hobaugh then plans to initiate a mostly-automated 360-degree back flip maneuver, exposing the heat shield tiles on the orbiter's belly to the crew of the space station for a detailed photo survey.

Commander Charles Hobaugh (NASA)

"Positioned in the aft portion of the International Space Station looking out windows in the Russian segment, several station crew members will have cameras and shoot digital still images out the window of the tile surfaces on board Atlantis," Sarafin said. "All of those digital images will be sent to the ground before we complete our docking for review by the Debris Assessment Team and the imagery analysts on the ground."

Hobaugh then plans to guide Atlantis up to a point some 450 feet directly in front of the station, with the shuttle's tail pointed toward Earth and its open payload bay facing a docking port on the front end of the lab's Harmony module.

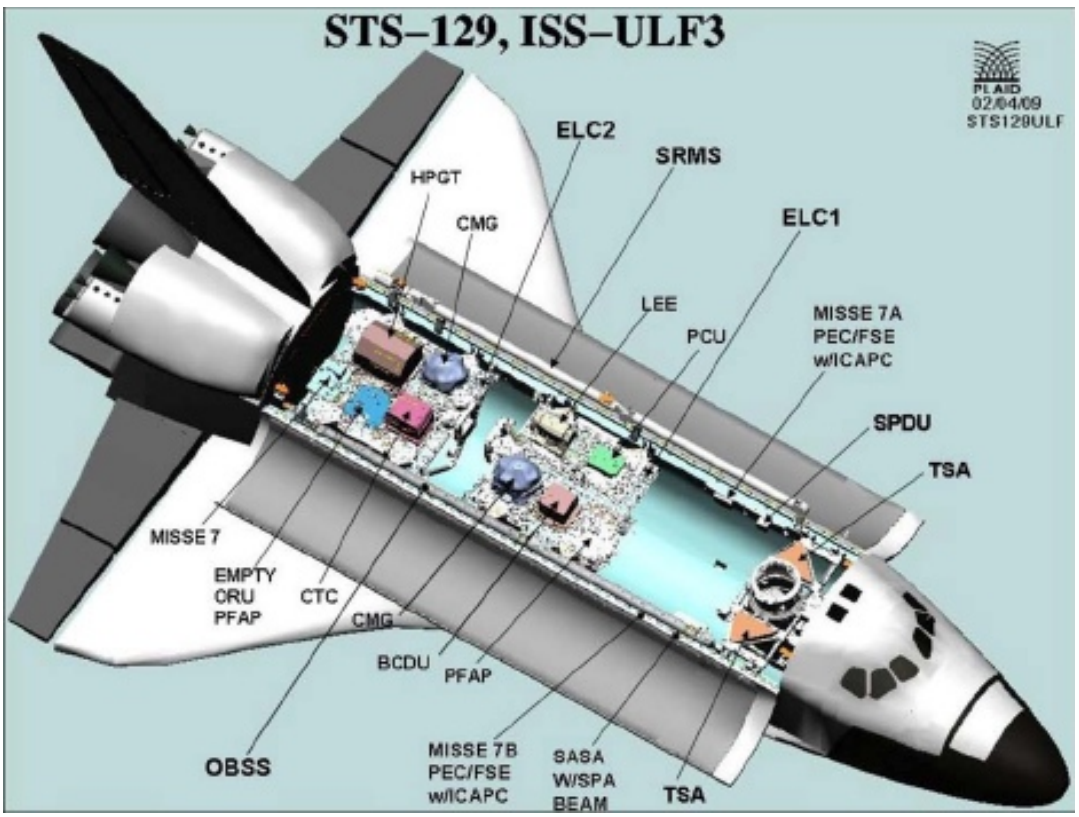
"From there, he'll maneuver in to the docking port," Sarafin said. "At a range of roughly 30 feet to the International Space Station, he'll perform a final alignment verification using the centerline camera. Once we verify we have a good alignment, we will go in and dock to the International Space Station.

"Once any residual motion has damped out, we'll retract the docking ring and complete a good hard mate to the International Space Station, verify there are no leaks at the pressure seals at that interface. Once those leak checks are performed, the crew will have a go to open the hatches and they'll greet each other and perform a safety briefing. And with that, the real core mission of STS-129 and ULF-3 will begin."

Waiting to welcome the shuttle crew aboard will be European Space Agency commander Frank De Winne of Belgium, cosmonauts Maxim Suraev and Roman Romanenko, NASA astronauts Jeffrey Williams and Stott and Canadian astronaut Robert Thirsk.

Williams and Suraev arrived at the space station in late September. Stott plans to return to Earth aboard Atlantis while De Winne, Romanenko and Thirsk plan to fly home aboard a Soyuz spacecraft Dec. 1. Williams and Suraev will have the station to themselves as the core members of the Expedition 22 crew until three more crew members arrive Dec. 23.

One of the first items on the agenda after Atlantis docks is to make Stott a member of the shuttle crew, meaning she will start sleeping aboard Atlantis for the duration of her stay in space. This is a normal procedure to protect against any unusual event that might force the shuttle crew to depart early or in a hurry.



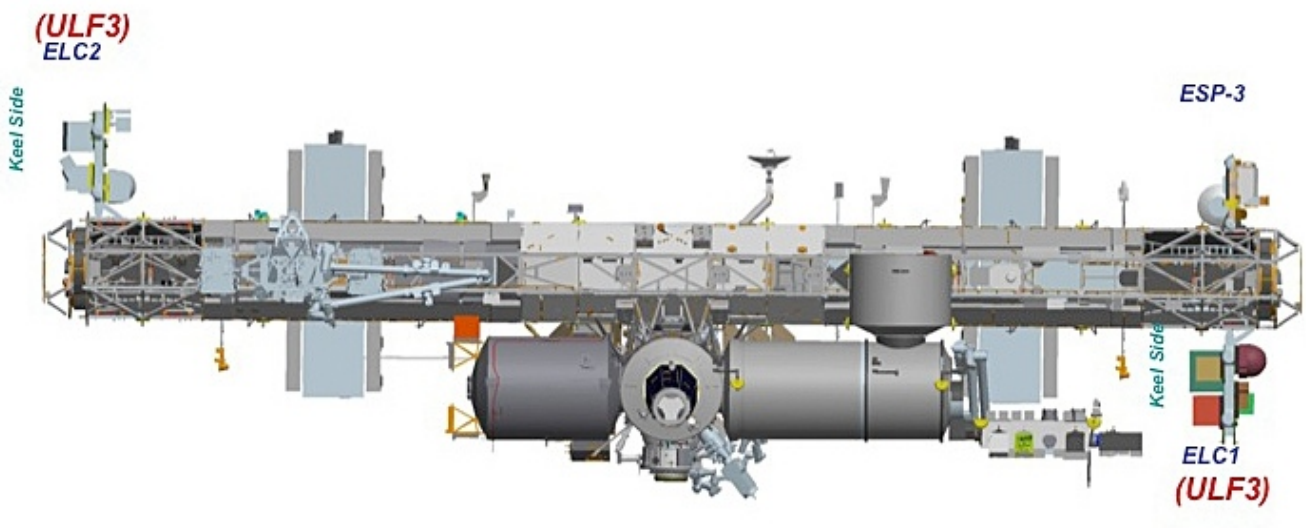
Two-and-a-half hours after docking, Bresnik and Melvin, operating the shuttle's robot arm, will carefully lift ExPRESS Logistics Carrier 1 - ELC-1 - from its perch in the shuttle's cargo bay just in front of ELC-2. The first cargo carrier will be maneuvered to a position on the left side of the shuttle where the station's robot arm, operated by Wilmore and Williams, will latch on and take over.

After the shuttle arm lets go, ELC-1 will be moved to the Earth-facing side of the port three (P3) truss segment on the left side of the station's power truss and locked into place.

The ELCs measure 16 feet by 14 feet and can carry 9,800 pounds of hardware with a volume of 98 cubic feet. The pallets are wired to provide station power and telemetry to attached payloads. For Atlantis' mission, ELC-1 and ELC-2 will carry cargo on both upper and lower surfaces.

Mounted on ELC-1's upper deck are a 600-pound control moment gyroscope, the battery charge-discharge unit, the plasma contactor arc prevention device and a latching end effector for the station's robot arm. Mounted on the lower surface are a 550-pound nitrogen tank assembly, a 780-pound external cooling system pump module and a 1,700-pound ammonia coolant tank.

While ELC-1 is being maneuvered into place, Foreman and Satcher will be reviewing procedures for the first spacewalk the next day before camping out in the Quest airlock module at a reduced pressure of 10 pounds per square inch. The campout protocol is designed to help prevent the bends after working in NASA's low-pressure spacesuits.



External spares and equipment storage locations on the space station's solar power truss.

"This is an agressive mission in the sense that we've got a lot of key objectives that if we don't accomplish those on the days they're planned, it's going to have a ripple effect downstream," Smith said. "Specifically, flight day three is really the linch pin on this mission.

"We need to get docked, get ExPRESS Logistics Carrier 1 out of the payload bay and installed and get the crew into EVA campout to go out the hatch on a spacewalk the very next day. That is a lot of activity in one day, and if the docking takes longer than planned, if the robotic activities associated with ELC-1 take longer than planned or we just get behind, that's going to ripple down stream.

"Atlantis doesn't have the power transfer capability that the other two vehicles have, so we also have limited consumables from a power production standpoint on board. So we've got to get three spacewalks done, two ELCs out of the payload bay in 11 days. It's complex from that standpoint."

Assuming the docking and transfer of ELC-1 go smoothly, Foreman and Satcher plan to begin a six-and-a-half-hour spacewalk on flight day four, Nov. 19, starting around 9:20 a.m. EST. Melvin and Wilmore will operate the station's robot arm during the spacewalk while Bresnik will serve as the spacewalk coordinator.

With Satcher anchored to the end of the station's robot arm, Foreman will unbolt the spare S-band antenna assembly in the shuttle's cargo bay and hand it to his crewmate, who will then carry it up to a storage point on the central Z1 truss that houses the station's four control moment gyroscopes.

"It's a really cool ride for Bobby, he's going to have a good time," Smith said.

Both spacewalkers then will bolt the antenna into place.

"Our first task is to take another spare part out of the space shuttle's payload bay, the SASA payload, which is S-band Antenna Support Assembly, which is basically a spare S-band antenna for the space station," Foreman said in a NASA interview. "It's an antenna that failed on orbit. They brought it back, refurbished it, now it's ready to go and we'll put it back into the spare location.

The ELC-1 pallet, ready for installation aboard shuttle Atlantis.

"So I will go out of the airlock, go over to the payload bay and start getting that thing ready to hand off to Bobby. Bobby's going to go out, get into the robotic arm and they'll maneuver him over into the payload bay on the end of the arm. He'll grab that thing after I unbolt it and he'll ride the arm back to Z1 where it gets installed in the spare location and I'll translate back over there and help him install it."

At that point, the two spacewalkers will split up.

"After we get (the SASA) installed, I will also pick up a set of cables from our tool box in the back of the payload bay, take those over to the Z1 location also and start stringing those things up for a future mission to use while Bobby continues to ride the arm and he goes into his lube-job-man role as the lubricator of a couple of the latching end effectors, the POA latching end effector and the JEM RMS latching end effector."

The former is a payload attach fitting on the robot arm's mobile transporter while the latter is the latching end of a Japanese robot arm attached to the Kibo laboratory module. Both latching systems utilize snares that rotate closed to lock onto a payload's grapple fixture. Because of past issues with the snares, regular lubrication is a now standard operation.

"He'll go and apply some grease to the snares inside those latching end effectors to make sure that they don't have a problem later in life," Foreman said. "So he's doing some preventive maintenance basically on those while I do that spare cable task. And then I go over to Node 1 and there's a slide wire over there, a safety slide wire, that is no longer usable, so I'm going to take that off, bring that back in and we'll also have a handrail to swap out over there. I take one handrail off, install a different handrail that actually has some ammonia line cable connectors on it that will be used on a future mission."

The day after the first spacewalk, flight day five, is reserved for a so-called focused inspection of the shuttle's heat shield if any problems are spotted during the inspections carried out the day after launch and during final approach to the space station. If no major problems are seen that require a second look, the crew will forego the focused inspection and devote the day instead to internal supply transfers and preparations for a spacewalk by Foreman and Bresnik.

Assuming an on-time launch, flight day five would fall on Nov. 20, the day Bresnik's daughter is scheduled for delivery.

Before the second spacewalk gets underway on flight day six, Hobaugh and Melvin will use Atlantis' robot arm to pull ELC-2 from the shuttle's cargo bay. Like ELC-1, hardware is mounted on both sides of ELC-2.

A second spare control moment gyroscope is mounted on the pallet's upper surface, along with the 1,240-pound high-pressure oxygen tank and a cargo transport container housing spare remote power control module circuit breakers.

Another nitrogen tank assembly is bolted to ELC-2's lower side, along with another coolant system pump module and a spooled power line designed to play out and retract as the robot arm's mobile transporter moves along the front side of the station's solar power truss.

After Hobaugh and Melvin pull ELC-2 from the cargo bay, Williams and De Winne will lock on with the station's robot arm to maneuver it into place on the right side of the power truss. About halfway through the ELC-2 installation procedure, Foreman and Bresnik will begin the mission's second spacewalk.

"On EVA 2 we go outside and we get a couple of antennas that are going to be put on the outside of the Columbus (laboratory) module," Bresnik said in a NASA interview. "One of them is a (maritime navigation system) antenna that will go on the front side of the Columbus. The other one's essentially a ham radio antenna that'll go on the bottom side out of the starboard end of Columbus. So we're both going to go ahead and put the antennas in and string the cable, get it powered up.

"Then we head over and we're going to go ahead and take an antenna that is up on the starboard side that has to be maneuvered over to the port side to make room for the AMS, or Alpha Magnetic Spectrometer, that's going to come up on the final shuttle mission."

Once that work is done, Foreman and Bresnik will make their way to the lower side of the S3 starboard truss segment to deploy another cargo mounting mechanism like the ones used to anchor the ELCs. That will allow "other flights to come up and put their hardware on the cupboard, or the shelf of the space station for later use," Bresnik said.

"And then the last thing we're going to do is we're going to take an antenna that helps with the wireless video system when we're doing EVAs, we're going to take and install an antenna that was inside the airlock, we're going to take it out with us and install it back on the S3, back where we're doing the (payload attach system) system and put that out there so we've got better coverage when we have our crew members going out to do an EVA."

Following EVA-2, the astronauts will enjoy a bit of off-duty time on flight day seven before reviewing procedures for the third and final spacewalk the next day. As with the previous two excursions, the spacewalkers - Satcher and Bresnik - will spend the night in the Quest airlock module.

The final spacewalk has three primary objectives: moving the new oxygen tank from ELC-2 to the hull of the Quest module and connecting it to the airlock's pressurization system; mounting the Materials on International Space Station Experiment 7 - MISSE-7 - on ELC-2; and deploying another external payload mounting mechanism on the upward-facing side of the S3 truss segment.

"The major task we're going to do is installing the oxygen gas tank so we're bringing up some atmosphere for the space station," Satcher said in a NASA interview. "It comes up actually on ELC-2, which is going to be stored all the way out on the end of the space station, on the starboard end. So we've got to go out, way out there and get it, coordinate with the robotic arm, SSRMS, because we have to take it off of ELC-2, hold it in position for the arm to grapple it and transport it all the way back over to the airlock where we will go and install it onto the airlock.

"Now before we can install it there, there're some MMOD shields, which are micrometeorite debris shields, that protect the space station from these strikes that we (have) got to move out of the way, so we'll be detaching those, moving them out of the way and then we can install the gas tank.

"The other major activity is we'll be deploying these material science experiments called MISSEs," Satcher said. "Actually Randy will be getting those out of the cargo bay of the shuttle and bringing those over to ELC-2 where they're installed and deployed and I'll also be doing some rerouting of some cables on Node 1 in anticipation of future install of Node 3. So those are the major activities that we're going to do and it should take us a full six or seven hours to get that done."

The day after the third spacewalk - Nov. 24 - the astronauts will hold a traditional in-flight news conference and enjoy a half day off before a brief farewell ceremony and hatch closure to wrap up the docked phase of the mission.

The next day, Nov. 25, Atlantis will undock from the International Space Station. Wilmore, flying the shuttle from the aft flight deck, will pilot Atlantis through a 360-degree loop of the lab complex before departing the area.

The astronauts will celebrate Thanksgiving in space with a crew meal following a test of the shuttle's re-entry system. The day after Thanksgiving, the shuttle will return to Earth, weather permitting, landing back at the Kennedy Space Center around 9:47 a.m.

With Atlantis back on the ground, NASA will be poised to enter its final few months of shuttle activity, working to complete the International Space Station and transitioning from assembly to utilization.

"Quite a few things are going on and we tend to stay that way," said space station Program Manager Mike Suffredini. "You'll see us start to transition more and talk more about the research and giving more priority to research up mass along the way. That's why we built the ISS and we're at that position, we're ready to start focusing more on that even though we have a little more assembly left to do. We're all looking forward to that over the next several years."

STS-129 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:

Mission Priorities [CAT 1 & 2]

- ❑ Return Expedition 21 Flight Engineer-2 (17A) crew member Nicole Stott.
- ❑ Install, activate, and check out ExPRESS Logistics Carrier (ELC)1 on an Unpressurized Cargo Carrier Attachment System (UCCAS) on the port side of the station's backbone.
- ❑ Install ELC2 to an upper outboard Payload Adapter System (PAS) on the starboard side of the station's backbone, activate and check out.
- ❑ Transfer S-Band Antenna and Support Assembly (SASA) to Z1 location on station and apply heater and operation power.
- ❑ Install Materials International Space Station Experiment-7 onto ELC2, activate and check out.
- ❑ Prepare for Node 3 (Tranquility) arrival.
  - ❑ Remove handrail on Unity and replace with ammonia line routing bracket.
  - ❑ Reposition Zarya Local Area Network (LAN) connector on Unity and tie down Micrometeoroid Orbital Debris shield.

  Connect the P181 electrical power connector for Unity.
- ❑ Transfer and install spare oxygen High Pressure Gas Tank from ELC2 to station airlock.
- ❑ Deploy the Common Attach System site for External Stowage Platform-3 relocation.
- ❑ Install Unity port bulkhead feedthroughs (if not performed in Stage).
- ❑ Install Unity avionics and fluids modification kit.
- ❑ Install Unity intermodule ventilation modification kit.
- ❑ Remove and replace airlock battery charger modules.
- ❑ Perform Payloads of Opportunity – Maui Analysis of Upper Atmospheric Injections (MAUI), Ram Burn Observations-2 (RAMBO-2), Shuttle Exhaust Ion Turbulence Experiment (SEITE) and Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX).

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

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NASA STS-129 Mission Overview[2]

There are no home improvement stores in space, so the next space shuttle mission to the International Space Station will deliver 14 tons of important spare parts for its electrical, plumbing, air conditioning, communications and robotics systems.

Atlantis, commanded by space veteran Charles O. Hobaugh, is scheduled to lift off from Kennedy Space Center at 2:28 p.m. EST, Nov. 16, on the third utilization and logistics flight, and arrive at the station the afternoon of Nov. 18.

For the STS-129 Utilization and Logistics Flight - 3 (ULF-3) mission, Atlantis will carry in its cargo bay two ExPRESS Logistics Carriers (ELC's), a new Materials on International Space Station Experiment (MISSE) carrier and an S-Band Antenna Sub-Assembly (SASA) package, plus additional equipment, supplies and scientific experiments that will be used by the continuing crew of six aboard the station.

While docked to the station, Atlantis' crew will conduct three spacewalks to transfer the spare parts from the shuttle's payload bay to the station's external structures and continue assembly activities.

At the end of the 11-day flight, Atlantis also will bring home Expedition 20 and 21 Flight Engineer Nicole Stott, the final astronaut scheduled to use a space shuttle for a lift to or from the station.

Hobaugh, who turns 48 the week before launch, served as pilot on STS-104 in 2001 and STS-118 in 2007. He'll be joined at launch by pilot Barry E. Wilmore, a U.S. Navy captain, and mission specialists Randy Bresnik, a U.S. Marine Corps lieutenant colonel; and Robert L. Satcher Jr., an orthopedic surgeon, all of whom will be making their first spaceflights.

Rounding out the crew are mission specialists Leland Melvin, 45, an 11th round draft pick for the NFL's Detroit Lions who flew on STS-122 in 2008, and Mike Foreman, a retired Navy captain who flew on STS-123 in March 2008. Stott, a former Kennedy Space Center shuttle processing director completing a 100-day mission aboard the station, will join the STS-129 crew for the ride home to Earth.

Aside from returning Stott and delivering supplies for station crew, the main objective of the STS-129 mission is to deliver, install and checkout two large logistics pallets and their spare parts, and to prepare the station for the arrival of the Tranquility module, the final U.S.-built component of the station, which will be delivered on the following flight in February. This will be the first flight of an ExPRESS (Expedite the Processing of Experiments to Space Station) Logistics Carrier.

ExPRESS Logistics Carrier-1 will launch with an Ammonia Tank Assembly (ATA), a Battery Charge Discharge Unit (BCDU), a Space Station Remote Manipulator System (SSRMS) Latching End Effector (LEE), a Control Moment Gyro (CMG), a Nitrogen Tank Assembly (NTA), a Pump Module (PM), a Plasma Contactor Unit (PCU) and two empty Passive Flight Releasable Attachment Mechanisms (PFRAMs).

ExPRESS Logistics Carrier-2 will launch with a High Pressure Gas Tank (HPGT), a Cargo Transport Container 1 (CTC-1) mounted to a Small Adapter Plate Assembly (SAPA), a Mobile Transporter/Trailing Umbilical System (MT/TUS), CMG, NTA, PM, Utility Transfer Assembly (UTA) Flight Support Equipment (FSE), one empty Payload PFRAM and MISSE-7, an experiment that will expose a variety of materials being considered for future spacecraft to the extreme conditions outside the station.

[2] Word for word from the NASA STS-129 Press Kit, available on line at: http://www.nasa.gov/mission_pages/shuttle/main/index.html

Several experiments that are considered pathfinders for U.S. National Laboratory investigations aboard the space station, also will be flown. One of those is part of a continuing investigation that is seeking a vaccine that can be used against food poisoning.

The day after launch, Hobaugh, Wilmore, Melvin and Bresnik will take turns from Atlantis' 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 crane 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 areas that experience the highest heating upon re-entry to the Earth's atmosphere. A follow-up inspection will take place after Atlantis undocks from the station.

While the inspection takes place, Bresnik, Foreman and Satcher will prepare the spacesuits they will wear for the three spacewalks to be conducted out of the Quest airlock at the station. As Foreman and Satcher prepare the spacesuits for transfer to the station, Bresnik will join the heat shield inspection team. Other pre-docking preparations will occupy the remainder of the crew's workday.

On the third day of the flight, Atlantis will be flown by Hobaugh and Wilmore on its approach for docking to the station. After a series of jet firings to fine-tune Atlantis' 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, Hobaugh will execute the rendezvous pitch maneuver, a one-degree-per-second rotational "backflip" to enable station crew members to snap 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, Hobaugh will fly Atlantis in front of the station before slowly closing in for a linkup to the forward docking port on the Harmony module at 11:56 a.m. EST Nov. 18. Less than two hours later, hatches will open between the two spacecraft and a combined crew of 12 will begin almost seven days of work between the two crews. Atlantis' crew will be working with Expedition 21 commander Frank De Winne of the European Space Agency, and NASA flight engineers Jeff Williams and Stott, Canadian flight engineer Bob Thirsk, and Russian flight engineers Roman Romanenko and Max Suraev.

After a station safety briefing, Melvin and Bresnik will grapple ELC-1 using the shuttle's robotic arm and hand it off to the station's arm, operated by Williams and Wilmore, who will then install it on an Unpressurized Cargo Carriers Attachment System (UCCAS) on the port side of the station's backbone.

Spacewalkers Foreman and Satcher 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 all three spacewalks.

The fourth day of the mission will focus on the first spacewalk, with Foreman and Satcher transferring the spare SASA antenna from Atlantis' cargo bay to the station's truss and attaching power for its heaters, lubricating the snares on the Kibo laboratory's robotic arm and a Payload and ORU Accommodation (POA), working with cabling and reseating a protective shield on the outside the Unity module. Wilmore and Melvin will drive the station's robotic arm to support the spacewalkers.

The fifth day is available for focused inspection of Atlantis' heat shield if mission managers deem it necessary, a move to position the station's robotic arm for the following day's ELC-2 transfer, and for preparations for the second spacewalk.

Day six will focus on the second spacewalk of the mission by Foreman and Bresnik. They'll install a Grappling Adaptor to On-orbit Railing (GATOR) assembly to the outside of the Columbus laboratory as part of a project is to demonstrate the performance of two different Automatic Identification System (AIS) receivers to identify and locate ships on the ocean. They'll also relocate a Floating Potential Measurement Unit, which is used to measure the electrical charge that occurs on the station's shell as it interacts with the natural plasma in low-Earth orbit. They'll also deploy an Earth- facing Payload Adapter System (PAS) on the station's truss and install a Wireless Video

System (WVS) External Transceiver Assembly Wireless Video System External Transceiver Assembly (WETA).

Half a day off is planned for the crew on the seventh day of the mission before the crew begins gearing up for the third and final planned spacewalk by Bresnik and Satcher. On the eighth day of the flight, they'll transfer a High Pressure Gas Tank (HPGT) full of oxygen from ELC-2 to a spot on the outside of the Quest airlock, placing it amidst the other dog house-shaped tanks that are used to replenish atmosphere lost when spacewalkers enter and exit the station. They'll also deploy a PAS on the space-facing side of the starboard truss and reseat debris shields on the airlock.

The final full day of docked operations will include some additional time off for the crew to rest up after their busy spacewalk pace, but focus on preparations for Atlantis' undocking and departure on the following day. The crew will finish packing, reconfigure spacesuits and transfer them to Atlantis, and check out the rendezvous tools that will be used for undocking, fly-around and separation. The Atlantis crew, with Stott now a member, will say their farewells to the five-member station crew, close the hatches between the two spacecraft and get a good night's rest.

After Atlantis undocks at 4:57 a.m. EST Nov. 25, Wilmore will guide the shuttle on a 360-degree fly-around of the station so that other crew members can documents the exterior condition of the orbiting outpost, with all of its new spare parts in position. After the fly-around is complete, Wilmore, Melvin and Bresknik will conduct one last inspection of Atlantis' heat shield using the shuttle's Canadarm and the OBSS.

The last full day of orbital activities by the STS-129 crew will focus on landing preparations. Hobaugh, Wilmore and Bresnik will conduct the traditional checkout of the shuttle's flight control systems and steering jets, setting Atlantis up for its supersonic return to Earth. A special recumbent seat will be set up in the shuttle's lower deck for Stott to ease her reorientation to Earth's gravity for the first time in more than three months.

On the 12th day of the mission, weather permitting, Hobaugh and Wilmore will guide Atlantis to a landing at the Kennedy Space Center at 9:57 a.m. EST Nov. 27 to wrap up the 31st flight for Atlantis, the 129th mission in shuttle program history and the 31st shuttle visit to the International Space Station.

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NASA STS-129 Payload Overview[3]

The STS-129 mission is a utility logistics support mission and will carry a number of spare parts, science experiments, and other items in its middeck and payload bay. The payload going up is approximately 29,458 pounds, not counting the middeck portion. The expected return weight in the payload bay is approximately 2,850 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 Expedite the Processing of Experiments to the Space Station (ExPRESS) rack.

The space shuttle will carry on its middeck (ascent) the following items: Advanced Biological Research System, National Lab Pathfinder (NLP) Cells/ Commercial Generic Bioprocessing Apparatus (CGBA), Mice Drawer System (MDS), NLP Vaccine, Advanced Plant EXperiments on Orbit-Cambium (APEX-Cambium), Japan Aerospace and Exploration Agency (JAXA) RNA interference and protein phosphorylation in space environment using the nematode Caenorhabditis elegans (CERISE) & Hair, European Space Agency (ESA) Dose Distribution inside the ISS (DOSIS), Human Research Program (HRP) Sample Collection Kits, and the Integrated Immune and Sleep Short.

S-BAND ANTENNA SUPPORT ASSEMBLY (SASA) AND RADIO FREQUENCY GROUP (RFG)

STS-129/ULF3 will carry the S-band Antenna Support Assembly (SASA) that will be attached to the sidewall inside the space shuttle payload pay. The SASA is an assembly that consists of the Assembly Contingency Radio Frequency Group (RFG or ACRFG), SASA Boom and Avionics Wire Harness.

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

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

The total envelope of the RFG is 36 inches × 59 inches × 33 inches (maximum dimensions). The SASA Boom is 61 inches × 30 1/4 inches × 43 inches. The entire SASA weighs 256 pounds. The unit that is being flown on this mission was refurbished by MacDonald Dettwiler and Associates Ltd. (MDA), under contract to Boeing, after it was returned in October 2007 after it had failed on orbit in September 2006 (it was replaced then with an on-orbit spare). This unit will be installed on the Zenith 1 truss as a spare.

EXPRESS LOGISTICS CARRIER 1 AND 2

The ExPRESS Logistics Carrier (ELC) is a platform designed to support external payloads mounted to the International Space Station (ISS) starboard and port trusses with either deep space or Earthward views. Each pallet spans the entire width of the shuttle's payload bay, carries science experiments, and serves as a parking place for spare hardware that

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[3] Word for word from the NASA STS-129 Press Kit, available on line at: http://www.nasa.gov/mission_pages/shuttle/main/index.html

can be replaced robotically once on-orbit. STS-129/ULF3 will mark the first flight of ELC1 and 2. ELC1 and 2 are grappled by the space shuttle and station robotics arms and are placed on the station's truss structure. ELC1 is mounted on the Port 3 truss element UCCAS while ELC2 is placed on the Starboard 3 truss upper outboard PAS. The UCCAS and PAS were deployed during the STS-128 mission.

The weight of ELC1 is approximately 13,850 pounds; ELC2 weighs 13,400 pounds.

Both ELC1 and 2 measure approximately 16 feet by 14 feet (without the ORUs installed). Because of their expertise in building the Hubble Space Telescope (HST) cargo carriers, NASA Goddard Space Center served as the overall integrator and manufacturer for ELC1 and 2. Remmele Engineering, based in Minneapolis, Minn., built the integral aluminum ELC decks for NASA. Engineers from GSFC's Carriers Development Office developed the challenging, lightweight ELC design, which incorporates elements of both the Express Pallet and the Unpressurized Logistics Carrier.

The ELC is designed to be carried in the space shuttle cargo bay to the ISS, fully integrated with cargo and/or payloads. Four ELCs will be delivered to ISS before the scheduled retirement of the space shuttle. Two ELCs will be attached to the starboard truss 3 (S3) and two ELCs will be attached to the port truss 3 (P3). By attaching at the S3/P3 sites, a variety of views such as zenith (deep space) or nadir (Earthward) direction with a combination of ram (forward) or wake (aft) pointing allows for many possible viewing opportunities.

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

At the ISS to ELC interface, there are two types of data ports: the High Rate Data Link (HRDL) and the Low Rate Data Link (LRDL). The HRDL uses fiber optics to provide ISS to ELC communication. At the ELC avionics module to payload interface, there are three data ports: HRDL, LRDL and Medium Rate Data Link (MDRL, Ethernet). For uplink MDRL, Ethernet is used; the ELC avionics module will convert the MDRL signal from HDRL interface and delivered to each payload attached site. The transmission rate between ELC avionics module to each payload attached site is no higher than 10 Mbps (megabits per second). For downlink MDRL and HDRL signals, they will be transmitted from the payload attached site to ELC avionics module by separated buses. The ELC avionics module will combine these two signals and send to ISS by using HDRL interface. The HDRL downlink service to the ground rate is no higher than 95 Mbps. The LRDL is for a two ways data/command distribution to/from each payload attached site via the ELC avionics module at maximum rate of 1 Mbps. External camera ports are also available for the ELC payloads. There are at least 14 camera port locations along the trusses that can be used for payload observation.

Five ELC units were built, with them all having full up avionics subsystems to support experiments' Command and Data Handling task. Manifested on ELC2 is the first ELC-based payload, Materials for ISS Experiment (MISSE-7). ELC4 is currently slated for mission STS-134 Endeavour, to launch July 29, 2010. ELC3 is currently slated for mission STS-133 Discovery, launching on Sept. 16, 2010. ELC5 is not manifested and is considered a flight spare. This extremely aggressive effort required the talents of more than 100 employees from GSFC, JSC, and KSC who worked together on the project.

A total of 14 large Orbital Replacement Units (ORUs) are being carried on ELC1 and 2. All of the hardware for this mission was processed by Boeing under its Checkout, Assembly and Payload Processing Services (CAPPS) contract with NASA. The STS-129 mission marks the largest number of spare ORUs processed in a single mission under the CAPPS contract. The ORUs include the Ammonia Tank Assembly (ATA), Battery Charger Discharge Unit (BCDU), Cargo Transportation Container (CTC), two Control Moment Gyroscopes (CMG), High-Pressure Gas Tank (HPGT), Canadarm2 Latching End Effector (LEE), Materials International Space Station Experiment 7 (MISSE-7), two Nitrogen

Tank Assemblies (NTA), Plasma Contactor Unit (PCU), two Pump Module Assemblies (PMA) and a Trailing Umbilical System-Reel Assembly (TUS-RA).

ORBITAL REPLACEMENT UNITS (ORUS) ON ELC1

- **Ammonia Tank Assembly (ATA)**

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

- **Battery Charger Discharge Unit (BCDU)**

The Battery Charge Discharge Unit (BCDU) is a bidirectional power converter that serves a dual function of charging the batteries during solar collection periods (isolation) and providing conditioned battery power to the primary power buses during eclipse periods. The BCDU has a battery charging capability of 8.4 kW and a continuous discharge capability of 6.6 kW (9.0 kW peak). The BCDU also includes provisions for battery status monitoring and protection from power circuit faults. The BCDU measures approximately 40 inches by 28 inches by 12 inches and weighs 235 pounds. There are 24 BCDUs on orbit that are used for normal Power System operation.

- **Control Moment Gyroscope (CMG)**

Both the Russian and U.S. segments can maintain attitude control. When the Russian segment is in control, attitude is maintained by thrusters, which consume propellant. When the U.S. segment is in control, Control Moment Gyroscopes, manufactured by L3 Communications Space and Navigation under contract to Boeing, are used. The set of four CMGs balance the effects of gravity gradient, aerodynamic, and other disturbance torques (i.e., robotics, venting, and plume impingement), maintaining the station at an equilibrium attitude without using propellant. The CMGs can also be used to perform attitude maneuvers. The CMGs rely on electrical power provided by the solar powered electrical subsystem.

A CMG consists of a single-piece 25-inch diameter, 220-pound stainless steel flywheel that rotates at a constant speed of 6,600 rpm and develops an angular momentum of 3,600 ft-lb-sec (4,880 N-m-s) about its spin axis. This rotating wheel is mounted in a two-degree-of-freedom gimbal system that can position the spin axis (momentum vector) of the wheel in any direction, allowing control torque generation in any direction. The station has four working CMGs that are mounted in the Zenith 1 truss segment. Each CMG assembly weighs approximately 600 pounds and measures 45 inches wide, 48 inches high, and 54 inches in length.

The CMGs have had some failures on board the ISS. Design improvements made to the spare CMGs, based on the findings from the two CMG failure investigations, include new bearing preload system materials, improvements to sliding fit lubrication, and modified covers and installation procedures to maintain bearing alignment.

- **Canadarm2 Latching End Effector (LEE)**

The Canadian Mobile Servicing System (MSS), a space robotics system astronauts and cosmonauts use to assemble and maintain the International Space Station, consists of the Canadian Space Station Remote Manipulator System (SSRMS) or Canadarm 2, the Mobile Base System (MBS) and the Special Purpose Dexterous Manipulator (SPDM) or Dextre. The SSRMS has two identical grapple end points called LEE that enable it to reattach either end to the station as its new base. It moves in inch worm fashion around the U.S. segment by placing one end on a mounting point and disengaging its other end and using it to grapple a payload or another mounting point. Each mounting point provides power and data to the SSRMS.

The SSRMS can also be mounted on one of several mounting points on the MBS, a movable base that moves back and forth on the United States On-Orbit truss segments. The MBS itself has a LEE (called the Payload Orbital Replacement Unit (ORU) Accommodation (POA)) that is used for temporarily stowing and providing power to payloads. And the SPDM has a LEE that can be used for positioning the SPDM on the station or on the MBS or that can be used to grapple payloads when the SPDM itself is at the end of the SSRMS. The LEE, SSRMS, MBS, and SPDM are all built by MacDonald Dettwiler and Associates Ltd. (MDA) and are provided by the Canadian Space Agency.

The LEE or mechanical hand of the MSS allows the SSRMS, the SPDM or the MBS to capture stationary payloads by providing a large capture envelope (a cylinder 8 inches in diameter by 4 inches deep) and a mechanism/structure capable of soft docking and rigidizing. This action is accomplished by a two-stage mechanism in the LEE that closes three cables (like a snare) around a grapple probe (knobbed pin) bolted onto the payload and then draws it into the device until close contact is established and a load of approximately 1,100 pounds is imparted to the grapple probe. The payload remains attached to the MSS component by the forces developed by the LEE on the payload through the grapple probe that allows for maneuvering of the payload without separation from the LEE. The LEE measures about 42 inches in length and about 35 inches in height and 28 inches in width, and weighs about 415 pounds.

- **Nitrogen Tank Assembly (NTA)**

The NTA provides a high-pressure gaseous nitrogen supply to control the flow of ammonia out of the ATA. The ATA contains two flexible, chambers incorporated into its ammonia tanks that expand as pressurized nitrogen expels liquid ammonia out of them. Designed by Boeing's Huntington Beach facility in California, the NTA controls ammonia pressure in the ATA as a key part of the External Active Thermal Control System, an external system that circulates ammonia to cool ISS segments.

Mounted to both of the Boeing-built Starboard 1 (S1) and P1 truss segments, the NTA is equipped with a Gas Pressure Regulating Valve (GPRV) and isolation valves as well as survival heaters. The GPRV and isolation valves provide control function and over pressure protection of downstream components. The heaters prevent the electronic equipment from getting too cold.

The NTA's support structure is made largely of aluminum, and the tank is a carbon composite. The NTA ORU has a full tank with a weight of about 80 pounds of nitrogen at approximately 2,500 pounds per square inch (psi) of pressure - nearly 80 times the pressure of an average automotive tire at 30 psi. It also provides the capability to be refilled while on orbit through its nitrogen fill Quick Disconnect (QD). The NTA weighs approximately 550 pounds.

- **Plasma Contactor Unit (PCU)**

As the International Space Station (ISS) travels through Low Earth Orbit (LEO), an electrical charge builds. This phenomenon can result in high voltages that may cause electrical discharges. These discharges, in turn, can damage precise electrical instruments and can also present a hazard to crew members performing EVA. The Plasma Contactor Unit (PCU) is used to disperse the electrical charge that builds up by providing an electrically conductive "ground path" to the plasma environment surrounding the ISS. This prevents the electrical discharges and provides a means of controlling crew shock hazard during EVA.

There are two PCUs located on the ISS Zenith 1 Truss, both of which are operated during EVA.

Each PCU contains a Xenon tank and a Hollow Cathode Assembly (HCA). When commanded, the HCA emits electrons by converting Xenon gas into Xenon plasma, thus creating the ground path for the ISS electrical charge build-up. The PCU measures approximately 28 inches by 23 inches by 18 inches, and weighs approximately 350 pounds. The PCU is provided by Boeing and utilizes an HCA designed and fabricated at NASA's Glenn Research Center (GRC).

❑ **Pump Module Assembly (PMA)**

The PMA is part of the station's complex Active Thermal Control System (ATCS), which provides vital cooling to internal and external avionics, crew members, and payloads. The station has two independent cooling loops. The external loops use an ammonia-based coolant and the internal loops use water cooling. At the heart of the ATCS is the pump module, which pumps the ammonia through the external system to provide cooling and eventually reject the residual heat into space via the radiators. The heat is generated by the electronic boxes throughout the station. Circulation, loop pressurization, and temperature control of the ammonia is provided by the Pump Module (PM). The major components in the PM include a Pump and Control Valve Package (PCVP), an accumulator, isolation and relief valves, and various temperatures, flow, and pressure sensors. The accumulator within the PM works in concert with the ATA accumulators to compensate for expansion and contraction of ammonia caused by the temperature changes and keeps the ammonia in the liquid phase via a fixed charge of pressurized nitrogen gas on the backside of its bellows. Manufactured by Boeing, the pump module weighs 780 pounds and measures approximately 5.5 feet (69 inches) long by 4 feet (50 inches) wide with a height of 3 feet (36 inches).

❑ **Passive Flight Releasable Attachment Mechanism (PFRAM)**

ELC1 will contain two sites designated to accommodate payloads launched on other missions. NASA uses a system on the external carriers to attach to Orbital Replacement Units (ORUs) and payloads consisting of the Flight Releasable Attachment Mechanism. This mechanism has an active side with moving mechanical components, and a passive side that the active side engages with mechanically driven pins and latches. The active FRAM is driven by an EVA astronaut using a Pistol Grip Tool, or the station's robotic arm. These FRAM mechanisms are mounted to the ELC on Passive Flight Releasable Attachment Mechanism (PFRAM) Adapter Plate Assemblies (PFAPs) and also provide an electrical connection that can be used if needed by the ORU or payload being attached.

ORBITAL REPLACEMENT UNITS ON ELC2

Orbital Replacement Units on ELC2 include another CMG, Pump Module, NTA and one empty P/L PFRAM. Besides those items, it will also carry the following items:

❑ **Cargo Transportation Container (CTC)**

ELC2 will carry a Cargo Transportation Container #1 that will contain 10 Remote Power Control Modules (like a large circuit breaker) and ORU Adapter Kits (OAKS) - basically brackets installed in the CTC to hold the ORUs. It will also carry an empty OAK. Orbital Sciences Corporation delivered five Cargo Transport Containers (CTCs) to NASA for use in conjunction with the resupply of the International Space Station (ISS). Each CTC measures about 4 feet by 3 feet by 3 feet, weighs about 680 pounds and is capable of carrying about 400 pounds of hardware to the ISS. The CTCs can be opened and their contents retrieved either through robotic methods or by astronauts performing extravehicular operations.

❑ **High-Pressure Gas Tank (HPGT)**

High pressure oxygen onboard the ISS provides support for EVA and contingency metabolic support for the crew. This high pressure O2 is brought to the ISS by the High-Pressure Gas Tanks (HPGT) and is replenished by the Space Shuttle by using the Oxygen Recharge Compressor Assembly (ORCA). There are several drivers that must be considered in managing the available high pressure oxygen on the ISS. The amount of oxygen the space shuttle can fly up is driven by manifest mass limitations, launch slips; and on orbit shuttle power requirements. The amount of oxygen that is used from the ISS HPGTs is driven by the number of shuttle docked and undocked EVAs, the type of EVA prebreathe protocol that is used, contingency use of oxygen for metabolic support, and emergency oxygen. The HPGT will be transferred from ELC2 to the ISS Airlock. The HPGT measures 5 feet by 6.2 feet by 4.5 feet and weights approximately 1,240 pounds of which 220 pounds is gaseous oxygen at 2,450 pounds per square inch of pressure. The HPGT was provided by Boeing.

❑ Materials International Space Station Experiment 7 (MISSE-7)

The Materials on International Space Station Experiment 7 (MISSE-7) is a test bed for advanced materials and electronics attached to the outside of the International Space Station (ISS). Results will provide a better understanding of the durability of advanced materials and electronics when they are exposed to vacuum, solar radiation, atomic oxygen, and extremes of heat and cold. These materials and electronics, including solar cells, coatings, thermal protection, optics, sensors, and computing elements, have the potential to increase the performance and useful life of the next generation of satellites and launch systems.

The samples are installed in experiment trays within two Passive Experiment Containers (PECs), which are opened on-orbit. Astronauts will install the PECs, 7A and 7B, to the MISSE-7 support base during an EVA. Each PEC holds samples on both sides, with PEC 7A orientated zenith/nadir (space facing/Earth facing), and PEC 7B oriented ram/wake (forward/backward) relative to the ISS orbit. MISSE-7 also includes electronic experiments in boxes mounted directly to the MISSE-7 support base.

The MISSE program has a rich history of testing advanced materials on ISS. MISSE-1 and 2 were delivered to ISS on STS-105 in August 2001 and returned on STS-114 in August 2005. MISSE-5 was deployed on STS-114 in July 2005 and returned on STS-115 in September 2006. MISSE-3 and 4 were delivered to ISS on STS-121 in July 2006 and returned on STS-118 in August 2007. MISSE-6A and 6B were delivered to the ISS on STS-123 in March 2008 and returned on STS-128 in September 2009. MISSE-7 is the latest and most advanced of the MISSE payloads, and will be the first to receive power directly from the ISS and use the ISS communication system to send commands and downlink real-time data.

❑ Trailing Umbilical System—Reel Assembly (TUS-RA)

The Mobile Transporter (MT) is a cart-like assembly that moves up and down rails along the ISS integrated truss. It provides mobility and the structural load path for the Canadian Mobile Base System (MBS) and the Canadian robotic arm (Space Station Robotic Manipulator System). The power and data to operate the MT and the video and data provided to (and from) the MBS/SSRMS, routes through a set of redundant cables that are part of the Trailing Umbilical System (TUS). The TUS Reel Assembly (TUS-RA) is basically a large spool much like a garden hose reel that pays out cable when the MT moves away and rolls it back up as the MT returns to the center of the truss. The TUS system was equipped with blade cutter devices (one for each cable) that can remotely sever the cable. However, due to anomalous behavior with this feature of the TUS system, this capability was removed on Flight ULF1.1 (STS-121).

The MT is used for assembly of large elements of the station. It must be latched down at various work sites before the robotic arm can operate. When the MT is latched down after translating, power is provided through the Umbilical Mechanism Assembly (UMA) system hardware to the SSRMS and several components on top of the MBS. At the worksites, the MT/MBS/SSRMS is much more structurally secure and the active half of the UMA on the MT mates with the passive half at the work site. NASA flight rules require both TUS cables to be intact before translating anything attached to the MT.

The MBS is a base platform for the robotic arm. The platform rests atop the MT, which allows it to glide down rails on the station's trusses. When Canadarm2 is attached to the MBS, it has the ability to travel to work sites along the truss structure. The top speed of the Mobile Transporter is about 2.5 cm per second. The proper and complete name of the MBS is the “MRS Base System,” where MRS stands for “Mobile Remote Servicer,” It is made out of aluminum and is expected to last at least 15 years. Like Canadarm2, it was built by MacDonald Dettwiler and Associates Ltd. (MDA).

The UMA (Active and Passive halves) and TUS subsystems (TUS RA, cable guide mechanisms and MT interface assemblies) was originally developed and built by the Huntington Beach (HB) division of Boeing (formerly McDonnell Douglas). Boeing HB also integrated the MT with TUS and UMA subsystems. Additionally, the MT and TUS Cables were subcontracted by Boeing HB to ASTRO, a subsidiary of Northrop Grumman and WL Gore Industries respectively.

The TUS-RA weighs approximately 334 pounds and measures about 60 inches by 62 inches by 28 inches.

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NASA STS-129 Spacewalk Overview[4]

There are three spacewalks scheduled for the STS-129 mission.

Mission Specialists Mike Foreman, Robert L. Satcher Jr., and Randy Bresnik will spend a combined total of 19.5 hours outside the station on flight days 4, 6, and 8. Foreman, the lead spacewalker for the mission, will suit up for the first and second spacewalks in a spacesuit marked with solid red stripes. He is a veteran spacewalker with three extravehicular activities, or EVAs, performed during the STS-123 mission in 2008.

Both Satcher and Bresnik will be performing their first spacewalks. Satcher will participating in the first and third spacewalks, wearing an all-white spacesuit. Bresnik will go outside the station for the second and third and wear a spacesuit with broken red stripes.

On each EVA day, the spacewalker left inside the station will act as the intravehicular officer, or spacewalk choreographer. The first and third spacewalks will also require astronauts inside the station to be at the controls of the station’s 58-foot-long robotic arm to carry and maneuver equipment and spacewalkers.

Preparations will start the night before each spacewalk, when the astronauts spend time in the station’s Quest Airlock. This practice is called the campout prebreathe protocol and is used to purge nitrogen from the spacewalkers’ systems and prevent decompression sickness, also known as “the bends.”

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

The procedure enables spacewalks to begin earlier in the crew’s day than was possible before the protocol was adopted.

[4] Word for word from the NASA STS-129 Press Kit, available on line at: http://www.nasa.gov/mission_pages/shuttle/main/index.html

EVA-1

Duration: 6 hours, 30 minutes
EVA Crew: Foreman and Satcher
IV CREW: Bresnik
Robotic Arm Operators: Charles O. Hobaugh, Leland Melvin, and Barry E. Wilmore

EVA Operations:

- ❑ **Install spare S-band antenna structural assembly**
- ❑ **Install redundant space-to-ground antenna cabling**
- ❑ **Remove Unity node handrail and replace with ammonia line routing bracket**
- ❑ **Lubricate Payload Orbital Replacement Unit Accommodation and Japanese robotic arm**
- ❑ **Reposition local area network cable on Zarya**
- ❑ **Troubleshoot S0 panel**

Most of the spare parts brought up by space shuttle Atlantis will be installed onto the space station's truss robotically, but a few will need spacewalker intervention. The first of those to be installed on the station will be the spare S-band antenna structural assembly. Foreman and Satcher will begin the first spacewalk of the mission by moving it from the space shuttle's cargo bay to the Z1 segment of the station's truss system.

For the transfer, Satcher will be doing the heavy lifting, with the help of the station's robotic arm. He'll climb onto the robotic arm from the S1 segment of the station's truss, then have Hobaugh "drive" him to the shuttle's cargo bay. There Foreman will be working to remove the assembly from its launch position by releasing four launch restraints, loosening two bolts and removing two caps from the antenna's connections. He'll then help Satcher lift it out of the cargo bay to begin the journey to the station's truss.

Before meeting Satcher at the Z1 truss, Foreman will retrieve a bundle of cables for another of the station's antennas and two ingress aids from a toolbox in the cargo bay. He'll install one of the ingress aids on a workstation interface at the airlock and stow the other inside the starboard crew and equipment translation aid – or CETA – cart. Then he will continue the installation of the antenna assembly by connecting its two cables to the Z1 truss segment and driving two bolts.

The two spacewalkers will split up for the rest of the spacewalk. Foreman will install a set of cables for the station's future space-to-ground antenna and secure its path along the Destiny laboratory with wire ties. He'll also remove a handrail on the Unity node and replace it with a bracket that will be used to route an ammonia cable required for the coming Tranquility Node. Removing the handrail will require Foreman to unscrew two bolts, and he'll drive two bolts to secure the new bracket.

Foreman's final tasks on the spacewalk will be repositioning a cable connector on the Unity node by wire-tying it into place and, at the same location, removing adjustable equipment tethers from an micrometeoroid orbital debris shield and securing it with wire ties. He also will be troubleshooting the connection of a cable on an S0 panel. The previous flight, STS-128, had difficulty connecting this cable, which is needed for the activation of the Tranquility Node. Foreman will troubleshoot the connector and use an adaptor to mate the cable to the backside of the S0 panel.

Meanwhile, Satcher will work with two of the station's robotics tools. He'll start at the mobile base system that allows the robotic arm to move along the truss system. The base, which is similar to a railroad cart for the robotic arm, includes a tool used to attach equipment and spares to the base that is similar to the robotic arm's latching end effector. Like the latching end effector, the wires that allow the tool to grip the equipment and spares needs to be lubricated. Satcher will use a modified grease gun to add lubrication to those wires and the bearings they're attached to. He'll then do the same to the latching end effector of the Japanese robotic arm. The end effectors of the shuttle's larger robotic arm, which Satcher will be riding, were lubricated in spacewalks earlier this year.

EVA-2

Duration: 6 hours, 30 minuts
EVA Crew: Foreman and Bresnik
IV Crew: Satcher
Robotic Arm Operators: None

EVA Operations

- **Install Grappling Adaptor To On-Orbit Railing (GATOR) assembly**
- **Relocate floating potential measurement unit**
- **Set up S3 nadir/outboard cargo attachment system**
- **Install wireless video system external transceiver assembly**

Foreman and Bresnik will spend the entire second spacewalk working together. They'll start by installing a GATOR assembly on the Columbus module. GATOR is part of a project to demonstrate two different types of Automatic Identification System receivers, which is an existing system that's currently used by ships and United States Coast Guard's Vessel Traffic Services to exchange data such as identification of the ships, their purpose, course and speed. The assembly also includes an antenna used for HAM radio.

The GATOR assembly includes two antennas, a cable harness and two clamps. To install it, Foreman and Bresnik will retrieve the assembly from a tool box in the shuttle's cargo bay and carry it to Columbus. Foreman will connect the assembly to its power source and wire tie its cables into place, while Bresnik extends the antennas and then installs them on the appropriate handrails. The antennas will be secured with two bolts apiece.

The next tasks on the spacewalkers' agenda will be the relocation of the station's floating potential measurement unit, a tool that measures the affect the station's solar arrays have on arcing hazards and verifies that the controls that prevent arcing hazards are working. The hardware is being moved from the innermost starboard truss segment to the innermost port segment. Three connections will have to be disconnected from the S1 truss segment and reconnected to the P1, and one bolt will hold the hardware in place.

Foreman and Bresnik will then move to the S3 segment of the truss, where they'll be setting up the first of two cargo attachment systems the spacewalkers are scheduled to work on during the mission.

This task was originally scheduled to be completed on previous missions, but for various reasons was delayed. The STS-127 spacewalkers completed the deployment of a similar cargo attachment system on the P3 truss segment, but had to leave the set up two S3 systems for this mission. And on STS-119 a jammed detent pin on the first of the systems prevented them from doing deploying the P3system. A special tool was built to assist with the deployment. The STS-127 spacewalkers were successful in clearing the jam. Foreman and Bresnik will have the same tool on hand for use, if needed; however, the STS-128 spacewalkers were able to deploy a similar cargo attachment system without any issues.

The system, which will allow future missions to store spare parts, like those that Atlantis delivered to the station during this mission, on the station's truss segment for future use. To set it up, the spacewalkers will first remove two truss braces blocking access to the system. That will allow them to swing the system out, replace the braces, and attach the system to the outside of the truss.

In the final task of the spacewalk, Foreman and Bresnik will be installing a wireless video system external transceiver assembly, or WETA, on the same segment. WETAs support the transmission of video from spacewalkers' helmet cameras. To do so, Foreman will remove a dummy box currently in the location, and then attach the WETA to a stanchion. Bresnik will connect three cables to the assembly.

EVA-3

Duration: 6 hours, 30 minuts
EVA Crew: Satcher and Bresnik
IV Crew: Foreman
Robotic Arm Operators: Melvin and Wilmore

EVA Operations

- **Transfer high pressure gas tank**
- **Install Materials International Space Station Experiment 7**
- **Set up S3 zenith/inboard cargo attachment system**

The final spacewalk of the STS-129 mission will start with a task that will make future spacewalks possible.

Satcher will begin by moving the high pressure gas tank delivered by space shuttle Atlantis, from the external logistics carrier that it arrived on to the Quest airlock, where it will someday be used to pressurize and depressurize the airlock for spacewalks and to supplement the space station's atmosphere if needed. He'll prepare the airlock for its arrival by closing a valve on one of its current high pressure gas tanks, and then move to the logistics carrier on the S3 segment of the truss to pick up the new tank. He'll unlock the two handles holding it in place to remove it and, with the help of Bresnik, hand it off to the station's robotic arm to carry it to the airlock.

While it's on the move, Satcher will make his way back to the airlock to remove two micrometeoroid orbital debris shields and store them out of the way. When the tank arrives at the airlock, both Satcher and Bresnik will climb into foot restraints to be able to take the tank back from the robotic arm. Then the two will move it into place, and Bresnik will rotate the handles into their locked position. While Satcher puts away his foot restraint, Bresnik will finish installing the tank by removing some insulation and connect its gas line to the airlock. He'll open the tank's valve to check its connection but close it again before he leaves the site in order to perform a leak check of the tank.

When Bresnik is not doing his part with the high pressure gas tank relocation, he'll be installing the seventh Materials International Space Station Experiment, or MISSE 7. He'll retrieve it from the shuttle's cargo bay at the beginning of the spacewalk and carry it with him to the express logistics carrier, so that he can assist with the retrieval of the high pressure gas tank. Then, while Satcher and the tank are making their way to the airlock, Bresnik will stay behind and install the experiment on the logistics carrier by connecting two cables. He'll also deploy the experiment by opening the two canisters its contained in.

The final task of the STS-129 spacewalks will be to deploy another cargo attachment system on the S3 truss segment, this time on the zenith, inboard side of the segment. The steps involved will be very similar to those of the cargo attachment system set up on the second spacewalk.

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STS-129: Quick-Look Mission Data

Position/Age	Astronaut/Flights	Family/TIS	DOB/Seat
Commander	USMC Col. Charles Hobaugh	M/4	11/05/61
48	2: STS-104,118	25.5 *	Up-1/Dn-1
Pilot	Navy Capt. Barry "Butch" Wilmore	M/0	12/29/62
46	0: Rookie	0.0	Up-2/Dn-2
MS1	Leland Melvin	S/0	02/15/64
45	1:STS-122	12.8	Up-3/Dn-4
MS2/EV3	USMC Lt. Col. Randolph Bresnik	M/1	09/11/67
42	0: Rookie	0.0	Up-4/Dn-3
MS3/EV1	Michael J. Foreman	M/3	03/29/57
52	1: STS-123	15.8	Up-5/Dn-5
MS4/EV2	Robert Satcher, Ph.D., M.D.	M/2	09/22/65
44	0: Rookie	0.0	Up-6/Dn-6
MS5 (down)	Nicole Stott	M/1	11/19/62
47	1: STS-128/ISS-20	72.4	Dn-7
ISS 20 CDR	Gennady Padalka, CIS	M/3	06/21/58
51	3: Mir E26, ISS-9,ISS-19/20	613.0	N/A
ISS-20 FE	Michael Barratt, M.D., NASA	M/5	04/16/59
50	1: ISS-19/20	228.0	N/A
ISS 20 FE	Nicole Stott	M/1	11/19/62
47	1: STS-128/ISS-20	72.4	Up-7
ISS-20 FE	Maj. Roman Romanenko, CIS	M/1	08/09/71
38	1: ISS-20	166.1	N/A
ISS-20 FE	Frank De Winne, ESA	M/3	04/25/61
48	2: Soyuz TMA-1,ISS-20	175.1	N/A
ISS-20 FE	Robert Thirsk, M.D., CSA	M/?	08/17/53
56	2: STS-78,ISS-20	183.1	N/A

Shuttle Hardware and Flight Data	
STS Mission	STS-129 (flight 129)
Orbiter	Atlantis (31st flight)
Payload	ELC-1, ELC-2
Launch	03:28:04 PM 11.16.09
Pad/MLP	LC-39A/MLP-3
Prime TAL	Zaragoza, Spain
Landing	09:47:04 AM 11.27.09
Landing Site	Kennedy Space Center
Duration	11+1+2
Atlantis	271/04:44:15
STS Program	1237/23:07:38
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	4,479,519
EOM Orbits	170
SSMEs	2048 / 2044 / 2058
ET/SRB	ET-133/Bi140/RSRM 108
Software	OI-34
Left OMS	LP04/31/F5
Right OMS	RP01/38/F5
Forward RCS	FRC4/31/F5
OBSS/RMS	TBD/301
Cryo/GN2	5 PRSD/5 GN2
Spacesuits	3

International Space Station

STS-129 Mission Patch

Flight Plan	EST
Docking	
11/18/09	11:56 AM
EVA-1	
11/19/09	09:18 AM
EVA-2	
11/21/09	08:18 AM
EVA-3	
11/23/09	07:18 AM
Undocking	
11/25/09	04:13 AM
Landing	
11/27/09	09:47 AM

Flight Control Personnel	
Bryan Lunney	Ascent
Mike Sarafin	Orbit 1 FD (lead)
Gary Horlacher	Orbit 2 FD
Paul Dye	Planning
Bryan Lunney	Entry
Emily Nelson	ISS Orbit 1 FD
Brian Smith	ISS Orbit 2 FD (lead)
Jerry Jason	ISS Orbit 3 FD
Mike Leinbach	Launch director
Steve Payne	NTD
Mike Moses	MMT
George Diller	Countdown PAO
Rob Navias	Ascent PAO

This will be the...	
129th	Shuttle mission
16th	Post-Columbia mission
104th	Post-Challenger mission
31st	Flight of Atlantis
96th	Day launch
76th	Launch off pad 39A
56th	Day launch off pad 39A
TBD	51.6-degree inclination
105th	Day landing
72nd	KSC landing
56th	KSC day landing
23.82	Years since STS-51L
6.80	Years since STS-107

* Ages as of launch date *Days in space as of: 11/9/09

Compiled by William Harwood

STS-129: 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	271/04:44:15	30	STS-125: 5/11/09
Endeavour	266/15:33:20	23	STS-127: 07/15/09
Total	**1237/23:07:38**	**128**	* Vehicle lost

Launches	LC-39A	LC-39B	Total	
Night	20	13	33	Daylight:
Daylight	55	40	95	SR+3 mins
Total	75	53	128	to
Most Recent	8/28/09	12/9/06		SS-3 mins

Landings	KSC	EAFB	WSSH	Total
Night	16	6	0	22
Daylight	55	48	1	104
Total	71	54	1	126
Most Recent	7/31/09	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	05/27/09	TBD	TBD	6

Demographics	TMA16	129
Total Fliers	507	510
Nations	36	36
Male	455	458
Female	52	52
Total Tickets	1,112	1,118
United States	327	330
United States men	284	287
United States Women	43	43
USSR	72	72
USSR Men	70	70
USSR Women	2	2
CIS	33	33
CIS Men	32	32
CIS Women	1	1
Non US/Russian	75	75
Men	69	69
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	59	59
Women/4	6	6
Men/3	70	71
Women/3	6	6
All/2	132	133
All/1	205	206

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-129 NASA Crew Thumbnails

Position/Age	Astronaut/Flights/Education	Fam/TS	DOB/Seat	Home/BKG	Hobbies/notes
Commander Age: 48	USMC Col. Charles Hobaugh 2: STS-104,118 Bachelor's in aerospace engineering	M/4 25.5 *	11/05/61 Up-1/Dn-1	Bar Harbor, ME Gulf War/test plt >5,000 hours	Weight lifting, volleyball, boating, water skiing, snow skiing, soccor, biking
Pilot 46	Navy Capt. Barry "Butch" Wilmore 0: Rookie Bachelor's in electrical engineering	M/0 0.0	12/29/62 Up-2/Dn-2	Mt. Juliet, TN Gulf War/test plt >5,900 hours	None listed 663 carrier landings
MS1 45	Leland Melvin 1:STS-122 Master's in materials science	S/0 12.8	02/15/64 Up-3/Dn-4	Lynchburg, VA NFL draftee Researcher	Photography, piano, tennis, reading, music, cycling, snow boarding
MS2/EV3 42	USMC Lt. Col. Randolph Bresnik 0: Rookie Master's, aviation systems	M/1 0.0	09/11/67 Up-4/Dn-3	Fort Knox, KY Topgun/test plt >4,500 hours	Travel, music, scuba, photography, weight lifting, motorcycles
MS3/EV1 52	Michael J. Foreman 1: STS-123 Master's in aeronautical engineering	M/3 15.8	03/29/57 Up-5/Dn-5	Wadsworth, OH Test pilot >5,000 hours	Golf, running, skiing, home repair/improvement, spending time with family
MS4/EV2 44	Robert Satcher, Ph.D., M.D. 0: Rookie M.D., Ph.D. in chemical engineering	M/2 0.0	09/22/65 Up-6/Dn-6	Hampton, VA Oncologist Orthopaedic surg.	Running, scuba diving, reading
MS5 (down) 47	Nicole Stott 1: STS-128/ISS-20 Master's in engineering management	M/1 72.4	11/19/62 Dn-7	Clearwater, Fla. Shuttle engineer Private pilot	Flying, snow skiing, scuba diving, woodworking, painting, gardening
ISS 20 CDR 51	Gennady Padalka, CIS 3: Mir E26, ISS-9,ISS-19/20 Engineering/ecology	M/3 613.0	06/21/58 N/A	Krasnodar, Russia AF pilot >1500 hours	Theater, sky diving >300 parachute jumps
ISS-20 FE 50	Michael Barratt, M.D., NASA 1: ISS-19/20 MD in aerospace medicine	M/5 228.0	04/16/59 N/A	Camas, Wash. NASA surgeon, Mir support	Family and church activity, writing, sailing, boat restoration and maintenance
ISS 20 FE 47	Nicole Stott 1: STS-128/ISS-20 Master's in engineering management	M/1 72.4	11/19/62 Up-7	Clearwater, Fla. Shuttle engineer Private pilot	Flying, snow skiing, scuba diving, woodworking, painting, gardening
ISS-20 FE	Maj. Roman Romanenko, CIS 1: ISS-20 Russian Air Force pilot school	M/1 166.1	08/09/71 N/A	Schelkovo, Russia Tu-134 pilot >500 hours	Underwater hunting, tennis, auto repair, tourism, yachting, volllyball, music
ISS-20 FE	Frank De Winne, ESA 2: Soyuz TMA-1,ISS-20 Master's, civil engineering	M/3 175.1	04/25/61 N/A	Ghent, Belgium Mirage pilot >2,300 hours	Football, small PC program, gastronomy
ISS-20 FE	Robert Thirsk, M.D., CSA 2: STS-78,ISS-20	M/? 183.1	08/17/53 N/A	New Westminster, B.C.; family doctor CSA astronaut	None listed

Current Space Demographics (post Soyuz TMA-16)

Post Soyuz TMA-16	
Total Fliers	**507**
Nations	36
Men	455
Women	52
Total Tickets	1112
United States	**327**
US Men	284
US Women	43
Soviet Union	**72**
USSR Men	70
USSR Women	2
CIS	**33**
CIS Men	32
CIS Women	1
Others	**75**
Other Men	69
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	59
Women with 4 flights	6
Men with 3 flights	70
Women with 3 flights	6
All with 2 flights	132
All with 1 flight	205
TOTAL	**507**
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	Britain	1
6	Bulgaria	2
7	Canada	9
8	China	6
9	CIS	33
10	Cuba	1
11	Czech.	1
12	E. Germany	1
13	France	9
14	Germany	9
15	Hungary	1
16	India	1
17	Israel	1
18	Italy	5
19	Japan	7
20	Malaysia	1
21	Mexico	1
22	Mongolia	1
23	Netherlands	2
24	N. Vietnam	1
25	Poland	1
26	Romania	1
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	USA	327
36	USSR	72
	TOTAL	**507**

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 STS-129)

Post STS-129	
Total Fliers	510
Nations	36
Men	458
Women	52
Total Tickets	1118
United States	330
US Men	287
US Women	43
Soviet Union	72
USSR Men	70
USSR Women	2
CIS	33
CIS Men	32
CIS Women	1
Others	75
Other Men	69
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	59
Women with 4 flights	6
Men with 3 flights	71
Women with 3 flights	6
All with 2 flights	133
All with 1 flight	206
TOTAL	510
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	Britain	1
6	Bulgaria	2
7	Canada	9
8	China	6
9	CIS	33
10	Cuba	1
11	Czech.	1
12	E. Germany	1
13	France	9
14	Germany	9
15	Hungary	1
16	India	1
17	Israel	1
18	Italy	5
19	Japan	7
20	Malaysia	1
21	Mexico	1
22	Mongolia	1
23	Netherlands	2
24	N. Vietnam	1
25	Poland	1
26	Romania	1
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	USA	330
36	USSR	72
	TOTAL	510

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-129/ISS-20 NASA Crew Biographies

1. Commander: USMC Col. Charles Hobaugh, 48

PERSONAL DATA: Born November 5, 1961 in Bar Harbor, Maine. Married to the former Corinna Lynn Leaman of East Petersburg, Pennsylvania. They have four children. He enjoys weight lifting, volleyball, boating, water skiing, snow skiing, soccer, bicycling, running and rowing. His parents, Jimmie and Virginia Hobaugh, reside in Sault Ste. Marie, Michigan. Her parents, Jerry and Dottie Leaman, reside in East Petersburg, Pennsylvania.

EDUCATION: Graduated from North Ridgeville High School, North Ridgeville Ohio, in 1980; received a Bachelor of Science degree Aerospace Engineering from the U.S. Naval Academy in 1984.

ORGANIZATIONS: U.S. Naval Academy Alumni Association.

SPECIAL HONORS: Distinguished Graduate U.S. Naval Academy, Joe Foss Award for Advanced Jet Training, Graduated with Distinction U.S. Naval Test Pilot School. Awarded the Strike/Flight Air Medal, Navy and Marine Corps Achievement Medal, Combat Action Ribbon, Navy Unit Commendation, and various other service awards.

EXPERIENCE: Hobaugh received his commission as a Second Lieutenant in the United States Marine Corps from the United States Naval Academy in May 1984. He graduated from the Marine Corps Basic School in December 1984. After a six month temporary assignment at the Naval Air Systems Command, he reported to Naval Aviation Training Command and was designated a Naval Aviator in February 1987. He then reported to Marine V/STOL Attack Squadron VMAT-203 for initial AV-8B Harrier Training. Upon completion of this training, he was assigned to Marine Attack Squadron VMA-331 and made overseas deployments to the Western Pacific at MCAS Iwakuni Japan and flew combat missions in the Persian Gulf during Desert Shield/Desert Storm embarked aboard the USS Nassau. While assigned to VMA-331, he attended Marine Aviation Warfare and Tactics Instructor Course and was subsequently assigned as the Squadron Weapons and Tactics Instructor. Hobaugh was selected for U.S. Naval Test Pilot School and began the course in June 1991. After graduation in June 1992, he was assigned to the Strike Aircraft Test Directorate as an AV-8 Project Officer and as the ASTOVL/JAST/JSF Program Officer. While there, he flew the AV-8B, YAV-8B (VSRA) and A-7E. In July 1994, he went back to the Naval Test Pilot School as an Instructor in the Systems Department, where he flew the F-18, T-2, U-6A and gliders. Hobaugh was assigned to the U.S. Naval Test Pilot School when he was selected for the astronaut program.

He has logged over 5,000 flight hours in more than 40 different aircraft and has over 200 V/STOL shipboard landings.

NASA EXPERIENCE: Selected by NASA in April 1996, Hobaugh reported to the Johnson Space Center in August 1996. He completed two years of training and evaluation, and was qualified for flight assignment as a pilot. Hobaugh was initially assigned technical duties in the Astronaut Office Spacecraft Systems/Operations Branch. Projects included Landing and Rollout, evaluator in the Shuttle Avionics Integration Laboratory, Advanced Projects, Multifunction Electronics Display Enhancements, Advanced Cockpit and Cockpit Upgrade, Rendezvous and Close Proximity Operations and Visiting Vehicles prior to his first flight assignment. He also served as Capsule Communicator, working in the Mission Control Center as the voice to the crew. A veteran of two space flights, Hobaugh has logged over 612 hours in space. He was the pilot on STS-104 in 2001 and STS-118 in 2007. Hobaugh is assigned to command the crew of the STS-129 mission, targeted for launch in November 2009. The mission and will deliver two Express Logistics Carriers (ELC racks) to the International Space Station. The mission will also feature three spacewalks and will bring back to earth NASA Astronaut, Nicole Stott.

SPACE FLIGHT EXPERIENCE: STS-104 (July 12-24, 2001) was the 10th mission to the International Space Station (ISS). During the 13-day flight the crew conducted joint operations with the Expedition-2 crew and performed three spacewalks to install the joint airlock "Quest" and to outfit it with four high-pressure gas tanks. The mission was accomplished in 200 Earth orbits, traveling 5.3 million miles in 306 hours and 35 minutes. STS-118 (August 7-21, 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. A new system that enables docked shuttles to draw electrical power from the station to extend visits to the outpost was activated successfully. A total of four spacewalks (EVAs) were performed by three crew members. Endeavour carried some 5,000 pounds of equipment and supplies to the station and returned to Earth with some 4,000 pounds of hardware and no longer needed equipment. Traveling 5.3 million miles in space, the STS-118 mission was completed in 12 days, 17 hours, 55 minutes and 34 seconds.

JUNE 2009

2. Pilot: Navy Capt. Barry "Butch" Wilmore, 46

PERSONAL DATA: He is married to the former Miss Deanna Newport of Helenwood, Tennessee and he was raised in Mt. Juliet, Tennessee where his parents Eugene and Faye Wilmore still reside. His brother Jack and family reside in Franklin, Tennessee.

EDUCATION: M.S. Electrical Engineering, Tennessee Technological University (TTU). M.S. Aviation Systems, University of Tennessee. B.S. Electrical Engineering, TTU. Mt. Juliet High School, Mt. Juliet, TN.

SPECIAL HONORS: Air Medal (5), 3 with the Combat 'V' designation. Navy Commendation Medal (6), 3 of which also hold the Combat 'V' designation. Navy Achievement Medal (2) and numerous Unit decorations. Aviation Officer Candidate School (AOCS) "Distinguished Naval Graduate". Initial Naval Flight Training "Commodores List With Distinction". U.S. Atlantic Fleet "Light Attack Wing One - Pilot Of The Year" (1991). U.S. Atlantic Fleet "Strike Fighter Aviator of the Year" (1999). Recipient of the Strike Fighter Wing Atlantic "Scott Speicher Award" for Weapons Employment Excellence (1998). Tennessee Technological University "Sports Hall of Fame" - 2003 Inductee (Football).

EXPERIENCE: Wilmore has accumulated over 5900 flight hours and 663 carrier landings, all in tactical jet aircraft, and is a graduate of the United States Naval Test Pilot School (USNTPS).

During his tenure as a fleet Naval officer and pilot, Wilmore has completed 4 operational deployments, flying the A-7E and FA-18 aircraft from the decks of the USS Forrestal, USS Kennedy, USS Enterprise and the USS Eisenhower aircraft carriers. He has flown missions in support of Operations Desert Shield, Desert Storm and Southern Watch over the skies of Iraq, as well as missions over Bosnia in support of U. S. and NATO interests. Wilmore successfully completed 21 combat missions during Operation Desert Storm while operating from the flight deck of the USS Kennedy. His most recent operational deployment was aboard the USS Eisenhower with the "Blue Blasters" of Strike Fighter Squadron 34 (VFA-34), an F/A-18 squadron based at Naval Air Station Oceana, Virginia.

As a Navy Test Pilot Wilmore participated in all aspects of the initial development of the T-45 jet trainer to include initial carrier landing certification and high angle of attack flight tests. His test tour also included a stint at USNTPS as a systems and fixed wing "Flight Test" instructor. Prior to his selection to NASA, Wilmore was on exchange to the Air Force as a "Flight Test" instructor at the United States Air Force Test Pilot School at Edwards Air Force Base, California.

NASA EXPERIENCE: Selected as a pilot by NASA in July 2000, Wilmore reported for training in August 2000. Following the completion of two years of training and evaluation, he was assigned technical duties representing the astronaut office on all propulsion systems issues including the space shuttle main engines, solid rocket motor, external tank, and also served on the astronaut support team that traveled to the Kennedy Space Center, Florida, in support of launch and landing operations. Wilmore has been assigned as pilot on the STS-129 crew. The mission is targeted for launch in November 2009, and will deliver two Express Logistics Carriers (ELC racks) to the International Space Station. The mission will also feature three spacewalks and will bring back to earth NASA Astronaut, Nicole Stott..

JUNE 2009

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3. MS-1: Leland Melvin, 45

PERSONAL DATA: Born February 15, 1964 in Lynchburg, Virginia. Unmarried. Recreational interests include photography, piano, reading, music, cycling, tennis, and snowboarding. Loves walking his dogs, Jake and Scout. Chosen by the Detroit Lions in the 11th round of the 1986 NFL college draft. Also participated in the Toronto Argonauts and Dallas Cowboys football training camps. His parents Deems and Grace Melvin, reside in Lynchburg, Virginia.

EDUCATION: Graduated from Heritage High School, Lynchburg, Virginia, in 1982; received a bachelor of science degree in chemistry from the University of Richmond, Richmond, Virginia in 1986; and a master of science degree in materials science engineering from the University of Virginia in 1991.

ORGANIZATIONS: National Technical Association (Hampton Roads Chapter Secretary 1993), American Chemical Society, The Society for Experimental Mechanics.

SPECIAL HONORS/AWARDS: Invention Disclosure Award for Lead Insensitive Fiber Optic Phase Locked Loop Sensor, NASA Outstanding Performance Awards (8), NASA Superior Accomplishment Award (2), Key to the City of Lynchburg, Virginia, NCAA Division I Academic All American, University of Richmond Athletic Hall of Fame Inductee.

EXPERIENCE: Mr. Melvin began working in the Fiber Optic Sensors group of the Nondestructive Evaluation Sciences Branch at NASA Langley Research Center in 1989 where he conducted research in the area of physical measurements for the development of advanced instrumentation for Nondestructive Evaluation (NDE). His responsibilities included using optical fiber sensors to measure strain, temperature, and chemical damage in both composite and metallic structures. Additional projects included developing optical interferometric techniques for quantitative determination of damage in aerospace structures and materials. In 1994, Mr. Melvin was selected to lead the Vehicle Health Monitoring (VHM) team for the cooperative Lockheed/NASA X-33 Reuseable Launch Vehicle (RLV) program. The team developed distributed fiber optic strain, temperature and hydrogen sensors for the reduction of vehicle operational costs and to monitor composite liquid oxygen tank and cryogenic insulation performance. In 1996, Mr. Melvin codesigned and monitored construction of an optical NDE facility capable of producing in-line fiber optic Bragg grating strain sensors at rates in excess of 1000 per hour. This facility will provide a means for performing advanced sensor and laser research for development of aerospace and civil health monitoring systems.

NASA EXPERIENCE: Selected by NASA JSC in June 1998, Mr. Melvin reported for training in August 1998. Astronaut Candidate Training included orientation briefings and tours, numerous scientific and technical briefings, intensive instruction in Shuttle and International Space Station systems, physiological training and ground school to prepare for T-38 flight training, as well as learning water and wilderness survival techniques. Mr. Melvin has served the Astronaut Office Space Station Operations Branch, the Education Department at NASA Headquarters, Washington, D.C, and the Robotics Branch of the Astronaut Office. As co-manager of NASA's Educator Astronaut Program, Leland Melvin traveled across the country, engaging thousands of students and teachers in the excitement of space exploration, and inspiring them to pursue careers in science, technology, engineering and mathematics. Mr. Melvin completed his first space flight on STS-122 in 2008 and has logged over 306 hours in space. Mr. Melvin is assigned as a mission specialist on the STS-129 crew. The mission is targeted for launch in November 2009, and will deliver two Express Logistics Carriers (ELC racks) to the International Space Station. The mission will also feature three spacewalks and will bring back to earth NASA Astronaut, Nicole Stott..

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.

JUNE 2009

4. MS-2/FE/EV-3: USMC Lt. Col. Randolph Bresnik, 42

PERSONAL DATA: Born September 11, 1967 in Fort Knox, Kentucky. Considers Santa Monica, California to be his hometown. Married to the former Rebecca Burgin of Pompton Plains, New Jersey, they have one son. He enjoys travel, music, photography, weight training, sports, scuba diving, motorcycling, and flying warbirds. His father Albert 'Randy' Bresnik resides in Santa Monica, California.

EDUCATION: Graduated from Santa Monica High School, Santa Monica, California, in 1985. B.A. in Mathematics from The Citadel, 1989. M.S. in Aviation Systems, University of Tennessee-Knoxville, 2002.

ORGANIZATIONS: Society of Experimental Test Pilots. Association of Naval Aviation.

AWARDS: Meritorious Service Medal, Strike/Flight Air Medal (3), Navy and Marine Corps Commendation Medal with Combat "V" (3), Navy and Marine Corps Achievement Medal (3), Presidential Unit Citation and various other service awards.

SPECIAL HONORS: Distinguished Graduate: The Citadel NROTC, Officer Candidate School, The Basic School, Navy Flight Training. "Iron Mike" Physical Fitness Award, USMC Officer Basic School. The Outstanding Student Award, U.S. Naval Test Pilot School. Empire Test Pilot School Award, U.S. Naval Test Pilot School. Stephen A. Hazelrigg Memorial Award for Best Test Pilot/Engineer Team, Naval Strike Aircraft Test Squadron. "Best Paper" Award, European Society of Experimental Test Pilots.

EXPERIENCE: Bresnik received his commission as a Second Lieutenant in the United States Marine Corps from the Naval Reserve Officer Training Corps at The Citadel, Charleston, South Carolina, in May 1989. After graduation he attended The Basic School (TBS) and Infantry Officers Course (IOC) in Quantico, Virginia. Following Aviation Indoctrination and Primary flight training in Pensacola, Florida, he entered Intermediate and Advanced flight training in Beeville, Texas, and was designated a Naval Aviator in 1992. He then reported to the Navy Fighter/Attack Training Squadron VFA-106, NAS Cecil Field, Florida, for initial F/A-18 training. Upon completion of training he reported to Marine Fighter/Attack Squadron, VMFA-212 at MCAS Kaneohe Bay, Hawaii, then MCAS El Toro, California, and additionally MCAS Miramar, California, where he made three overseas deployments to the Western Pacific. While assigned to VMFA-212, he attended the Marine Corps Weapons and Tactics Instructors Course (WTI) and Naval Fighter Weapons School (TOPGUN). Bresnik was selected for U.S. Naval Test Pilot School (USNTPS) at NAS Patuxent River, Maryland, and began the course in January 1999. After graduation in December 1999, he was assigned as a F/A-18 Test Pilot/Project Officer at the Naval Strike Aircraft Test Squadron (NSATS). While at Strike, Bresnik flew the F/A-18 A-D and F/A-18 E/F in all manners of flight test. In January 2001, he returned to the USNTPS as a Fixed-Wing and Systems Flight Instructor, where he instructed in the F/A-18, T-38, and T-2. Bresnik returned to NSATS in January 2002 to continue flight test on the F/A-18 A-F as the Platform/Project Coordinator. In November 2002, he reported to Marine Aircraft Group Eleven (MAG-11) as the Future Operations Officer. In January 2003 MAG-11 deployed to Ahmed Al Jaber Air Base, Kuwait. From Al Jaber he flew combat missions in the F/A-18 with VMFA-225 in support of Operation Southern Watch and Operation Iraqi Freedom. Bresnik was the Operations Officer of VMFA-232 when he was selected for the astronaut program.

He has logged over 4,500 hours in 79 types of aircraft. He holds an Airline Transport Pilot Rating and an Unlimited Piston Engine Letter of Authorization.

NASA EXPERIENCE: Selected by NASA in May 2004. 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. Bresnik is assigned as a mission specialist on the STS-129 crew. The mission is targeted for launch in November 2009, and will deliver two Express Logistics Carriers (ELC racks) to the International Space Station. The mission will also feature three spacewalks and will bring back to earth NASA Astronaut, Nicole Stott..

JUNE 2009

5. MS-3/EV-1: Michael Foreman, 52

PERSONAL DATA: Born March 29, 1957 in Columbus, Ohio. His hometown is Wadsworth, Ohio. Married to the former Lorrie Dancer of Oklahoma City, Oklahoma. They have three children. Recreational interests include golf, running, skiing, home repair/improvement and spending time with his family. His mother, Nancy C. Foreman, resides in Wadsworth, Ohio. His father, James W. Foreman, is deceased. Her parents, Jim and Pat Dancer, reside in Tulsa, Oklahoma.

EDUCATION: Graduated from Wadsworth High School, Wadsworth, Ohio in 1975; received a bachelor of science degree in aerospace engineering from the U.S. Naval Academy in 1979 and a master of science degree in aeronautical engineering from the U.S. Naval Postgraduate School in 1986.

ORGANIZATIONS: Association of Naval Aviation, United States Naval Academy Alumni Association.

AWARDS: Legion of Merit, Defense Meritorious Service Medal, Meritorious Service Medal, Navy Commendation Medal, Navy Achievement Medal and various other service awards.

SPECIAL HONORS: Graduated with Distinction, U.S. Naval Postgraduate School; Admiral William Adger Moffett Aeronautics Award, U.S. Naval Postgraduate School; Distinguished Graduate, U.S. Naval Test Pilot School; Empire Test Pilots School-sponsored award for best final report (DT-IIA), U.S. Naval Test Pilot School.

EXPERIENCE: Foreman was designated a Naval Aviator in January 1981 and assigned to Patrol Squadron Twenty-Three at NAS Brunswick, Maine. He made deployments to Rota, Spain; Lajes, Azores; Bermuda and Panama. Following this tour he attended the U.S. Naval Postgraduate School in Monterey, California where he earned a Master of Science degree in Aeronautical Engineering in 1986. As a graduate student, Foreman conducted thesis research at the NASA Ames Research Center in Mountainview, California. Following graduation he was assigned as the Assistant Air Operations Officer in USS CORAL SEA (CV-43) homeported in Norfolk, Virginia. In addition to his Air Operations duties, he flew as an E-2 pilot with VAW-120 and VAW-127. Upon selection to the U.S. Naval Test Pilot School (USNTPS) in 1989 he moved to NAS Patuxent River, Maryland. He graduated from USNTPS in June 1990 and was assigned to the Force Warfare Aircraft Test Directorate. In 1991 he was reassigned as a flight instructor and the Operations Officer at USNTPS. During his tenure there he instructed in the F-18, P-3, T-2, T-38, U-21, U-6 and X-26 glider. In 1993, Foreman was assigned to the Naval Air Systems Command in Crystal City, Virginia, first as the deputy, and then as the Class Desk (Chief Engineer) Officer for the T-45 Goshawk aircraft program. Following that tour he returned to NAS Patuxent River, this time as the Military Director for the Research and Engineering Group of the Naval Air Warfare Center Aircraft Division. In addition to his duties at Patuxent River, he was assigned as the Navy liaison to NASA's Advanced Orbiter Cockpit Project at the Johnson Space Center. Foreman was working as the technical lead for the Advanced Orbiter Cockpit Project team when he was selected for the astronaut program. Foreman retired from the Navy in June 2009.

He has logged over 5,000 hours in more than 50 different aircraft.

NASA EXPERIENCE: Selected by NASA in June 1998, he reported for training in August 1998. Astronaut Candidate Training included orientation briefings and tours, numerous scientific and technical briefings, intensive instruction in Shuttle and International Space Station systems, physiological training and ground school to prepare for T-38 flight training, as well as learning water and wilderness survival techniques. He was initially assigned technical duties in the Astronaut Office Space Station Branch where he represented the Astronaut Office on training issues. He was then assigned to the Space Shuttle Branch as a liaison between the Johnson Space Center and the Kennedy Space Center, and also served as the Deputy, Space Shuttle Branch. Foreman flew on STS-123 in March 2008 and has logged over

378 hours in space, including 19 hours and 35 minutes of EVA hours in three spacewalks. Foreman is assigned as a mission specialist on the STS-129 crew. The mission is targeted for launch in November 2009, and will deliver two Express Logistics Carriers (ELC racks) to the International Space Station. The mission will also feature three spacewalks and will bring back to earth NASA Astronaut, Nicole Stott.

SPACE FLIGHT EXPERIENCE: STS-123 Endeavour (March 11-26, 2008) was a night launch and landing. It was the 25th Shuttle/Station assembly mission. Endeavour's crew delivered the Japanese Experiment Logistics Module – Pressurized Section, the first pressurized component of JAXA's Kibo Laboratory, and the final element of the station's Mobile Servicing System, the Canadian-built Dextre, also known as the Special Purpose Dextrous Manipulator. While on the station Foreman performed three spacewalks. The STS-123 crew also delivered Expedition 16 Flight Engineer Garrett Reisman, and returned to Earth with ESA's Léopold Eyharts. The mission was accomplished in 250 orbits of the Earth, traveling over 6.5 million miles in 15 days, 18 hours, 10 minutes and 54 seconds.

JULY 2009

6. MS-4/EV-2: Robert Satcher, Ph.D., M.D., 44

PERSONAL DATA: Born September 22, 1965, in Hampton, Virginia. Married to the former D'Juanna O. White, MPH, MD of New York, New York. They have two children. He enjoys running, scuba diving, and reading. His parents, Robert and Marian, reside in Lawerenceville, Virginia. Her parents, Edward and Geraldine, reside in New York, New York.

EDUCATION: Graduated from Denmark-Olar High School, Denmark, South Carolina in 1982; received a bachelor of science degree in chemical engineering from Massachusetts Institute of Technology in 1986; a doctor of philosophy in chemical engineering from MIT in 1993; a doctorate of medicine degree from Harvard Medical School in 1994; completed internship and residency in orthopaedic surgery at University of California, San Francisco in 2000; postdoctoral research fellowships at MIT in 1994 and University of California, Berkeley in 1998; and completed a fellowhip in musculoskeletal oncology at the University of Florida in 2001.

PROFESSIONAL QUALIFICATIONS: American Board of Orthopaedic Surgery; Illinois Medical License; Texas Medical License, Medical Board of California: Physicians and Surgeon's Certificate; National Board of Medical Examiners; DEA Authorization; Medical Board of California: Physician Assistant Supervisor; California Fluoroscopy X-Ray Supervisor and Operator; ATLS and CPR Certifications; Professional Association of Divers International (SCUBA).

ORGANIZATIONS: American Academy of Orthopaedic Surgeons, Musculoskeletal Tumor Society, American Academy of Cancer Research, Connective Tissue Oncology Society, National Medical Association, Society of Black Academic Surgeons, Doctors United in Medical Missions, National Comprehensive Cancer Network, Orthopaedic Research Society, MIT Alumni Association, Black Alumni at MIT, Harvard Alumni Association.

SPECIAL HONORS: Leadership Fellow of American Academy of Orthopaedic Surgeons, ABC Fellow of American Orthopaedic Association, UNCF/Merck Research Fellow, Robert Wood Johnson Foundation Fellow, Bloomberg Leadership Fellow, Johns Hopkins University, Tau Beta Pi Engineering Honor Society.

Dr. Satcher completed 12 Research Grants from 1991-2004. He has 15 Peer-reviewed publications, and over 25 presentations at National and International Research Meetings

NON-MEDICAL ACTIVITIES & INTERESTS: Dr. Satcher has been active in numerous community organizations including Big Brother for Youth at Risk Counseling Program, Department of Corrections, San Francisco, California; Tutor for Black Student's Union Tutorial Program, MIT; National Society of Black Engineers; American Institute of Chemical Engineering; Supervising Adult for Cub Scout Camp for Boys, Nashville, Tennessee; Open Airways Tutor (asthma awareness); Proctor for Freshman Dormitory at Harvard University, Cambridge, Massachusetts; Lay Episcopal Minister (primary responsibility is visiting sick and shut in members of church) at St. Edmund's Episcopal Church, Chicago, Illinois and at St. James Episcopal Church in Houston, Texas.

EXPERIENCE: Most recently an Assistant Professor at The Feinberg School of Medicine, Northwestern University, in the Department of Orthopaedic Surgery. Dr. Satcher also held an appointment as an Attending Physician in Orthopaedic Surgery at Children's Memorial Hospital in Chicago, Illinois, specializing in Musculoskeletal Oncology; and an Adjunct Appointment in The Biomedical Engineering Department at Northeastern University School of Engineering. Dr. Satcher was also a member of the Robert H. Lurie Comprehensive Cancer Center and the Institute for Bioengineering and Nanotechnology in Advanced Medicine at Northwestern University. Prior to this, he completed clinical fellowships in Musculoskeletal Oncology at the University of Florida; and as Schweitzer Fellow at the Albert Schweitzer Hospital, Lambarene, Gabon. Dr. Satcher also completed numerous medical missions for outreach care to underserved areas in Nicaragua, Venezuala, Nigeria, Burkina Faso, and Gabon. Prior experience in engineering includes internships at E.I. DuPont deNemours & Company, Inc., Wilmington, Delaware, in the Textile Fibers Research Group, and the Polymer Products Division.

NASA EXPERIENCE: Selected by NASA in May 2004. 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. Satcher is assigned as a mission specialist on the STS-129 crew. The mission is targeted for launch in November 2009, and will deliver two Express Logistics Carriers (ELC racks) to the International Space Station. The mission will also feature three spacewalks and will bring back to earth NASA Astronaut, Nicole Stott..

JUNE 2009

7. MS5/EV-3/ISS-20 FE: Nicole Stott, 46 (landing only)

PERSONAL DATA: Born in Albany, New York. Her hometown is Clearwater, Florida. She enjoys flying, snow skiing, SCUBA diving, woodworking, painting, and gardening.

EDUCATION: Clearwater High School, Clearwater, Florida, 1980. B.S., Aeronautical Engineering, Embry-Riddle Aeronautical University, 1987. M.S., Engineering Management, University of Central Florida, 1992.

SPECIAL HONORS: Aircraft Operations Division, Newt Myers Team Spirit Award, KSC Public Affairs Certificate of Appreciation for Service; NASA Exceptional Achievement Medal; NASA Certificates of Commendation; NASA Performance Awards; NASA On-the-Spot Award; Lockheed Certificate of Appreciation.

EXPERIENCE: Ms. Stott began her career in 1987 as a structural design engineer with Pratt and Whitney Government Engines in West Palm Beach, Florida. She spent a year with the Advanced Engines Group performing structural analyses of advanced jet engine component designs. She is an instrument rated private pilot.

NASA EXPERIENCE: In 1988, Ms. Stott joined NASA at the Kennedy Space Center (KSC), Florida as an Operations Engineer in the Orbiter Processing Facility (OPF). After 6 months, she was detailed to the Director of Shuttle Processing as part of a two-person team tasked with assessing the overall efficiency of Shuttle processing flows, and implementing tools for measuring the effectiveness of improvements. She was the NASA KSC Lead for a joint Ames/KSC software project to develop intelligent scheduling tools. The Ground Processing Scheduling System (GPSS) was developed as the technology demonstrator for this project. GPSS was a success at KSC, and also a commercial success that is part of the PeopleSoft suite of software products. During her time at KSC, Ms. Stott also held a variety of positions within NASA Shuttle Processing, including Vehicle Operations Engineer; NASA Convoy Commander; Shuttle Flow Director for Endeavour; and Orbiter Project Engineer for Columbia. During her last two years at KSC, she was a member of the Space Station Hardware Integration Office and relocated to Huntington Beach, CA where she served as the NASA Project Lead for the ISS truss elements under construction at the Boeing Space Station facility. In 1998, she joined the Johnson Space Center (JSC) team in Houston, TX as a member of the NASA Aircraft Operations Division, where she served as a Flight Simulation Engineer (FSE) on the Shuttle Training Aircraft (STA).

Selected as a mission specialist by NASA in July 2000, Nicole reported for astronaut candidate training in August 2000. Following the completion of two years of training and evaluation, she was assigned technical duties in the Astronaut Office Station Operations Branch, where she performed crew evaluations of station payloads. She also worked as a support astronaut for the Expedition 10 crew and as an ISS CAPCOM. In April 2006 she was a crew member on the NEEMO 9 mission (NASA Extreme Environment Mission Operations) where she lived and worked with a 6 person crew for 18 days on the Aquarius undersea research habitat. Nicole is currently assigned to a long duration space flight as a member of the ISS Expeditions 20 and 21 crews. She is scheduled to launch to the International Space Station with the crew of STS-129 and return with the crew of STS-129.

MARCH 2009

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1. ISS-20 CDR: Frank De Winne, 48

PERSONAL DATA: Born in Ghent, Belgium, 25 April 1961. He is married and has three children. Enjoys football, small PC applications and gastronomy .

EDUCATION: Frank De Winne graduated from the Royal School of Cadets, Lier, in 1979. He received a Masters degree in telecommunications and civil engineering from the Royal Military Academy, Brussels, in 1984. He was awarded the AIA Prize for the best thesis. In 1991, he completed the Staff Course at the Defence College in Brussels gaining the highest distinction. In 1992, he graduated from the Empire Test Pilots School (ETPS) in Boscombe Down, England, where he was awarded the McKenna Trophy.

ORGANIZATIONS: Chairman of the Belgian Armed Forces Flying Personnel Association.

SPECIAL HONORS: First non-American pilot to receive the Joe Bill Dryden Semper Viper Award, in 1997, for demonstrating exceptional skills during a flight. Appointed "Officier in de Orde van Oranje Nassau" by the Dutch Queen for shown leadership during operation Allied Force (July 1999). He was awarded the "Medal of Friendship" from the Russian Federation. In 2003 De Winne received an honorary doctorate from the University of Limburg.

EXPERIENCE : After completing his pilot training with the Belgian Air Force, in 1986, Frank De Winne was an operational pilot on Mirage V aircraft. Detached to the Company SAGEM in Paris in 1989, he then worked in the Mirage Safety Improvement Programme where he was responsible for the preparation of the operational and technical specifications of the Mirage upgrade programme.

In December 1992, he was appointed to the Test and Evaluation Branch of the Belgian Air Force. As a test pilot, he was involved in various activities, such as CARAPACE (an electronic warfare programme on F16) at Eglin Air Force Base, USA, and a Self-Protection Programme for the C130 aircraft. During that period, he also flew in Gosselies as a reception pilot in different aircraft types.

From January 1994 to April 1995, Frank De Winne was responsible for the flight safety programme of the 1st Fighter Wing at Beauvechain, Belgium.

From April 1995 to July 1996, as a senior test pilot in the European Participating Air Forces (EPAF), he was detached to Edwards Air Force Base, California, where he worked on the mid-life update of the F16 aircraft, focussing on radar testing.

From 1996 to August 1998, he was senior test pilot in the Belgian Air Force, responsible for all test programmes and for all pilot-vehicle interfaces for future aircraft/software updates.

From August 1998 to January 2000, Frank De Winne was the Squadron Commander of the 349th Fighter Squadron at Kleine Brogel Airbase, Belgium.

During Operation Allied Force, Frank De Winne was the detachment commander of the Deployable Air Task Force, a combined Belgian/Dutch detachment that flew about 2000 sorties during this Nato campaign. He has logged 17 combat sorties.

Frank De Winne has logged more than 2300 hours flying time on several types of high-performance aircraft including Mirage, F16, Jaguar and Tornado.

In January 2000, Frank De Winne joined the European Astronaut Corps of the European Space Agency (ESA), whose homebase is the European Astronaut Centre in Cologne, Germany.

De Winne provided technical support for the X38/ CRV Project Division within the Directorate of Manned Spaceflight and Microgravity, located at ESTEC, Noordwijk/Netherlands.

In August 2001, De Winne took up training at the Gagarin Cosmonaut Training Centre GCTC (Star City) near Moscow. Training includes elements of Basic Training for the International Space Station as well as training as Soyuz board engineer.

De Winne also supported the implementation of the White Paper on Space Policy with the European Commission and preparatory activities for the Soyuz at CSG (Guiana Space Centre) project.

In February 2007 De Winne was assigned as Expedition-16 back-up crew member and commenced training with Leo Eyharts, prime for Expedition-16.

He is currently assigned to the Expedition-19 crew and scheduled to arrive at the International Space Station in May 2009 aboard a Soyuz spacecraft

SPACEFLIGHT EXPERIENCE: From 30 October to 10 November 2002 De Winne participated in the Odissea mission, a support flight to the International Space Station. He served as flight engineer on the newly designed Soyuz TMA spacecraft during ascent, and on Soyuz TM during reentry.

A prime task of the 11-day mission was the replacement of the TM-34 Soyuz vehicle attached to the Space Station by the new TMA-1 spacecraft, in order to deliver a fresh "lifeboat" for the resident crew to be used in case of an emergency.

During his nine days on board the Space Station, De Winne, whose flight was sponsored by the Belgian Federal Office for Scientific, Technical and Cultural Affairs (OSTC), carried out successfully a programme of 23 experiments in the fields of life and physical sciences and education, including experiments in an important new research facility designed and developed in Europe, the Microgravity Science Glovebox (MSG).

FEBRUARY 2008

2. ISS-20 FE: Jeffrey Williams, 51

PERSONAL DATA: Born, January 18, 1958 in Superior, Wisconsin, but considers Winter, Wisconsin to be his hometown. Married to the former Anna-Marie Moore of Newburgh, New York. They have two sons. Enjoys running, fishing, camping, skiing, scuba diving and woodworking. His parents, Lloyd D. and Eunice A. Williams, reside in Winter, Wisconsin. Her mother, Gloria M. Moore, resides in Modena, New York. Her father, S. Stevens Moore, is deceased.

EDUCATION: Graduated from Winter High School, Winter, Wisconsin, in 1976; received a bachelor of science degree in applied science and engineering from the U.S. Military Academy (USMA) in 1980, a master of science degree in aeronautical engineering and the degree of aeronautical engineer from the U.S. Naval Postgraduate School, both in 1987, and a master of arts degree in National security and strategic studies from the U.S. Naval War College in 1996.

ORGANIZATIONS: Association of the U.S. Army, Society of Experimental Test Pilots, Army Aviation Association of America, USMA Association of Graduates, Order of Daedalians, Officer Christian Fellowship, Association of Space Explorers.

SPECIAL HONORS: Graduated first in U.S. Naval Test Pilot School class 103; 1988 Admiral William Adger Moffett Award for Excellence in Aeronautical Engineering, Naval Postgraduate School; 1985 Daedalian Foundation Fellowship Award for Graduate Study in Aeronautics. Awarded 2 Defense Superior Service Medals, 2 Legions of Merit, 2 Meritorious Service Medals, the Army Commendation Medal, 2 NASA Space Flight Medal, NASA Distinguished Service and Exceptional Service Medals, and various other service awards. Master Army Aviator, Senior Space and Parachutist badges. Honorary Doctorate of Business Administration from Johnson and Wales University.

PREVIOUS EXPERIENCE: As a cadet Williams competed on the West Point sport parachute team and also held ratings of sport parachute jumpmaster and instructor. Williams received his commission as a second lieutenant from the U.S. Military Academy in May 1980 and was designated an Army aviator in September 1981. He completed a three-year assignment in Germany where he served in the 3rd Armored Division's aviation battalion. Following his return to the United States, Williams completed a graduate program in aeronautical engineering, and was subsequently selected for an Army assignment at the Johnson Space Center (JSC), where he served for over 4 years. In 1992, Williams was selected for the Naval Test Pilot School. After graduation in June 1993, he served as an experimental test pilot and Flight Test Division Chief in the Army's Airworthiness Qualification Test Directorate at Edwards Air Force Base, California. In 1995, he was selected for attendance at the Naval War College command and staff course as an Army exchange officer. Williams retired from the Army in June 2007.

Williams has logged over 2,500 hours in more than 50 different aircraft.

NASA EXPERIENCE: Williams began an Army assignment at JSC in 1987. Until his transfer in 1992, he served as a Shuttle launch and landing operations engineer, a pilot in the Shuttle Avionics Integration Laboratory, and chief of the Operations Development Office, Flight Crew Operations Directorate. Selected by NASA in May 1996, Williams again reported to JSC in August 1996. After completing two years of training and evaluation, he performed technical duties in the Spacecraft Systems Branch and later in the Space Station Operations Branch on temporary assignment to Marshall Space Flight Center. In May 2000, he served as the flight engineer and lead spacewalker on STS-101. Subsequently he served in the EVA Branch of the Astronaut Office, led the development of the cockpit upgrade requirements for the Space Shuttle, and completed a temporary assignment at NASA Headquarters in support of legislative affairs. In July 2002, Williams commanded a nine-day undersea coral reef expedition operating from the National Oceanic & Atmospheric Administration's Aquarius habitat off the coast of Florida. In November 2002, he began training for a long-duration expedition on the International Space Station (ISS) shuttling between JSC and Star City, Russia. Williams was the backup Commander and Soyuz Flight Engineer for the 12th Expedition to the ISS launched on September 30, 2005. In 2006 he served as Expedition 13 Flight Engineer aboard the ISS. Twice flown, Williams has logged over 193 days in space, including over 19 hours in 3 EVAs. Williams is currently training as a backup crewmember for ISS Expeditions 19 and 20, launching on the March 2009 Soyuz and as a prime crewmember for Expeditions 21 and 22, launching on the October 2009 Soyuz.

SPACE FLIGHT EXPERIENCE: STS-101 Atlantis(May 19-29, 2000) was the third Shuttle mission devoted to International Space Station (ISS) construction. Objectives included transporting and installing over 5,000 pounds of equipment and supplies, and included Williams' first EVA (space walk) lasting nearly 7 hours. The mission was accomplished in 155 orbits of the Earth, traveling 4.1 million miles in 236 hours and 9 minutes.

Jeff Williams was the Expedition 13 Flight Engineer and Science Officer aboard the International Space Station. The Expedition 13 crew was launched on March 29, 2006 on the Russian Soyuz TMA 8 from Baikonur, Kazakhstan, docking with the station on March 31, 2006. During 6-months tour of duty aboard the ISS, in addition to station maintenance and some science activities, Williams performed two successful spacewalks logging 12 hours and 25 mins of EVA wearing both Russian and U.S. spacesuits, and also saw the arrival of two space shuttle missions, the resumption of construction of the orbiting laboratory, and the restoration of a three-person crew. The Expedition 13 mission concluded on September 28, 2006 with a safe landing in the steppes of Kazakhstan.

JANUARY 2009

3. ISS-20 FE: Nicole Stott, 46

PERSONAL DATA: Born in Albany, New York. Her hometown is Clearwater, Florida. She enjoys flying, snow skiing, SCUBA diving, woodworking, painting, and gardening.

EDUCATION: Clearwater High School, Clearwater, Florida, 1980. B.S., Aeronautical Engineering, Embry-Riddle Aeronautical University, 1987. M.S., Engineering Management, University of Central Florida, 1992.

SPECIAL HONORS: Aircraft Operations Division, Newt Myers Team Spirit Award, KSC Public Affairs Certificate of Appreciation for Service; NASA Exceptional Achievement Medal; NASA Certificates of Commendation; NASA Performance Awards; NASA On-the-Spot Award; Lockheed Certificate of Appreciation.

EXPERIENCE: Ms. Stott began her career in 1987 as a structural design engineer with Pratt and Whitney Government Engines in West Palm Beach, Florida. She spent a year with the Advanced Engines Group performing structural analyses of advanced jet engine component designs. She is an instrument rated private pilot.

NASA EXPERIENCE: In 1988, Ms. Stott joined NASA at the Kennedy Space Center (KSC), Florida as an Operations Engineer in the Orbiter Processing Facility (OPF). After 6 months, she was detailed to the Director of Shuttle Processing as part of a two-person team tasked with assessing the overall efficiency of Shuttle processing flows, and implementing tools for measuring the effectiveness of improvements. She was the NASA KSC Lead for a joint Ames/KSC software project to develop intelligent scheduling tools. The Ground Processing Scheduling System (GPSS) was developed as the technology demonstrator for this project. GPSS was a success at KSC, and also a commercial success that is part of the PeopleSoft suite of software products. During her time at KSC, Ms. Stott also held a variety of positions within NASA Shuttle Processing, including Vehicle Operations Engineer; NASA Convoy Commander; Shuttle Flow Director for Endeavour; and Orbiter Project Engineer for Columbia. During her last two years at KSC, she was a member of the Space Station Hardware Integration Office and relocated to Huntington Beach, CA where she served as the NASA Project Lead for the ISS truss elements under construction at the Boeing Space Station facility. In 1998, she joined the Johnson Space Center (JSC) team in Houston, TX as a member of the NASA Aircraft Operations Division, where she served as a Flight Simulation Engineer (FSE) on the Shuttle Training Aircraft (STA).

Selected as a mission specialist by NASA in July 2000, Nicole reported for astronaut candidate training in August 2000. Following the completion of two years of training and evaluation, she was assigned technical duties in the Astronaut Office Station Operations Branch, where she performed crew evaluations of station payloads. She also worked as a support astronaut for the Expedition 10 crew and as an ISS CAPCOM. In April 2006 she was a crew member on the NEEMO 9 mission (NASA Extreme Environment Mission Operations) where she lived and worked with a 6 person crew for 18 days on the Aquarius undersea research habitat. Nicole is currently assigned to a long duration space flight as a member of the ISS Expeditions 20 and 21 crews. She is scheduled to launch to the International Space Station with the crew of STS-129 and return with the crew of STS-129.

MARCH 2009

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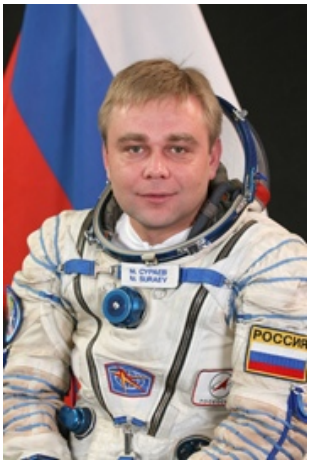
4. ISS-20 FE: Maxim Suraev, 37



PERSONAL DATA: Born May 24, 1972, in Chelyabinsk. Married to Suraeva (nee Khorokhordina) Anna Alexandrovna. They have two daughters, Arina and Ksenia Hobbies include sports and reading.

EDUCATION: In 1994, he graduated with honors from the Kachin Air Force Pilot School as pilot-engineer; graduated with honors from the Zhukovski Air Force Academy in 1997 as pilot-engineer-researcher; received a law degree from the Russian Academy of Civil Service in 2007.

EXPERIENCE: Suraev is qualified to fly L-39 and Su-27 aircraft, and has logged around 700 hours of flight time. Suraev is a Class 3 Air Force pilot, a qualified diver and paraborne instructor.

From December 1997 to November 1999, Suraev completed basic space training. In November 1999 he was qualified as a test-cosmonaut.

Starting January 2000 he was in ISS advanced training. From March 2006 until April 2008 Suraev was assigned as a backup ISS 17 crewmember. From April 2008 until March 2009 he was a member of the ISS 19 backup crew.

Since April 2009 Suraev is assigned to the ISS 21/22 prime mission.

AUGUST 2009

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5. ISS-20 FE: Roman Romanenko, 37

PERSONAL DATA: Born August 9, 1971, in Schelkovo, Moscow Region. His parents, Yuri Victorovich Romanenko and Aleftina Ivanovna, reside in Star City. He is married to Yulia Leonidovna Romanenko (Danilovskaya). They have one son. His hobbies include underwater hunting, tennis, car repairs, tourism, yachting, volleyball, and music.

EDUCATION: After graduation from Star City high school in 1986 Romanenko entered the Leningrad Suvorov military school from which he graduated in 1988. In 1988 he entered the Chernigov High Air Force School of pilots from which he graduated in 1992 as a pilot-engineer.

EXPERIENCE: Following graduation from pilot school Romanenko served as a second commander in the Air Force. He flew L-39 and Tu-134 aircraft. Romanenko has logged over 500 hours of flight time. He is a Class 3 Air Force pilot.

Romanenko was selected as a test-cosmonaut candidate of the Gagarin Cosmonaut Training Center Cosmonaut Office in December 1997. From January 1998 to November 1999, he completed his basic training course. In November 1999, he was qualified as a test cosmonaut.

AUGUST 2002

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6. ISS-20 FE: Robert Thirsk, M.D., 55

PERSONAL DATA: Born August 17, 1953, New Westminster, British Columbia.

EDUCATION: Attended primary and secondary schools in British Columbia, Alberta, and Manitoba. Received a Bachelor of Science degree in Mechanical Engineering from the University of Calgary in 1976, a Master of Science in Mechanical Engineering from the Massachusetts Institute of Technology (MIT) in 1978, a Doctorate of Medicine from McGill University in 1982, and a Master of Business Administration from the MIT Sloan School of Management in 1998.

EXPERIENCE: Dr. Thirsk was in the family medicine residency program at the Queen Elizabeth Hospital in Montréal when he was selected in December 1983 for the Canadian Astronaut Program. He began astronaut training in February 1984 and served as backup payload specialist to Marc Garneau for the October 1984 space shuttle mission STS-41G.

Dr. Thirsk has been involved in various Canadian Space Agency projects including parabolic flight campaigns and mission planning. He served as crew commander for two space mission simulations: the seven-day CAPSULS mission in 1994, at Defence Research and Development Canada in Toronto, and the 11-day NEEMO 7 undersea mission in 2004 at the National Undersea Research Center in Key Largo, Florida. He led an international research team investigating the effect of weightlessness on the heart and blood vessels. He works with educational specialists in Canada to develop space-related curriculum for grade school students. Initiatives such as Canolab, Space for Species, and Tomatosphere have allowed thousands of young Canadians to experience the thrill of scientific discovery.

In June and July 1996, Dr. Thirsk flew as a payload specialist aboard space shuttle mission STS-78, the Life and Microgravity Spacelab (LMS) mission. During this 17-day flight aboard Columbia, he and his six crewmates performed 43 international experiments devoted to the study of life and materials sciences. The life science experiments investigated changes in plants, animals, and humans under space flight conditions. The materials science experiments examined protein crystallization, fluid physics and high-temperature solidification of multi-phase materials in a weightless environment.

In 1998, Dr. Thirsk was assigned by the Canadian Space Agency to NASA's Johnson Space Center in Houston to pursue mission specialist training. This training program involved advanced instruction on both shuttle and space station systems, EVA (spacewalking), robotic operations, and Russian language. Within the NASA Astronaut Office, Dr. Thirsk serves as a Capcom (capsule communicator) for the International Space Station (ISS) program. Capcoms participate in actual and simulated space missions as a communication link between the ground team at Mission Control and the astronauts in orbit. Capcoms speak directly with the space station crew, and assist with technical planning for the mission and last-minute troubleshooting.

In 2004, Dr. Thirsk trained at the Yuri Gagarin Cosmonaut Training Centre near Moscow and became certified as a Flight Engineer for the Soyuz spacecraft. He served as backup Flight Engineer to European Space Agency (ESA) astronaut Roberto Vittori for the Soyuz 10S taxi mission to the ISS in April 2005. During the 10-day mission, Dr. Thirsk worked as Crew Interface Coordinator (i.e. European Capcom) at the Columbus Control Centre in Germany.

Dr. Thirsk has now returned to the Johnson Space Center in Houston and has begun ISS Expedition crew training. He is currently assigned to the Expedition-19 crew and scheduled to arrive at the International Space Station in May 2009 aboard a Soyuz spacecraft.

FEBRUARY 2008

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STS-129 Crew Photographs

CDR Charles Hobaugh

PLT Barry Wilmore

MS1 Leland Melvin

MS2/FE/EV-3 Randolph Bresnik

MS3/EV1 Michael Foreman

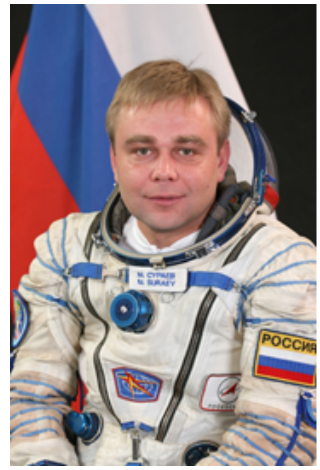
MS4/EV2 Robert Satcher

MS5/EV3 Nicole Stott

ISS-21 Crew Photographs


ISS-21 FE Jeffrey Williams


ISS-21 FE: Nicole Stott



ISS-21 FE Maxim Suraev


ISS-21 FE Roman Romanenko


ISS-21 FE Robert Thirsk, M.D.


ISS-21 CDR Frank DeWinne

STS-129 Launch Windows

The launch window for STS-129 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.

STS-129 Launch Windows

Date	Window Open	Launch	Window Close	Space Station Docking
11/16/09	02:23:04 PM	02:28:04 PM	02:33:04 PM	FD 3
11/17/09	01:57:22 PM	02:02:22 PM	02:07:22 PM	FD 3
			02:10:32 PM	FD 4
11/18/09	01:34:51 PM	01:39:51 PM	01:44:51 PM	FD 3
11/19/09	01:09:08 PM	01:14:08 PM	01:19:08 PM	FD 3
			01:22:19 PM	FD 4

Beta Angle Cutout[5]

12/06/09	06:20:42 AM	06:25:42 AM	06:30:42 AM	FD TBD
12/07/09	05:54:59 AM	05:59:59 AM	06:04:59 AM	FD TBD
12/08/09	05:32:28 AM	05:37:28 AM	05:42:28 AM	FD TBD
12/09/09	05:06:45 AM	05:11:45 AM	05:16:45 AM	FD TBD
12/10/09	04:44:14 AM	04:49:14 AM	04:54:14 AM	FD TBD
12/11/09	04:18:31 AM	04:23:31 AM	04:28:31 AM	FD TBD

[5] A beta-angle cutout begins on 11/20 and ends 12/5. Atlantis can launch on 11/20, but mission managers would have to give up the crew's "plus-one" contingency day.

STS-129 Launch and Flight Control Personnel

KSC/LCC	Launch Ops	LCC PAO	Fueling PAO
STS-129 LD	Mike Leinbach	George Diller	N/A
STS-129 NTD	Steve Payne		
STS-129 OTC	Jeffrey Lauffer		

JSC/MCC	Flight Ops	MCC PAO	STS CAPCOM
Space Shuttle			
Ascent FD	Bryan Lunney	Rob Navias	Eric Boe
Weather			Steve Frick
Orbit 1 FD (ld)	Mike Sarafin	Josh Byerly	Stan Love
Orbit 2 FD	Gary Horlacher	Kelly Humphries	Megan McArthur
Planning FD	Paul Dye	TBD	Aki Hoshide
Entry FD	Bryan Lunney	Brandi Dean	Eric Boe
Weather			Steve Frick
Team 4	Kwatsi Alibaruho		
ISS			
Orbit 1	Emily Nelson	N/A	Drew Feustel
Orbit 2 (ld)	Brian Smith	N/A	Steve Swanson
Orbit 3	Jerry Jason	N/A	Ryan Lien
Team 4	N/A		

Flight Support	Prime	Backup	Backup
STS manager	John Shannon		
MMT (JSC)	LeRoy Cain		
MMT (KSC)	Mike Moses		
Weather Coord.	TBD		
Weather flight	TBD		
Launch STA	Steve Lindsey		
Entry STA (KSC)	Steve Lindsey	Dom Gorie	
Entry STA (EAFB)	Rick Sturckow		
TAL Zaragoza	Kevin Ford		
TAL Istres	Dom Gorie		
TAL Moron	Rick Sturckow		
JSC PAO at KSC	Kyle Herring		
HQ PAO at KSC	TBD		
Astro Support	Joe Acaba		
Family Support	TBD		

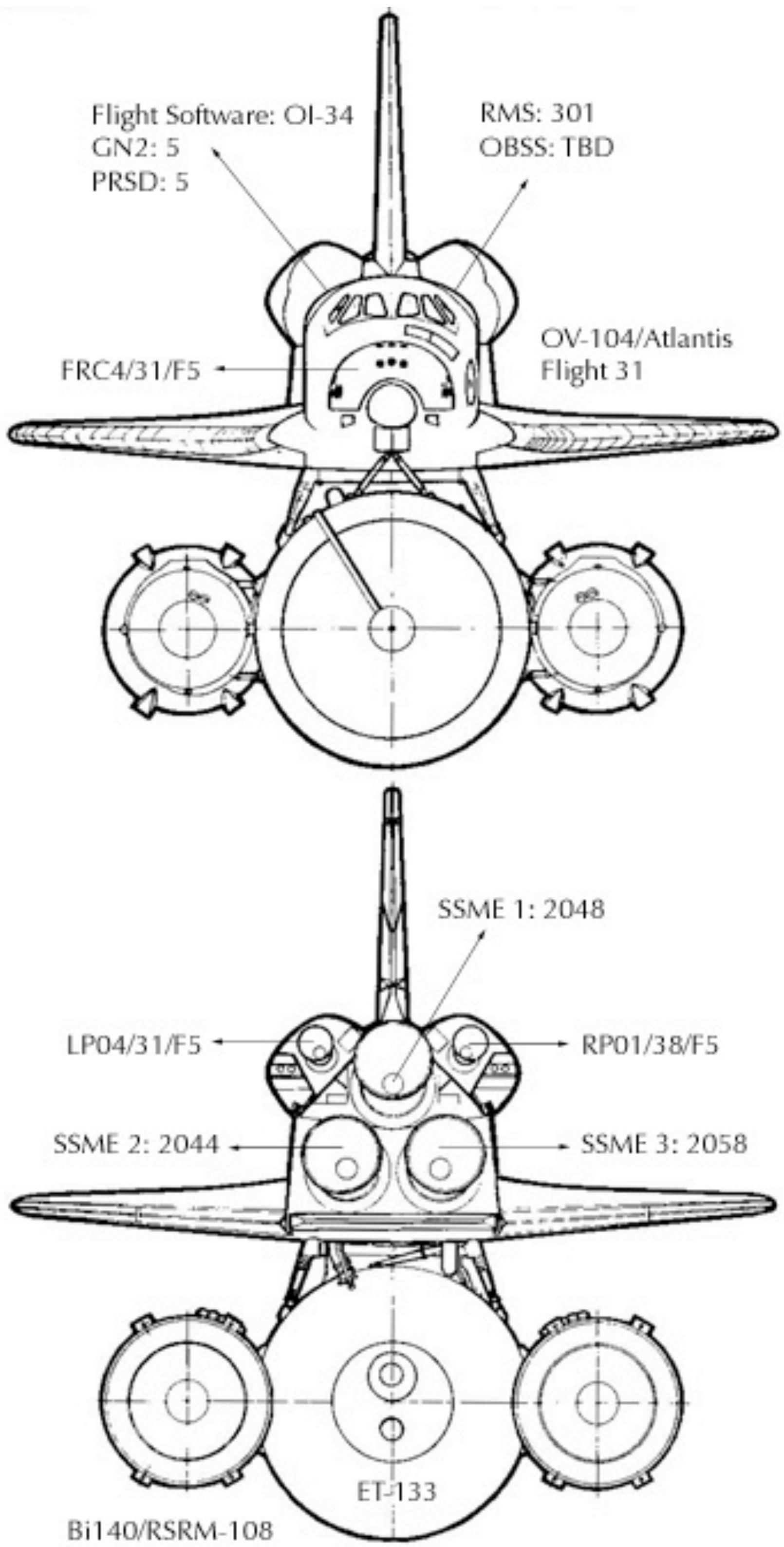
STS-129 Crew	Name	Launch Seating	Entry Seating
Commander	Charles Hobaugh	Up-1	Up-1
Pilot	Barry Wilmore	Up-2	Up-2
MS1	Leland Melvin	Up-3	Up-4
MS2/FE/EV3	Randy Bresknik	Up-4	Up-3
MS3/EV1	Mike Foreman	Down-5	Down-5
MS4/EV2	Robert Satcher	Down-6	Down-6
MS5 (dn)	Nicole Stott	N/A	Down-7

Bailout Order (ascent): TBD
Bailout Order (entry): TBD

Detail	Prime	Backup	Backup
ET Photo	Foreman	Melvin	
IVA suit	Wilmore	Hobaugh	
EVA R1	Hobaugh		
EVA M1/M2	Melvin		
SRMS	Wilmore	Melvin	
SSRMS	Melvin	Wilmore	

EVAs	Crew	Suit Markings	IV	Notes
EVA-1	Foreman	Red stripes	Bresnik	
	Satcher	Unmarked		
EVA-2	Foreman		Satcher	
	Bresnik	Broken stripes		
EVA-3	Satcher		Foreman	
	Bresnik			

STS-129 Flight Hardware/Software



Atlantis Flight History

Source: NASA

Atlantis (OV-104) was delivered to Kennedy Space Center in April 1985. It lifted off on its maiden voyage on Oct. 3, 1985, on mission 51-J, the second dedicated Department of Defense flight. Later missions included the launch of the Galileo interplanetary probe to Jupiter on STS-34 in October 1989, and STS-37, with the Gamma Ray Observatory (GRO) as its primary payload, in April 1991.

Atlantis is named after a two-masted sailing ship that was operated for the Woods Hole Oceanographic Institute from 1930 to 1966.

FLT	#	STS	DD	HH	MM	SS	Launch	Mission Description
N/A		51J	00	00	00	00	9/12/85	Flight readiness firing
01	21	51J	04	01	44	38	10/3/85	DOD
02	23	61B	06	21	04	49	11/26/85	3 comsats, EASE/ACCESS
03	27	27	04	09	05	37	12/2/88	DOD (Lacrosse?)
04	29	30	04	00	56	27	5/4/89	Magellan Venus probe
05	31	34	04	23	39	21	10/18/89	Galileo Jupiter probe
06	34	36	04	10	18	22	2/28/90	DOD
07	37	38	04	21	54	31	11/15/90	DOD
08	39	37	05	23	32	44	4/5/91	Gamma Ray Observatory
09	42	43	08	21	21	25	8/2/91	TDRS-5
10	44	44	06	22	50	44	11/19/91	DSP
11	46	45	08	22	09	28	3/24/92	ATLAS-1
12	49	46	07	23	15	03	7/31/92	TSS; EURECA deployment
13	66	66	10	22	34	02	11/3/94	ATLAS-3
14	69	71	09	19	22	17	6/27/95	Mir Docking No. 1
15	73	74	08	04	30	46	11/12/95	Mir Docking No. 2
16	76	76	09	05	15	53	3/22/96	Mir Docking No. 3
17	79	79	10	03	19	28	9/16/96	Mir Docking No. 4
18	81	81	10	04	55	21	1/12/97	Mir Docking No. 5
19	84	84	09	05	19	56	5/15/97	Mir Docking No. 6
20	87	86	10	19	20	50	9/25/97	Mir Docking No. 7
21	98	101	09	20	09	08	5/19/00	ISS 2A.2a (Zarya refurb)
22	99	106	11	19	11	01	9/8/00	ISS 2A.2b (outfitting)
23	102	98	12	21	20	03	2/7/01	ISS 5A (Destiny lab module)
24	105	104	12	18	34	56	7/12/01	ISS 7A (Airlock module)
25	109	110	10	19	42	38	4/8/02	ISS 8A (S0 truss)
26	111	112	10	19	57	49	10/7/02	ISS 9A (S1 truss)
27	116	115	11	19	06	35	9/9/06	ISS 12A (P3/P4 truss)
28	118	117	13	20	11	34	6/8/07	ISS-13A (S3/S4)
29	121	122	12	18	21	40	2/7/08	ISS-1E (Columbus)
30	126	125	12	21	37	09	5/11/09	HST-SM4
Vehicle Total			**271**	**04**	**44**	**15**		

STS-129 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 11/13/09	
12:30 PM	Call to stations
01:00 PM	Countdown begins
11:00 PM	Begin 4-hour built-in hold
Sat 11/14/09	
02:00 AM	Clear pad for Atlas 5/Intelsat launch
03:00 AM	Countdown resumes
03:00 AM	Fuel cell reactant load preps
08:30 AM	MEC/SRB power up
09:00 AM	Clear crew module
09:00 AM	Begin 4-hour built-in hold
09:00 AM	Clear blast danger area
09:45 AM	Orbiter pyro-initiator controller test
09:55 AM	SRB PIC test
10:55 AM	Master events controller pre-flight BITE test
01:00 PM	Resume countdown
02:30 PM	Fuel cell oxygen loading begins
05:00 PM	Fuel cell oxygen load complete
05:00 PM	Fuel cell hydrogen loading begins
07:30 PM	Fuel cell hydrogen loading complete
08:30 PM	Pad open; ingress white room
09:00 PM	Begin 4-hour built-in hold
09:00 PM	Crew module clean and vacuum
09:30 PM	OMBUU demate
Sun 11/15/09	
12:00 AM	Remove APU vent covers
12:30 AM	MPS 2000 psi GSE
01:00 AM	Countdown resumes
01:00 AM	Main engine preps
01:00 AM	MECs 1 and 2 on; avionics system checkout
01:00 AM	Remove OMS engine covers, throat plugs
07:30 AM	Deflate RSS dock seals; tile inspection
08:00 AM	Tile inspection

EDT	EVENT
08:00 AM	TSM prepped for fueling
09:00 AM	Begin 13-hour 3-minute hold
09:00 AM	L-1 engineering briefing
09:15 AM	Crew weather briefing
10:30 AM	ASP crew module inspection
10:30 AM	OIS communications check
12:30 PM	Comm activation
01:00 PM	Crew module voice checks
02:00 PM	Flight crew equipment late stow
03:15 PM	JSC flight control team on station
05:30 PM	RSS to park position
06:30 PM	Final TPS, debris inspection
09:30 PM	Ascent switch list
10:03 PM	Resume countdown
10:23 PM	Pad clear of non-essential personnel
10:23 PM	APU bite test
11:13 PM	Fuel cell activation

Mon 11/16/09

EDT	EVENT
12:03 AM	Booster joint heater activation
12:33 AM	MEC pre-flight bite test
12:48 AM	Tanking weather update
01:33 AM	Final fueling preps; launch area clear
02:03 AM	Red crew assembled
02:48 AM	Fuel cell integrity checks complete
03:03 AM	Begin 2-hour built-in hold (T-minus 6 hours)
03:13 AM	Safe-and-arm PIC test
04:03 AM	External tank ready for loading
04:26 AM	Mission management team tanking meeting
05:03 AM	Resume countdown (T-minus 6 hours)
05:03 AM	LO2, LH2 transfer line chilldown
05:13 AM	Main propulsion system chill down
05:13 AM	LH2 slow fill
05:43 AM	LO2 slow fill
05:48 AM	Hydrogen ECO sensors go wet
05:53 AM	LO2 fast fill
05:56 AM	Crew medical checks
06:03 AM	LH2 fast fill
07:58 AM	LH2 topping
08:03 AM	LH2 replenish
08:03 AM	LO2 replenish
08:03 AM	Begin 2-hour 30-minute built-in hold (T-minus 3 hours)
08:03 AM	Closeout crew to white room
08:03 AM	External tank in stable replenish mode
08:18 AM	Astronaut support personnel comm checks

EDT	EVENT
08:48 AM	Pre-ingress switch reconfig
09:30 AM	NASA TV coverage begins
10:03 AM	Final crew weather briefing
10:08 AM	Crew suit up begins
10:33 AM	Resume countdown (T-minus 3 hours)
10:38 AM	Crew departs O&C building
11:08 AM	Crew ingress
11:58 AM	Astronaut comm checks
12:23 PM	Hatch closure
12:53 PM	White room closeout
01:13 PM	Begin 10-minute built-in hold (T-minus 20m)
01:23 PM	NASA test director countdown briefing
01:23 PM	Resume countdown (T-minus 20m)
01:24 PM	Backup flight computer to OPS 1
01:28 PM	KSC area clear to launch
01:34 PM	Begin final built-in hold (T-minus 9m)
02:04:04 PM	NTD launch status verification
02:19:04 PM	Resume countdown (T-minus 9m)
02:23:04 PM	Orbiter access arm retraction
02:23:04 PM	Launch window opens
02:23:04 PM	Hydraulic power system (APU) start
02:23:09 PM	Terminate LO2 replenish
02:24:04 PM	Purge sequence 4 hydraulic test
02:24:04 PM	IMUs to inertial
02:24:09 PM	Aerosurface profile
02:24:34 PM	Main engine steering test
02:25:09 PM	LO2 tank pressurization
02:25:29 PM	Fuel cells to internal reactants
02:25:34 PM	Clear caution-and-warning memory
02:26:04 PM	Crew closes visors
02:26:07 PM	LH2 tank pressurization
02:27:14 PM	SRB joint heater deactivation
02:27:33 PM	Shuttle GPCs take control of countdown
02:27:43 PM	SRB steering test
02:27:57 PM	Main engine start (T-6.6 seconds)
02:28:04 PM	SRB ignition (LAUNCH)

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STS-129 Weather Guidelines[6]

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.

[6] 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)

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STS-129 Ascent Events Summary

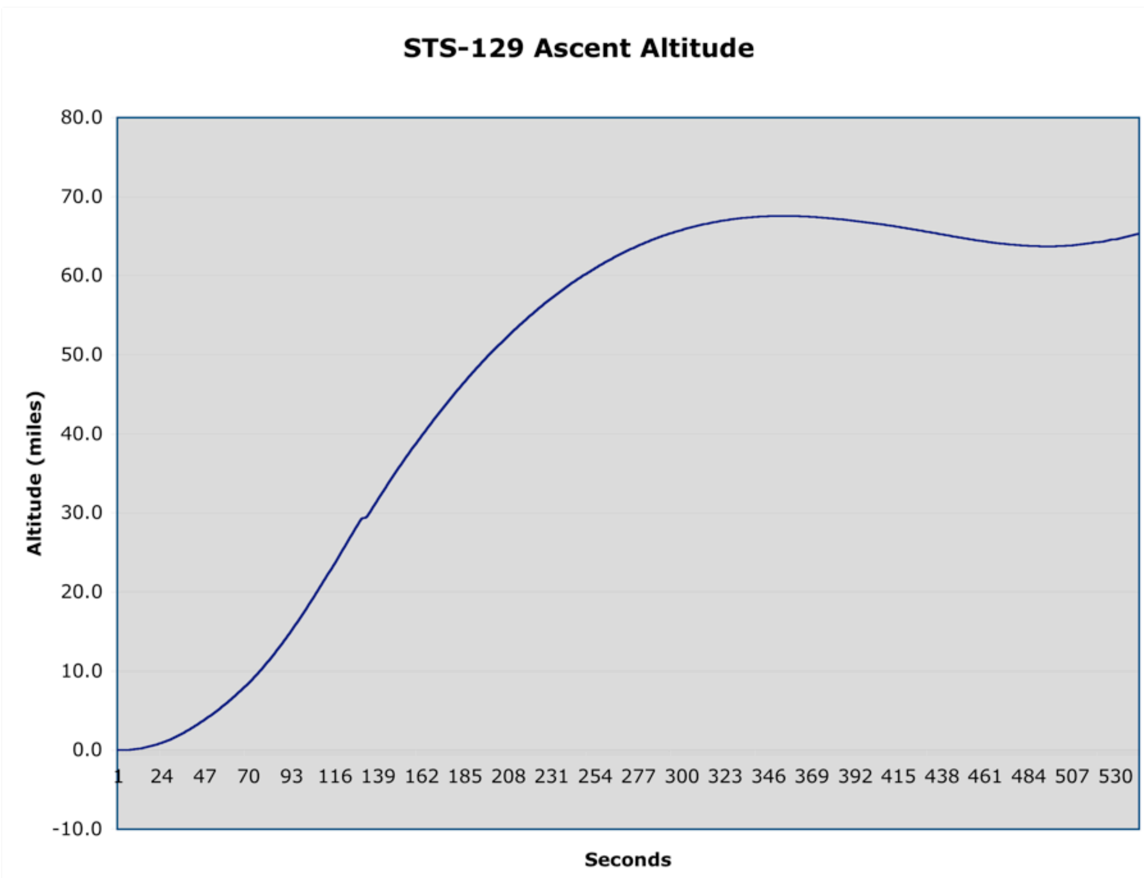
Flight Data	EDT	L-MM:SS	Terminal Countdown		
STS-128	12:42:05 AM	L-45:00	**T-9 hold begins**		
25-Aug-09	1:27:05 AM	L-09:00	Resume countdown		
01:36:05 AM	1:28:35 AM	L-07:30	Orbiter access arm retraction		
Win Close	1:31:05 AM	L-05:00	Auxilliary power unit start		
01:41:05 AM	1:31:10 AM	L-04:55	Liquid oxygen drainback begins		
-121:55:30	1:32:05 AM	L-03:55	Purge sequence 4 hydraulic test		
	1:33:10 AM	L-02:55	Oxygen tank at flight pressure		
SLF Max Wind:	1:33:15 AM	L-02:50	Gaseous oxygen vent arm retraction		
TBD	1:33:30 AM	L-02:35	Fuel cells to internal		
Wind Direction:	1:34:08 AM	L-01:57	Hydrogen tank at flight pressure		
TBD	1:35:15 AM	L-00:50	Orbiter to internal power		
SLF Crosswind:	1:35:34 AM	L-00:31	Shuttle computers control countdown		
TBD	1:35:44 AM	L-00:21	Booster steering test		
TBD	1:35:58 AM	L-00:06.6	Main engine ignition		
Abort Data		**L+MM:SS**	**Ascent Events Timeline**	**MPH**	**FPS**
0:02:30	**1:36:05 AM**	**T+0:00**	**LAUNCH**		
RTLS	1:36:16 AM	T+00:11	START ROLL MANEUVER	927	1,360
ONLY	1:36:23 AM	T+00:18	END ROLL MANEUVER	1,002	1,470
	1:36:39 AM	T+00:34	START THROTTLE DOWN (72%)	1,221	1,790
	1:36:54 AM	T+00:49	START THROTTLE UP (104.5%)	1,425	2,090
	1:37:07 AM	T+01:02	MAX Q (754 psf)	1,664	2,440
	1:38:08 AM	T+02:03	SRB STAGING	3,621	5,310
	1:38:18 AM	T+02:13	START OMS ASSIST (1:36 duration)	3,744	5,490
0:02:25	1:38:35 AM	T+02:30	**2 ENGINE TAL MORON (104.5%, 2s)**	4,023	5,900
TAL	1:38:40 AM	T+02:35	2 ENGINE TAL ZARAGOZA (104.5%, 2s)	4,091	6,000
	1:38:51 AM	T+02:46	2 ENGINE TAL ISTRES (104.5%, 2s)	4,296	6,300
	1:39:57 AM	T+03:52	NEGATIVE RETURN (KSC) (104.5%, 3s)	5,523	8,100
0:01:52	1:41:00 AM	T+04:55	**PRESS TO ATO (104.5%, 2s, 160 u/s)**	7,296	10,700
ATO	1:41:28 AM	T+05:23	DROOP ZARAGOZA (109%,0s)	8,183	12,000
	1:41:31 AM	T+05:26	SINGLE ENGINE OPS-3 ZARAGOZA (109%,0s,2EO SIMO)	8,251	12,100
	1:42:10 AM	T+06:05	SINGLE ENGINE TAL ZARAGOZA (104.5%,2s,2EO SIMO)	9,751	14,300
	1:42:10 AM	T+06:05	SINGLE ENGINE TAL MORON (109%,0s,2EO SEQ,1st EO @ VI)	11,115	16,300
	1:42:10 AM	T+06:05	SINGLE ENGINE TAL ISTRES (109%,0s,2EO SEQ,1st EO @ VI)	11,524	16,900
MECO Ha/Hp	1:42:52 AM	T+06:47	**PRESS TO MECO (104.5%, 2s, 160 u/s)**	11,660	17,100
	1:43:14 AM	T+07:09	SINGLE ENGINE PRESS-TO-MECO (104.5%, 2s, 588 u/s)	12,888	18,900
136 X 36 sm	1:43:27 AM	T+07:22	NEGATIVE MORON (2@67%)	13,569	19,900
	1:43:47 AM	T+07:42	LAST 2 ENG PRE-MECO TAL ZARAGOZA (67%)	14,865	21,800
OMS-2 Ha/Hp	1:43:47 AM	T+07:42	NEGATIVE ISTRES (2@67%)	14,865	21,800
141 X 98 sm	1:43:53 AM	T+07:48	LAST SINGLE ENG PRE-MECO TAL ZARAGOZA (104.5%)	15,342	22,500
	1:43:59 AM	T+07:54	LAST 3 ENG PRE-MECO TAL ZARAGOZA (67%)	15,683	23,000
	1:44:24 AM	T+08:19	LAST TAL DIEGO GARCIA	17,252	25,300
	1:44:29 AM	T+08:24	MECO COMMANDED	17,552	25,740
	1:44:40 AM	T+08:35	ZERO THRUST	17,592	25,800
			Compiled by William Harwood	**Inertial Velocity**	

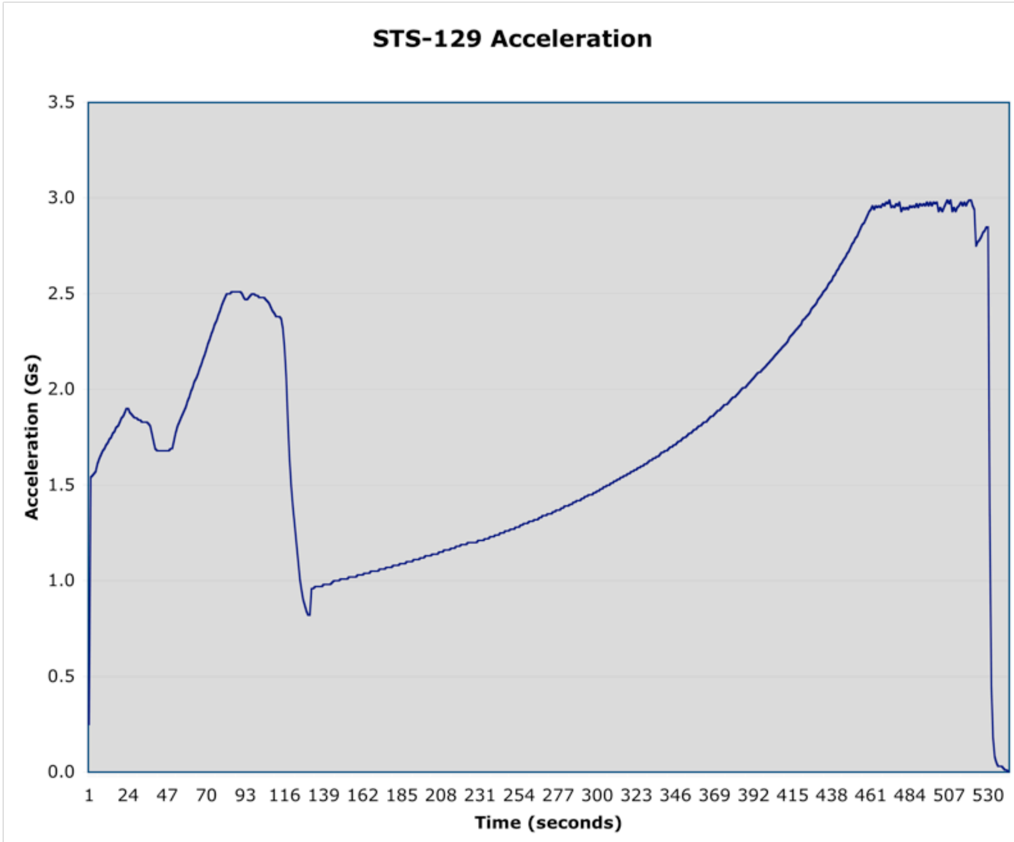
STS-129 Trajectory Data[7]

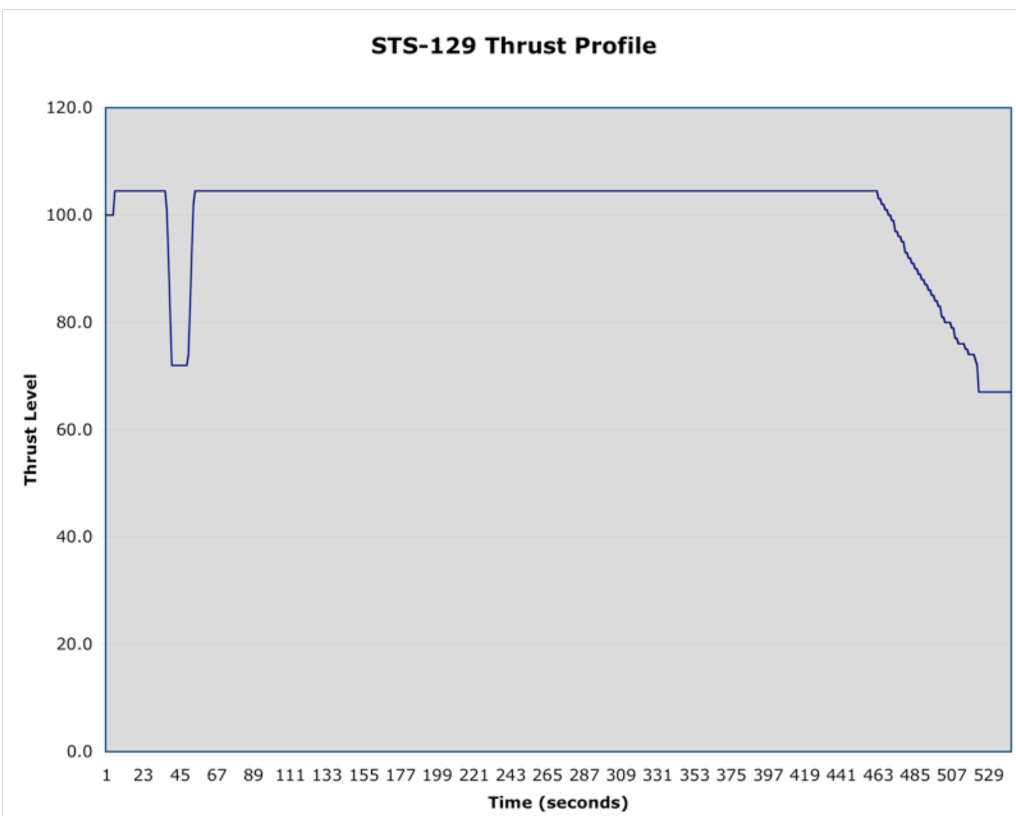
T+ MM:SS	Thrust (%)	Altitude FT	Mach Number	Vi MPH	Vi FPS	Gs (sm)	Range
00:00	100.0	-23	0.0	0.0	914.4	0.3	0.0
00:10	104.5	776	0.2	124.8	922.6	1.7	0.0
00:20	104.5	3,970	0.4	306.8	1,040.5	1.9	0.1
00:30	104.5	9,137	0.7	492.3	1,181.0	1.8	0.5
00:40	72.0	17,095	0.9	671.7	1,334.4	1.7	1.2
00:50	102.0	25,871	1.1	814.8	1,466.7	1.8	2.1
01:00	104.5	36,174	1.4	994.9	1,629.0	2.0	3.4
01:10	104.5	49,855	1.9	1,260.1	1,876.5	2.3	5.1
01:20	104.5	64,724	2.4	1,578.6	2,195.7	2.5	7.3
01:30	104.5	83,563	2.9	1,973.4	2,601.4	2.5	10.6
01:40	104.5	102,569	3.4	2,352.5	2,989.4	2.5	14.4
01:50	104.5	125,146	3.8	2,767.1	3,413.5	2.2	19.8
02:00	104.5	146,270	3.9	2,961.4	3,618.0	1.0	25.5
02:10	104.5	167,802	4.0	3,059.6	3,727.2	1.0	31.9
02:20	104.5	186,877	4.2	3,174.1	3,854.0	1.0	38.4
02:30	104.5	206,567	4.5	3,316.0	4,006.7	1.0	45.9
02:40	104.5	223,290	4.9	3,457.8	4,156.7	1.1	53.2
02:50	104.5	238,902	5.4	3,611.9	4,317.0	1.1	60.9
03:00	104.5	254,814	5.9	3,793.3	4,504.5	1.1	69.8
03:10	104.5	268,154	6.3	3,969.9	4,684.5	1.1	78.4
03:20	104.5	281,614	6.8	4,176.5	4,893.8	1.2	88.5
03:30	104.5	292,771	7.2	4,374.9	5,094.3	1.2	98.1
03:40	104.5	302,920	7.5	4,582.2	5,303.0	1.2	108.2
03:50	104.5	312,954	7.7	4,820.9	5,541.6	1.3	119.8
04:00	104.5	321,082	7.9	5,048.0	5,768.0	1.3	131.0
04:10	104.5	328,961	8.1	5,309.8	6,028.5	1.3	144.0
04:20	104.5	335,188	8.3	5,558.0	6,276.0	1.4	156.3
04:30	104.5	341,040	8.6	5,843.7	6,560.4	1.4	170.6
04:40	104.5	345,486	8.9	6,115.1	6,829.7	1.5	184.2
04:50	104.5	349,132	9.2	6,397.4	7,110.0	1.5	198.4
05:00	104.5	352,259	9.5	6,721.3	7,431.1	1.6	214.9
05:10	104.5	354,344	9.9	7,028.8	7,736.6	1.6	230.5
05:20	104.5	355,852	10.4	7,381.3	8,086.4	1.7	248.6
05:30	104.5	356,553	10.8	7,716.8	8,419.2	1.7	265.8
05:40	104.5	356,663	11.3	8,065.9	8,765.6	1.8	283.7
05:50	104.5	356,159	11.9	8,468.3	9,165.1	1.9	304.4
06:00	104.5	355,209	12.4	8,850.8	9,544.3	1.9	324.2
06:10	104.5	353,784	13.1	9,289.2	9,980.0	2.0	346.9
06:20	104.5	352,268	13.7	9,707.9	10,395.2	2.1	368.5
06:30	104.5	350,344	14.5	10,196.1	10,880.1	2.2	393.4
06:40	104.5	348,326	15.3	10,664.6	11,345.1	2.3	417.2
06:50	104.5	346,145	16.1	11,158.3	11,835.4	2.5	442.0
07:00	104.5	343,688	17.1	11,732.4	12,406.1	2.6	470.7
07:00	104.5	343,688	17.1	11,732.4	12,406.1	2.6	470.7
07:10	104.5	341,540	18.0	12,286.8	12,957.1	2.8	498.1
07:20	104.5	339,430	19.1	12,936.6	13,603.5	3.0	529.7

[7] Predicted data.

T+ MM:SS	Thrust (%)	Altitude FT	Mach Number	Vi MPH	Vi FPS	Gs (sm)	Range (sm)
07:30	99.0	337,907	20.1	13,549.6	14,212.4	3.0	559.8
07:40	92.0	336,880	21.1	14,161.9	14,821.3	3.0	591.4
07:50	86.0	336,412	22.1	14,835.6	15,492.3	3.0	627.7
08:00	80.0	336,724	23.0	15,450.0	16,103.9	2.9	662.2
08:10	76.0	338,043	23.9	16,123.7	16,774.9	3.0	701.8
08:30	67.0	343,446	24.7	16,957.7	17,604.8	0.0	780.2
08:31	67.0	343,756	24.7	16,957.7	17,604.8	0.0	784.1
08:32	67.0	344,066	24.7	16,957.7	17,604.8	0.0	788.0
08:33	67.0	344,377	24.6	16,957.7	17,604.8	0.0	791.8
08:34	67.0	344,662	24.6	16,957.7	17,604.8	0.0	795.4




STS-129 Acceleration
Acceleration (Gs)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1 24 47 70 93 116 139 162 185 208 231 254 277 300 323 346 369 392 415 438 461 484 507 530
Time (seconds)


STS-129 Thrust Profile
Thrust Level
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1 23 45 67 89 111 133 155 177 199 221 243 265 287 309 331 353 375 397 419 441 463 485 507 529
Time (seconds)

STS-129 Flight Plan

Editor's Note…
Current as of 11/09/09

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					
11/16/09					
Mon 02:28 PM	00	00	00	00	Launch
Mon 03:05 PM	00	00	37	00	OMS-2 rocket firing
Mon 03:18 PM	00	00	50	00	Post insertion timeline begins
Mon 05:08 PM	00	02	40	00	SRMS powerup
Mon 05:23 PM	00	02	55	00	Laptop computer setup (part 1)
Mon 06:02 PM	00	03	34	44	NC-1 rendezvous rocket firing
Mon 06:13 PM	00	03	45	00	SRMS checkout
Mon 06:23 PM	00	03	55	00	Group B computer powerdown
Mon 06:28 PM	00	04	00	00	GIRA installation
Mon 06:58 PM	00	04	30	00	Wing leading edge sensors activated
Mon 07:03 PM	00	04	35	00	ET video downlink
Mon 07:08 PM	00	04	40	00	ET photo
Mon 07:23 PM	00	04	55	00	Umbilcal camera downlink
Mon 07:28 PM	00	05	00	00	SEE setup
Mon 08:28 PM	00	06	00	00	Crew sleep begins
Flight Day 2					
11/17/09					
Tue 04:28 AM	00	14	00	00	Crew wakeup
Tue 05:58 AM	00	15	30	00	Minicam downlink
Tue 06:38 AM	00	16	10	26	NC-2 rendezvous rocket firing
Tue 06:58 AM	00	16	30	00	SRMS unberths OBSS
Tue 07:23 AM	00	16	55	00	Ergometer setup
Tue 07:53 AM	00	17	25	00	Spacesuit checkout preps
Tue 08:13 AM	00	17	45	00	OBSS starboard wing survey
Tue 08:23 AM	00	17	55	00	Spacesuit checkout
Tue 10:08 AM	00	19	40	00	Crew meals begin
Tue 11:08 AM	00	20	40	00	OBSS nose cap survey
Tue 11:08 AM	00	20	40	00	Spacesuit prepped for transfer to station
Tue 11:58 AM	00	21	30	00	OBSS port wing survey
Tue 02:13 PM	00	23	45	00	SRMS berths OBSS
Tue 03:08 PM	01	00	40	00	SRMS grapples ELC1
Tue 03:23 PM	01	00	55	00	OMS pod survey
Tue 03:28 PM	01	01	00	00	Centerline camera setup
Tue 03:33 PM	01	01	05	00	LDRI downlink
Tue 03:58 PM	01	01	30	00	Orbiter docking system ring extension
Tue 04:28 PM	01	02	00	00	Rendezvous tools checkout

DATE/ET	DD	HH	MM	SS	EVENT
Tue 05:45 PM	01	03	17	39	NC-3 rendezvous rocket firing
Tue 08:28 PM	01	06	00	00	Crew sleep begins
Flight Day 3					
11/18/09					
Wed 04:28 AM	01	14	00	00	STS/ISS crew wakeup
Wed 05:53 AM	01	15	25	00	Group B computer powerup
Wed 06:08 AM	01	15	40	00	Rendezvous timeline begins
Wed 06:28 AM	01	16	00	00	ISS daily planning conference
Wed 07:36 AM	01	17	08	38	NC-4 rendezvous rocket firing
Wed 07:58 AM	01	17	30	00	Spacesuits removed from airlock
Wed 09:08 AM	01	18	40	30	TI burn
Wed 11:56 AM	01	21	28	00	DOCKING
Wed 12:18 PM	01	21	50	00	Leak checks
Wed 12:38 PM	01	22	10	00	Post docking laptop reconfig
Wed 12:48 PM	01	22	20	00	Orbiter docking system prepped for ingress
Wed 12:48 PM	01	22	20	00	Group B computer powerdown
Wed 01:08 PM	01	22	40	00	Hatch open
Wed 01:53 PM	01	23	25	00	Welcome aboard!
Wed 02:03 PM	01	23	35	00	Safety briefing
Wed 02:33 PM	02	00	05	00	Spacesuits moved to ISS
Wed 02:33 PM	02	00	05	00	SRMS unberths ELC1
Wed 02:38 PM	02	00	10	00	EVA-1: Tools configured
Wed 03:13 PM	02	00	45	00	SSRMS grapples ELC1
Wed 03:38 PM	02	01	10	00	SRMS ungrapples ELC1
Wed 03:48 PM	02	01	20	00	SSRMS moves ELC1 to install point
Wed 04:08 PM	02	01	40	00	EVA-1: Equipment lock preps
Wed 04:23 PM	02	01	55	00	EVA-1: Procedures review
Wed 04:38 PM	02	02	10	00	SSRMS installs ELC1
Wed 05:43 PM	02	03	15	00	ISS evening planning conference
Wed 06:53 PM	02	04	25	00	EVA-1: Mask/pre-breathe
Wed 07:33 PM	02	05	05	00	EVA-1: Airlock depress to 10.2 psi
Wed 07:58 PM	02	05	30	00	ISS crew sleep begins
Wed 08:28 PM	02	06	00	00	STS crew sleep begins
Flight Day 4					
11/19/09					
Thu 04:28 AM	02	14	00	00	Crew wakeup
Thu 05:03 AM	02	14	35	00	EVA-1: 14.7 psi repress/hygiene break
Thu 05:48 AM	02	15	20	00	EVA-1: Airlock depress to 10.2 psi
Thu 05:58 AM	02	15	30	00	ISS daily planning conference
Thu 06:13 AM	02	15	45	00	EVA-1: Campout EVA preps
Thu 07:43 AM	02	17	15	00	EVA-1: Spacesuit purge
Thu 07:58 AM	02	17	30	00	EVA-1: Spacesuit prebreathe
Thu 08:48 AM	02	18	20	00	EVA-1: Crew lock depressurization
Thu 09:18 AM	02	18	50	00	EVA-1: Spacesuits to battery power
Thu 09:23 AM	02	18	55	00	EVA-1: Airlock egress/setup
Thu 09:48 AM	02	19	20	00	EVA-1: Spare SASA install
Thu 12:33 PM	02	22	05	00	EVA-1/Satcher: PAO lube

DATE/ET	DD	HH	MM	SS	EVENT
Thu 12:33 PM	02	22	05	00	EVA-1/Foreman: SGANT cable install
Thu 01:23 PM	02	22	55	00	EVA-1/Foreman: NH3 bracket install
Thu 01:48 PM	02	23	20	00	EVA-1/Satcher: JEM RMS EE lube
Thu 02:03 PM	02	23	35	00	EVA-1/Foreman: Node 1/FGB MMOD shield
Thu 02:48 PM	03	00	20	00	EVA-1/Foreman: S0 1/4 cable
Thu 03:03 PM	03	00	35	00	EVA-1/Satcher: Cleanup and ingress
Thu 03:18 PM	03	00	50	00	EVA-1/Foreman: Cleanup and airlock ingress
Thu 03:48 PM	03	01	20	00	EVA-1: Airlock pressurization
Thu 04:03 PM	03	01	35	00	Spacesuit servicing
Thu 05:13 PM	03	02	45	00	ISS evening planning conference
Thu 07:28 PM	03	05	00	00	ISS crew sleep begins
Thu 07:58 PM	03	05	30	00	STS crew sleep begins
Flight Day 5					
11/20/09					
Fri 03:58 AM	03	13	30	00	Crew wakeup
Fri 05:58 AM	03	15	30	00	ISS daily planning conference
Fri 06:08 AM	03	15	40	00	PAO event
Fri 07:43 AM	03	17	15	00	SSRMS grapples OBSS
Fri 08:18 AM	03	17	50	00	SSRMS moves OBSS to handoff position
Fri 08:43 AM	03	18	15	00	Spacesuit swap
Fri 09:03 AM	03	18	35	00	SRMS grapples OBSS
Fri 09:18 AM	03	18	50	00	SSRMS ungrapples OBSS
Fri 09:48 AM	03	19	20	00	Crew meals begin
Fri 10:03 AM	03	19	35	00	Focused inspection
Fri 10:43 AM	03	20	15	00	EVA-2: Equipment lock preps
Fri 11:33 AM	03	21	05	00	EVA-2: Tools configured
Fri 01:33 PM	03	23	05	00	SSRMS grapples OBSS
Fri 01:43 PM	03	23	15	00	SRMS ungrapples OBSS
Fri 01:58 PM	03	23	30	00	SSRMS berths OBSS
Fri 02:48 PM	04	00	20	00	SSRMS grapples PDGF-1
Fri 03:23 PM	04	00	55	00	EVA-2: Procedures review
Fri 04:38 PM	04	02	10	00	PAO event
Fri 04:43 PM	04	02	15	00	Evening planning conference
Fri 05:53 PM	04	03	25	00	EVA-2: Mask pre-breathe
Fri 06:33 PM	04	04	05	00	EVA-2: Airlock depress to 10.2 psi
Fri 06:58 PM	04	04	30	00	ISS crew sleep begins
Fri 07:28 PM	04	05	00	00	STS crew sleep begins
Flight Day 6					
11/21/09					
Sat 03:28 AM	04	13	00	00	Crew wakeup
Sat 04:03 AM	04	13	35	00	EVA-2: 14.7 psi repress/hygiene break
Sat 04:48 AM	04	14	20	00	EVA-2: Airlock depress to 10.2 psi
Sat 05:13 AM	04	14	45	00	EVA-2: Campout EVA preps
Sat 05:28 AM	04	15	00	00	ISS daily planning conference
Sat 05:58 AM	04	15	30	00	SRMS grapples ELC2
Sat 06:13 AM	04	15	45	00	SRMS unberths ELC2
Sat 06:43 AM	04	16	15	00	EVA-2: Spacesuit purge

DATE/ET	DD	HH	MM	SS	EVENT
Sat 06:53 AM	04	16	25	00	SSRMS grapples ELC2
Sat 06:58 AM	04	16	30	00	EVA-2: Spacesuit prebreathe
Sat 07:08 AM	04	16	40	00	SRMS ungrapples ELC2
Sat 07:48 AM	04	17	20	00	EVA-2: Crew lock depressurization
Sat 08:18 AM	04	17	50	00	EVA-2: Spacesuits to battery power
Sat 08:23 AM	04	17	55	00	EVA-2: Airlock egress
Sat 08:48 AM	04	18	20	00	EVA-2: GATOR install
Sat 09:08 AM	04	18	40	00	SSRMS installs ELC2
Sat 09:53 AM	04	19	25	00	SSRMS grapples MBS-1
Sat 10:03 AM	04	19	35	00	EVA-2: FPMU relocate
Sat 11:33 AM	04	21	05	00	EVA-2: S3 nadir PAS deploy
Sat 01:03 PM	04	22	35	00	EVA-2: CP1 WETA install
Sat 01:48 PM	04	23	20	00	EVA-2: Get aheads
Sat 01:58 PM	04	23	30	00	SSRMS releases MBS-2
Sat 02:28 PM	05	00	00	00	EVA-2: Cleanup and ingress
Sat 02:48 PM	05	00	20	00	EVA-2: Airlock repressurization
Sat 03:03 PM	05	00	35	00	Spacesuit servicing
Sat 04:13 PM	05	01	45	00	Evening planning conference
Sat 06:28 PM	05	04	00	00	ISS crew sleep begins
Sat 06:58 PM	05	04	30	00	STS crew sleep begins
Flight Day 7					
11/22/09					
Sun 02:58 AM	05	12	30	00	Crew wakeup
Sun 04:58 AM	05	14	30	00	ISS daily planning conference
Sun 06:08 AM	05	15	40	00	Shuttle crew off duty
Sun 10:08 AM	05	19	40	00	Crew meals
Sun 10:08 AM	05	19	40	00	Spacesuit swap
Sun 11:53 AM	05	21	25	00	PAO event
Sun 12:08 PM	05	21	40	00	Equipment lock preps
Sun 12:38 PM	05	22	10	00	EVA-3: Tools configured
Sun 02:03 PM	05	23	35	00	PAO event
Sun 02:23 PM	05	23	55	00	EVA-3: Procedures review
Sun 03:43 PM	06	01	15	00	Evening planning conference
Sun 04:53 PM	06	02	25	00	EVA-3: Mask pre-breathe
Sun 05:33 PM	06	03	05	00	EVA-3: Airlock depress to 10.2 psi
Sun 05:58 PM	06	03	30	00	ISS crew sleep begins
Sun 06:28 PM	06	04	00	00	STS crew sleep begins
Flight Day 8					
11/23/09					
Mon 02:28 AM	06	12	00	00	STS/ISS crew wakeup
Mon 03:03 AM	06	12	35	00	EVA-3: 14.7 psi repress/hygiene break
Mon 03:48 AM	06	13	20	00	EVA-3: Airlock depress to 10.2 psi
Mon 04:03 AM	06	13	35	00	ISS daily planning conference
Mon 04:13 AM	06	13	45	00	EVA-3: Campout EVA preps
Mon 05:43 AM	06	15	15	00	EVA-3: Spacesuit purge
Mon 05:58 AM	06	15	30	00	EVA-3: Spacesuit prebreathe
Mon 06:48 AM	06	16	20	00	EVA-3: Crew lock depressurization

DATE/ET	DD	HH	MM	SS	EVENT
Mon 07:18 AM	06	16	50	00	EVA-3: Spacesuits to battery power
Mon 07:23 AM	06	16	55	00	EVA-3: Airlock egress/setup
Mon 07:48 AM	06	17	20	00	EVA-3: HPGT transfer and MISSE 7
Mon 10:48 AM	06	20	20	00	EVA-3: S3 zenith PAS deploy
Mon 11:48 AM	06	21	20	00	EVA-3/Satcher: Get aheads
Mon 12:18 PM	06	21	50	00	EVA-3/Bresnik: Airlock MMOD shields
Mon 12:48 PM	06	22	20	00	EVA-3/Bresnik: Get aheads
Mon 01:18 PM	06	22	50	00	EVA-3: Cleanup and ingress
Mon 01:48 PM	06	23	20	00	EVA-3: Airlock repressurization
Mon 02:03 PM	06	23	35	00	Spacesuit servicing
Mon 03:13 PM	07	00	45	00	Evening planning conference
Mon 05:28 PM	07	03	00	00	ISS crew sleep begins
Mon 05:58 PM	07	03	30	00	STS crew sleep begins

Flight Day 9

DATE/ET	DD	HH	MM	SS	EVENT
11/24/09					
Tue 01:58 AM	07	11	30	00	Crew wakeup
Tue 02:58 AM	07	12	30	00	ISS daily planning conference
Tue 04:13 AM	07	13	45	00	Post-EVA reconfig/transfer
Tue 04:48 AM	07	14	20	00	Reboost operations
Tue 05:43 AM	07	15	15	00	EVA transfer to shuttle
Tue 01:13 PM	07	22	45	00	Rendezvous tools checkout
Tue 08:13 AM	07	17	45	00	Crew news conference
Tue 08:53 AM	07	18	25	00	Joint crew photo
Tue 09:13 AM	07	18	45	00	Joint crew meal
Tue 10:13 AM	07	19	45	00	Crew off duty
Tue 12:28 PM	07	22	00	00	Farewell ceremony
Tue 12:43 PM	07	22	15	00	Hatches closed
Tue 01:13 PM	07	22	45	00	Centerline camera install
Tue 01:13 PM	07	22	45	00	ODS leak checks
Tue 03:43 PM	08	01	15	00	Evening planning conference
Tue 05:28 PM	08	03	00	00	STS crew sleep begins
Tue 05:28 PM	08	03	00	00	ISS crew sleep begins

Flight Day 10

DATE/ET	DD	HH	MM	SS	EVENT
11/25/09					
Wed 01:28 AM	08	11	00	00	ISS crew wakeup
Wed 01:58 AM	08	11	30	00	STS crew wakeup
Wed 03:23 AM	08	12	55	00	Group B computer powerup
Wed 03:28 AM	08	13	00	00	ISS daily planning conference
Wed 03:43 AM	08	13	15	00	Maneuver to undocking attitude
Wed 04:13 AM	08	13	45	00	Undocking timeline begins
Wed 04:57 AM	08	14	29	00	UNDOCKING
Wed 04:58 AM	08	14	30	00	Initial separation
Wed 06:12 AM	08	15	44	00	Separation burn 1
Wed 06:40 AM	08	16	12	00	Separation burn 2
Wed 06:48 AM	08	16	20	00	Post-undocking PGSC reconfig
Wed 07:03 AM	08	16	35	00	Group B computer powerdown
Wed 07:18 AM	08	16	50	00	Crew meals begin

DATE/ET	DD	HH	MM	SS	EVENT
Wed 08:18 AM	08	17	50	00	OBSS starboard wing survey
Wed 08:18 AM	08	17	50	00	EVA unpack and stow
Wed 09:48 AM	08	19	20	00	PST ISS EVA entry preps
Wed 11:03 AM	08	20	35	00	Nose cap survey
Wed 11:53 AM	08	21	25	00	Port wing survey
Wed 01:38 PM	08	23	10	00	OBSS berthing
Wed 01:38 PM	08	23	10	00	LDRI downlink
Wed 02:38 PM	09	00	10	00	SRMS powerdown
Wed 05:28 PM	09	03	00	00	STS crew sleep begins
Flight Day 11					
11/26/09					
Thu 01:28 AM	09	11	00	00	STS crew wakeup
Thu 05:23 AM	09	14	55	00	Cabin stow begins
Thu 05:38 AM	09	15	10	00	FCS checkout
Thu 06:48 AM	09	16	20	00	RCS hotfire
Thu 07:03 AM	09	16	35	00	PILOT operations
Thu 08:03 AM	09	17	35	00	Deorbit review
Thu 08:33 AM	09	18	05	00	PAO event
Thu 08:53 AM	09	18	25	00	Crew meal
Thu 09:53 AM	09	19	25	00	Cabin stow resumes
Thu 12:58 PM	09	22	30	00	Ergometer stow
Thu 01:28 PM	09	23	00	00	Recumbent seat setup
Thu 01:58 PM	09	23	30	00	LES checkout
Thu 02:03 PM	09	23	35	00	Wing leading edge sensor deact
Thu 02:28 PM	10	00	00	00	KU antenna stow
Thu 02:38 PM	10	00	10	00	PGSC stow (part 1)
Thu 05:28 PM	10	03	00	00	Crew sleep begins
Flight Day 12					
11/27/09					
Fri 01:28 AM	10	11	00	00	Crew wakeup
Fri 03:53 AM	10	13	25	00	Group B computer powerup
Fri 04:08 AM	10	13	40	00	IMU alignment
Fri 04:43 AM	10	14	15	00	Deorbit timeline begins
Fri 08:44:04 AM	10	18	16	00	Deorbit ignition (rev. 171)
Fri 09:47:04 AM	10	19	19	00	Landing

STS-129 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 EST GMT

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THURSDAY, NOVEMBER 12...
...MRM-2 DOCKING TO ISS COVERAGE.......................10:00 AM...15:00
...EXPEDITION 21 ISS COMMENTARY........................11:00 AM...16:00
...STS-129 CREW ARRIVAL................................12:00 PM...17:00
...VIDEO FILE..........................................01:00 PM...18:00

FRIDAY, NOVEMBER 13...
...COUNTDOWN STATUS BRIEFING...........................10:00 AM...15:00
...EXPEDITION 21 ISS COMMENTARY........................11:00 AM...16:00
...VIDEO FILE..........................................12:00 PM...17:00

SATURDAY, NOVEMBER 14...
...STS-129 PRELAUNCH NEWS CONFERENCE...................11:00 AM...16:00

SUNDAY, NOVEMBER 15
...COUNTDOWN STATUS BRIEFING...........................10:00 AM...15:00
...ISS SCIENCE BRIEFING................................01:00 PM...18:00
...ROTATING SERVICE STRUCTURE RETRACTION...............05:30 PM...22:30

MONDAY, NOVEMBER 16 - FD 1
...STS-129 FUELING COVERAGE BEGINS.....................05:00 AM...10:00
...STS-129 LAUNCH COVERAGE BEGINS......................09:30 AM...14:30
...LAUNCH..................................00/00:00...02:28 PM...19:28
...MECO....................................00/00:08...02:36 PM...19:36
1...LAUNCH REPLAYS.........................00/00:13...02:41 PM...19:41
1...ADDITIONAL LAUNCH REPLAYS FROM KSC.......00/00:45...03:13 PM...20:13
1...POST LAUNCH NEWS CONFERENCE.............00/01:02...03:30 PM...20:30
2...PAYLOAD BAY DOOR OPENING................00/01:25...03:53 PM...20:53
3...RMS CHECKOUT............................00/03:45...06:13 PM...23:13
3...ASCENT FLIGHT CONTROL TEAM VIDEO REPLAY..00/04:02...06:30 PM...23:30
4...EXTERNAL TANK HANDHELD VIDEO DOWNLINK....00/04:35...07:03 PM...00:03
5...ATLANTIS CREW SLEEP BEGINS..............00/06:00...08:28 PM...01:28
5...FLIGHT DAY 1 HIGHLIGHTS.................00/06:32...09:00 PM...02:00

TUESDAY, NOVEMBER 17 - FD 2
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ORBIT	EVENT	MET	EST	GMT
10	ATLANTIS CREW WAKE UP (FD 2)	00/14:00	04:28 AM	09:28
11	VIDEO FILE	00/15:32	06:00 AM	11:00
12	OBSS UNBERTH	00/16:30	06:58 AM	11:58
12	RMS/OBSS SURVEY OF ATLANTIS TPS BEGINS	00/17:45	08:13 AM	13:13
12	EMU CHECKOUT	00/17:55	08:23 AM	13:23
14	WISE PRELAUNCH NEWS CONFERENCE	00/21:32	12:00 PM	17:00
	(EDUCATION CHANNEL)			
16	MISSION STATUS BRIEFING	00/23:32	02:00 PM	19:00
16	OBSS BERTH	00/23:45	02:13 PM	19:13
17	SRMS GRAPPLES ELC 1	01/00:40	03:08 PM	20:08
17	RMS OMS POD SURVEY	01/00:55	03:23 PM	20:23
17	CENTERLINE CAMERA INSTALLATION	01/01:00	03:28 PM	20:28
17	ODS RING EXTENSION	01/01:30	03:58 PM	20:58
18	RENDEZVOUS TOOL CHECKOUT	01/02:00	04:28 PM	21:28
18	POST MMT BRIEFING	01/02:32	05:00 PM	22:00
21	ATLANTIS CREW SLEEP BEGINS	01/06:00	08:28 PM	01:28
21	FLIGHT DAY 2 HIGHLIGHTS	01/06:32	09:00 PM	02:00
	WEDNESDAY, NOVEMBER 18 - FD 3			
26	ATLANTIS CREW WAKE UP (FD 3)	01/14:00	04:28 AM	09:28
27	RENDEZVOUS OPERATIONS BEGIN	01/15:40	06:08 AM	11:08
27	VIDEO FILE	01/15:32	06:00 AM	11:00
29	TI BURN	01/18:35	09:03 AM	14:03
30	ATLANTIS RPM	01/20:27	10:55 AM	15:55
30	ATLANTIS/ISS DOCKING	01/21:25	11:53 AM	16:53
30	SHUTTLE VTR PLAYBACK OF DOCKING	01/21:50	12:18 PM	17:18
32	ATLANTIS/ISS CREW HATCH OPENING	01/23:25	01:53 PM	18:53
33	MISSION STATUS BRIEFING	02/00:02	02:30 PM	19:30
32	SRMS UNBERTH ELC1	02/00:05	02:33 PM	19:33
33	SRMS HANDOFF ELC1 TO SSRMS	02/00:45	03:13 PM	20:13
33	EVA # 1 PROCEDURE REVIEW	02/01:55	04:23 PM	21:23
34	INSTALLATION OF ELC1 ON P3 NADIR UCCAS	02/02:10	04:38 PM	21:38
34	POST-MMT BRIEFING	02/02:32	05:00 PM	22:00
35	EVA # 1 CAMPOUT BEGINS	02/04:25	06:53 PM	23:53
36	ISS CREW SLEEP BEGINS	02/05:30	07:58 PM	00:58
36	ATLANTIS CREW SLEEP BEGINS	02/06:00	08:28 PM	01:28
37	FLIGHT DAY 3 HIGHLIGHTS)	02/06:32	09:00 PM	02:00
38	HD FLIGHT DAY 3 CREW HIGHLIGHTS	02/08:32	11:00 PM	04:00
	THURSDAY, NOVEMBER 19 - FD 4			
41	ISS FLIGHT DIRECTOR UPDATE	02/11:32	02:00 AM	07:00
41	ISS FLIGHT DIRECTOR UPDATE REPLAY	02/13:02	03:30 AM	08:30
41	ATLANTIS/ISS CREW WAKE UP (FD 4)	02/14:00	04:28 AM	09:28
42	EVA # 1 PREPARATIONS RESUME	02/14:35	05:03 AM	10:03
43	VIDEO FILE	02/15:32	06:00 AM	11:00
45	EVA # 1 BEGINS (Foreman and Satcher)	02/18:50	09:18 AM	14:18
45	SPARE SASA INSTALLATION ON Z1 TRUSS	02/19:20	09:48 AM	14:48
47	MBS POA LUBRICATION	02/22:05	12:33 PM	17:33
47	SGANT CABLE ROUTING	02/22:05	12:33 PM	17:33
47	SLIDE WIRE REMOVAL/NH3 BRACKET INSTALL	02/23:00	01:28 PM	18:28
47	JEM RMS EE LUBRICATION	02/23:20	01:48 PM	18:48
48	SSRMS BASE CHANGE	03/00:35	03:03 PM	20:03

ORBIT EVENT **MET** **EST** **GMT**

49...EVA # 1 ENDS............................03/01:20...03:48 PM...20:48
50...MISSION STATUS/POST-MMT BRIEFING........03/03:02...05:30 PM...22:30
51...ISS CREW SLEEP BEGINS...................03/05:00...07:28 PM...00:28
52...ATLANTIS CREW SLEEP BEGINS..............03/05:30...07:58 PM...00:58
52...FLIGHT DAY 4 HIGHLIGHTS)................03/05:32...08:00 PM...01:00
54...HD FLIGHT DAY 4 CREW HIGHLIGHTS ....03/08:32...11:00 PM...04:00

FRIDAY, NOVEMBER 20 - FD 5
56...ISS FLIGHT DIRECTOR UPDATE..............03/11:02...01:30 AM...06:30
56...ISS FLIGHT DIRECTOR UPDATE REPLAY.......03/13:02...03:30 AM...08:30
57...ATLANTIS/ISS CREW WAKE UP (FD 5)........03/13:30...03:58 AM...08:58
58...U.S. PAO EVENT..........................03/15:40...06:08 AM...11:08
59...VIDEO FILE..............................03/16:32...07:00 AM...12:00
59...SSRMS GRAPPLE & UNBERTH OBSS...........03/17:15...07:43 AM...12:43
60...SSRMS HANDFF OBSS TO SRMS...............03/18:50...09:18 AM...14:18
61...OBSS FOCUSED INSPECTION.................03/19:35...10:03 AM...15:03
63...SRMS HANDOFF TO SSRMS...................03/23:05...01:33 PM...18:33
64...EVA # 2 PROCEDURE REVIEW................04/00:55...03:23 PM...20:23
65...SRMS GRAPPLE OF ELC 2...................04/01:20...03:48 PM...20:48
65...U.S. PAO EVENT..........................04/02:10...04:38 PM...21:38
65...MISSION STATUS BRIEFING.................04/02:47...05:15 PM...22:15
66...EVA # 2 CAMPOUT BEGINS..................04/03:25...05:53 PM...22:53
67...ISS CREW SLEEP BEGINS...................04/04:30...06:58 PM...23:58
67...ATLANTIS CREW SLEEP BEGINS..............04/05:00...07:28 PM...00:28
68...FLIGHT DAY 5 HIGHLIGHTS.................04/05:32...08:00 PM...01:00
69...HD FLIGHT DAY 5 CREW HIGHLIGHTS.........04/07:32...10:00 PM...03:00

SATURDAY, NOVEMBER 21 - FD 6
71...ISS FLIGHT DIRECTOR UPDATE..............04/10:32...01:00 AM...06:00
72...ISS FLIGHT DIRECTOR UPDATE REPLAY.......04/12:02...02:30 AM...07:30
72...ATLANTIS/ISS CREW WAKE UP (FD 6)........04/13:00...03:28 AM...08:28
73...EVA # 2 PREPARATIONS RESUME.............04/13:30...03:58 AM...08:58
74...SRMS UNBERTH ELC2.......................04/15:45...06:13 AM...11:13
75...SRMS HANDOFF ELC2 TO SSRMS..............04/16:40...07:08 AM...12:08
75...EVA # 2 BEGINS (Foreman and Bresnik)....04/17:50...08:18 AM...13:18
76...GATOR HAM RADIO BRACKET INSTALLATION....04/18:20...08:48 AM...13:48
76...SSRMS INSTALLATION OF ELC2..............04/18:40...09:08 AM...14:08
78...SSRMS BASE CHANGE.......................04/19:25...09:53 AM...14:53
78...FPMU RELOCATION FROM S1 TO P1 TRUSS.....04/19:35...10:03 AM...15:03
78...S3 NADIR PAS DEPLOY.....................04/21:05...11:33 AM...16:33
79...CAMERA POSITION 1 WETA INSTALL..........04/22:35...01:03 PM...18:03
80...EVA # 2 ENDS............................05/00:20...02:48 PM...19:48
80...MISSION STATUS BRIEFING.................05/02:02...04:30 PM...21:30
82...ISS CREW SLEEP BEGINS...................05/04:00...06:28 PM...23:28
82...ATLANTIS CREW SLEEP BEGINS..............05/04:30...06:58 PM...23:58
83...FLIGHT DAY 6 HIGHLIGHTS.................05/04:32...07:00 PM...00:00
85...HD FLIGHT DAY 6 CREW HIGHLIGHTS.........05/07:32...10:00 PM...03:00
86...ISS FLIGHT DIRECTOR UPDATE..............05/10:02...12:30 AM...05:30

SUNDAY, NOVEMBER 22 - FD 7
87...ISS FLIGHT DIRECTOR UPDATE REPLAY.......05/12:02...02:30 AM...07:30
88...ATLANTIS/ISS CREW WAKE UP (FD 7)........05/12:30...02:58 AM...07:58

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ORBIT  EVENT                                      MET        EST        GMT

90...ATLANTIS OFF-DUTY PERIOD BEGINS.........05/15:40...06:08 AM...11:08
93...U.S. PAO EVENT..........................05/21:25...11:53 AM...16:53
95...U.S. PAO EVENT..........................05/23:35...02:03 PM...19:03
95...EVA # 3 PROCEDURE REVIEW................05/23:55...02:23 PM...19:23
96...MISSION STATUS BRIEFING.................06/01:32...04:00 PM...21:00
97...EVA # 3 CAMPOUT BEGINS..................06/02:25...04:53 PM...21:53
97...ISS CREW SLEEP BEGINS...................06/03:30...05:58 PM...22:58
98...ATLANTIS CREW SLEEP BEGINS..............06/04:00...06:28 PM...23:28
98...FLIGHT DAY 7 HIGHLIGHTS.................06/04:32...07:00 PM...00:00
100...HD FLIGHT DAY 8 CREW HIGHLIGHTS........06/07:32...10:00 PM...03:00
102...ISS FLIGHT DIRECTOR UPDATE.............06/09:32...12:00 AM...05:00

MONDAY, NOVEMBER 23 - FD 8
103...ISS FLIGHT DIRECTOR UPDATE REPLAY......06/11:02...01:30 AM...06:30
103...ATLANTIS/ISS CREW WAKE UP (FD 8).......06/12:00...02:28 AM...07:28
103...EVA #3 PREPARATIONS RESUME.............06/12:35...03:03 AM...08:03
106...EVA #3 BEGINS  (Satcher and Bresnik)...06/16:50...07:18 AM...12:18
106...HPGT & MISSE-7 TRANSFER TO QUEST.......06/17:20...07:48 AM...12:48
107...PMA-3 HEATER CABLE STOWAGE.............06/19:50...10:18 AM...15:18
108...S3 INBOARD UPPER PAS DEPLOYMENT........06/20:20...10:48 AM...15:48
110...EVA #3 ENDS............................06/23:20...01:48 PM...18:48
111...MISSION STATUS BRIEFING................07/01:02...03:30 PM...20:30
113...VIDEO FILE.............................07/02:32...05:00 PM...22:00
113...ATLANTIS/ISS CREW SLEEP BEGINS.........07/03:30...05:58 PM...22:58
113...FLIGHT DAY 8 HIGHLIGHTS................07/03:32...06:00 PM...23:00
115...HD FLIGHT DAY 8 CREW HIGHLIGHTS........07/06:32...09:00 PM...02:00
117...ISS FLIGHT DIRECTOR UPDATE.............07/09:02...11:30 PM...04:30

TUESDAY, NOVEMBER 24 - FD 9
118...ISS FLIGHT DIRECTOR UPDATE REPLAY......07/11:02...01:30 AM...06:30
118...ATLANTIS  CREW WAKE UP (FD 9)..........07/11:30...01:58 AM...06:58
118...ISS CREW WAKE UP.......................07/12:00...02:28 AM...07:28
121...ISS REBOOST (If required)..............07/15:20...05:48 AM...10:48
123...JOINT CREW NEWS CONFERENCE.............07/17:45...08:13 AM...13:13
124...ATLANTIS CREW OFF DUTY PERIOD..........07/19:45...10:13 AM...15:13
125...MISSION STATUS BRIEFING................07/20:32...11:00 AM...16:00
125...ATLANTIS/ISS FAREWELL/HATCH CLOSE......07/22:00...12:28 PM...17:28
126...RENDEZVOUS TOOLS CHECKOUT..............07/22:45...01:13 PM...18:13
126...CENTERLINE CAMERA INSTALLATION.........07/22:45...01:13 PM...18:13
128...VIDEO FILE.............................08/00:32...03:00 PM...20:00
129...ATLANTIS/ISS CREW SLEEP BEGINS.........08/03:00...05:28 PM...22:28
129...FLIGHT DAY 9 HIGHLIGHTS................08/03:32...06:00 PM...23:00
130...HD FLIGHT DAY 9 CREW HIGHLIGHTS........08/05:32...08:00 PM...01:00
131...ISS FLIGHT DIRECTOR UPDATE.............08/09:02...11:30 PM...04:30
131...ISS FLIGHT DIRECTOR UPDATE REPLAY......08/10:02...12:30 AM...05:30

WEDNESDAY, NOVEMBER 25 - FD 10
133...ATLANTIS CREW WAKE UP (FD 10)..........08/11:00...01:28 AM...06:28
133...ISS CREW WAKE UP.......................08/11:30...01:58 AM...06:58
135...ATLANTIS UNDOCKS FROM ISS..............08/14:26...04:54 AM...09:54
136...ATLANTIS FLYAROUND OF ISS BEGINS.......08/14:51...05:19 AM...10:19
137...ATLANTIS FINAL SEPARATION FROM ISS.....08/16:09...06:37 AM...11:37
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ORBIT  EVENT                                     MET      EST      GMT

138...SHUTTLE VTR PLAYBACK OF UNDOCKING......08/16:35...07:03 AM...12:03
138...OBSS UNBERTH...........................08/17:50...08:18 AM...13:18
140...RMS/OBSS LATE INSPECTION...............08/18:55...09:23 AM...14:23
141...MISSION STATUS BRIEFING................08/21:02...11:30 AM...16:30
141...OBSS BERTH.............................08/23:10...01:38 PM...18:38
144...VIDEO FILE.............................08/23:32...02:00 PM...19:00
145...POST-MMT BRIEFING......................08/01:02...03:30 PM...20:30
145...ATLANTIS CREW SLEEP BEGINS.............09/03:00...05:28 PM...22:28
146...FLIGHT DAY 10 HIGHLIGHTS...............09/03:32...06:00 PM...23:00
146...HD FLIGHT DAY 10 CREW HIGHLIGHTS.......09/05:32...08:00 PM...01:00

THURSDAY, NOVEMBER 26 - FD 11
150...ATLANTIS CREW WAKE UP (FD 11)..........09/11:00...01:28 AM...06:28
152...CABIN STOWAGE BEGINS...................09/14:55...05:23 AM...10:23
153...FCS CHECKOUT...........................09/15:10...05:38 AM...10:38
154...RCS HOT-FIRE TEST......................09/16:20...06:48 AM...11:48
154...ATLANTIS U.S. PAO EVENT................09/18:05...08:33 AM...13:33
159...MISSION STATUS BRIEFING................09/21:02...11:30 AM...16:30
158...STOTT'S RECUMBENT SEAT SET UP..........09/23:00...01:28 PM...18:28
159...KU-BAND ANTENNA STOWAGE................10/00:00...02:28 PM...19:28
162...ATLANTIS CREW SLEEP BEGINS.............10/03:00...05:28 PM...22:28
162...FLIGHT DAY 11 HIGHLIGHTS...............10/03:32...06:00 PM...23:00
163...HD FLIGHT DAY 11 CREW HIGHLIGHTS.......10/05:32...08:00 PM...01:00

FRIDAY, NOVEMBER 27 - FD 12
166...ATLANTIS CREW WAKE UP (FD 12)..........10/11:00...01:28 AM...06:28
168...ATLANTIS DEORBIT PREPARATIONS BEGIN....10/14:10...04:38 AM...09:38
169...PAYLOAD BAY DOOR CLOSING...............10/15:32...06:00 AM...11:00
170...ATLANTIS DEORBIT BURN..................10/18:12...08:40 AM...13:40
171...MILA C-BAND RADAR ACQUISITION..........10/19:02...09:30 AM...14:30
171...KSC LANDING............................10/19:15...09:43 AM...14:43
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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[8]

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.

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8 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.

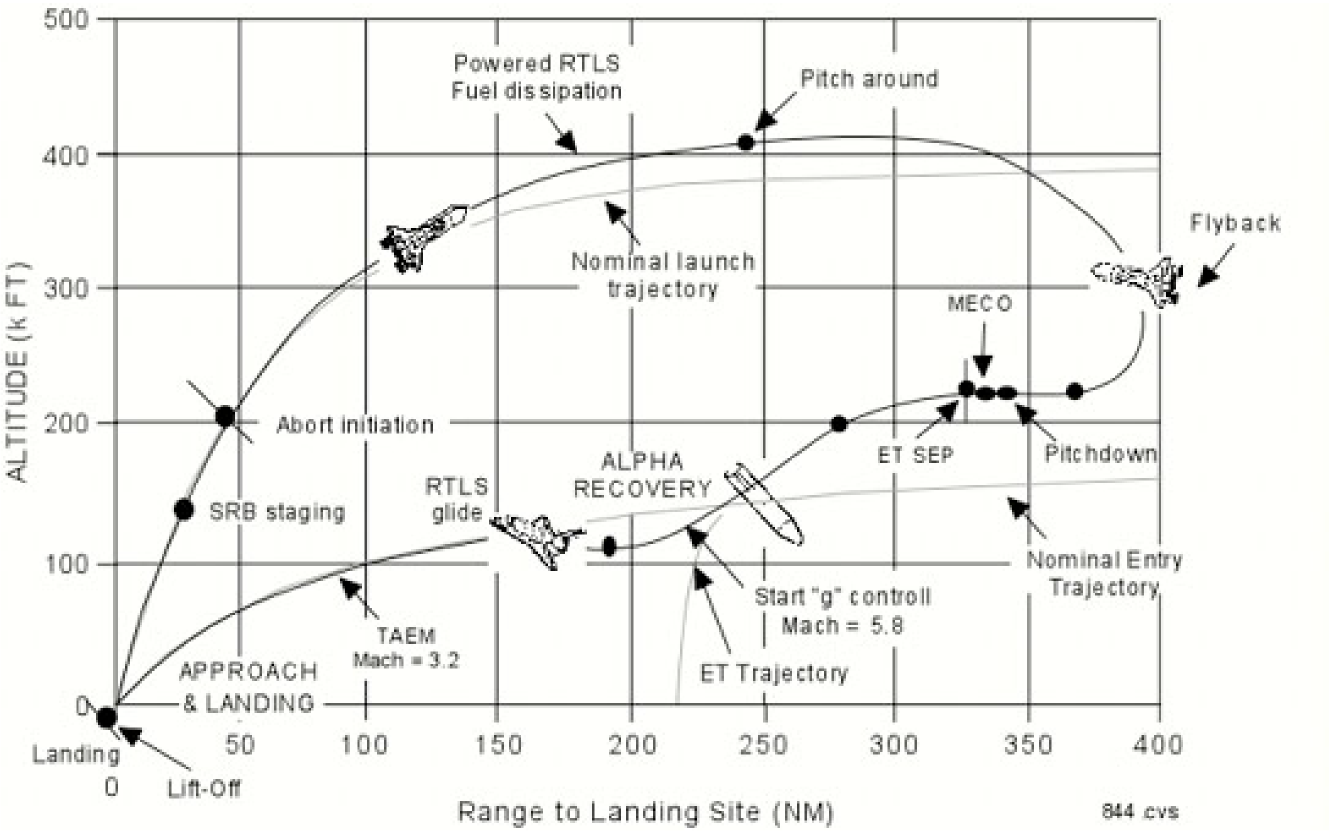
If the problem is a system failure that jeopardizes the vehicle, the fastest abort mode that results in the earliest vehicle landing is chosen. RTLS and TAL are the quickest options (35 minutes), whereas an AOA requires approximately 90 minutes. Which of these is selected depends on the time of the failure 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)[9] 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.

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[9] 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)[10] 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.

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[10] 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.

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Appendix 2: STS-51L and STS-107 Remembering Challenger and Columbia[11]

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.

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11 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.

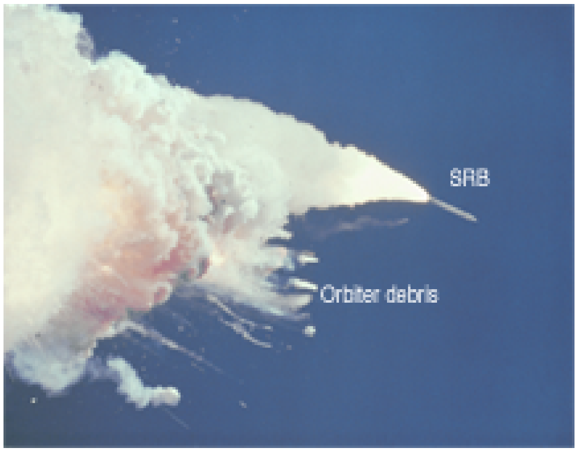
Unlike the shuttle Columbia during its first flights at the dawn of the shuttle era, Challenger was not equipped with ejection seats or other ways for the crew to get out of the spacecraft. McAuliffe's parents, Edward and Grace Corrigan, watching from the VIP site three miles from the launch pad, hugged 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 25^{th} shuttle flight, the 10^{th} 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 whe4n 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.

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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.

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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.

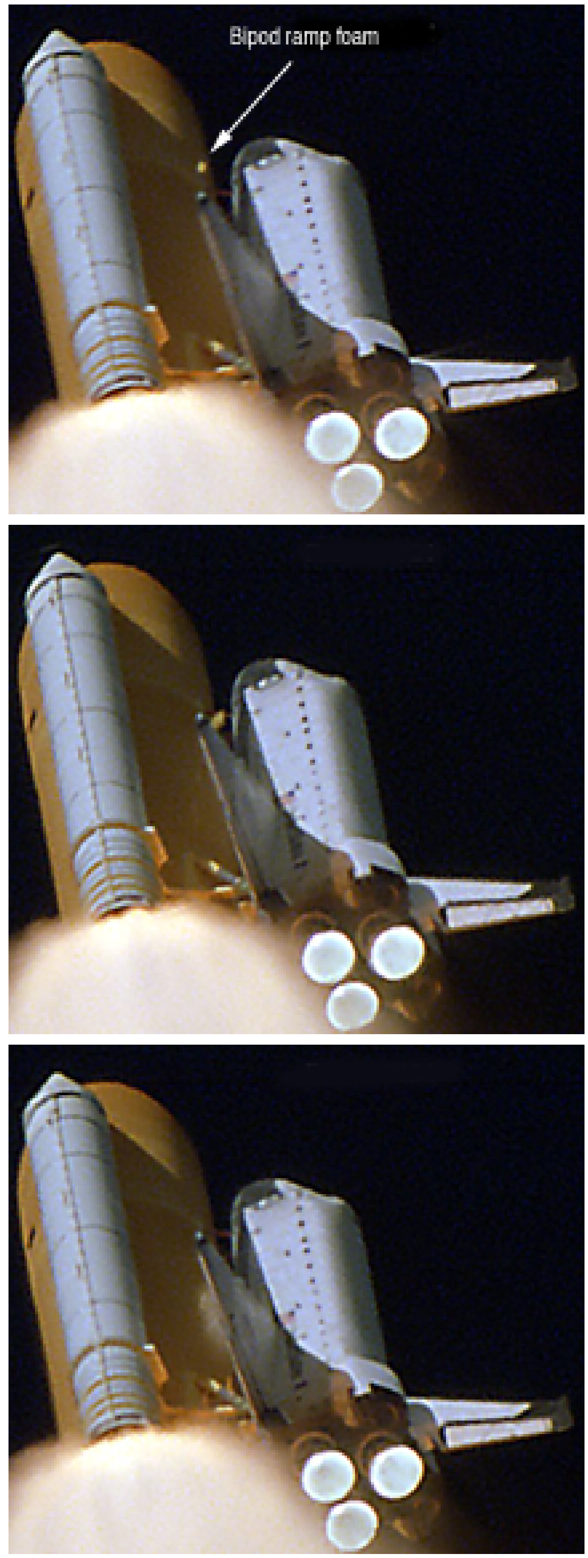
"Today was a very stark reminder this is a very risky endevour, pushing back the frontiers in outer space. Unfortunately, people have a tendency to look at it as something that is more or less routine. I can assure you, it is not.

"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."

❏ ❏ ❏

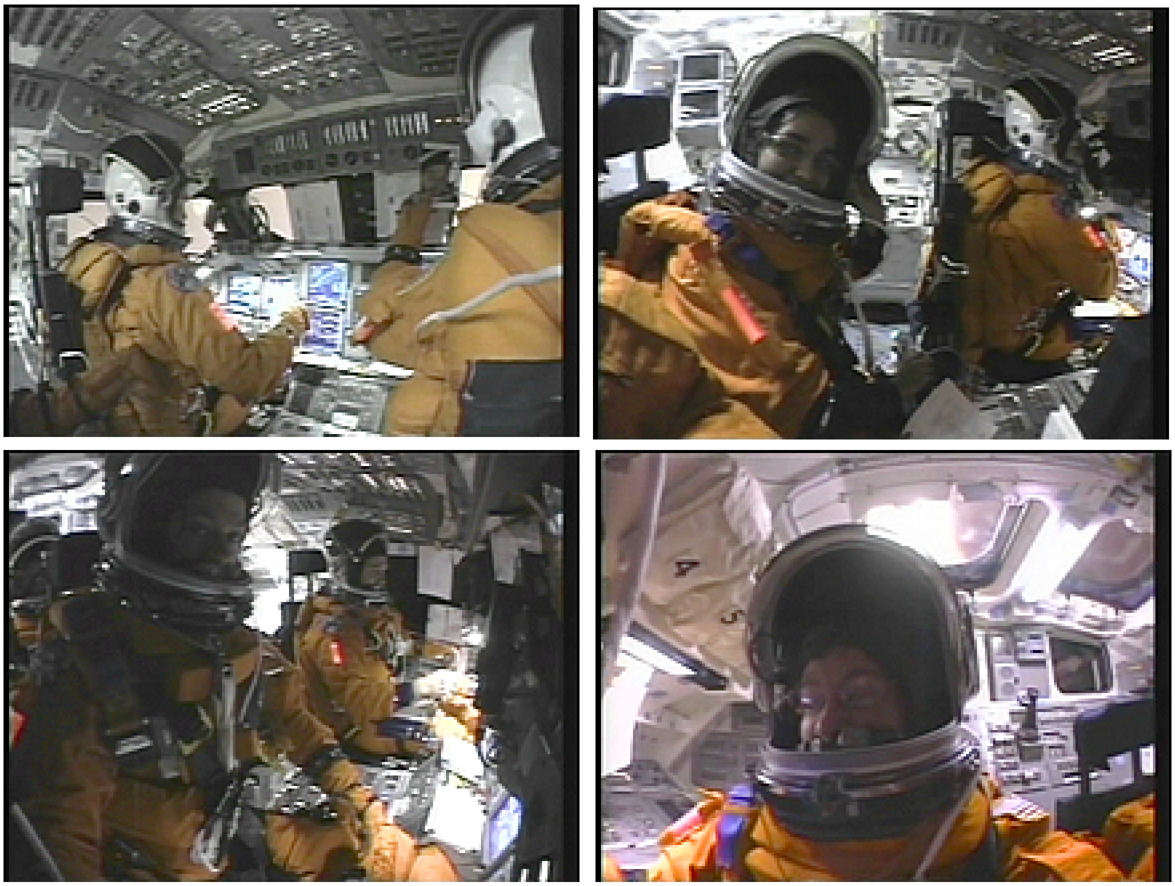
In the days, weeks and months ahead, an investigation of the disaster revealed echoes of Challenger: a long history of foam insulation problems that represented an unrecognized risk; bureaucratic inertia; slipshod internal communications and ineffective management at the top levels of NASA. The Columbia 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.

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

"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."

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 desceased 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 degradaton 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.

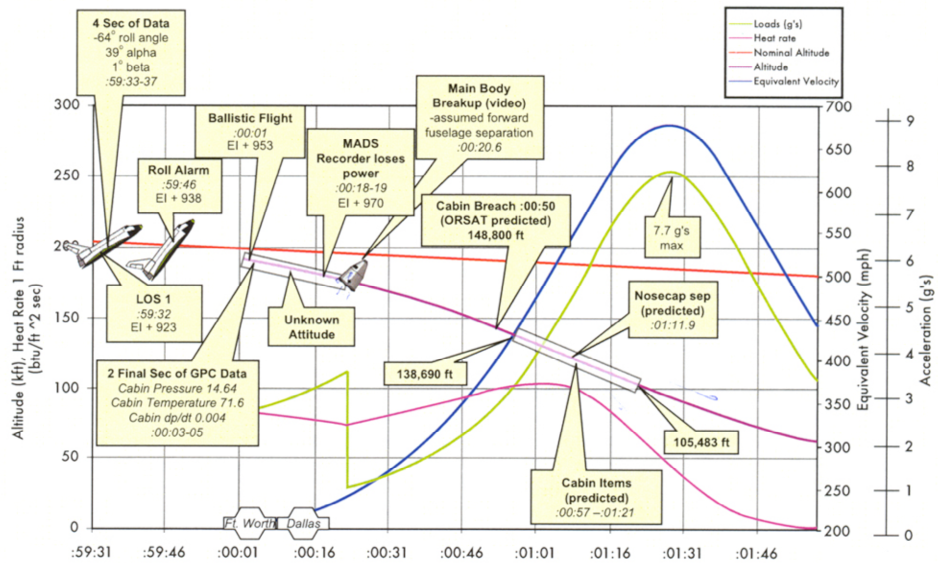
"The SCSIIT investigation was performed with the belief that a comprehensive, respectful investigation could provide knowledge that would improve the safety of future space flight crews and explorers," the group wrote. "By learning these lessons and ensuring that we continue the journey begun by the 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[12]

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

[12] From the NASA STS-129 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