Operations of the Space Shuttle
Texas A&M University
October 7, 2014
Wayne Hale
Director of Human Spaceflight

Notice: Information Subject to Export Control Laws.
This document contains NO “Technical Data” as defined under
The International Traffic in Arms Regulations (ITAR) (22 C. F. R. 120.10).
DTC Case TA 2777-09.

SAS Approved For Release
AKIN’S LAWS
OF SPACECRAFT DESIGN

Engineering is done with numbers. Analysis without numbers is only an opinion. Not having all the information you need is never a satisfactory excuse for not starting the analysis. Space is a completely unforgiving environment. If you screw up the engineering, somebody dies (and there’s no partial credit because most of the analysis was right...)”

*David Akin is Associate Professor, Space Systems Laboratory Director at the University of Maryland*
Agenda

- My Background
- Why Have Mission Control Center
  - Plan, Train, Fly
- Space Shuttle Basics
- Flight Planning
- Trajectory Planning
- System Engineering
My Career in short

- Engineering – Academic Preparation at Rice and Purdue
- Summer Work in the Energy (Oilfield) Business
- Flight Control at NASA
- Flight Director
- Launch Integration Manager for the Space Shuttle Program
- Deputy Program Manager and Chairman of the Mission Management Team
- Program Manager for the Space Shuttle Program
- Deputy Associate Administrator of Space Operations Mission Directorate, NASA HQ
- NASA Retiree – Consulting Engineer, Grandpa, Volunteer
Foundations of Mission Operations

1. To instill within ourselves these qualities essential to professional excellence

   **Discipline**...Being able to follow as well as to lead, knowing that we must master ourselves before we can master our task.

   **Competence**...There being no substitute for total preparation and complete dedication, for space will not tolerate the careless or indifferent.

   **Confidence**...Believing in ourselves as well as others, knowing that we must master fear and hesitation before we can succeed.

   **Responsibility**...Realizing that it cannot be shifted to others, for it belongs to each of us; we must answer for what we do, or fail to do.

   **Toughness**...Taking a stand when we must; to try again, and again, even if it means following a more difficult path.

   **Teamwork**...Respecting and utilizing the abilities of others, realizing that we work toward a common goal, for success depends upon the efforts of all.

   **Vigilance**... Always attentive to the dangers of spaceflight; Never accepting success as a substitute for rigor in everything we do.

2. To always be aware that suddenly and unexpectedly we may find ourselves in a role where our performance has ultimate consequences.

3. To recognize that the greatest error is not to have tried and failed, but that in the trying we do not give it our best effort.
Why Have a Mission Control?

- **Safety:** The Shuttle is the most complicated flying machine ever built. Depending on the phase of flight, there are up to 80 people in mission control scrutinizing the vehicle, the systems, the telemetry, and the trends.

- **Flexibility:** The Mission Control’s flight controllers have worked for months to understand the needs of the Shuttle customers, what they want, and how best to do it. They also understand the criteria for choosing between various means of assuring mission success. As a result, they can make changes to flight plans to account for unexpected events.

- **Let the crews focus on their jobs:** Because the mission control center does all the jobs that can be done on the ground, the astronauts can focus on those things that can only be done in space.

- **Some jobs can only be done on the ground:** Mission Control monitors the weather at landing sites, tracks the Shuttle with radar, and does all the other integration work necessary to make every flight work.
What is Mission Control?

Each console manages one subsystem (guidance, electrical, life support, crew medical, timeline…)

Each engineer controller divides time between office and console

Each controller has completed a documented training and evaluation plan for MCC ops, most including computer driven simulation
= Manned 24 x 7 x 365

FLIGHT DIRECTOR

CAPCOM
Crew Communicator

ADCO
Guidance and Control

ETHOS
Life Support

SPARTAN
Thermal & Electrical

CRONUS
Flight Computers, Communications

OSO
In Flight Maintenance

ISE
Visiting Vehicle Systems

ROBO
Robotics

TOPO
Trajectory

OPS PLAN
Crew Timeline

RIO
Interface to other centers

PLUTO
Onboard Laptops

VVO
Rendezvousing Vehicles

EVA
Spacewalks

SURGEON
BME
Crew Health

ISO
Stowage

GC
Ground Systems
International Space Station

Space Station -
• Assembled in orbit between 1998-2011, manned continuously since 2000
• Components built by hundreds of companies across 16 nations. 100+ launches from Florida, Russia, Japan, and French Guiana
• Research crew of 6 astronauts and cosmonauts serve 6 month stays, rotating 3 at a time from Earth by a Russian Soyuz spacecraft.
THE SPACE SHUTTLE
What is the Space Shuttle?

- World’s first reusable heavy-lift spacecraft
- Launches like a rocket, maneuvers in Earth orbit like a spacecraft and lands like a airplane
- Orbiter design life of 100 missions - 135 missions flown by 5 orbiters
Space Shuttle Capabilities

- Cargo/payload delivery and retrieval
  - Up to 25 tons of payload to orbit
  - Up to 20 tons of payload on re-entry
- On-orbit assembly and service (ISS, HST)
- Crew transfer (ISS)
- Satellite retrieval and repair
- On-orbit, point-to-point maneuvering of people and cargo
- Science payloads/Space Lab/SpaceHab
Space Shuttle Processing Flow

**Orbiter**
- Boeing
  - Huntington Beach, CA
  - Sustaining Eng
  - Modifications
  - ONDR's
- Lands from Previous Mission
- OR
- Demate
- Orbits/SCA Airlift to OPF
- OPF
  - Orbiter Processing Facility
  - Remove Left and Right OMS Pods to the IMB
  - (If Required)
- OR
- Orbiter De-Servicing/Cargo
  - Remove/Transfer Cargo
  - Orbiter Systems Tests and Maintenance
  - Orbiter Integrated Non-Critical Cargo, MCP1 IF Test
- Overhaul
- SSME Shop
  - VAB Low Bay
  - Subsystem Maintenance
- Orbits/ET Mate
- Launch
- VAB
  - Vehicle Assembly Building
- VAB Low Bay
- Tracked to KSC
- SSME Shop
  - SSME
  - Fabrication
  - Assembly
  - Checkout
- S exploring Space Center
  - Canoga Park, CA
  - Fabrication
  - Assembly
  - Checkout
- SSME
  - Fabrication
  - Assembly
  - Checkout
  - Test
  - Green Run
  - Screen Run
- VAB
  - Vehicle Assembly Building
  - Tracked to KSC
  - SSME Shop
  - SSME
  - Fabrication
  - Assembly
  - Checkout
  - VAB Low Bay
  - Subsystem Maintenance
  - Orbits/ET Mate
  - Launch

**ET**
- Lockheed Martin
  - New Orleans, LA
  - Fabrication
  - Assembly
  - Checkout
- ET
  - Barge to KSC
  - VAB
  - Vehicle Assembly Building
  - Tracked to KSC

**RSRM**
- Thiokol Space Operations
  - Clearfield, UT
  - Post-Flight Inspection
  - Refurbishment
  - Metal Parts Preparation
- RSRM
  - Fabrication
  - Assembly
  - Checkout
  - Case Preparation
  - Insulation and Lining
  - Propellant Mixing and Casting
  - Nozzle Manufacturing
  - Ignition System Fabrication
  - Final Assembly
- RSRM
  - Fabrication
  - Assembly
  - Checkout
  - Case Preparation
  - Insulation and Lining
  - Propellant Mixing and Casting
  - Nozzle Manufacturing
  - Ignition System Fabrication
  - Final Assembly

**SRB**
- United Space Alliance
  - Huntsville/KSC
- SRB
  - Fabrication
  - Assembly
  - Checkout
  - Post-Flight Inspection
  - Forward Skirts
  - Frustums
  - RSRM Segments
- SRB
  - Fabrication
  - Assembly
  - Checkout
  - Post-Flight Inspection
  - Forward Skirts
  - Frustums
  - RSRM Segments
- SRB Booster Toward to Cape Canaveral AFS
  - Hangar AF
- SRB
  - Fabrication
  - Assembly
  - Checkout
  - Post-Flight Inspection
  - Forward Skirts
  - Frustums
  - RSRM Segments
- SRB Booster Toward to Cape Canaveral AFS
  - Hangar AF
Orbiter

**Length**: 121 ft (36.9 meters)

**Wingspan**: 78 ft (23.8 meters)

**Dry Weight**: 151,315 lbs (68,635 kg) w/o Main Engines

**Payload Bay**: 60 x 15 ft (18.3 x 4.6 meters)

**Max Payload**: 63,500 lbs (28,803 kg) to low-Earth orbit

*Discovery, OV-103, performs a “pirouet” maneuver while approaching the International Space Station on STS-114.*
Space Shuttle Main Engine (SSME)

- **Length**: 14 ft (4.3 meters)
- **Diameter**: 7.5 ft (2.3 meters)
- **# Per Flight**: 3
- **Propellants**: Liquid hydrogen and liquid oxygen from the External Tank
- **Thrust**: 418,000 lbs (189,600 kg) sea-level
- **ISP**: 452 seconds
- **Lifetime**: 7.5 hours, 55 starts

Main Engines 2045, 2054, and 2056 installed in *Discovery* for STS-121.
Reusable Solid Rocket Motor (RSRM) and Solid Rocket Booster (SRB)

LENGTH 149 ft (45.4 meters)
DIAMETER 12.2 ft (3.7 meters)
# PER FLIGHT 2
PROPELLANT 1.1 million lbs (500,000 kg) of ammonium perchlorate fuel and aluminum oxidizer
THRUST 2.9 million lbs (1.3 million kg)
BURN DURATION 123 seconds

STS-121 Solid Rocket Boosters being stacked in the Vehicle Assembly Building at KSC

Diagram showing SRB Forward Assembly, Igniter, Forward Attach Point, System Tunnel, Propellant, Field Joints, Aft Attach Ring, Aft Skirt, Separation Motors, Nozzle, and SRB Forward Assembly.
Solid Rocket Motor Transportation
The STS-121 External Tank, ET-119, arrives at the Kennedy Space Center in Florida, from the Michoud Assembly Facility in Louisiana.

- **LENGTH**: 153.8 ft (46.9 meters)
- **DIAMETER**: 27.6 ft (8.4 meters)
- **FUEL**: liquid hydrogen 385,265 gallons
- **OXIDIZER**: liquid oxygen 143,351 gallons
- **WEIGHT, EMPTY**: 66,000 lbs (29,937 kg)
- **WEIGHT, FUELED**: 1,655,600 lbs (750,967 kg)
FLIGHT PLANNING

WHAT DO YOU WANT TO DO
AND
WHEN DO YOU WANT TO DO IT?
3.0 PRIMARY FLIGHT REQUIREMENTS

Flight Definition and Requirements Directive (FDRD) controlled requirements are indicated by a single asterisk (*). Requirements impacting ISS Vehicle standardization (reference ISS Std MECSLSI V072-201000, PRCB Directive S061487, PRCB Directive S061751, and DMICB CR M8863) are indicated by a double asterisk (**). Changes to either single or double asterisk items are under PRCB control.

3.1 General Flight Requirements

a. Launch Date: July 13, 2005* Eastern Daylight Time (EDT) / July 13, 2005 Greenwich Mean Time (GMT).

1. Daylight launch is required (see NSTS-21075, Level B Groundrules and Constraints, 4.1.1.c, for specific definition of daylight).
2. Acceptable lighting is required for ET photography. For selecting launch opportunities, acceptable lighting for umbilical well camera photography is required whereas lighting for crew handheld photography is highly desired. Lighting for ET umbilical camera photography (reference section 3.1.m.6) is required from 08:30 to 09:30 (mm:ss) Mission Elapsed Time (MET), and lighting for crew hand-held camera photography (reference section 3.1.m.7) is required from 11:30 to 13:30 MET.

b. Launch Window: The launch time on July 13, 2005* is 15:45 EDT which is 19:45 GMT. The launch window duration is 10 minutes.

Detailed launch window information is included in Level A Groundrules and Constraints.

c. Launch Period: The launch period begins 10 minutes before the launch window opens and ends 10 minutes after the launch window closes.
d. Launch Site: John F. Kennedy Space Center (KSC), Pad B*, MLP-3*

e. Inclination: 51.6 degrees*

f. Altitude: Insertion altitude (direct insertion*) 122 nautical miles (nm)*
Perigee 85 nm
ISS Stage rendezvous altitude 190 nm

g. Space Shuttle Main Engine (SSME) Performance Plan: 104.5% nominal*,
104.5% intact abort*

h. Crew Size: 7 up/0 down*
Workshift: single shift

i. Flight Duration: 12+0+2 *. Nominal duration is 12 days with 8 docked days.
Consumables, crew provisions, and planning will assume a Flight Day 3 rendezvous.
Rendezvous phasing limit calculations will also protect Flight Day 4 rendezvous
capability. The capability will also be provided for two additional days for orbiter
contingency operations and weather avoidance.

j. Landing Sites:
1. Nominal End-of-Mission (EOM):
   Primary - KSC*
   First Alternate - Edwards Air Force Base (EAFB)
   Second Alternate (Backup weather alternate) - White Sands Space Harbor (WSSH)

2. Aborts:
   (a) Return to Launch Site (RTLS): KSC
   (b) Transoceanic Abort Landing (TAL): Primary - Zaragoza* Alternates - Moron and Istres
   (c) Abort-Once-Around (AOA): Primary - KSC, Alternate - WSSH
   (d) Emergency: The Emergency Landing Sites (ELS) available for this flight are listed in the Level A Groundrules and Constraints.

Reference NSTS 07700 Volume X, Book 3, for specific information on all Space Shuttle Landing Sites.

1. Flight-Unique Ground Support Requirements

   Note: For each payload, detailed handling requirements are controlled by the MIP/PIP and/or Annexes S and OMRSD and/or mission-unique Time-critical Ground Handling Requirements (TGHR) table.

1. Launch Site Support Requirements:
   (a) Pre-launch Payload Bay Purge
   (b) Late delivery of Multi-Purpose Logistics Module (MPLM), Unpressurized Cargo Pallet (UCP), and Lightweight Multipurpose Experiment Support Structure Carrier (LMC) to the pad (after Orbiter arrival). Late MPLM stowage access at the pad is not required. Reference LF1 MIP, NSTS 21497.
   (c) The capability to deploy the radiators on orbit is required.
# Flight Definition and Requirements Directive

## Flight Definition and Requirements

<table>
<thead>
<tr>
<th>Activity</th>
<th>FLT DATE</th>
<th>STS-300/LON</th>
<th>STS-121</th>
<th>STS-301/LON</th>
<th>STS-115</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONFIGURATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- ORB (FLT IV)</td>
<td>CV-104(27)</td>
<td>CV-104(27)</td>
<td>CV-103(22)</td>
<td>CV-104(22)</td>
<td></td>
</tr>
<tr>
<td>- ET</td>
<td>ET-120</td>
<td>ET-120</td>
<td>TBO</td>
<td>TBO</td>
<td></td>
</tr>
<tr>
<td>- ERCs</td>
<td>B-124</td>
<td>B-124</td>
<td>B-126</td>
<td>B-125</td>
<td></td>
</tr>
<tr>
<td>- SRM</td>
<td>Warning RSRM-98</td>
<td>Warning RSRM-98</td>
<td>RSRM-94</td>
<td>RSRM-94</td>
<td></td>
</tr>
<tr>
<td>- ISSM SETTING</td>
<td>104.5/104.5%</td>
<td>104.5/104.5%</td>
<td>104.5/104.5%</td>
<td>104.5/104.5%</td>
<td></td>
</tr>
<tr>
<td>- POSITION 1</td>
<td>2044.0</td>
<td>2044.0</td>
<td>2044.0</td>
<td>2044.0</td>
<td></td>
</tr>
<tr>
<td>- POSITION 2</td>
<td>2045.0</td>
<td>2045.0</td>
<td>2045.0</td>
<td>2047.0</td>
<td></td>
</tr>
<tr>
<td>- POSITION 3</td>
<td>2045.0</td>
<td>2045.0</td>
<td>2047.0</td>
<td>2047.0</td>
<td></td>
</tr>
<tr>
<td>- SOFTWARE REL</td>
<td>CV-30</td>
<td>CV-20</td>
<td>CV-20</td>
<td>CV-20</td>
<td></td>
</tr>
<tr>
<td>- CRG TANKS</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>- UNC TANKS</td>
<td>RMS, DDS, OS888</td>
<td>RMS, DDS, OS888</td>
<td>RMS, DDS, OS888</td>
<td>RMS, DDS, OS888</td>
<td></td>
</tr>
<tr>
<td>PIL MANIFEST</td>
<td>ISS UFL1.1</td>
<td>NONE</td>
<td>ISS UFL1.1</td>
<td>RAMBO</td>
<td></td>
</tr>
<tr>
<td>- PAYLOAD BAY</td>
<td>(MPLM, LMC, IOD)</td>
<td></td>
<td>(SEGMENT)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- MID-DECK</td>
<td>NONE</td>
<td>NONE</td>
<td>NONE</td>
<td>RAMBO</td>
<td></td>
</tr>
<tr>
<td>OPERATIONS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- RAD MLP</td>
<td>B-1</td>
<td>B-1</td>
<td>B-2</td>
<td>B-2</td>
<td></td>
</tr>
<tr>
<td>- INCLINATION</td>
<td>31.6 DEG</td>
<td>31.6 DEG</td>
<td>122 NM</td>
<td>122 NM</td>
<td></td>
</tr>
<tr>
<td>- INSERTION ALT</td>
<td>122 NM</td>
<td>122 NM</td>
<td>122 NM</td>
<td>122 NM</td>
<td></td>
</tr>
<tr>
<td>- WLCO GT</td>
<td>DIR INSERTION</td>
<td>DIR INSERTION</td>
<td>DIR INSERTION</td>
<td>DIR INSERTION</td>
<td></td>
</tr>
<tr>
<td>- TAL SITE</td>
<td>ZARAGOZA</td>
<td>ZARAGOZA</td>
<td>ZARAGOZA</td>
<td>ZARAGOZA</td>
<td></td>
</tr>
<tr>
<td>- PLT DURATION</td>
<td>6–2 DAYS</td>
<td>11–1 DAYS</td>
<td>11–1 DAYS</td>
<td>11–1 DAYS</td>
<td></td>
</tr>
<tr>
<td>- TVAC</td>
<td>0–0</td>
<td>0–0</td>
<td>0–0</td>
<td>0–0</td>
<td></td>
</tr>
<tr>
<td>- CERW SIZE</td>
<td>4 UP/11 DOWN</td>
<td>7 UP/6 DOWN</td>
<td>7 UP/6 DOWN</td>
<td>7 UP/6 DOWN</td>
<td></td>
</tr>
<tr>
<td>- LANDING SITE</td>
<td>KSC</td>
<td>KSC</td>
<td>KSC</td>
<td>KSC</td>
<td></td>
</tr>
<tr>
<td>INSTRUMENTATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REMARKS</td>
<td># BLOCK II CLUSTER</td>
<td># CREW AUGMENTATION # BLOCK III CLUSTER</td>
<td># PAYLOAD OF OPPORTUNITY, DECKED BURN NOT REQUIRED</td>
<td># BLOCK II CLUSTER</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Warning - Critical Pre-Flight Check
- # Block II - Critical Mission Elements
- # Block III - Critical Mission Elements

*STS-115 - 07-26-05*
Flight Plan
Timeline - Keys

- Crew, Houston, other centers execute from a common timeline.
- Delays to critical events are reported on the Flight Loop - everyone hears them so they can work up a recovery plan. Mission Cognizance is key.
- Changes/deviations to the timeline are approved only by Flight
# Flight Planning Checklists

<table>
<thead>
<tr>
<th>Control articles</th>
<th>Off-nominal articles</th>
<th>Support articles</th>
<th>Reference articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Checklists – Ascent Entry</td>
<td>Pocket Checklists – Ascent Orbit Entry</td>
<td>Orbit Operations Checklist Cue Cards Extravehicular Checklist Extravehicular Cuff Checklist Photo/Television Checklist</td>
<td>Data Processing System Dictionary Reference Data Book Systems Data Book Charts and Maps Book</td>
</tr>
<tr>
<td>Post-Insertion Crew Activity Plan Deorbit Preparation Cue Cards</td>
<td>Cue Cards Ascent/Entry Systems Procedures Contingency Deorbit Preparation Contingency Extravehicular Operations In Flight Maintenance Checklist Medical Checklist Malfunction Procedures</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---
Figure 4-24: Flight data file items (typical).
Flight Rules

SECTION 1 - GENERAL, AUTHORITY, AND DEFINITIONS

SHUTTLE ONLY RULES

LF1_A1-1  CONFLICTING RULES ........................................ 1-1
LF1_A1-2  DEVELOPMENT TEST OBJECTIVE (DTO)/DETAILED SUPPLEMENTARY OBJECTIVE (DSO) FOR RESPONSIBILITIES ........................................ 1-1
LF1_A1-3  VEHICLE CONFIGURATION ........................................ 1-2
TABLE LF1_A1-3-I - VEHICLE CONFIGURATION ........................................ 1-2

ISS ONLY RULES

LF1_B1-1  ISS SUPPORT EQUIPMENT FOR RESPONSIBILITY ........ 1-4
LF1_B1-2  SUB-INCREMENT DURATION DEFINITION[RI] ........ 1-4

JOINT SHUTTLE/ISS RULES

LF1_C1-1  FLIGHT CONTROL TEAM (FCT) [RI] ......................... 1-5
TABLE LF1_C1-1-I ............................................................... 1-6
LF1_C1-2  SHUTTLE/LF1 DOCKED SUPPORT EQUIPMENT FOR RESPONSIBILITY ......................... 1-6
FLIGHT RULES

A. THE ET UNBILICAL WELL PHOTOGRAPHY +X TRANSLATION MANEUVER WILL BE NO-GO FOR THE FOLLOWING:
   1. OMS/RCS PROPELLANT LEAKS, HELIUM SYSTEM LEAKS, OR TANK FAILURES THAT RESULT IN A PROPELLANT CRITICAL MISSION.
   2. MECO UNDERSPEED THAT RESULTS IN AN INABILITY TO SUPPORT A FIRST DAY PLSS DEBOIT.
   3. ET PREDICTED TO BE IN DARKNESS FOR BOTH UNBILICAL WELL AND ET HANDHELD PHOTOGRAPHY.

B. THE +X TRANSLATION MAY BE PERFORMED AFTER A DELAYED ET SEPARATION, PROVIDED THAT THE ME3 DUMP IS COMPLETE OR HAS BEEN DELAYED UNTIL AFTER THE +X MANEUVER.

C. THE CREW HANDHELD ET PHOTOGRAPHY PITCH MANEUVER WILL BE NO-GO FOR THE FOLLOWING: #67201
   1. NO +X TRANSLATION MANEUVER PERFORMED.
   2. FAILURES THAT RESULT IN A PROPELLANT CRITICAL MISSION:
      a. LOSS OF AN OMS ENGINE.
      b. LOSS OF VERMIER RCS ATTITUDE CONTROL.
      c. MECO UNDERSPEED GREATER THAN 26 FPS. #67201
      d. UNPLANNED PRE-MECO OMS DUMP.
   3. BFS ENGAGED.
   4. ET IN DARKNESS AT PHOTOGRAPHY TIME.

THIS RULE CONTINUED ON NEXT PAGE
Flight Rules

ET Photography (Continued)

There are two methods of photographing the External Tank. Method 1 utilizes automatic cameras in the ET umbilical wells of the orbiter and requires an 11-second +X translation immediately following the -Z separation burn. The +X maneuver requires about 120 pounds of RCS propellant. This propellant goes directly in-plane and is an aid to achieving the proper orbit for rendezvous flights so it is not an impact to perform this translation maneuver for such missions. Method 2 utilizes crew handheld cameras and requires an orbiter pitch maneuver using moments provided by the MPS dump. Method 2, if not performed via the MPS dump, requires an additional 70 pounds of aft and 30 pounds of forward RCS propellant. Method 1 is considered primary and Method 2 is considered as secondary for obtaining engineering analysis photography of the ET. Method 1 provides the highest resolution photographs of the ET. These priorities are reflected in the constraints of this rule.

+X Translation Constraint:

Significant failures in the OMS and RCS systems (propellant or helium leaks or tank failures) result in a loss of delta-V capability, and the ET photography propellant may be needed to accomplish flight-critical maneuvers (e.g., OMS-1, deploy) or for entry control. Each failure will be assessed independently, but in general failures which severely impact OMS or RCS capabilities will be cause to NO-GO both photography methods so that a safe orbit may still be achieved. Considerations will be given to performing the +X translation maneuver if the failure does not result in a propellant critical mission.

Certain LEO underspeed/OMS remaining combinations result in an AOA shallow. For these cases, we are propellant critical and an uncertified abort is required. Therefore, it is not prudent to perform the +X translation in these cases. For the loss of common case, the crew uses an HA cue for GO/NO-GO status on the +X. To be conservative, the HA will be based on the design MECO underspeed. Assuming a full ATO dump, if the underspeed is greater than the design MECO underspeed, the result would be an AOA shallow. If time allows, the ground can make the call based on the underspeed/OMS remaining resulting in an ATO dump at 600 or greater.

ET photography typically is scheduled on all flights where at least part of the launch window allows sunlight for the photos. Photos of the ET in darkness are not useful. Flighting changes during the launch window, ET photography can be planned and trained for but will be canceled if sunlight will not be present at the same time photos are to be taken. Each of the two methods will be evaluated on its own lighting conditions.
Flight Rules

A. IF THERMAL PROTECTION SYSTEM (TPS) INSPECTIONS ARE REPLANNED IN FLIGHT, THEY WILL BE PLANNED PER THE FOLLOWING PRIORITIES BEFORE ISS DOCKING:

1. STAB BOARD WING LEADING EDGE "BLACK" AND LOW CLEARANCE AREAS
2. NOSE CAP
3. PORT WING LEADING EDGE "BLACK" AREAS
4. REMAINING WING LEADING EDGE AREAS
5. CHIN PANEL AND ARROW HEAD
6. TPS SITES WITH SUSPECTED IMPACT OR DAMAGE
7. LOWER SURFACE DOOR SEALS
8. REMAINING ACREAGE AREA
9. REMAINING EXTERIOR SURFACES

The planned ED2 Reinforced Carbon-Carbon (RCC) inspections have no timeline margin for the day. While docked to ISS, 5 feet clearance cannot be maintained for a Laser Dynamic Range Imagery (LDR) motion scan at the required resolutions on starboard lower RCC panels 3-4 and starboard upper RCC panels 1-4 (0.25 inch and 1.0 inch resolution, respectively) and an area on the lower, starboard side of the nose cap. Further, there are areas around the orbiter that cannot be imaged at the desired resolutions with only the SRMS and effector camera. Thus, the OBSS must be used to inspect these areas for entry critical damage, or ESA digital still imagery is required with a high crew time and mission objective impact. These areas are referred to as the "Black" areas, based on the black and white diagrams used to depict the SRMS and effector camera’s ability to inspect TPS at Space Shuttle Vehicle Inspection and Repair OPTP #11. The nose cap "Black" area can be seen in STS-114 JIP #23 minutes.

Based on the combination of these constraints, if the TPS inspections are replanned before docking, the revised plan will optimize obtaining the data most difficult to get after docking. The next priority before docking is on the least impact tolerant RCC any areas with suspected impact or damage (based on ascendant video, BT imagery, or impact sensors), door seals, and tile.
Flight Rules

**TPS Inspection and Impact Detection Priorities (Continued)**

B. After ISS docking, TPS inspection priorities are as follows:

1. TPS Sites with Suspected Impact or Damage
2. Wing Leading Edges, with areas having the smallest acceptable damage tolerance also having the highest relative priority
3. Nose Cap, Chin Panel and Arrow Head
4. Lower Surface Door Seals
5. Remaining Acreage Area
6. Remaining Exterior Surfaces

C. If there is a conflict, data will be downlinked according to the following priorities:

1. Focused Inspection Data
2. UVE Impact Sensor Ascent Peaks
3. UVE Impact Sensor Detailed Data it required to identify a suspected ascent impact location.
4. Scheduled Inspection Data, with relative priorities per paragraph B.
5. ET Umbilical Photos
6. Crew Hand Held ET Photos

It is assumed that any focused inspection data was gathered due to a suspected impact or suspected TPS damage. Thus, once gathered, downlinking this data has the highest priority in order to maximize the ground analysis time. Similarly, UVE impact sensor data has a high relative priority since it may provide a user focused UVE inspections which have a higher probability of detecting small ROC damage than a scheduled inspection. ET photos are a lower priority since they are primarily intended to validate the ET certification. Since it is possible that foam less seen in these photos may provide some clue not seen in any other source, there is still a goal to bring these photos down in flight. These priorities were approved by the December 6, 2009 POFC.
Flight Definition and Requirements Directive
TRAJECTORY PLANNING

GETTING WHERE YOU WANT TO GO
Comparison of the Space Shuttle to a Boeing 737

- B737 max takeoff weight 174,200 lbs
  - 31% is fuel
  - 41% is vehicle
  - 30% is payload (passengers, crew, baggage)
  - FAA required fuel reserve: 45 minutes loiter plus divert

- Total Shuttle vehicle weight at liftoff: 4.5 million lbs
  - 85% is propellant
  - 14% is vehicle structure
  - 1.3% is payload and crew
  - Propellant reserve at MECO---2,300 lbs = 0.060%
    - Less than 1/3 second run time
Abort Mode as a function of SSME failure time
STS-114 Abort Regions Chart

**STS 114 OCFR4 ABORT REGIONS CHART**

TDP: OCFEF114(010)
Ascent Performance Margin: -217 lbs
Ascent Intact Engineer: Paul Bailey
Date: Thu Sep 23 10:31:50 CDT 2004

**LEGEND**

- E.O. Time (secs)
- Rel. Velocity (fps)
- Inert. Velocity (fps)

**Note:** For missions manifested with a negative APM, coverage between PTx to PTM may not be continuous.

<table>
<thead>
<tr>
<th>Location</th>
<th>RTLS</th>
<th>ZARAGOZA</th>
<th>MORON</th>
<th>LE TUBE</th>
<th>PTA</th>
<th>PTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>232/7099/8159</td>
<td>461/20877/21845</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>4886/5903</td>
<td>148/4783/5793</td>
<td>164/5129/6160</td>
<td>294/9557/10604</td>
<td>412/16524/17519</td>
<td></td>
</tr>
<tr>
<td>MET</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>461/20877/21845</td>
<td></td>
</tr>
</tbody>
</table>

Last RTLS boundary based on third peak heating. Last RTLS performance boundary: 233/7133/8104. The Late ZZA boundary is based on the 23k VI constraint. The Late MRN boundary is based on the +/- 50 deg BETA constraint. The Late FMI boundary is based on the 23k VI constraint.
Nominal Abort Mission Profile
Ground Tracks for Various Launch Inclination

<table>
<thead>
<tr>
<th>Inclination</th>
<th>Available TAL Sites in geographic order of preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.45°</td>
<td>BYD Banjul, The Gambia, BEN Ben Guerir, Morocco, MRN Moron, Spain</td>
</tr>
<tr>
<td>39.00°</td>
<td>MRN Moron, Spain, ZZA Zaragoza, Spain, BEN Ben Guerir, Morocco</td>
</tr>
<tr>
<td>51.60°</td>
<td>FMI Le Tube, France, ZZA Zaragoza, Spain, MRN Moron, Spain, BEN Ben Guerir, Morocco</td>
</tr>
<tr>
<td>57.00°</td>
<td>FMI Le Tube, France, ZZA Zaragoza, Spain, MRN Moron, Spain, BEN Ben Guerir, Morocco</td>
</tr>
</tbody>
</table>

ISS missions

SAS Approved for Release
Space Shuttle Contingency Landing Sites
External Tank Entry  
Sequence of Events

- ET travels \( \frac{3}{4} \) around the globe on a sub-orbital trajectory to Pacific Ocean disposal
- Shuttle Main Engine Cut Off (MECO)—8 \( \frac{1}{2} \) minutes after lift-off
- ET Separation 18 seconds after MECO
  - Orbiter umbilical well camera and pitch around maneuver used to capture post-separation imagery
- Exo-atmospheric Coasting – MECO to atmosphere entry interface
- ET Rupture Sequence
  - Initial LH2 tank failure—25 structural pieces observed less than 1 second after breakup
    - Estimated delta velocity up to 160 miles per second imparted to debris
    - Both benign breakup and explosive initial events have been observed
  - LOX tank breakup—follows about 20 seconds after initial tank failure.

ET separation on STS-114
ET Footprint and Disposal

- All surviving ET reentry debris is contained in the ET footprint
  - The nominal footprint bounds all debris with 99.74% certainty
    - Determined through dispersed debris trajectory flydown analysis
    - Footprint size protects for worst case predicted explosive rupture
- Mission specific ET footprint placement required to maintain a minimum 25 NM distance off US landmass
  - Footprint placement within 200 NM of foreign landmass requires Department of State coordination
- USAF Eastern Range issues NOTAMs for ET disposal 24-48 hours prior to Shuttle launches
  - Clears airspace and ocean disposal area
  - Based on mission-specific ET footprint data developed by NASA

90% probability
1670 x 56 km

95% probability
2390 x 65 km

99.74% probability
3260 x 102 km
(nominal footprint)

ET Disposal for Generic ISS Mission

ET Disposal for Everyday ISS Launch Opportunity

NOTE: The "Two orange Islands." from West to East are:
1. Manihiki
2. Mavara
3. Maivara
4. Malaeipera
5. Tauamoa
STS-114 Nominal ET Impact Area
SYSTEMS ENGINEERING

The basis for good operations

Examples from the Space Shuttle
Absolute certainty can never be attained for many reasons, one of them being that even without limits on time and other resources, engineers can never be sure they have foreseen all possible contingencies, asked and answered every question, played out every scenario.

Many technologies…cannot be tested in laboratory conditions. Tests are conducted on models, which can only approximate the complex systemic forces of nature and technical environment. This situation creates risk: the world outside the laboratory becomes the setting for experiments.

The essence of engineering as a craft is to convert uncertainty to certainty, figuring probabilities and predictions for technologies that seldom stay the same…in the workplace, engineers formulate the rules as they go along, attempting to capture the unruly technology with numbers, experienced based theories, and practical rules.
A human should be able to change a diaper, plan an invasion, butcher a hog, conn a ship, design a building, write a sonnet, balance accounts, build a wall, set a bone, comfort the dying, take orders, give orders, cooperate, act alone, pitch manure, solve equations, analyze a new problem, program a computer, cook a tasty meal, fight efficiently, die gallantly.

Specialization is for insects.
System Engineering - Structures
System Engineering – Integrated Functions

Solid Rocket Booster

4 separation motors
22,050 lbs. thrust each

SRB external tank thrust attachment

Nozzle and thrust vector control system

Alt skin and launch support

SRB - external tank attachment ring, aft avionics and sway braces

4 separation motors
22,050 lbs. thrust each

Main parachutes (3)

Drogue chute

Nose fairing

Frustum

Rate gyro assemblies (2)
separation avionics, operational flight instrumentation, recovery avionics and range safety system

DIMENSIONS

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>149.16 ft</td>
</tr>
<tr>
<td>Diameter</td>
<td>12.17 ft</td>
</tr>
</tbody>
</table>

SAS Approved for Release
Space Shuttle Orbiter Systems

- Auxiliary Power Unit / Hydraulics
- Caution and Warning System
- Closed Circuit Television
- Communications
- Crew Systems
- Data Processing System
- Dedicated Display Systems
- Electrical Power System
- Environmental Control and Life Support System
- Escape Systems
- Extravehicular Activity
- Galley / Food
- Guidance, Navigation, and Control
- Landing / Deceleration
- Lighting System
- Main Propulsion System
- Orbital Maneuvering System
- Orbiter Docking System
- Payload Deployment and Retrieval System
- Reaction Control System
- Stowage
- Waste Management System
Auxiliary Power Unit / Hydraulics
Improved APU Fuel System Schematic
Caution and Warning System

Alarm Annunciation

Emergency Class 1
- Fire Smoke
- dP/dT

Caution & Warning class 2
- Primary C&W
- Backup C&W

Alert Class 3
- Software
- Alert tone
- SM light
- Fault message

Limit Sensing Class D
- Software
- Status parameters

Hardware Only
- Siren
- MA lights
- Smoke detection lights
- Klaxon
- MA lights
- C&W tone
- MA lights
- F7 lights
- R13 lights
- C&W tone
- MA lights
- F7 B/U light
- Fault msg

Caution and Warning Diagram
Communications

Ground Command Interface Logic
Communications

S-Band PM System Interfaces and Data Flow
Communications
Communications

Operational Instrumentation System Overview

A/G  —  Air-to-Ground
CIU  —  Communication Interface Unit
GPC  —  General Purpose Computer
MDM  —  Multiplexer/Demultiplexer
MMU  —  Memory Unit
NSP  —  Network Signal Processor
OI  —  Operational Instrumentation
SSR  —  Solid State Recorders

PCMMU  —  Pulse Code Modulation Master Unit
PDI  —  Payload Data Interleaver
PI  —  Payload Interrogator
PL  —  Payload
PSP  —  Payload Signal Processor
SM  —  Systems Management
TFL  —  Telemetry Format Load
TLM  —  Telemetry
Crew Systems

Crew Clothing/Worn Equipment.
Personal Hygiene Provisions.........
Sleeping Provisions..................
Exercise Equipment..................
Housekeeping Equipment ...........
Restraints and Mobility Aids......
Stowage Containers ..................
Reach and Visibility Aids.......... 
Photographic Equipment .......... 
Sighting Aids ....................... 
Window Shades and Filters ........
Shuttle Orbiter Medical System ...
Operational Bioinstrumentation System ........ 
Radiation Equipment ............... 
Air Sampling System ...............
Data Processing System Interfacing Hardware
Data Processing System
Data Processing System

MEDS Data Bus Network
### Data Processing System - Software

<table>
<thead>
<tr>
<th>Mission phase</th>
<th>Launch - 20 min to lift-off</th>
<th>Launch to solid rocket booster sep</th>
<th>SRB sep to external tank sep maneuver complete</th>
<th>ET sep to completion of OMS-1 burn</th>
<th>Completion of OMS-1 burn to completion of OMS-2 burn</th>
<th>Completion of OMS-2 burn to selection of GNC Ops-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major mode (for Ops-1)</td>
<td>101</td>
<td>102</td>
<td>103</td>
<td>104</td>
<td>105</td>
<td>106</td>
</tr>
</tbody>
</table>

**Notes:***
- SRB separation
- ET Sep maneuver complete
- OMS-1
- OMS-2
- GNC major function
- Ops-1
- Major mode 101, 102, 103, 104, 105, 106
Data Processing System - Displays

MEDS Edgekey Menu Hierarchy
Electrical Power System

The Electrical Power System

Switch inputs and dedicated displays

Power reactant storage and distribution

Fuel cells

Oxygen

Heat and water

Environmental control and life support system

Data processing system

Instrumentation

Telemetry

To CRTs

Switch inputs and dedicated displays

To annunciator matrix

Caution/warning

Displays and controls

AC generation & distribution

Loads

DC bus distribution system (main, essential, control, and payload buses)

DC power

H₂

O₂

H₂O

Environmental control and life support system

SAS Approved for Release
Pad Emergency Escape Systems

Launch Pad Emergency Egress System

- Slidewire anchor poles
- Arresting nets
- Underground bunker
- M113 parking area
- Landing zone area
- Deceleration chain system
- Slidewires
- Fixed service structure
- Embarkation area (catwalks)
- Elevators

18 in

Orbiter

Orbiter access arm

W

17 ft 6 in

1000 ft

1152 ft

40 ft

20 ft spacing (Typical)

16 Ft

416.cvs
Pressure Suits

Advanced Crew Escape Suit (ACES)

- Helmet
- Communication/Carrier Assembly (CCA)
- Counter Pressure/Anti-Exposure Garment
- G-Suit

Survival Gear:
- Strobe Light
- Olive Drab Flare Kit
- Eyeglasses/Flares
- Survival Water (one in each pocket)

- Eacked: Survival Radio
- Signal Mirror
- Motion Sickness Pills
- Survival Whistle (one in each pocket)

- Ereeked: Canopy
- Sea Anchor
- Bailing Cup
- Flare
- SARSAT Personal Locator Beacon

Emergency Oxygen System (EOS):
- 24 Cyanide Cells
- Pressure Reducer
- In Activation System
- in Noze

Parachute Pack:
- Main Canopy
- Automatic Actuation Device (AAD)

Pressure Suits
EVA

Extravehicular Mobility Unit
Galley/Food

- Storage (straws)
- Wet wipe dispenser
- RHS controls
- Oven fan switch
- Aux port
- Water heater switches
- Oven/RHS switch

Shuttle Galley
Flight Control Interfaces

**GN&C Hardware**
- Crew controllers
- Inertial measurement unit
- Rate gyro assembly
- Accelerometer assembly
- Air data transducer assembly

**GN&C Data Processing**
- Commands
- Angles
- Rates
- Acceleration
- Air Data

**GN&C Software**
- Guidance
  - Auto steering commands
  - Engine-on and gimbals commands
- Flight Control
  - Manual steering commands
  - Attitude
  - Rates
  - Accelerations
  - Air data parameters
- Aerosurface commands
- Engine-on and gimbals commands

**GN&C Hardware**
- Engines
- Aerosurface servoactuator

**Flight Control Interfaces**
Landing/Deceleration Interfaces
Main Propulsion System
Main Propulsion System
# Mechanical Systems

## Vent Locations

<table>
<thead>
<tr>
<th>Vent</th>
<th>Area Vented</th>
<th>Positions</th>
<th>Type Actuator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2</td>
<td>FWD RCS and fuselage</td>
<td>OPEN/CLOSE/PURGE</td>
<td>Common</td>
</tr>
<tr>
<td>3, 5</td>
<td>Midbody, payload</td>
<td>OPEN/CLOSE</td>
<td>Single</td>
</tr>
<tr>
<td>6</td>
<td>Midbody, payload</td>
<td>OPEN/CLOSE/PURGE</td>
<td>Single</td>
</tr>
<tr>
<td>4, 7</td>
<td>Midbody, payload/wing*</td>
<td>SEALED</td>
<td>Removed</td>
</tr>
<tr>
<td>9, 8</td>
<td>Aft fuselage/CMS PCDS</td>
<td>OPEN/CLOSE/PURGE</td>
<td>Common</td>
</tr>
</tbody>
</table>

* OV-105 and others after Orbiter Maintenance Down Period (Major Mod) J-1.

---

**Mechanical Systems**

---

SAS Approved for Release
Mechanical Systems

ET Door Positions

Right Side ET Umbilical Door
Mechanical Systems

Payload Bay Door Latch Locations

- Centerline latches
  - 13-16
  - 9-12
  - 5-8
  - 1-4

- Forward bulkhead latches
- AFT bulkhead latches

- 1 - 4 PORT
- 1 - 4 STBD

- 13 hinges
  - □ = 5 fixed hinges
  - ◇ = 8 floating hinges
Payload Bay Door Drive System Mechanical Block Diagram
Orbital Maneuvering System
Orbital Maneuvering System Pressurization and Propellant Feed System for One Engine (other Engine Identical)
Orbiter Docking System
Payload Deployment and Retrieval System

RMS-Stowed Position and General Arrangement
Payload Deployment and Retrieval System

RMS Components

- BDA - Backup drive amplifier
- EEEU - End effector electronics unit
- GPC - General-purpose computer
- MCIU - Manipulator controller interface unit
- MM/SCU - Motor module/signal conditioning unit
- RHC - Rotational hand controller
- SPA - Servo power amplifier
- THC - Translational hand controller

usa007587_691r1.cvx
Reaction Control System

RCS Redundancy Management Schematic
RCS
Stowage

Various provisions are available for stowing loose onboard equipment and trash/waste materials during different phases of the flight. Provisions consist primarily of rigid and flexible containers.

Rigid containers include:

- Modular lockers
- Floor compartments
- Volume B return trash containers

The flexible containers are as follows:

- Flight deck stowage bags
- Helmet stowage bag
- Seat FDF containers
- Soft stowage containers
- Trash containers
- Jettison stowage bags
- In-flight stowage bags
- Middeck retention net
- Airlock stowage bags
- Airlock retention net

Stowage areas in the orbiter crew compartment are located on the flight deck, the middeck, in the airlock, and lower equipment bay.
Waste Management System

Diagram:
- Crewmember
- Biowastes
- Extravehicular Mobility Unit/Airlock
  - Liquid
  - Gas
  - 115 Volts ac
  - 28 Volts dc
- Wet Trash
- Electrical Power System
- Waste Collection System
  - Cabin Air
  - Cleaned Air
- Wastewater Storage Tank and Overboard Dump System
- Vacuum Vent System

Overall: Waste Management System
Waste Management System
ETERNAL VIGILANCE
IS THE PRICE OF LIBERTY
FLIGHT SAFETY

SPACE PROGRAM

COMMERCIAL AIRLINES

SAFETY WORKERS

PASSENGERS

ASK COLORADO SPRINGS GAZETTE TELEGRAPH
Aviation in itself is not inherently dangerous. But to an even greater degree than the sea, it is terribly unforgiving of any carelessness, incapacity or neglect.

~ Captain A. G. Lamplugh, RAF 1930
The Future of Humanity is in Your Hands

Don’t screw it up - No pressure