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THIS IS SEGMENT 17 COVERING CHAPTER 17.

TO NAVIGATE

CLICK ON THE BOOKMARKS AND CLICK ON THE (+) SYMBOLS, THEN CLICK ON SUBJECT LINKS TO GO TO SPECIFIC VIEWS IN THIS SEGMENT.

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TECHNICAL ORDER 00-105E-9 TECHNICAL CONTENT MANAGER

WRITTEN CORRESPONDENCE:

HQ AFCESA/CEXF
ATTN: Fire and Emergency Services Egress Manager
139 Barnes Drive Suite 1
Tyndall AFB, Florida 32403-5319

E-MAIL: **HQAFCESA.CEXF@tyndall.af.mil**

INTERNET: **HQ AFCESA Fire and Emergency Services PUBLIC WEB PAGE:**
http://www.afcesa.af.mil/CEX/cexf/index.asp
Safety Supplements: http://www.afcesa.af.mil/CEX/cexf/_firemgt.asp

PHONE: **(850) 283-6150**
DSN 523-6150

FAX: **(850) 283-6383**
DSN 523-6383

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SEGMENT 17 INFORMATION CHANGE NOTICE

This page is provided to notifiy the user of any informational changes made to Technical Order 00-105E-9 in this Segment and the current Revision. Informational changes will be referenced in the Adobe Reader's Bookmark tool as a designator symbol illustrated as a <[C]> for quick reference to the right of the affected aircraft. The user shall insure the most current information contained in this TO is used for his operation. Retaining out of date rescue information can negatively affect the user's operability and outcome of emergencies. If the user prints out pages his unit requires, the user shall print the affected page(s), remove and destroy the existing page(s), and insert the newly printed page(s) in the binder provided for that purpose. A Master of this TO shall be retained in the unit's library for reference, future printing requirements and inspections.

CHAPTER	AIRCRAFT	PAGE	EXPLANATION OF CHANGE
17	N/A	ALL	Recovery and Egress Procedures file updated.
17	N/A	ALL	Information added for fire behavior, fire fighting, and suppression in micro-gravity environments.

NOTE

Chapter 17 contains emergency rescue and mishap response information for the following aircraft:

NASA	**INTERNATIONAL SPACE STATION**
NASA	**ORBITER VEHICLE**
NASA	**ORBITER CARRIER**
NASA	**T-38N**

CHAPTER 17

NASA

AEROSPACE EMERGENCY RESCUE AND MISHAP RESPONSE INFORMATION

17-1. INTRODUCTION AND USE.

17-2. This section contains emergency rescue and mishap response information illustrations in alphanumerical order relative to type and model of aircraft. This arrangement of illustrations is maintained from Chapter 4 throughout the remainder of the publication.

17-3. GENERAL ARRANGEMENT.

17-4. Aircraft type designation has been positioned in the upper right corner of the horizontal illustration for rapid identification. Additional aids to rapid orientation are:

a. Recent technological advances in aviation have caused concern for the modern firefighter. Aircraft hazards, cabin configurations, airframe materials, and any other information that would be helpful in fighting fires, the locating and rescue of personnel will be added as the information becomes available.

b. Suggested special tools/equipment are listed in the upper left corner, on the Aircraft/Entry page of each listed aircraft.

c. Procedural steps covering emergency/normal entrances, cut-ins, engine/APU shutdown, safetying ejection/escape systems, and aircrew extraction are outlined on the left side of each page with coordinated illustrations on the right.

d. Illustrations located on right side of pages are coordinated with text by numerals and small letters depicting both paragraph and subparagraph on the page.

e. Each illustration is consistently colored and/or pattern keyed to highlight essential emergency rescue information.

f. Details are pulled directly from the illustration to highlight an area, thus eliminating unnecessary searching for desired information.

17-5. NASA PLATFORMS.

17-6. Most aircraft in the active NASA inventory are included in this manual while prototype aircraft platforms are not. Those aircraft not yet included will be added in the near future.

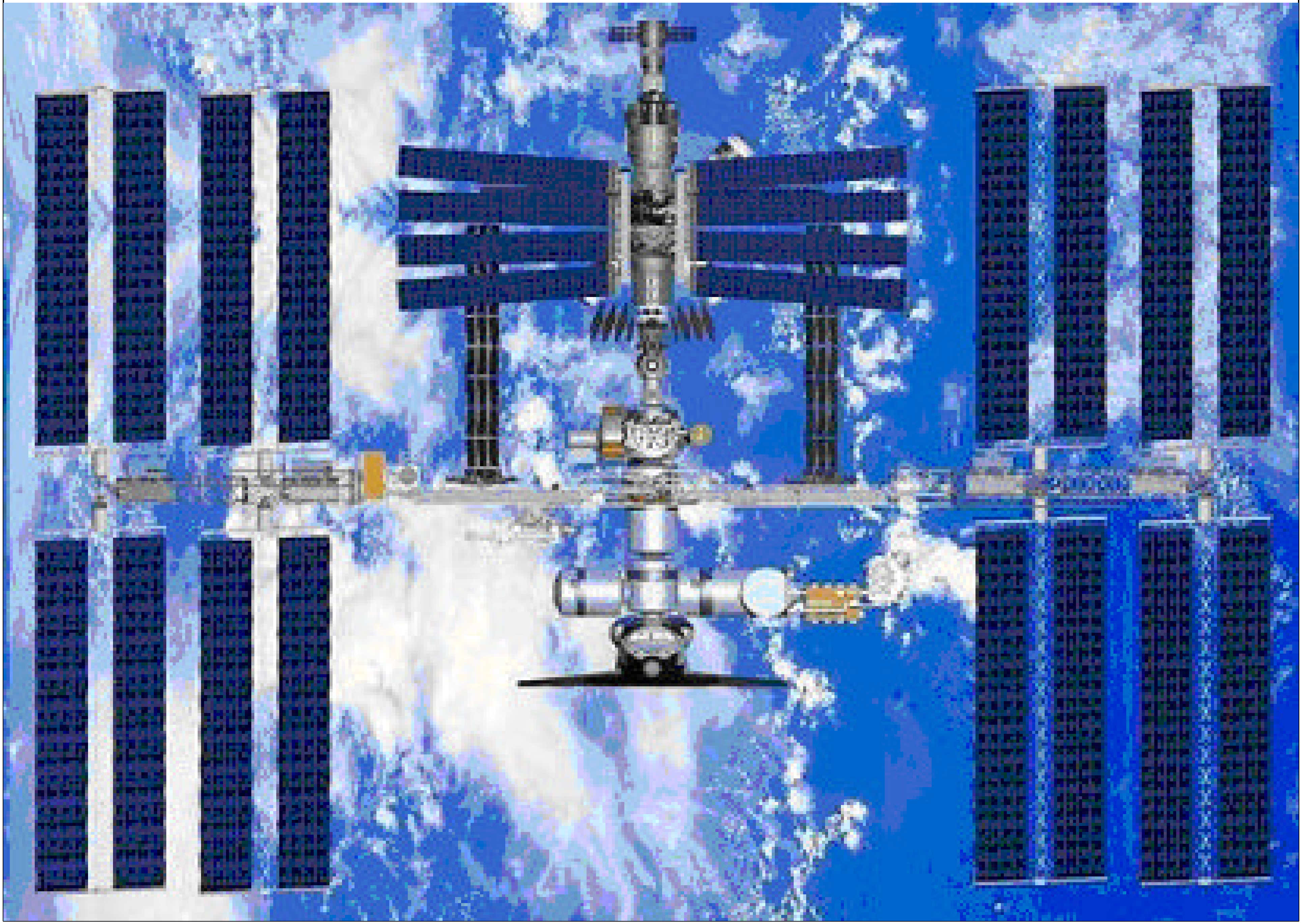
a. **ER-2** (civilian version of the U-2)**, P3-B, DC-8** are assigned full-time to support Earth Science research and applications investigations. The NASA Earth Science platforms take advantage of NASA's aeronautics expertise to permit complete reconfiguration of the aircraft payloads for each investigation, so that all aircraft deployments are usually unique and focused on changing and interdisciplinary science objectives.

b. NASA also contracts with university and commercial sources for part-time access to various light aircraft, commercial remote sensing services, unmanned aerial vehicles (e.g. **Altair, Altus, Pathfinder Plus, etc.), and the Proteus prototype aircraft**.

c. NASA verifies airworthiness and safety of all platforms, NASA & non-NASA, when reconfigured for NASA-sponsored earth science research and applications. NASA maintains a number of other platforms for space science, microgravity research and aeronautical research. These other platforms include the **WB-57F, B-52, Learjet Model 24, DH-6 Twin Otter, OV-10, Beechcraft B200 King Air, 747, 757, F-15, F-16, F-18, T-38, C-130, Guflstream G-I, and Gulfstream G-II.**

d. They are available on a non-interference basis, but may not be configured for geoscience research.

INTERNATIONAL SPACE STATION (ISS)



ISS GENERAL INFORMATION

The International Space Station is the largest and most complex international scientific project in history. And when it is complete just after the turn of the century, the station will represent a move of unprecedented scale off the home planet. Led by the United States, the International Space Station draws upon the scientific and technological resources of 16 nations: Canada, Japan, Russia, 11 nations of the European Space Agency and Brazil.

More than four times as large as the Russian Mir space station, the completed International Space Station will have a mass of about 1,040,000 pounds. It will measure 356 feet across and 290 feet long, with almost an acre of solar panels to provide electrical power to six state-of-the-art laboratories.

The station will be in an orbit with an altitude of 250 statute miles with an inclination of 51.6 degrees. This orbit allows the station to be reached by the launch vehicles of all the international partners to provide a robust capability for the delivery of crews and supplies. The orbit also provides excellent Earth observations with coverage of 85 percent of the globe and over flight of 95 percent of the population. By the end of this year, about 500,000 pounds of station components will be have been built at factories around the world.

U.S. ROLE AND CONTRIBUTIONS

The United States has the responsibility for developing and ultimately operating major elements and systems aboard the station. The U.S. elements include three connecting modules, or nodes; a laboratory module; truss segments; four solar arrays; a habitation module; three mating adapters; a cupola; an unpressurized logistics carrier and a centrifuge module. The various systems being developed by the U.S. include thermal control; life support; guidance, navigation and control; data handling; power systems; communications and tracking; ground operations facilities and launch-site processing facilities.

INTERNATIONAL CONTRIBUTIONS

The international partners, Canada, Japan, the European Space Agency, and Russia, will contribute the following key elements to the International Space Station:

· Canada is providing a 55-foot-long robotic arm to be used for assembly and maintenance tasks on the Space Station.

· The European Space Agency is building a pressurized laboratory to be launched on the Space Shuttle and logistics transport vehicles to be launched on the Ariane 5 launch vehicle.

· Japan is building a laboratory with an attached exposed exterior platform for experiments as well as logistics transport vehicles.

· Russia is providing two research modules; an early living quarters called the Service Module with its own life support and habitation systems; a science power platform of solar arrays that can supply about 20 kilowatts of electrical power; logistics transport vehicles; and Soyuz spacecraft for crew return and transfer.

In addition, Brazil and Italy are contributing some equipment to the station through agreements with the United States.

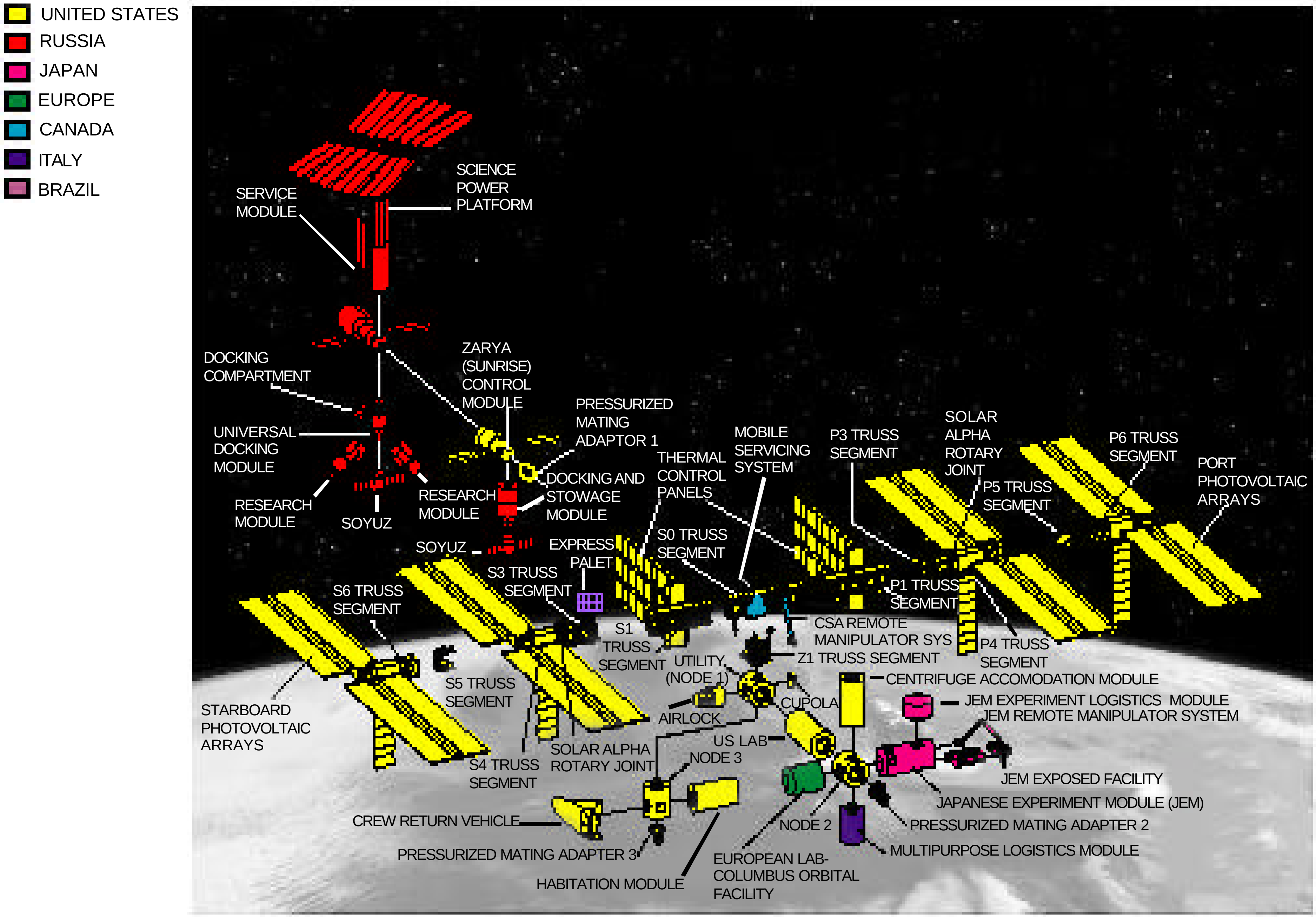
ISS PHASE ONE: THE SHUTTLE-MIR PROGRAM

The first phase of the International Space Station, the Shuttle-Mir Program, began in 1995 and involved more than two years of continuous stays by astronauts aboard the Russian Mir Space Station and nine Shuttle-Mir docking missions. Knowledge was gained in technology, international space operations and scientific research.

Seven U.S. astronauts spent a cumulative total of 32 months aboard Mir with 28 months of continuous occupancy since March 1996. By contrast, it took the U.S. Space Shuttle fleet more than a dozen years and 60 flights to achieve an accumulated one year in orbit. Many of the research programs planned for the International Space Station benefit from longer stay times in space. The U.S. science program aboard the Mir was a pathfinder for more ambitious experiments planned for the new station.

For less than two percent of the total cost of the International Space Station program, NASA gained knowledge and experience through Shuttle-Mir that could not be achieved any other way. That included valuable experience in international crew training activities; the operation of an international space program; and the challenges of long duration spaceflight for astronauts and ground controllers. Dealing with the real-time challenges experienced during Shuttle-Mir missions also has resulted in an unprecedented cooperation and trust between the U.S. and Russian space programs, and that cooperation and trust has enhanced the development of the International Space Station.

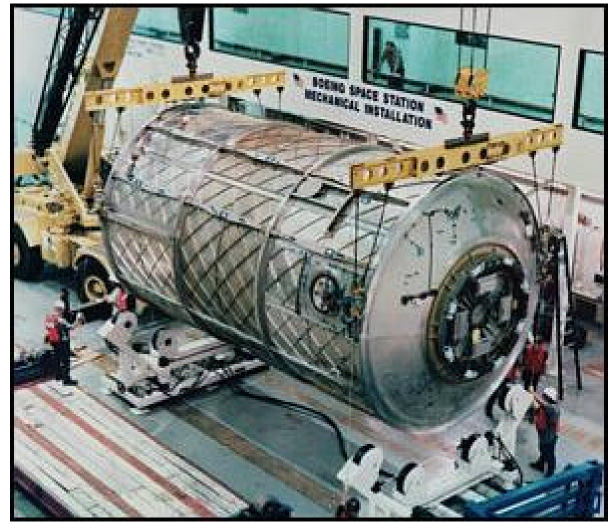
ISS MODULES AND ELEMENTS ASSEMBLY



ISS MODULES

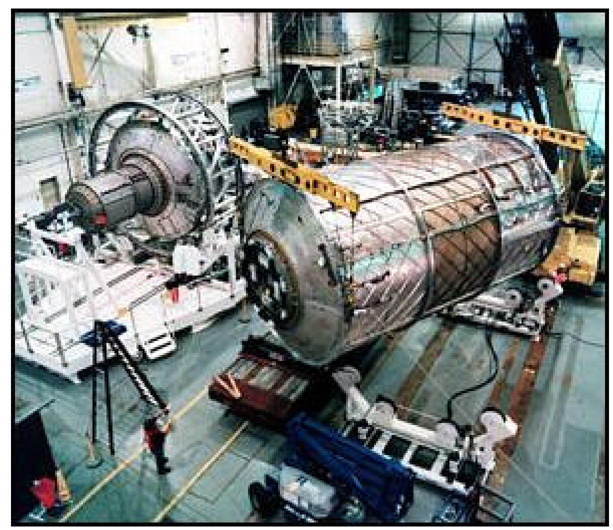
1. UNITED STATES MODULES

The U.S. Habitation module is lifted by crane during manufacturing at the Marshall Space Flight Center's Space Station Manufacturing Facility in Huntsville, Alabama. The Habitation module will be the living quarters for the crew of the International Space Station when it is launched in 2003. Visible in this photo on the right side of the module is one of two windows. Also visible is a hatch at the end of the module. The habitat module is 28 feet long and 14 feet wide. 15 countries led by the U.S. are cooperating to build the International Space Station, the first piece of which was launched in June 1998.



US HABITATION MODULE

Two modules for the International Space Station are shown under construction recently at the Space Station manufacturing Facility at the Marshall Space Flight Center in Huntsville, Alabama. On the left is the airlock, which was launched on STS-100 in August 1999. On the right is the U.S. Habitation Module, where the astronauts will live after it is launched to complete the station's orbital assembly originally scheduled in 2003. The timeline schedule will have to be re-adjusted based on the disaster of STS-107. Assembly of the station began in the summer of 1998.

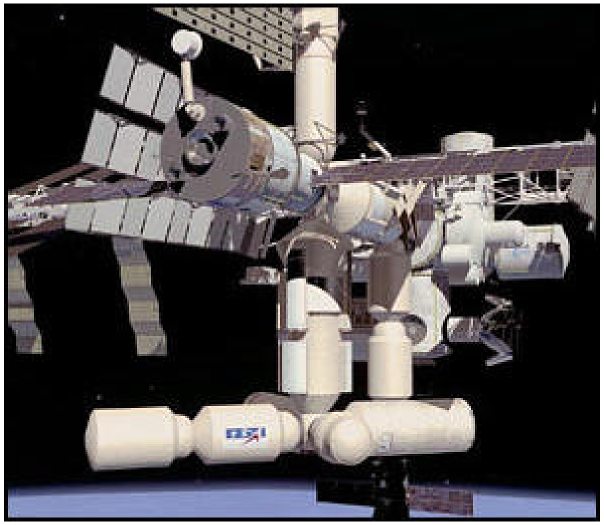


US AIRLOCK AND HABITATION MODULE

ISS MODULES-Continued

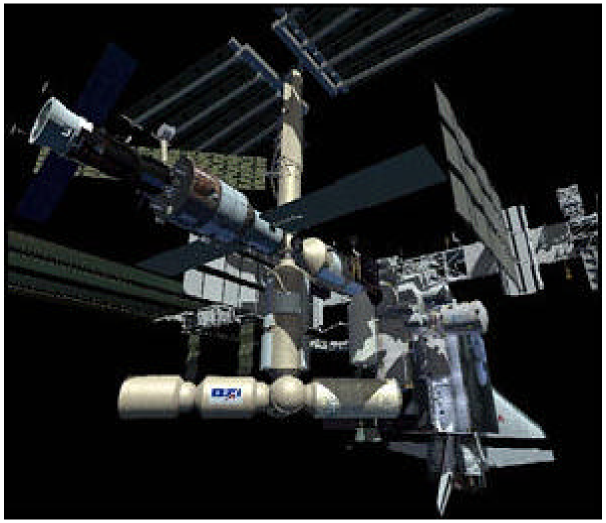
2. RUSSIAN MODULES

This artist's concept depicts the Russian segment of the International Space Station (ISS) when assembly is completed in 2003. A project involving contributions from 16 nations, it is the largest and most complex international scientific project ever undertaken. Along with Russia (RSA), major partners in the ISS are the United States (NASA), European Space Agency (ESA), Japan (NASDA), and Canada (CSA). Assembly in orbit of the station will begin in 1998 and include 45 flights on the Space Shuttle and two types of Russian launch vehicles over five years. When complete, the ISS will have a mass of more than 1 million pounds (453,000 kilograms) and provide six state-of-the-art laboratories for international research.



RUSSIAN MODULES (CLOSE VIEW)

This digital artist's concept shows a close-up of Russian segments of the International Space Station after all assembly is completed in 2003. Russia is providing more than a third of the total pressurized volume of the station, including a Service Module in the center of this view that will be the early living quarters and cornerstone of the station, a solar power platform seen at the top of this view, a Soyuz spacecraft that will serve as one of the station's "lifeboats," and several research modules. The finished station will have a mass of almost 1 million pounds. Led by the U.S., station modules will be provided by the U.S., Russia, Europe and Japan. Canada will provide a mechanical arm and "Canada hand." In total, 16 countries are cooperating to provide the state-of-the-art complex of laboratories in the weightless environment of Earth orbit. The first piece of the station, the U.S.-funded and Russian-built Functional Cargo Block, is scheduled to launch from Kazahkstan in June 1998, beginning a challenging five-year, 45-flight sequence of assembly in orbit.



RUSSIAN MODULES (DISTANT VIEW)

ISS MODULES-Continued

3. JAPAN MODULES
   Japanese Experimental Module (JEM), JEM Exposed Facility and other information pending.

4. EUROPEAN MODULES
   European Lab - Columbus Orbital Facility and other information pending.

5. CANADIAN MODULES
   Mobile Servicing System and CSA Remote Manipulator System. A Canadian "handshake in space" occurred on April 28, 2001 as the Canadian-built space station robotic arm transferred its launch cradle over to Endeavour's Canadian-built robotic arm. A Canadian mission specialist of the Canadian Space Agency (CSA) was also instrumental in the activity as he was at the controls of the original robot arm from his post on the aft flight deck of the shuttle. The Spacelab pallet that carried the arm to the Station, was developed at the Marshall Space Flight Center in Huntsville, Alabama.

6. ITALIAN MODULES
   The Marshall Center supervised the design, development and testing of the Multi Purpose Logistics Module for NASA and provides sustaining engineering for the modules, built by the Italian Space Agency. The modules serve as carriers for cargo to and from the ISS.

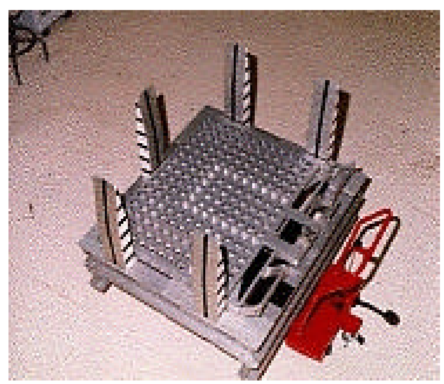
7. BRAZILIAN EXPRESS PALET (ExPS)
   The ExPS is an unpresurized external equipment which, by means of adapter mechanisms, will support external payloads. Each ExPS will accommodate up to six payloads of up to 225kg for a total launch of 1.36 tons. For each one of them it will be supplied power and data. The adapters will be fully compatible with external robotics operations (EVR) and with crew external activities (EVA). The full up ExPS will be compatible with robotics operations for removal from orbiter cargo bay and assembly in the ISS truss. It will be operational for up to 10 years in orbit with the capability to be launched and returned to Earth several times. It will meet all launching requirements imposed by the Space Shuttle. Brazil will supply four flight units of this equipment. Other equipment will be delivered to the ISS in the future.

JAPANESE EXPERIMENTAL MODULE

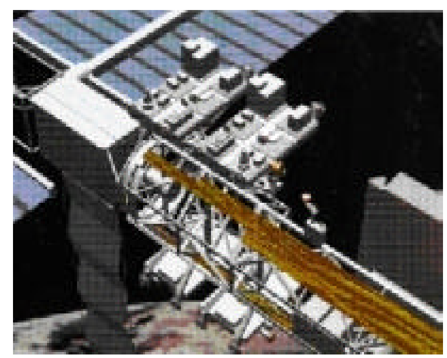
EUROPEAN SPACELAB PALLET

CANADIAN MANIPULATOR ARM

ITALIAN MULTIPURPOSE LOGISTICS MODULE
(MODULE INSIDE SHUTTLE CARGO HOLD)



BRAZILIAN EXPRESS PALLET



BRAZILIAN EXPRESS PALLET
(ARTISTIC VIEW)

FIRE SAFETY FOR HUMAN EXPLORATION AND UTILIZATION OF SPACE

1. OBJECTIVE FOR SPACE FIRE SAFETY

NOTE:

Space travel is inherently dangerous so safety is of primary concern in the space program. The vehicle structure and the crew are exposed to high levels of stress, and the hostile external environment makes escape and rescue nearly impossible. Many potential hazards can arise in space operations, among which are fire, atmospheric contamination, injury, explosion, loss of pressure, and meteroroid and debris penetration. These are examples of prompt-effect hazards, which are those requiring less urgent or timely response, such as contamination, hidden damage, and corrosion. Fire is a foremost and greatly feared prompt-effect hazard, but it also contributes to the delayed-effect hazards. Hence, fire-protection strategies must cover the restoration, repair, and clean up activities after a fire event in addition to the obvious prevention and control before and during a fire. Probably the most important factor distinguishing spacecraft fire protection from terrestrial procedures in extreme environments (e.g., submarines and aircraft) is the strong influence of the low-gravity environment that dominates fire and particulate behavior and control in spacecraft. The substantial upward buoyant flow generated by large density gradients in fires at 1-g is practically eliminated in spacecraft. Heat and and mass-transport rates - and consequently ignition, flammability, fire characteristics, and flame-spread rates - vary considerably from those experienced in conventional, terrestrial fires. At partial gravity levels, the effects of buoyancy, convection, and diffusion can combine to produce unique combustion results. Thus, fire prevention, detection, and suppression practices for spacecraft and extraterrestrial habitats must be developed specifically to respond to the unique aspects of microgravity combustion.

The NASA Microgravity Research Division has sponsored workshops from various Fire Disciplines and experts related to fire safety specifically related to spacecraft. There are three Working Groups: (1) Fire and Post-Fire Response, (2) Smoke and Fire Detection, and (3) Fire Prevention and Material Flammability of which Air Force Fire Protection is a member. The objectives of the Working Group are to collectively:

a. Identify research needed to ensure fire safety in future Shuttle and ISS systems and payloads.

b. Promote ISS fire safety through proposals for innovative designs, operations, and validation procedures.

c. Identify areas of concern related to fire safety inherent to long-duration space missions in Earth orbit and beyond.

d. Anticipate research required to plan and design habitats for planetary exploration.

2. FIRE SAFETY RESEARCH PRIORITIES

a. Research on electrical system diagnostics to provide an early, pre-incident warning to breakdowns possibly resistivity or continuity checks.

b. Determination of flammability, flame spread, flame luminosity, limiting oxygen, & soot sizes under various atmospheres for thick materials and polymers @ 1/3g.

c. Determination of flames sizes, soot sizes, and flammability from thick materials with imposed heat flux under microgravity conditions.

d. Determination of combustion limits, ignitability, and flame luminosity of premixed methane and oxygen for propulsion and fire safety.

e. Research on fundamental behavior of various gaseous, liquid extinguishants, and solid-surface fires @ 1/3g and microgravity with modeling and experiment verification.

3. PLANETARY HABITATION FOR THE MOON AND MARS RESEARCH

a. Evaluation of fire initiation hazards arising from waste disposal, trash storage, laundry, household activities, and storage of fuel gas and oxygen systems.

b. Development of technology for the efficient detection systems required for long-duration missions in terms of rapid response, discrimination, false-alarm rejection, multiple-sensor logic, etc.

c. Identification and evaluation of new suppression agents and techniques required for long-range missions, Lunar or Martian habitation, and in-situ resource utilization (ISRU) extinguishment.

d. Identification of fire safety issues in ISRU operations such as operations at high temperature and pressures, oxygen handling, propellant storage, and safety in welding and thermal operations.

FIREFIGHTING IN MICROGRAVITY

Astronauts on the Columbia Space Shuttle mission tested a new firefighting system that battles blazes with a fine water mist - or fog - instead of using harmful chemicals or large quantities of water that damage property. To fine-tune the designs of their fire-fighting systems, two companies flew a commercial experiment on the STS-107 flight. The study was managed by NASA's Space Product Development Program at the Marshall Center.

During the mission flight of Space Shuttle Columbia, astronauts tested a new commercial fire-fighting system that puts out blazes with a fine water mist - instead of using harmful chemicals or large quantities of water that damage property.

The firefighting industry is in search of a new tool that doesn't use dangerous chemicals or douse fires with huge quantities of water that cause extensive property damage. By flying the commercial experiment on the STS-107 Columbia mission, NASA is helping industry design a cost-effective, environmentally friendly system for putting out fires.

Until recently, halons, bromine-based compounds, were used to attack fires chemically - especially in places like computer rooms, aircraft, and document storage rooms where water sprinklers were inappropriate. In 1998, the production of these chemicals was banned worldwide because they damage Earth's protective ozone layer. This part of the atmosphere shields us from the Sun's harmful ultraviolet radiation.

Working to find an acceptable replacement for halons, and water mist appears to be the best choice. The NASA Commercial Space Center specializes in helping industry conduct combustion research in space through NASA's Space Product Development Program at the Marshall Center.

The Shuttle tests use a humidifier-like device to produce water drops about 20 microns in size. That is about one-tenth the diameter of a human hair, as opposed to drops produced by conventional sprinklers that are about one millimeter, or 50 times the size of our droplets.

The water mist research team is working with companies that manufacture water mist systems for putting out fires and for other purposes, such as outdoor cooling and industrial humidification.

Firefighters in US locations have tested ultra-fine mist nozzles. The cooling effect of mist removes one of the key components of fire - heat.

NASA and interested companies will use information from the STS-107 experiment to fine-tune their designs of firefighting systems. Water mist systems. Water mist systems create a fog instead of sending out blasts of water. Since the fog removes heat and replaces oxygen as the water evaporates, it prevents the fire from expanding and starting new fires.

This is particularly important when fire starts in a closed compartment on a ship, aircraft, or even on the Space Shuttle. The U.S. Navy is already working with the airline industry and The Center for Commercial Applications of Combustion in Space on water mists studies.

With halon replacements expected to be an important part of the $2-billion-a-year fire suppression industry, it is easy to understand why companies are flying this experiment. Companies are testing the system in space because it's easier to observe the interaction between a flame and water when Earth's gravity does not cause air currents around the flame and does not cause water droplets to settle.

Prior combustion experiments have shown that space is the ideal place to study the physics of fire. On Earth, gravity causes lighter, hotter air to rise - creating air currents that make it difficult to study combustion processes. In microgravity - the low-gravity inside the Shuttle orbiting Earth - air currents are reduced or eliminated, making it easier for scientists to observe exactly how water interacts with a flame to put it out.

The Shuttle experiment will help to determine the optimum water concentration and water droplet size needed to suppress fires learned from short tests on NASA's KC-135 reduced-gravity aircraft and inside drop towers that water mists take one-tenth the water of traditional sprinklers to extinguish a flame.

More extensive measurements in periods of microgravity longer than a few minutes will be possible during the Space Shuttle Columbia's16-day mission. A mixture of propane and air will ignite inside a clear tube to produce a thin flame - known as a laminar flame. On the opposite end of the tube, a water mist will be released. Digital images will record how different size water droplets and water concentrations affect the flame.

The experiment will take place inside the safety of the Combustion Module - a NASA facility flown on a previous Shuttle flight. It was developed by NASA's Glenn Research Center in Cleveland, Ohio, and is the forerunner of a similar facility under development for the International Space Station. Future water mist investigations on the Space Station will be larger and longer, enabling companies to test different water injection systems, droplet sizes and fire scenarios.

Columbia's fire experiments' results are pending public release.

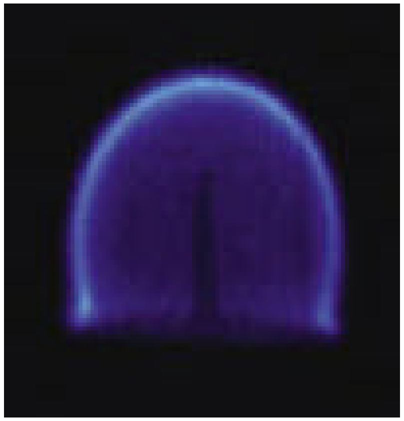
FIREFIGHTING IN MICROGRAVITY

1. MICROGRAVITY COMBUSTION
   Combustion in a microgravity environment eliminates gravitational effects and slows many combustion processes so they become easier to study. Almost everything about fire changes in microgravity and many differences are counter-intuitive:

   - Microgravity fires may spread faster upwind than downwind, opposite to the behavior seen on Earth.
   - While fire in space is often weaker than on Earth, flames in microgravity can be sustained under more extreme conditions than flames on Earth.
   - Turbulent flames, thought to be completely independent of gravitational influence, have doubled in size in microgravity conditions.

2. FLAME BALLS FIRE CHARACTERISTICS AND BEHAVIOR
   Flame balls, accidently discovered in 1984, in a weight-less environment are only stable and exist in microgravity. Flame balls are the weakest fires yet produced in space or on Earth. Typically each flame ball produces only 1 watt of thermal power. The hazard attributed to flame balls are, under normally lighted conditions in a space module, are invisible to the eye and fire detectors. Flame balls are a spherical shell filled with combustion products. Fuel and oxygen products diffuse inward while heat and combustion products diffuse outward. This diffusion-controlled combustion process produces the weakest known flame, however flame ball behavior can not always be predicted. Further tests are required to measure size, brightness, temperature, radiant emission, lifetime, and combustion product composition.

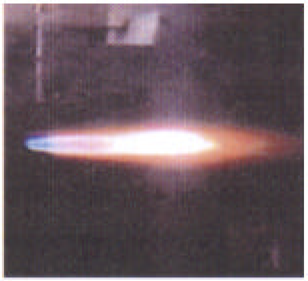
3. STS-107 SCIENTIFIC RESEARCH MISSION
   Highlighting the investigations were the SOFBALL (Structures of Flame Balls) and ARMS (Advanced Respiratory Monitoring System) experiments. Mission Specialists initiated runs with the SOFBALL experiment, which created tiny ball-shaped flames using hydrogen as the fuel. The tiny flames, which approached some of the leanest and longest-lasting ever, were invisible to the human eye, but visible to the crew and investigators on the ground through special video equipment. The team hoped to discover new properties about combustion to improve engine efficiency and fire safety, as well as reduce emissions. 39 tests were performed.



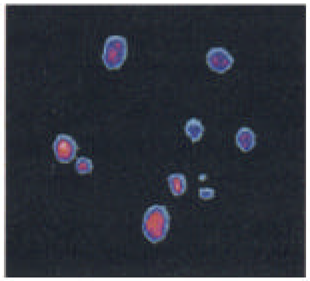
MICROGRAVITY FLAME
(DOME SHAPE)

EARTHLY FLAME
(CONE SHAPE)

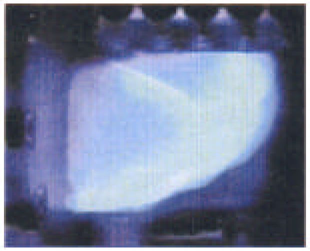
NASA EXPERIMENTS



LAMINAR SOOT PROCESSES (LSP): Evaluate and predict flame shape and internal structures; determine the nature of the soot emission process; validate new universal equations for soot and temperature in a flame; and investigate the soot-bursting hypothesis. Results will improve the understanding of turbulent flames found in many combustion devices on Earth.



STRUCTURES OF FLAME BALLS AT LOW LEWIS-NUMBER (SOFBALL-2): Improve the understanding of the flame ball phenomenon and lean (low fuel) burning combustion; determine the conditions under which they can exist; test predictions of duration; and derive better data for critical model comparison. Results will lead to improvements in engine efficiency, reduced emissions, and fire safety.



MIST: Measure the effectiveness of fine water mists to extinguish a flame propagating inside a tube to gain a better understanding of the mist fire-suppression phenomenon. What is learned will help design and build more effective mist fire-suppression systems for use on Earth, as well as in space.

FIRE SAFETY ON AND BEYOND ORBIT

National Aeronautics and
Space Administration
John H. Glenn Research Center

MICROGRAVITY RESEARCH TIMELINE

Microgravity Science Division
NASA Glenn Research Center

2001-2004 | **2004-2007** | **2007-2010**

FLAMMABILITY OF PRACTICAL MATERIALS IN REDUCED GRAVITY

- Evaluate potential for deep seated fires in non-1g environments
- Determine potential for autoignition and explosion of in-situ propellants, during high temperature processing

2001-2004:
- Determine flammability and flame spread of plastic and composite materials in partial g with variations in flow and imposed heat flux
- Improved test methods to rank materials

2004-2007:
- Determine limiting O_2 and flow for flame propagation on the same materials in ug and partial-g
- Determine effects of sub-limit in-situ propellant concentrations in standard and enriched O_2 atm on practical material flammability

2007-2010:
Flammability measurements and correlation from mg to 1g, including new validated test methods for material rankings

FIRE SIGNATURES AND DETECTION

2001-2004:
- Develop sensors at component level
- Determine method to establish pre-fire and fire signatures of practical materials

2004-2007:
- Develop and demonstrate integrated sensor (chemical/smoke)
- Establish pre-fire and fire signatures of practical materials in low g

2007-2010:
Complete data base for fire signatures and demonstration of new detection systems

FIRE SUPPRESSION FOR MISSIONS ON AND BEYOND EARTH ORBIT

- Evaluate in-situ fire extinguishants
- Develop model of flame growth and stability in practical configurations to extend applicability of data base and to guide design of new systems

2001-2004:
- Integrate understanding of extinguishment strategy and flame behavior in non-1-g environments
- Fundamental/system-level trade-offs of flame-suppression techniques

2004-2007:
- Analyze/test physical dispersion techniques for extinguishment
- Test and validate flame suppression methods in enriched O_2/exotic atmospheres

2007-2010:
Experimentally (microgravity and partial g) validated fire suppressant performance, analysis and models

EVALUATION OF CO_2, N_2 AND HE AS FIRE SUPPRESSION AGENTS IN MICROGRAVITY

Gary A. Ruff and Michael Hicks
NASA Glenn Research Center

Richard Pettegrew
National Center for Microgravity Research

The U.S. modules of the International Space Station use gaseous CO_2 as the fire extinguishing agent. This was selected as a result of extensive experience with CO_2 as a fire suppressant in terrestrial applications, trade studies on various suppressants, and experiments. The selection of fire suppressants and suppression strategies for NASA's Lunar and Martian exploration missions will be based on the same studies and normal-gravity data unless reduced gravity fire suppression data is obtained. In this study, the suppressant agent concentrations required to extinguish a flame in low velocity convective flows within the 20-sec of low gravity on the KC-135 aircraft were investigated. Suppressant gas mixtures of CO_2, N_2, and He with the balance being oxygen/nitrogen mixtures with either 21% or 25% O_2 were used to suppress flames on a 19-mm diameter PMMA cylinder in reduced gravity. For each of the suppressant mixtures, limiting concentrations were established that would extinguish the flame at any velocity. Similarly, concentrations were established that would not extinguish the flame. The limiting concentrations were generally consistent with previous studies but did suggest that geometry had an effect on the limiting conditions. Between the extinction and non-extinction limits, the suppression characteristics depended on the extinguishing agent, flow velocity, and O_2 concentration. The limiting velocity data from the CO_2, He, and N_2 suppressants were well correlated using an effective mixture enthalpy per mole of O_2, indicating that all act via O_2 displacement and cooling mechanisms. In reduced gravity, the agent concentration required to suppress the flames increased as the velocity increased, up to approximately 10 cm/s (the maximum velocity evaluated in this experiment). The effective enthalpy required to extinguish flames at velocities of 10 cm/s is approximately the same as the concentrations in normal gravity. A computational study is underway to further evaluate these findings.

Assessment of CO_2, N_2, and He as Suppressants in Microgravity Environments

Conference-Workshop on

Strategic Research to Enable NASA's exploration Missions

June 22nd -23rd, 2004

Gary A. Ruff - *NASA Glenn Research Center*
Michael C. Hicks - *NASA Glenn Research Center*
Rick Pettegrew - *National Center for Microgravity Research*

Fire Suppression on ISS

Carbon Dioxide is the current suppressant of choice on the ISS. The requirements were developed based on NFPA 12 Regulations that specify that a 50% concentration by volume are required to extinguish smoldering fires (with a 20 minute hold). A concentration of 30% by volume was required to extinguish flaming fires. Carbon dioxide was selected through trade studies that evaluated suppressants based on:

- **Effectiveness on potential spacecraft fires**
- **Reliability**
- **Maintainability**
- **System Weight**
- **Required post-fire clean-up**
- **Compatibility with other spacecraft systems**
- **Toxicity of suppressant and/or post-fire suppression products**

These studies generally conclude that CO_2 and N_2 are close in acceptability with the first choice depending on the weighting of the above criteria. These studies also recommend use of a water-based suppressant should be used for smoldering fires.

Normal-gravity tests were conducted by Sircar *et al.* (1992) that evaluated CO_2, He, N_2, and Halon in a NASA STD 6001 Test 1 configuration (Upward Flame Propagation) with quiescent delivery of the suppressant mixture. Halon was the most effective followed by CO_2. N_2 and He were equally less effective.

ISS Portable Fire Extinguisher
(6 lbs of CO_2 at 850 psi; discharges in 45 sec)

Motivation and Objectives

- Fire response procedure on ISS dictates that ventilation flow is ceased and power removed after annunciation of a fire alarm
- Discharge of a fire extinguisher will induce flow with varying CO_2 concentration
- Effectiveness of these suppressants has never been evaluated in low-velocity convective flows (up to 10-15 cm/s) in microgravity
- Design of next generation, exploration spacecraft will ask the same questions with little new data

➢ Determine the effectiveness of the flow of CO_2, He, and N_2 to suppress fires in microgravity

➢ Conduct tests on the KC-135 on PMMA cylinders for a variety of suppressants and suppressant mixtures

Spacecraft Fire Safety Facility

- **Combustion Chamber**
  - (25.4 cm diam, 51 cm high)
- **Flows up to 17 cm/s**
  - Three mass flow controllers
    - Two 500 slpm
    - 2000 slpm
- **Pressure up to 3 atm**

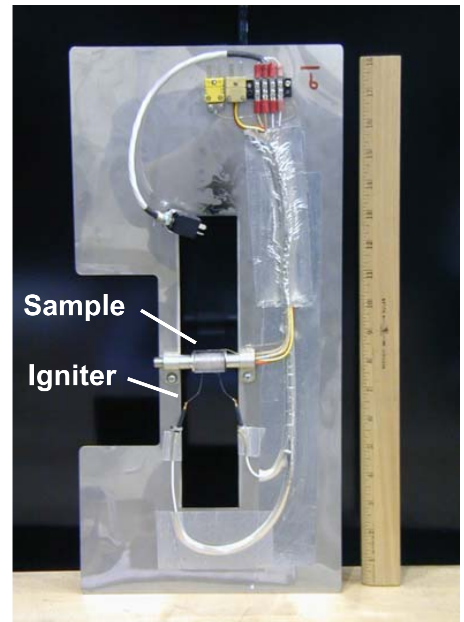
Test Matrix and Samples

- Chamber Pressure = 1 atm
- Standard Air - 21% O_2, 79% N_2
- Rich Air - 25% O_2, 75% N_2
- Velocity: 1 – 10 cm/s

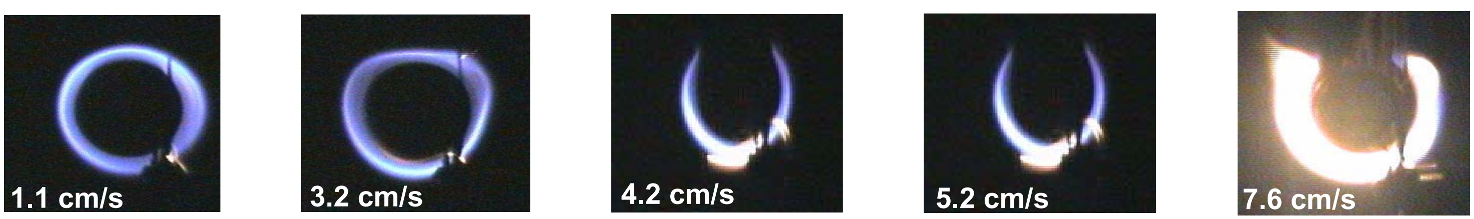
- 19.1 mm diam x 25.4 mm long PMMA cylinders
- Cartridge heater through center
- Surface and heater t/c

- Hot wire igniter
- Flow from bottom to top

Oxidizer	Suppressant	Concentrations (% vol)
Standard Air	CO_2	12.5%, 25%
	He	12.5%, 25%
	N_2	25%
Rich Air	CO_2	12.5%, 25%
	He	12.5%, 25%
	N_2	25%



Sample card with sample and cartridge heater



Typical low-g flames for 25% O_2, 75% N_2

Microgravity Results

CO_2, He, N_2 Suppressants

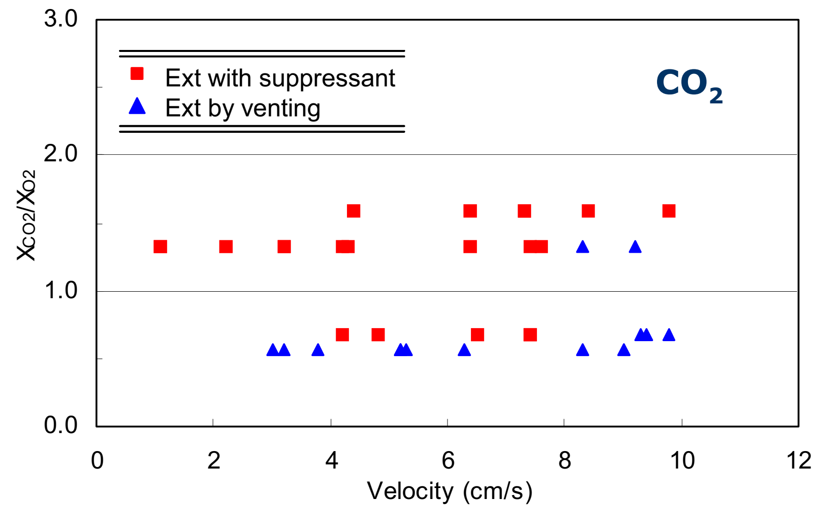
- **Suppressant mole fraction / mole fraction of O_2 as a function of velocity ...**
  - Extinguishment limits in slow flow regime (i.e., less than 10 cm/s) show dependence on velocity
  - Previous studies ...

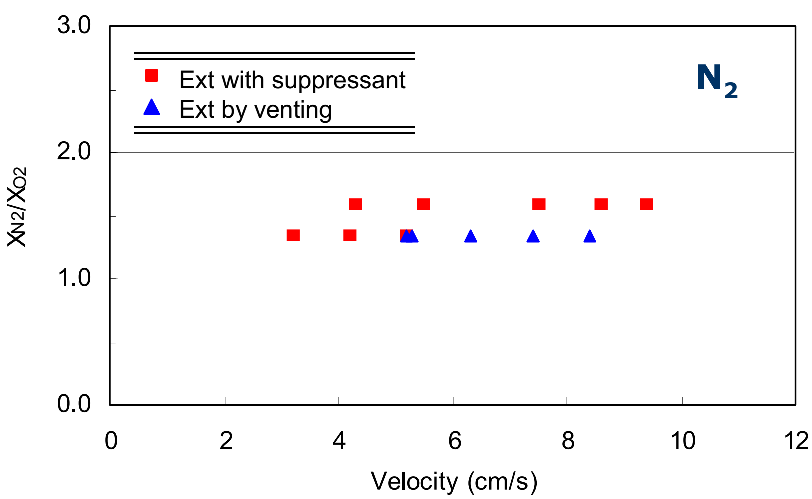
    CO_2 : $X_{CO2} / X_{O2} = 0.62$ (Prasad *et al.*)

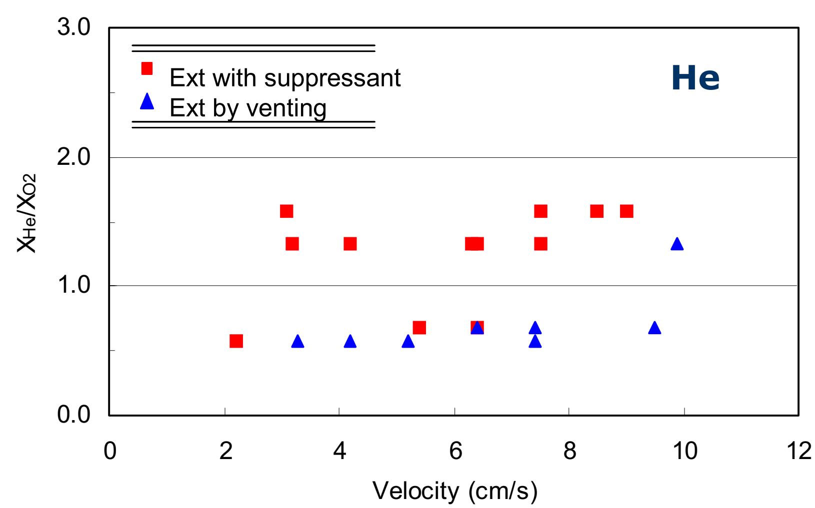
    $X_{CO2} / X_{O2} = 1.12$ (Takahashi *et al.*)

    He : $X_{He} / X_{O2} = 2.1$ (Takahashi *et al.*)

    N_2: $X_{N2}/X_{O2}=2.92$ (Takahashi *et al.*)







Effective Enthalpy/Mol O_2

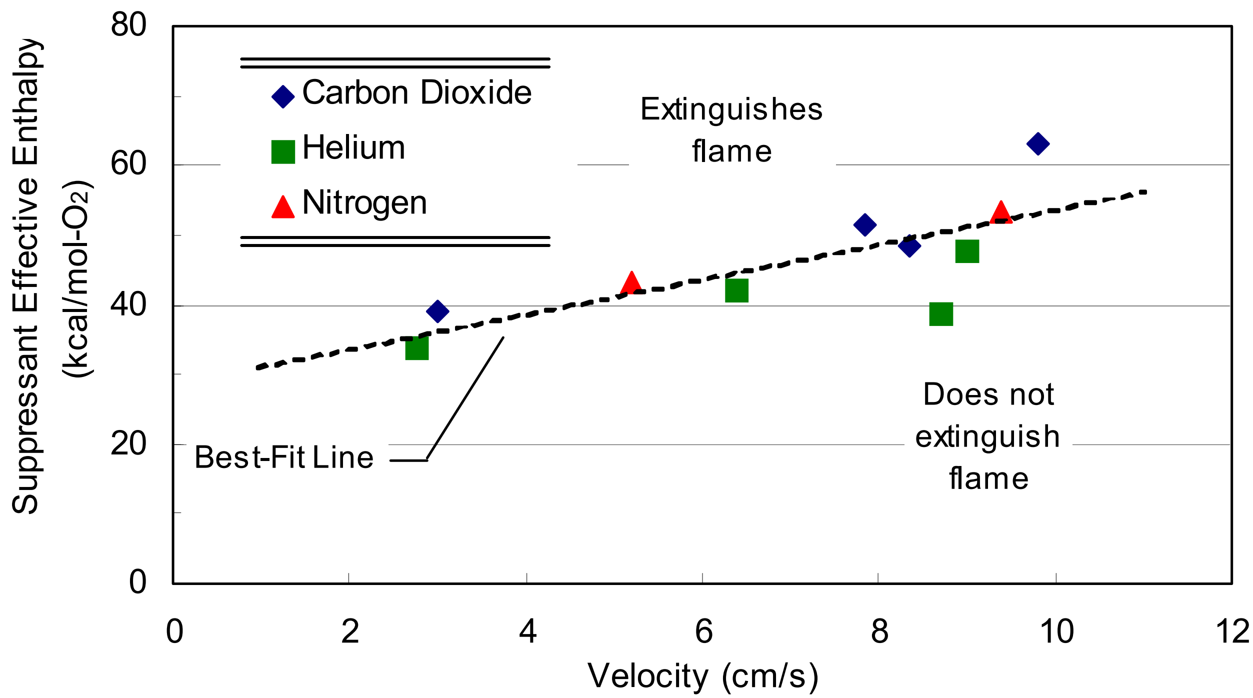
- **Huggett (1969, 1973) proposed a "threshold" heat capacity above which organic fuels cease to burn**
  - Showed that at a "mixture" specific heat greater than 40 – 50 cal/C-mol O_2 a flame could not be sustained (at a pressure of 1.0 atm)
  - Determined from strained laminar diffusion flames
- **Sheinson *et al*. (1989) applied this concept to evaluate the physical and chemical performance of various suppressant mixtures**
  - Defined an effective mixture enthalpy as energy required to heat mixture from 298 K to 1600K

$$\Delta H' = \sum_i \frac{X_i}{X_{O2}} \int_{298}^{1600} Cp_i dT$$

- **Calculated the effective enthalpy/mol O_2 for each suppressant mixture**
- **Established a limiting velocity at which there was a transition in suppression characteristics**
  - Averaged bounding velocities
  - Plotted highest velocity tested if no transition was observed

Correlation with Effective Enthalpy

- Helium lies slightly below CO_2 and N_2 presumably because of higher thermal conductivity
- Microgravity flame on PMMA requires less suppressant to extinguish at lower velocities
- Normal gravity suppression is at 63.2 kcal/mol O_2



Conclusions

- **Higher suppressant concentrations are required to extinguish flames in microgravity as velocity increases**
  - Up to 10 cm/s investigated in this experiment
  - Effective enthalpy/mol-O_2 correlates limiting velocity fairly well
  - Effective enthalpy at 10 cm/s is nearly normal-gravity value
- **For these conditions, CO_2, N_2, and He all act as passive suppressants**
  - O_2 replacement and cooling
- **Procedures on ISS are reasonable for flaming fires**
  - Specifications for CO_2 concentrations are high enough for smoldering fires but no provision for hold time
  - Use of water-based foam in U.S. modules is not “recommended”

Future Work

- **Continue modeling of the CO_2, He, and N_2 suppression results**
  - Can the suppression and limiting velocity boundaries be duplicated?
- **Complete analysis of partial gravity suppression data**
  - Data obtained for CO_2 at 0.1-g_o, 0.17-g_o(Lunar), 0.38-g_o (Martian), and 0.5-g_o

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Fire Prevention, Detection, and Suppression

Organizing Questions for Research in Fire Suppression and Response

Background

- Limited research to date directed toward extinguishment of existing fires
  - Venting extinguishment testing (Skylab and KC-135)
  - CO_2 extinguishment testing (KC-135)
  - Thin-fuel Flammability limit testing (drop towers and KC-135)
- Testing has been limited to partially developed small fires
- Development of a reliable extinguishment system will require testing of extinguishment of a variety types of fires in a range of geometries, including well established fires

Organizing Questions

1. **What is the relative effectiveness of candidate suppressants to extinguish a representative fire in reduced gravity, including high-O_2 mole fraction, low-pressure environments?**
2. **What are the relative advantages and disadvantages of physically-acting and chemically-acting agents in spacecraft fire suppression?**
3. **What are the O_2 mole fraction and absolute pressure below which a fire cannot exist?**
4. **What effect does gas-phase radiation play in the overall fire and post-fire environments?**
5. **Are the candidate suppressants effective to extinguish fires on practical solid fuels?**
6. **What is required to suppress non-flaming fires (smoldering and deep-seated fires) in reduced gravity?**
7. **How can idealized space experiment results be applied to a practical fire scenario?**
8. **What is the optimal agent deployment strategy for space fire suppression?**

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1. What is the relative effectiveness of candidate suppressants to extinguish a representative fire in reduced gravity, including high-O_2 mole fraction, low-pressure environments?

- CO_2, N_2, He, water mist, microencapsulated water, ...
- What metric do you use for effectiveness when evaluating different suppressants?
- What test configuration (or range of configurations) should be used?

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2. What are the relative advantages and disadvantages of physically-acting and chemically -acting agents in spacecraft fire suppression?

- Chemical suppressants may be effective at concentrations below SMAC values
- Are chemical suppressants equally effective in reduced gravity?
- What metric do you use for effectiveness when evaluating different suppressants?
- What test configuration (or range of configurations) should be used?

3. What are the O_2 mole fraction and absolute pressure below which a fire cannot exist?

- Provides a lower limit for design of a suppression delivery system
- Presume a physically-acting extinguishing agent
- Value will depend on configuration, fuel, and diluent
  - Testing with μg droplet combustion has shown the limiting oxygen index (LOI) for droplet combustion to be substantially (~4 mol %) below that for solids or normal gravity droplet testing.

4. What effect does radiative absorption in the gas phase play in the overall fire and post-fire environments?

- Prior work with radiatively participating gases indicate that extinguishing CO_2 concentrations in oxidizing environments might result in broader flammability limits due to radiative feedback from the CO_2 rich ambient.
- Effect is minimized in normal gravity because of buoyancy.

5. Are the candidate suppressants effective to extinguish fires on practical solid fuels?

- Evaluating agent effectiveness may require a simple geometry
- How is the connection made to a practical solid fuel?
- Is a space flight verification test required?

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6. What is required to suppress non-flaming fires (smoldering and deep-seated fires) in reduced gravity?

- NFPA Standard 12 requires a 20-minute holding time with CO_2
- Smoldering combustion is one of the most probable spacecraft fire scenarios (cable overheat, trash and bio-matter storage) yet holding times are unknown
- Deep seated fires (i.e., fires that can re-ignite after suppression of the gas-phase flame) have not been addressed for microgravity conditions
- Competition between heat loss (diffusion) and oxidant diffusion timescales
- Geometry can be either smoldering or dispersed solid (e.g. crib or trash fire)
- Testing will first establish whether re-ignition can occur and then extinguishment criteria will be established

7. How can idealized space experiment results be applied to a practical fire scenario?

- Real fire geometries are complex and involve radiative interaction between burning solids.
- Model development concurrent with small scale extinguishment tests will build framework for large scale tests.
- Model validation with large scale testing will ultimately be required to assure extinguishment effectiveness

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8. What is the optimal agent deployment strategy for space fire suppression?

- Normal gravity buoyant pumping of agent into fire is absent in μg (in both flooding and targeted application of agent)
- Fire brand transport and flammability must be considered in the design of hand-held extinguishers
- Fire brands released by agent deployment will not settle as in 1-g
- Flooding applications must be validated by computational modeling of agent deployment combined with experimental understanding of local extinguishment
- Data from the prior questions should be able to help address this issue

Programmatic Background

- The Combustion Integrated Rack is currently scheduled for launch on ULF-2 in October 2006
- In March, a proposal was made at HQ to move the CIR launch to ULF-1.1 in June 2005
- What experiment can be run that supports the exploration mission?
  - Existing hardware → MDCA or MGFA inserts
- Two concepts were developed for rapid deployment
- The proposal was not accepted but the concepts remain relevant

Brainstorming

- Fire Suppression
  - Carriers
    - ISS Glovebox
    - CIR new insert
    - FEANICS
  - Experiments
    - GBEX (cup burner)
    - FLEX (MDCA hardware)
    - Porous plate/cylinder
- Backward Facing Step
- Real Materials
- Smoldering Materials

Most Probable Fire Scenarios in Spacecraft and Extraterrestrial Habitats - Why NASA's Current Test 1 Might Not Always Be Conservative

S.L. Olson, NASA Glenn Research Center

NASA's current method of material screening determines fire resistance under conditions representing a worst-case for normal gravity flammability - the Upward Flame Propagation Test (Test 1[1]). Its simple pass-fail criteria eliminates materials that burn for more than 12 inches from a standardized ignition source. In addition, if a material drips burning pieces that ignite a flammable fabric below, it fails.

The applicability of Test 1 to fires in microgravity and extraterrestrial environments, however, is uncertain because the relationship between this buoyancy-dominated test and actual extraterrestrial fire hazards is not understood. There is compelling evidence that the Test 1 may not be the worst case for spacecraft fires, and we don't have enough information to assess if it is adequate at Lunar or Martian gravity levels.

Microgravity Flames do Strange Things

Flames in microgravity are known to preferentially spread upwind (ie opposed flow) [2], not downwind (i.e. concurrent flow) as in the normal gravity upward flammability screening Test 1. Over most of the range of air ventilation rates (5-20 cm/s) comparable to spacecraft ventilation, upstream flame spread was the only viable flame. Only when the flow becomes strong enough (estimated to be $\geq$ 10 cm/s), will at least a partial downstream flame become viable. Numerical and experimental results [7] predict an upstream flame only at 5.0 cm/s, an upstream flame and two localized edge flames propagating downstream at 10.0 cm/s, and both an upstream and downstream flame at 20.0 cm/s.

This propensity to spread upwind does not only occur for thin materials, but also occurs for thicker materials and other shapes. For example, experiments were conducted aboard the Mir space station using plastic cylinders. The intent was to burn them with a concurrent flame spread similar to that of Test 1. However, rather than spread along the rod, the flame stabilized at the front tip of the rod and burned like a candle flame at the end of a fat wick [3,4] ,

Under the right flow conditions in space, things will burn that won't burn on Earth. This is most clearly demonstrated by a flammability map [5,6]. In the opposed flow flame spread flammability map for a cellulose fuel, the LOI, or limiting oxygen index on Earth in opposed flow is 16.5% O_2. However, if the flow is on the order of spacecraft ventilation (5-20 cm/s), flames can be sustained even at 14 % O_2. Thus a normal gravity measure of flammability does not guarantee that the material won't burn in space.

Some preliminary work on independent opposed and concurrent flame spread was conducted in a glovebox experiment [8]. The flame spread results in the cabin air (~21% O2) show that the quenching region spans from +0.5 to -2 cm/s, so even correcting for the small spread rate, the concurrent flame has a higher flow flammability boundary than the opposed flow flame.

On the Moon or Mars (0.17g and 0.38 g, respectively), where buoyant flows will be greater than 20 cm/s, the concurrent flame spread will be viable simultaneously with any opposed flow flame. Experiments conducted aboard the KC-135 [9] demonstrate the faster burning of concurrent flames in partial gravity environments. These higher flow test conditions are on the blowoff side of the flammability boundary.

If a fire is initiated, and the crew takes steps to extinguish it, the first line of defense is to turn off the flow. As demonstrated by the data above, the flame cannot survive indefinitely without a supply of fresh oxygen. Once the fire is out, the crew would reactivate the flow to clean up any residual smoke.

However, experiments have shown that even a very slight air flow of a fraction of a cm/s [4] is sufficient to allow the flame to survive. These flames can become almost undetectable (small, non-luminous) and yet persist for many minutes [10, 11] for a fingering flame spread observed under very weak ventilation. The tiny flamelet (~6 mm x 2mm) spread steadily, albeit slowly, for 80 seconds. When the flow was turned up 100-fold to 50 cm/s, the flame did not blow out as one would expect, but flared up into a much larger spreading flame. The fingering behavior is unique to low gravity. The formation of these different flame structures is due to changes in lateral diffusive flux of oxygen from the outer flow to the flame, convective flow patterns and oxygen shadow caused by oxygen consumption at the upstream flamelet. These types of behaviors must be known and understood so that the crew can watch for them.

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Most Probable Fire Scenarios in Spacecraft and Extraterrestrial Habitats - Why NASA's Current Test 1 Might Not Always Be Conservative

S.L. Olson, NASA GRC

NASA's current method of material screening determines fire resistance under conditions representing a worst-case for normal gravity flammability - the Upward Flame Propagation Test (Test 1[1]). Its simple pass-fail criteria eliminates materials that burn for more than 12 inches from a standardized ignition source. In addition, if a material drips burning pieces that ignite a flammable fabric below, it fails.

The applicability of Test 1 to fires in microgravity and extraterrestrial environments, however, is uncertain because the relationship between this buoyancy-dominated test and actual extraterrestrial fire hazards is not understood. There is compelling evidence that the Test 1 may not be the worst case for spacecraft fires, or at Lunar or Martian gravity levels. This poster is a summary of what we know about the most likely forms a fire will take in space. (Please see reference list for cited works presented here).

Microgravity flames go the wrong way

Flames in microgravity are known to preferentially spread upwind (ie opposed flow) [2], not downwind (i.e. concurrent flow) as in the normal gravity upward flammability screening Test 1. Over most of the range of air ventilation rates (5-20 cm/s) comparable to spacecraft ventilation, upstream flame spread was the only viable flame. Figure 1 shows an image of a thin cellulose sample ignited in the middle. The blue half-dome flame is spreading upstream – into the fresh air. The downstream half of the dome is not viable because the oxygen has been consumed by the upstream side of the flame.

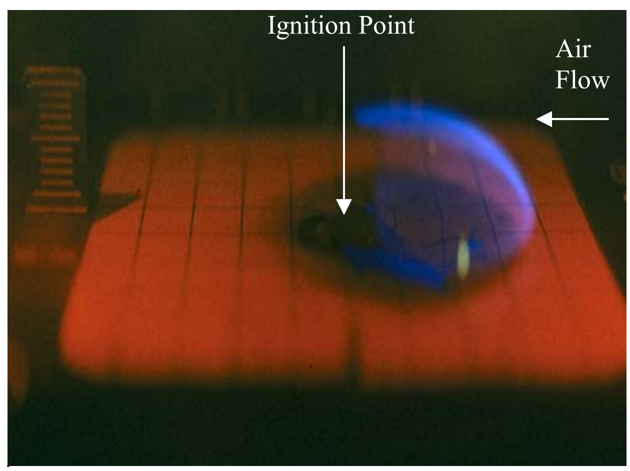

Figure 1: When ignited in the middle, the flame preferentially spreads upstream at low speed airflows

Only when the flow becomes strong enough (estimated to be ≥ 10 cm/s), will at least a partial downstream flame become viable. Numerical and experimental results [7]. predict an upstream flame only at 5.0 cm/s, an upstream flame and two localized edge flames propagating downstream at 10.0 cm/s, and both an upstream and downstream flame at 20.0 cm/s.

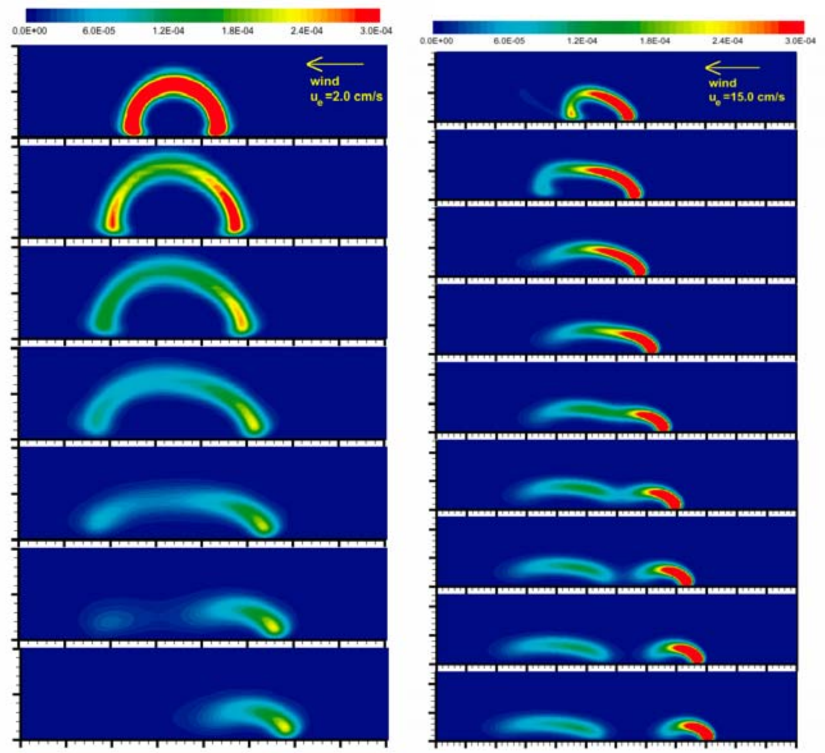

Figure 2: Computational Results of ignition and transition to flame spread for 5 cm/s (left) and 20 cm/s (right). The downstream flame is not viable at low wind velocities, but the two flames separate successfully at 20 cm/s as the thin fuel burns out in the middle. Notice even then how much weaker the downstream flame is. [7]

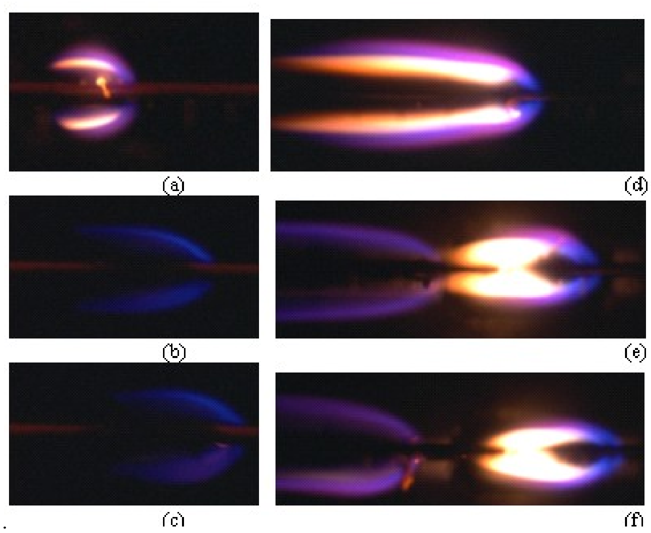

Figure 3: Color images of the edge view for flame spread in microgravity conditions obtained from the drop tower experiments. Figures 3. a, b and c are for an imposed flow velocity of 5 cm/s at t=2 s (a), 6.5 s (b) and 9.5 s (c) from the onset of external radiation. Figures 3. d, e and f are for an imposed flow velocity of 20 cm/s at t=4 s (a), 8 s (b) and 9.5 s (c) from the onset of external radiation. The flow is from right to left and the flames are propagating in air. Notice the similarities in the flame separation between these images and the computations of Figure 2.[7]

The computations and experimental results [7] at 5 cm/s and 20 cm/s are shown in Figures 2 and 3.

This propensity to spread upwind does not only occur for thin materials, but also occurs for thicker materials and other shapes. For example, experiments were conducted aboard the Mir space station using plastic cylinders. The intent was to burn them with a concurrent flame spread similar to that of Test 1. However, rather than spread along the rod, the flame stabilized at the front tip of the rod and burned like a candle flame at the end of a fat wick [3,4], as shown in Figure 4.

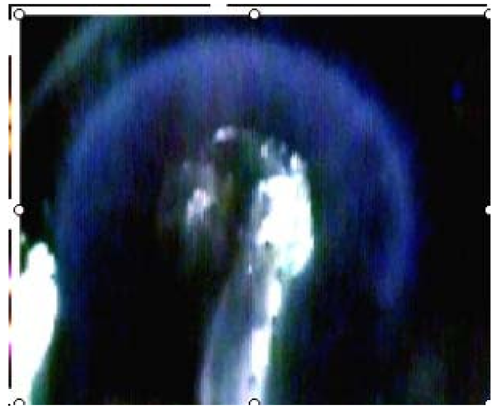

Figure 4: Candle-like flame burning at the upstream end of a plastic rod [4].

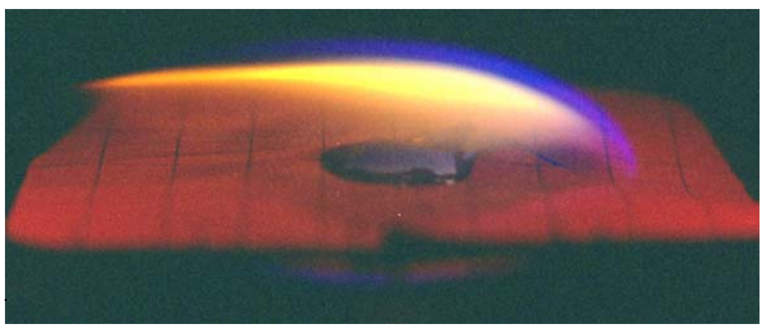

Figure 5: 3D flame spread with only upstream spread and a long downstream tail.

It is conceivable that a thermally thick sample would result in only one flame propagating upstream, with a long tail instead of the two flame structure for a thermally thin sample (because fuel burnout does not occur). [Takashi Kashiwagi, private communication]. Flame would look similar to Fig. 5.

Things burn in space that don't burn on Earth

Under the right flow conditions in space, things will burn that won't burn on Earth. This is most clearly demonstrated by a flammability map [5,6]. Figure 5 shows the opposed flow flame spread flammability map for a cellulose fuel. The LOI, or limiting oxygen index on Earth for this material in opposed flow is 16.5% O_2. **However, if the flow is on the order of spacecraft ventilation (5-20 cm/s), flames can be sustained even at 14 % O_2. Thus a normal gravity measure of flammability does not guarantee that the material won't burn in space.**

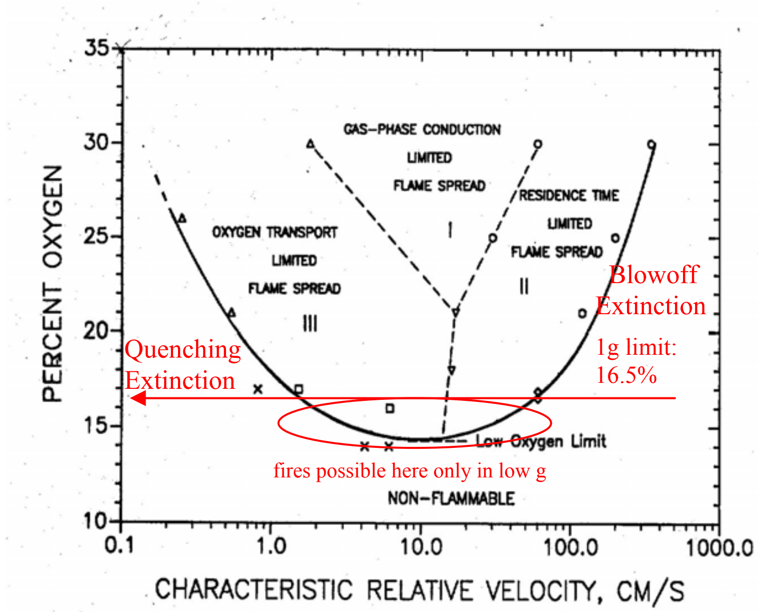

Figure 5: Experimentally-based flammability map for opposed flow flame spread over cellulose [5].

Shown in Figure 6 are 2D numerical predictions [6] of opposed flow vs concurrent flow flame spread (not simultaneous as described above).

As can be seen in Fig. 6, the fundamental LOI occurs at very low free stream velocities, which are in the range of spacecraft ventilation velocities (5-20 cm/s). Thus a 1g upward (concurrent) flame spread test, where buoyant flows are higher than 20 cm/s, is not conservative for these environments.

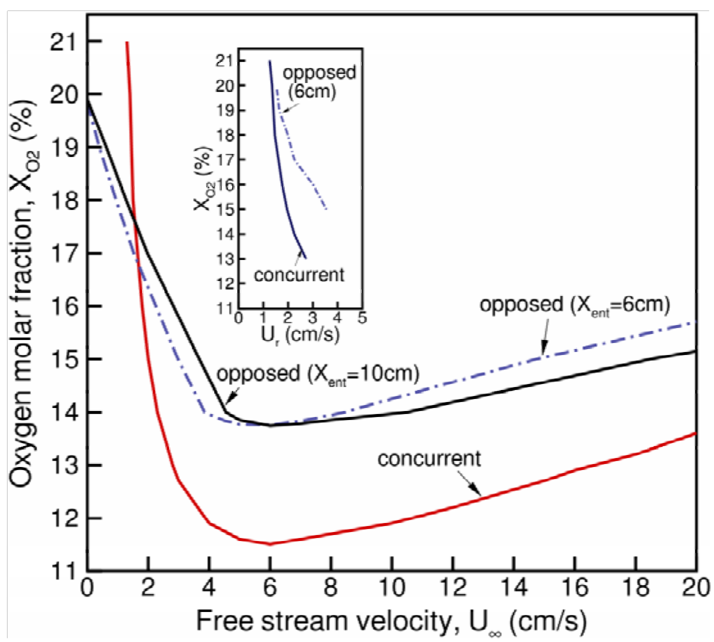

Figure 6: 2D theoretical flammability boundaries for independent opposed and concurrent flame spread. Notice the concurrent boundary extends to much lower oxygen concentrations than the opposed boundary except at very low speed forced flows, where the trend is reversed. [6]

These predictions show that oxygen limits (including the fundamental limit) are lower for the concurrent flame than for the opposed flames except in the very low velocity range. 3D computations are underway, and the extinction boundaries are expected to shift somewhat due to the importance of lateral oxygen transport, especially at low flows and low oxygen concentrations.

In the very low velocity range, oxygen supply is limiting. Therefore opposed spread, by moving against the oxygen flow, acquires a higher rate of oxygen transport into the flame, thus can have a lower oxygen limit. This point is illustrated further by plotting the flammability map using the relative velocity (between the flame and the flow) as the abscissa, shown in the inset of Fig. 6. Experiments are planned for ISS to measure the concurrent-only flame spread limits to verify these predictions.

Some preliminary work on independent opposed and concurrent flame spread was conducted in a glovebox experiment [8]. The flame spread results in the cabin air (~21% O2) are shown in Figure 7. The quenching region spans from +0.5 to -2 cm/s, so even correcting for the small spread rate, the concurrent flame has a higher flow flammability boundary than the opposed flow flame. This contradicts the inset of Figure 6, where the concurrent flame, once corrected for flame spread rate, has a comparable flammability limit.

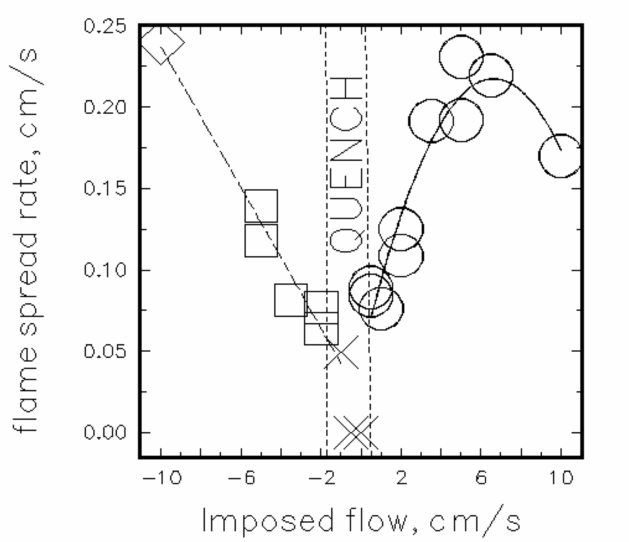

Figure 7: Flame spread rates in shuttle cabin air plotted against imposed flow. Negative flow is concurrent flow, whereas positive flow is opposed flow.

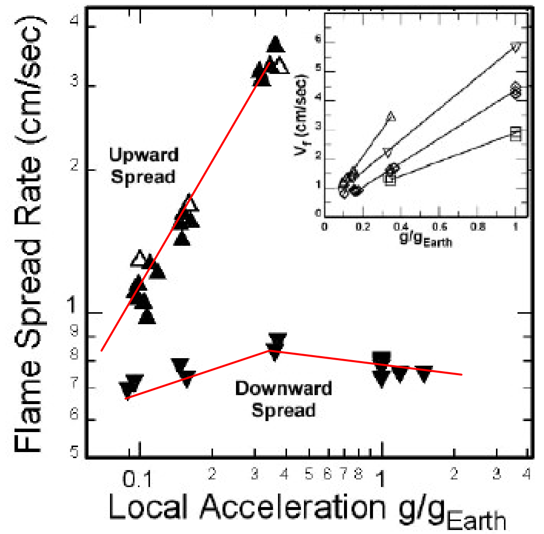

Figure 8: Upward and downward flame spread rates for narrow samples (2 cm) in low pressure (4 psia) air at various gravity levels. Closed symbols are experiments, open symbols are numerical simulations. Inset is 1 cm wide samples [9].

On the Moon or Mars (0.17g and 0.38 g, respectively), where buoyant flows will be greater than 20 cm/s, the concurrent flame spread will be viable simultaneously with any opposed flow flame. Experiments conducted aboard the KC-135 [9] demonstrate the faster burning of concurrent flames in partial gravity environments, as shown in Figure 8. These higher flow test conditions are on the blowoff side of the flammability boundary (Figure 5). Thus while upward burning here is worse than downward burning, the **normal gravity upward test is still not conservative because the minimum flammability is at low velocities only achievable in reduced gravity (Fig. 6).**

Flames Do Strange Things in Space

If a fire is initiated, and the crew takes steps to extinguish it, the first line of defense is to turn off the flow. As demonstrated by the data above, the flame cannot survive indefinitely without a supply of fresh oxygen. Once the fire is out, the crew would reactivate the flow to clean up any residual smoke.

However, experiments have shown that even a very slight air flow of a fraction of a cm/s [4] is sufficient to allow the flame to survive. **We cannot rely on quiescence to extinguish flames, because even the slightest flow *O*(mm/s) will support flames.** These flames, which near the limit will likely be flamelets, can become almost undetectable (small, non-luminous) and yet persist for many minutes[10], as shown in Figure 9 for a fingering flame spread observed under very weak ventilation (5 mm/s). The tiny flamelet (~6 mm x 2mm) spread steadily, albeit slowly, for 80 seconds. When the flow was turned up 100-fold to 50 cm/s, the flame did not blow out as one would expect, but flared up into a much larger spreading flame.

Figure 9: A tiny flame at 0.5 cm/s flares up within seconds when the flow is suddenly increased. Flow enters from right.

This fingering flamelet behavior, currently being studied as part of an ISS flight experiment, (Fig 10, 11) occurs near the quenching extinction boundary. The formation of these different flame structures is due to changes in lateral diffusive flux of oxygen from the outer flow to the flame, convective flow patterns and oxygen shadow caused by oxygen consumption at the upstream flamelet.

Flamelet fingering occurs in either opposed-flow spread (flame spreading against the wind) or concurrent spread (with the wind) under weak ventilation conditions. The fingering nature of the two spread modes is different, however, as shown in Figure 10.

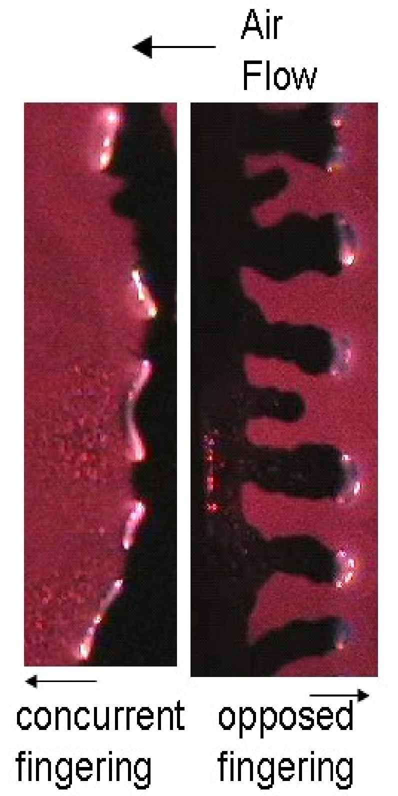

Figure 10: Concurrent flamelet fingering tends to travel along the edges of the unburned material like caterpillars eating a leaf, whereas opposed flamelet fingering tends to tunnel into the pristine fuel. While the concurrent flamelets spread more slowly than the opposed flamelets, overall, they consume more of the fuel. [10]

If ignited in the middle of the fuel, the predominant mode is opposed flow spread, because the upstream-most flame will consume the oxygen and any downstream reactions are unable to survive in the vitiated air [7]. However, if ignited at the upstream edge, then concurrent flamelets can survive since the fresh oxidizer reaches them directly. However, they stabilize on the edge of the burning material and cannot tunnel into the material very far before turning back upstream toward the fresh oxidizer.

Figure 11: Smoldering fingering [11] has also been seen in microgravity. 1 cm grid. Flow enters from right. Large circle is ignition point.

These types of flaming and smoldering must be better understood so that we can gain confidence that we can detect these hard-to-detect fires and fully-extinguish them so that they do not flare up into a large fire.

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NASA/CP—2004-213205/VOL2

Understanding Material Property Impacts on Co-Current Flame Spread: Improving Understanding Crucial for Fire Safety

Ali S. Rangwala[A], Steven G. Buckley[A] and Jose L. Torero[B]

[A] *Department of Mechanical and Aerospace Engineering, University of California, San Diego, CA*

[B] *School of Engineering and Electronics, University of Edinburgh, Scotland, UK.*

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Introduction

The prospect of long-term manned space flight brings fresh urgency to the development of an integrated and fundamental approach to the study of material flammability. Currently, NASA uses two tests, the upward flame propagation test and heat and visible smoke release rate test, to assess the flammability properties of materials to be used in space under microgravity conditions. The upward flame propagation test can be considered in the context of the 2-D analysis of Emmons (1956)[1]. This solution incorporates material properties by a "mass transfer number," B in the boundary conditions, given by.

$$B = \frac{(1-\chi)(\Delta H_C Y_{O_2,\infty}) - Cp_\infty (T_{ig} - T_\infty)}{\Delta H_P + Q_C}$$

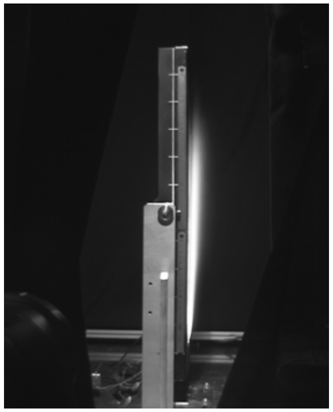
In this expression for B, the numerator denotes the amount of heat release and the denominator represents the amount of heat needed to gasify the fuel; hence larger values of B represent a greater potential driving force for combustion and a greater potential flammability. Experimental and theoretical calculations of the B number, however, don't give similar results. The primary reason for this appears to be air entrainment, which is not accounted for in the Emmons 2-D model. Current experimental and analysis work aims to provide a more solid foundation for the prediction of material property influence on flammability.

[1] H. Emmons, Z. angew. Math. Mech. 36 (1-2) (1956) 60-71.

Experiment

- Measurements of flame stand-off distance and pyrolysis length enable determination of B in a configuration analogous to NASA's flame spread test (Figures 1, 2, 5)
- Particle image velocimetry measurements illustrate air entrainment from the 3rd dimension, this has been verified using the Fire Dynamic Simulator Code from NIST (Figure 3, 4).

Experimental setup



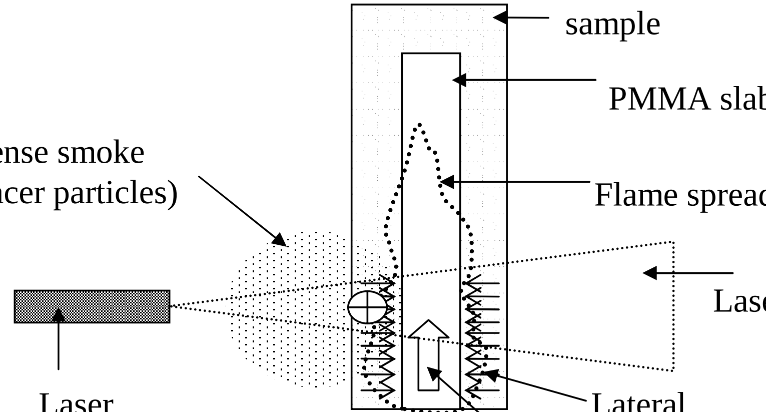
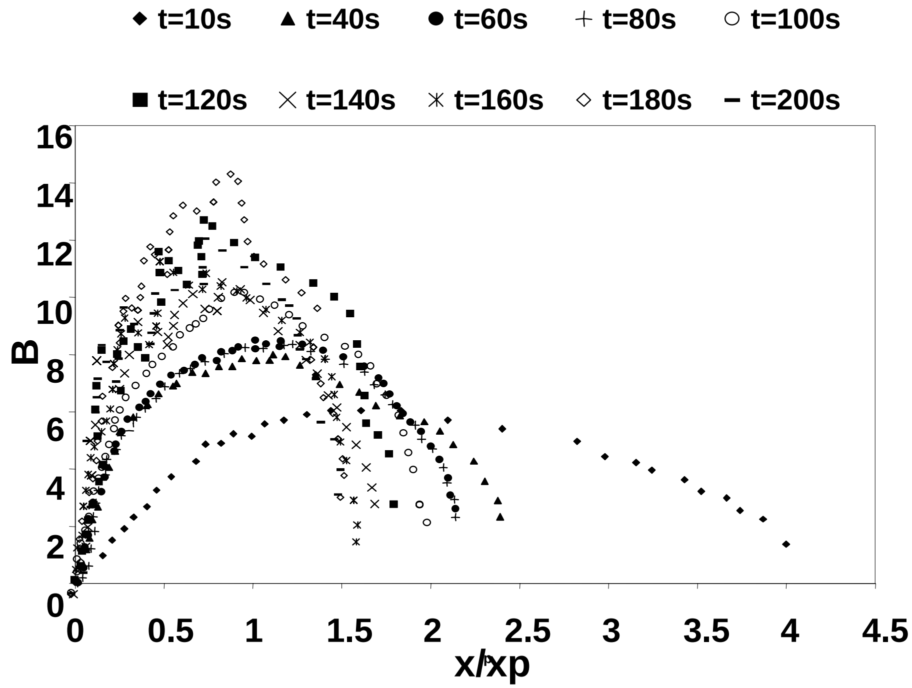
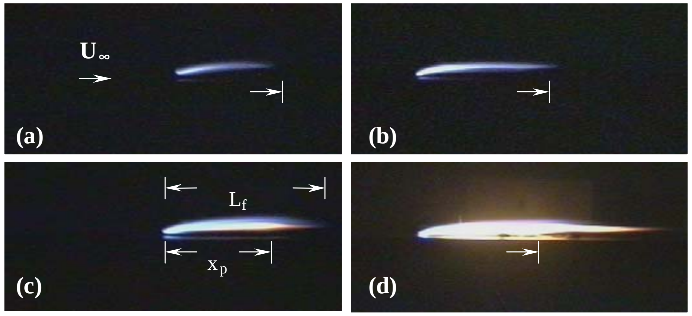


Fig 1, 2**:** Experimental set up to measure stand off distance is shown by the picture on left hand side. The right hand side above shows the particle image velocimetry (PIV) set up.

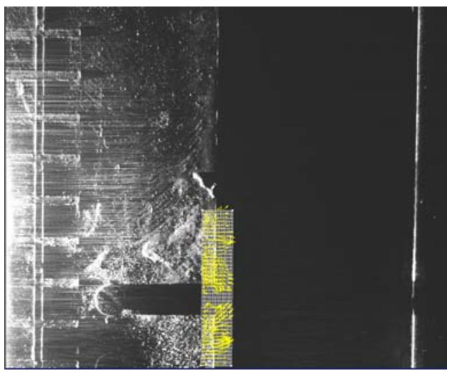
Typical stand-off distances measured as a function of time





Significance/Findings

The two-dimensional classical boundary layer solution of Emmons[1] is insufficient to describe the buoyantly-driven flame propagation investigated here due to the influence of air entrainment in the 3rd dimension. However, this does not invalidate the significance of the B number or the importance of material properties on flame spread.



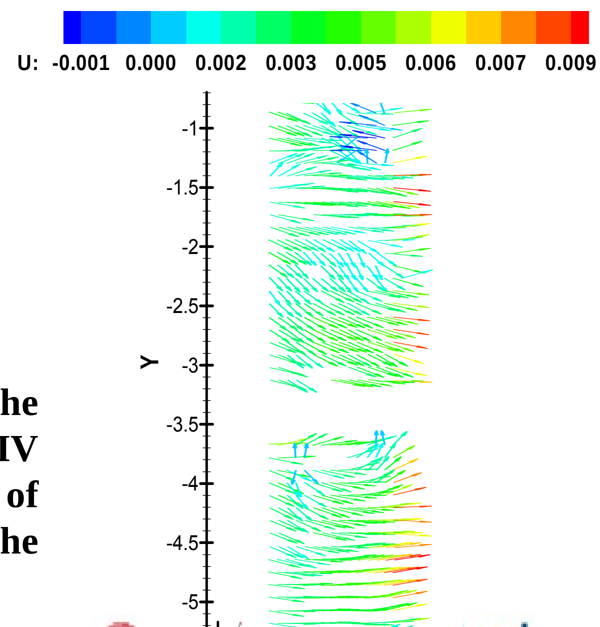


Fig 3**: Above: the fuel, with the yellow square on the edge of the fuel showing the location of the PIV measurements. The PIV measurements (right) illustrate entrainment from the side of the fuel: Average velocity is 7-10 mm/s at 4 to 5 mm from the surface of the fuel.**

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Experimental and FDS results

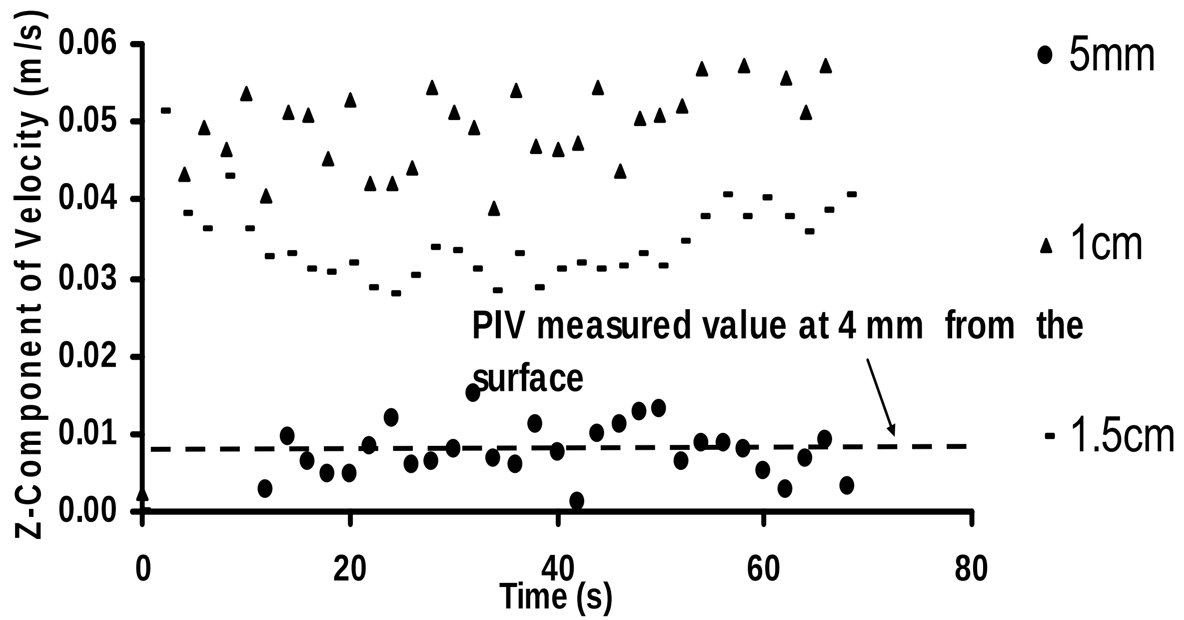

***Fig 4*: The lateral entrainment velocity predicted by FDS (fire dynamic simulator). As the distance from the surface increases the lateral entrainment velocity increases, reaching a maximum value at about 1 cm from the surface before decreasing. The entrainment velocity of 7-10 mm/s we measured from our experiments was a distance of between 4 to 5 mm from the surface of the fuel in good agreement with FDS.**

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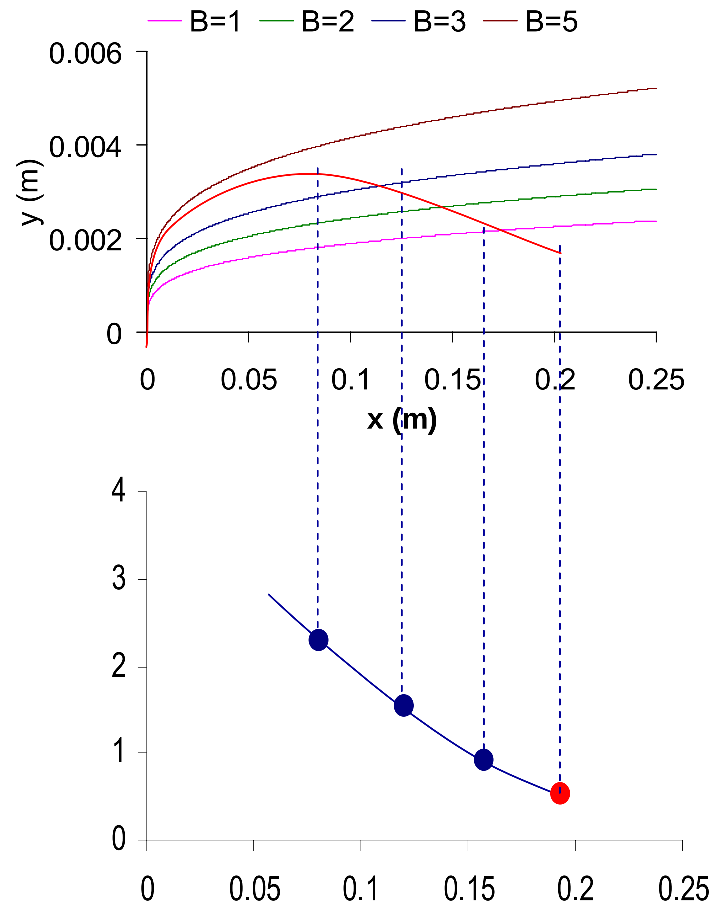
***Fig 5*: The flame shape has a direct relationship with the B number. Four of the curves with similar shapes are from theory, while the red curve shows the experimentally measured flame shape. The experimentally-determined B number should be a constant, but it is not. The evolution of the B number obtained from the stand off distance shows that theory and experiment don't match.**



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Conclusions to date

- Lateral flame spread has a significant impact on the upward flame spread problem under study. The traditional Emmons solution is not able to capture the impact of flow in this 3rd dimension and thus modifications are required to apply theory to this problem.
- Material properties, such as those embodied in the mass transfer number B, should play a vital role in our understanding of flammability and flame spread

Continuing Work

- New experiments are planned to better examine the linkage between the material properties, B number, and flammability.
- Direct numerical modeling of the experiments to better quantify flow field.
- Analytical solution of the flow in the third dimension

Acknowledgements

NASA Fire Safety Program of the Bioastronautics Initiative: Grant #NAG-32568

NASA technical contact: Dr. Gary Ruff

Experimental assistance: Dr. Mickey Coutin

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Advanced Human Support Technology

Fire Prevention, Detection, and Suppression

Gary A. Ruff
NASA John H. Glenn Research Center

Workshop on

Strategic Research to Enable NASA's Exploration Missions

June 22 - 23, 2004
Marriott Downtown at Key Center
Cleveland, Ohio USA

Bioastronautics Initiative - History

- **In mid-1999, the Space and Life Sciences Directorate at Johnson Space Center was challenged to develop a new paradigm for NASA human life sciences**
  - Space Medicine
  - Space Biomedical Research and Countermeasures
  - Advanced Human Support Technology

- **A new thrust - *Bioastronautics* - was formulated with a budget augmentation request**

- **Objective:**
  - Expanded extramural community participation through the National Space Biomedical Research Institute
  - Initiated the detailed planning and implementation of Bioastronautics
    - *An Integrated Approach to Ensure Healthy and Safe Human Space Travel*
    - *Assist in the Solution of Earth-based Problems*

Bioastronautics Initiative

- **Builds upon previous and ongoing work**
  - A significant amount of fundamental knowledge has been created through ground and flight research
  - Apply this knowledge base to applications and solutions which will provide *safer human operations in space*
- **Utilizes new research resources**
  - ISS/STS research opportunities
  - Ground analogs
- **Leverages new and unique capabilities**
  - Scientific community to focus on NASA issues
  - Transfer knowledge to Earth based problems
  - Cooperate with other Federal Agencies
  - Develop new technologies
    - smart medical systems
    - biologically-inspired technologies
    - fire protection

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Advanced Human Support Technology

NASA Bioastronautics Initiative – Combustion Science

- ***Substantially improve spacecraft fire safety***
  - $1M per year for four years (initial funding level)
  - Grant-based through NRAs and directed research

- **Fire safety practices and procedures**
  - ISS and Shuttle operations
  - Prolonged human-crew missions in Earth orbit and beyond
  - Lunar and/or Martian habitats
    - In-situ resource utilization
    - Propellant manufacture and storage

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Spacecraft Fire Safety Research Roadmap

	2001-2004	2004-2007	2007-2010
FLAMMABILITY OF PRACTICAL MATERIALS	•deep seated fires in non-1g environments •ignition and combustion of high-P GOx •flammability of plastic and composites in hypo-g •improved test methods to rank materials	•Limiting oxygen and flow for flame propagation •practical material flammability for in-situ propellant manufacture	Flammability measurements and correlation from μg to 1g; new validated test methods for material rankings
FIRE SIGNATURES AND DETECTION	•component level sensors •method to characterize fire signatures	•integrated sensors •fire and pre-fire signatures of practical materials	Complete data base for fire signatures and demonstration of new detection systems
FIRE SUPPRESSION AND RESPONSE	•fire extinguishants •flame growth and stability models in practical configurations •extinguishment in non-1-g •trade-off of flame-suppression techniques	•dispersion techniques • flame suppression methods in high O2	Experimentally (microgravity and partial-g) validated fire suppressant performance, analysis & models

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Microgravity Combustion Science Program

- 99 NRA – Bioastronautics
  - **Test methods for material flammability (2 GRD)**
  - **Smoldering/fire initiation (FLT)**
  - **Fire suppression (2 GRD)**
  - **Fire signatures and detection (FLT)**
- 01 NRA
  - **Fire signatures in reduced gravity (GRD)**
  - **Fire suppression (4 GRD)**
- 02 NRA – Human Research Initiative
  - **Fire suppression (2 GRD)**
  - **Fire detection (1 GRD)**
  - **Large-scale modeling (2 GRD)**

Combustion Integrated Rack (CIR) Launch: Oct 2006

Microgravity Science Glovebox (MSG) in the Destiny laboratory on the ISS (Astronaut: Peggy A. Whitson)

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Spacecraft Fire Safety Research Roadmap

	2001-2004	2004-2007	2007-2010

FLAMMABILITY OF PRACTICAL MATERIALS

- deep seated fires in non-1g environments
- ignition and combustion of high-P GOx

2001-2004:
- flammability of plastic and composites in hypo-g
- improved test methods to rank materials

2004-2007:
- Limiting oxygen and flow for flame propagation
- practical material flammability for in-situ propellant manufacture

2007-2010: Flammability measurements and correlation from μg to 1g; new validated test methods for material rankings

FIRE SIGNATURES AND DETECTION

2001-2004:
- component level sensors
- method to characterize fire signatures

2004-2007:
- integrated sensors
- fire and pre-fire signatures of practical materials

2007-2010: Complete data base for fire signatures and demonstration of new detection systems

FIRE SUPPRESSION AND RESPONSE

- fire extinguishants
- flame growth and stability models in practical configurations

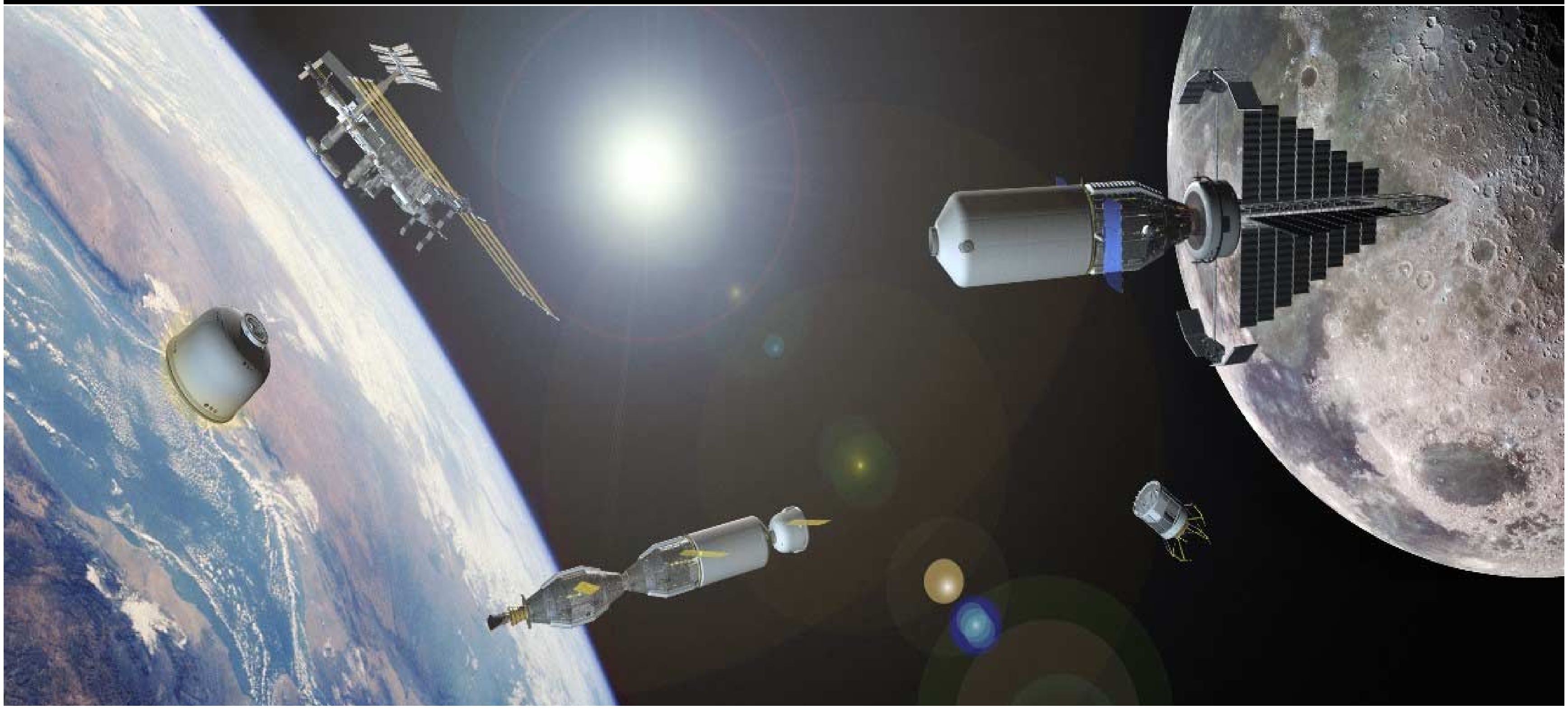
2001-2004:
- extinguishment in non-1-g
- trade-off of flame-suppression techniques

2004-2007:
- dispersion techniques
- flame suppression methods in high O2

2007-2010: Experimentally (microgravity and partial-g) validated fire suppressant performance, analysis & models

Vision for Space Exploration

"This cause of exploration and discovery is not an option we choose; it is a desire written in the human heart." – President Bush



Vision for Space Exploration

- **Pursue Compelling Questions**
  - Exploration of the solar system will be guided by compelling questions of scientific and societal importance.
  - Consistent with the NASA Vision and Mission, NASA exploration programs will seek profound answers to questions of our origins, whether life exists beyond Earth, and how we could live on other worlds.
- **For Sustainable Exploration**
  - NASA will pursue breakthrough technologies, investigate planetary resources, and *align ongoing programs to develop sustainable, affordable, and flexible solar system exploration strategies.*
  - The vision is not about one-time events and, thus, costs will be reduced to maintain the affordability of the vision
- **Starting Now**
  - *NASA will pursue this vision as our highest priority*
  - Consistent with the FY 2005 Budget, NASA will immediately begin to realign programs and organization, demonstrate new technical capabilities, and undertake new robotic precursor missions to the Moon and Mars before the end of the decade.

Fire Prevention, Detection, and Suppression

- Office of Biological and Physical Research addressed how to develop products for The Vision for Space Exploration
- Fire Prevention, Detection, and Suppression was designated a sub-element in the Advanced Human Support Technology product line

So What?

- Outcomes are now products to support exploration missions
  - **Required for design points in the development of CEV**
- Opportunity to expand efforts in each of the areas on the research roadmap

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Advanced Human Support Technology

What Do We Do Now?

Needs

- Identify needs and issues from “customers”
  - ISS Materials and Processes
  - ISS Environmental Control and Life Support
  - ISS Fire Detection and Suppression

Potential Products

Questions

- Scientific and technological questions that must be answered to deliver the products
  - assessment of knowns and unknowns
  - incomplete answers increases risk

Concepts

- How do you answer the questions?
  - experiments (flight and ground)
  - modeling
  - system verifications

Products

- What is finally used by the customer
  - contract specification
  - design rules
  - procedures

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Issues and Needs Identified in 2001 Workshop

Fire Prevention and Material Flammability

1. Flammability at Elevated Oxygen Levels
   - Ignition mechanisms and flammability for pressurized oxygen systems was the highest priority
   - Increased O_2 fraction and sub-atmospheric pressure considered for exploration vehicles and habitats
2. Fire Scenarios for ISS/STS
   - Overheating of electrical cables, short circuits, SFOG, pressurized gaseous oxygen systems
3. Testing/Screening Methods
   - Augment existing test methods (flaming and non-flaming)
   - Improved understanding of relationship between 1-g testing and microgravity performance

"Research Needs in Fire Safety for the Human Exploration and Utilization of Space," NASA/CP-2003-212103, April 2003.

Issues and Needs Identified in 2001 Workshop

Fire Prevention and Material Flammability

4. Development of New Materials
   - Foams, fabrics, and films
   - Radiation shielding
   - Composites

5. ISRU Processes and Storage
   - "Little activity, probably premature given absence of even long-term plans for manned missions beyond moon (if that)" 7th International Workshop on Microgravity Combustion and Reacting Systems, June 2003, Cleveland, OH

"Research Needs in Fire Safety for the Human Exploration and Utilization of Space," NASA/CP-2003-212103, April 2003.

Issues and Need Identified in 2001 Workshop

Smoke and Fire Detection

1. Detection Systems
   - What should we detect for different types of fires?
   - Where do we put the detectors?
   - Does the detector produce frequent nuisance alarms?

2. Crew Response
   - Is detection quick enough to give the crew adequate time to respond?
   - How does the crew know where the fire is?
   - Can the senor give an indication of the danger level?
   - What capability is require for post-fire sensing?

"Research Needs in Fire Safety for the Human Exploration and Utilization of Space," NASA/CP-2003-212103, April 2003.

Issues and Needs Identified in 2001 Workshop

Fire Suppression and Response

1. Specification of the Conditions Prior to the Response
   - Simulation and verification of flow in compartments
   - Characterization of fire events
2. Evaluation of Fire Suppressants
   - Agent transport in low gravity
   - Extinguishing agent performance in low gravity
   - Gaseous and particulate emissions from fires and suppressants
3. Effectiveness of Fire Response Strategies
   - Development of fire-response concepts
     - Obscuration mitigation
   - Agent distribution requirements and behavior
   - Post-fire sampling and characterization

"Research Needs in Fire Safety for the Human Exploration and Utilization of Space," NASA/CP-2003-212103, April 2003.

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Fire Prevention, Detection, and Suppression Sub-Element Products

1. Normal gravity material flammability test
   a. Candidate test(s) identified
   b. Suitable acceptance criteria for reduced gravity flammability
   c. Reduced gravity verification of normal gravity flammability test
   d. Revision/supplement to NASA-STD-6001
2. Material flammability assessment in candidate atmospheres for exploration vehicles
   – 30% O_2 fraction and 0.7 atm
   – Higher oxygen fractions for EVA
3. Design rules to prevent ignition and flame spread of practical materials
   a. Gain understanding with simple materials
   b. Relationship between the materials you can understand and materials that are actually used

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Fire Prevention, Detection, and Suppression Sub-Element Products

4. Verified models of fire precursor transport in low and partial gravity
   a. Development of models for large-scale transport in reduced gravity
   b. Validated CFD simulations of transport of fire precursors and contaminants
   c. Evaluation of the effect of scale on transport and reduced-gravity fires
5. Advanced fire detection system for gaseous and particulate pre-fire and fire signatures
   a. Quantification of pre-fire pyrolysis products in microgravity
   b. Suite of gas and particulate sensors
   c. Reduced gravity evaluation of candidate detector technologies
   d. Reduced gravity verification of advanced fire detection system
   e. Validated database of fire and pre-fire signatures in low and partial gravity

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Fire Prevention, Detection, and Suppression Sub-Element Products

6. Verified design rules for reduced gravity suppressant systems
   a. Quantification of suppressant effectiveness in low and partial gravity
   b. Reduced gravity verification of suppressant system performance

7. Virtual Reality Simulations of fire scenarios
   a. Realistic visual representation of a fire environment
   b. Interactive participation in fire simulation
   c. Fire response module for crew training

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What Do We Do Now?

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Potential Products

Questions

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  - assessment of knowns and unknowns
  - incomplete answers increases risk

Concepts

- How do you answer the questions?
  - experiments (flight and ground)
  - modeling
  - system verifications

Products

- What is finally used by the customer
  - contract specification
  - design rules
  - procedures

FPDS Organizing Questions

- Organizing questions were drafted in the areas of
  - Fire prevention and material flammability
  - Fire suppression and response
  - Fire detection
- Working groups were formed within the Microgravity Combustion Science Branch (NASA and NCMR)
  - Fire prevention and material flammability
    - Facilitator: Dr. Fletcher Miller
  - Fire suppression
    - Facilitator: Dr. Fumiaka Takahashi
- Purpose of working groups
  - Review organizing questions
  - Which are addressed by current experiments/hardware?
    - How well are they addressed?
  - Develop concepts for experiments that address the questions

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What Do We Do Now?

Needs

- Identify needs and issues from "customers"
  - ISS Materials and Processes
  - ISS Environmental Control and Life Support
  - ISS Fire Detection and Suppression

Potential Products

Questions

- Scientific and technological questions that must be answered to deliver the products
  - assessment of knowns and unknowns
  - incomplete answers increases risk

Tomorrow

Concepts

- How do you answer the questions?
  - experiments (flight and ground)
  - modeling
  - system verifications

Products

- What is finally used by the customer
  - contract specification
  - design rules
  - procedures

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What do you want from us?

Discussion, critique, and ideas

- organizing questions
- products to be delivered
- concepts of potential experiments
- research needs

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Summary

- Much has changed since January 2004
- We have the opportunity to impact the Vision for Space Exploration
  - Provide fire safe designs and countermeasures for exploration spacecraft and habitats
- The process we have been following has expanded the research plan developed at previous workshops
  - Increased scope and imposed a schedule
- We can deliver the best products through the collaboration of
  - NASA (Scientists, operations, and flight support personnel)
  - Government labs
  - Academia
  - Industry

SPACECRAFT FIRE SUPPRESSION: TESTING & EVALUATION

Angel Abbud-Madrid, J. Thomas McKinnon, and Jean-Pierre Delplanque
Center for Commercial Applications of Combustion in Space
Colorado School of Mines
Golden, CO 80401
Phone: (303) 384-2300 E-mail: aabbudma@mines.edu

Kazhikathra Kailasanath
Center for Reactive Flow & Dynamical Systems
Naval Research Laboratory
Washington, DC 20375

Suleyman Gokoglu and Ming-Shin Wu
NASA Glenn Research Center
Cleveland, OH 44135

The objective of this project is the testing and evaluation of the effectiveness of a variety of fire suppressants and fire-response techniques that will be used in the next generation of spacecraft (Crew Exploration Vehicle, CEV) and planetary habitats. From the many lessons learned in the last 40 years of space travel, there is common agreement in the spacecraft fire-safety community that a new fire suppression system will be needed for the various types of fire threats anticipated in new space vehicles and habitats. To date, there is no single fire extinguishing system that can address all possible fire situations in a spacecraft in an effective, reliable, clean, and safe way. The testing conducted under this investigation will not only validate the various numerical models that are currently being developed, but it will provide new design standards on fire suppression that can then be applied to the next generation of spacecraft extinguishment systems.

The test program will provide validation of scaling methods by conducting small, medium, and large scale fires. A variety of suppression methods will be tested, such as water-mist, carbon dioxide, and nitrogen with single and multiple injection points and direct or distributed agent deployment. These injection methods cover the current ISS fire suppression method of a portable hand-held fire extinguisher spraying through a port in a rack and also next-generation spacecraft units that may have a multi-point suppression delivery system built into the design. Consideration will be given to the need of a crew to clean-up the agent and recharge the extinguishers in flight in a long-duration mission.

The fire suppression methods mentioned above will be used to extinguish several fire scenarios that have been identified as the most relevant to spaceflight, such as overheated wires, cable bundles, and circuit boards, as well as burning cloth and paper. As it has been shown in our previous work, the threat of these scenarios is not only the fire itself but also the smoke generated from flight-rated materials and wiring insulation that can be extremely toxic. Further testing will be conducted in which obstructions and ventilation will be added to represent actual spacecraft conditions (e.g., a series of cards in a card rack). The transport of the suppressant agent at various locations in the enclosure will be measured. The system will also test the effectiveness of fire suppressants in fighting low (28 VDC) and high (120 VDC) voltage electrical fires. Tests will be conducted at the lowest gravity level possible in NASA's Reduced-Gravity Aircraft, as well as at Lunar (0.16 *g*) and Martian (0.38 *g*) levels. The Fire Suppression Testing Facility (FSTF) that will be built and used for this investigation may in the future serve as a prototype for the development of a Fire Suppression Insert that may use the Combustion Integrated Rack onboard the ISS to conduct long-duration μg tests. This insert will be capable of providing a demonstration of a fire-suppression system prototype under spaceflight conditions, raising the technology readiness level of the project to a prototype demonstration level (TRL 6). This prototype may help in the design of the fire extinguisher to be used in the first manned flight of the Crew Exploration Vehicle planned for 2014.

The main deliverable of this project will be the evaluation and practical demonstration of the most effective fire extinguishing and fire response strategy that will efficiently put out a fire inside an equipment rack and in any spacecraft module or planetary habitat with a minimum amount of suppressant agent and toxic byproducts, and with easy cleanup and recovery after the fire event is over. The experimental study will include testing under various gravity levels (normal, microgravity, Lunar, and Martian conditions) and under the worst-case fire scenarios and environments (pressure, ventilation, power, materials, and surrounding fluids) anticipated in future spacecraft and planetary habitats considered under the new NASA Vision for Exploration Agenda.

SPACECRAFT FIRE SUPPRESSION: TESTING AND EVALUATION

Angel Abbud-Madrid
J. Thomas McKinnon
Jean-Pierre Delplanque

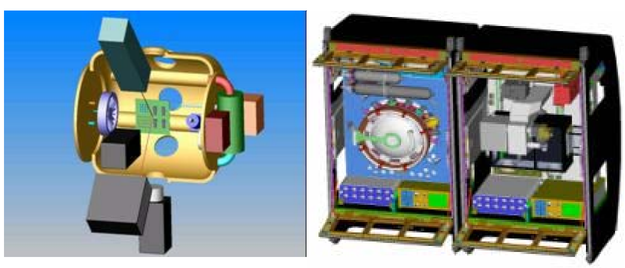
Center for Commercial Applications of Combustion in Space/Colorado School of Mines

Kazhikathra Kailasanath

Naval Research Laboratory

Suleyman Gokoglu
Ming-Shin Wu

NASA Glenn Research Center



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OBJECTIVE

- **TESTING AND EVALUATION OF THE EFFECTIVENESS OF:**
  - FIRE SUPPRESANTS
  - FIRE RESPONSE TECHNIQUES

- **FOR NEXT GENERATION OF:**
  - SPACECRAFT
  - PLANETARY HABITATS

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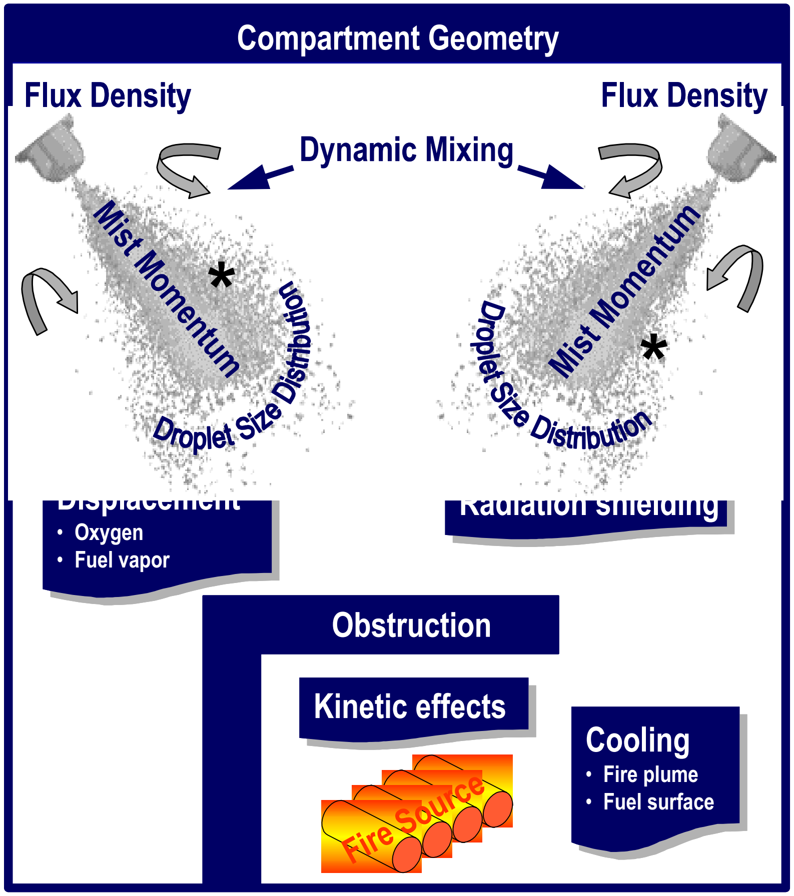
FIRE SUPPRESSION PROCESS



Drawing after Liu and Kim (2000)

SUPPRESSION MECHANISMS:

- **Thermal**
  - Cooling by sensible and latent heats
- **Physical**
  - Oxygen depletion
  - Cooling surfaces
  - Reduction in radiative transfer of energy
- **Chemical**
  - Enhance radical recombination

FACTORS AFFECTING PERFORMANCE:

- Suppressant flux density and momentum
- Mixing
- Obstructions
- Gravity

* Suppressant can be water mist or any other gaseous agent

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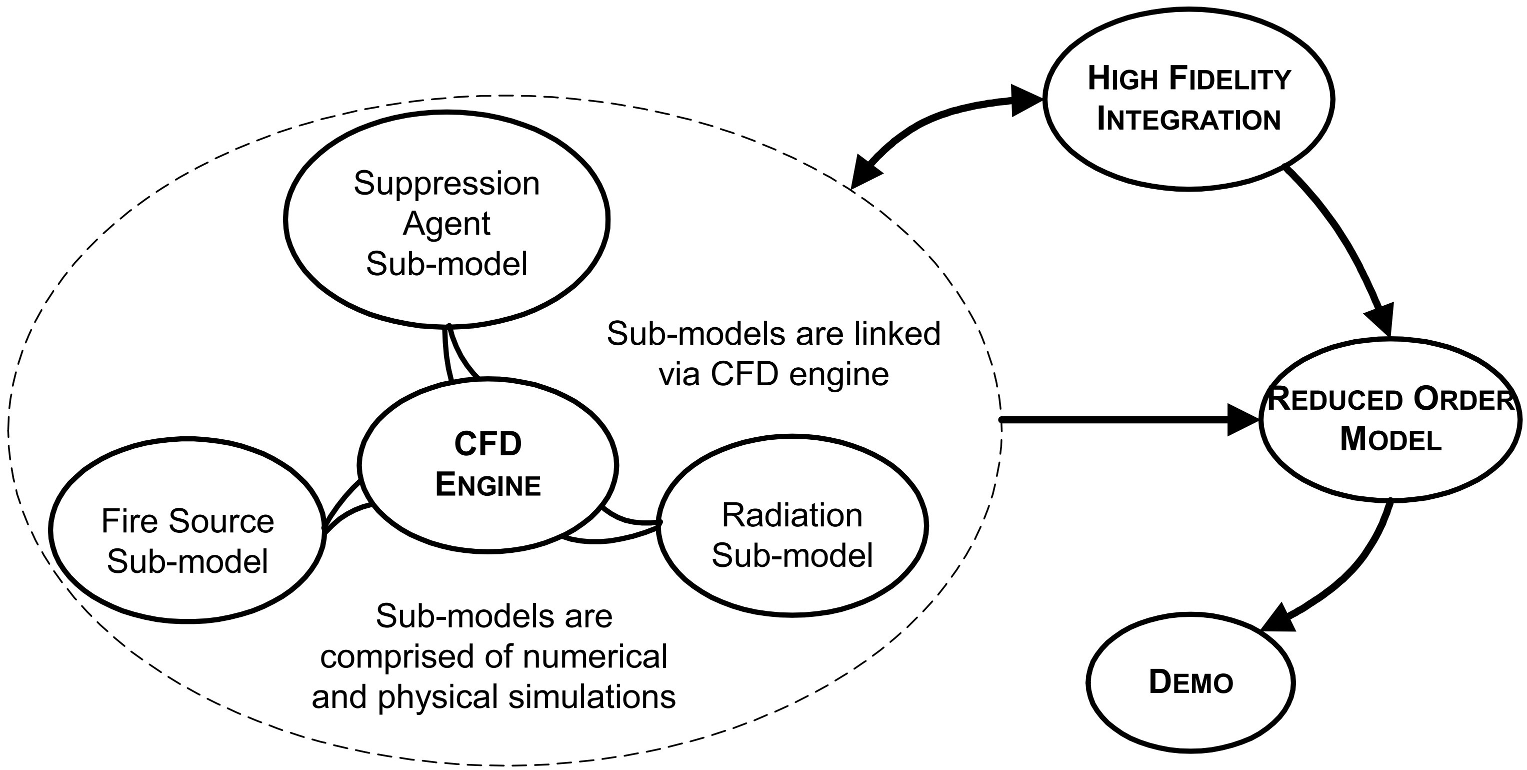
CHALLENGES

- Conduct evaluation and practical demonstration of:
  - Most effective fire suppression and response strategy
  - Fire suppression under spacecraft conditions
  - Use of minimum amount of suppressant agent
  - Generation of minimum amount of toxic byproducts
  - Easy agent clean up and prompt recovery
  - Worst-case scenarios and environments (pressure, ventilation, power, materials, surrounding fluids)
  - Effect of gravity (micro, partial, and normal *g*)

NASA/CP—2004-213205/VOL2

NUMERICAL APPROACH



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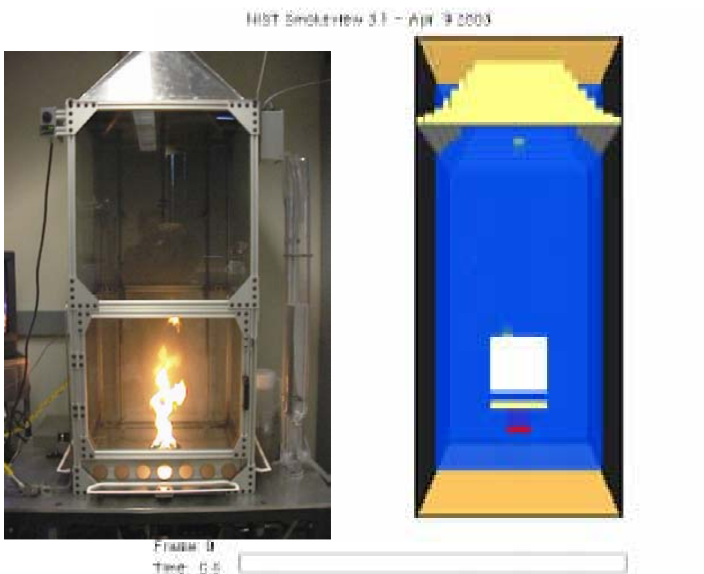
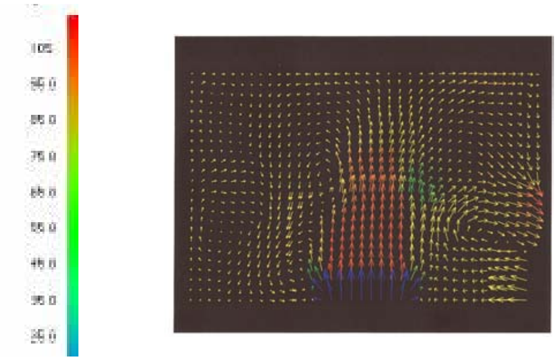
NUMERICAL APPROACH (II)

- Small and large-scale experiments to verify and validate numerical submodels and final reduced-order model



COMPONENTS OF MODEL

- Fire source (chemical kinetics)
- Fluid dynamics
- Suppressant agents (water mist, CO_2, N_2)
- Radiation
- Normal and partial gravity



NUMERICAL STUDY DELIVERABLE

Software code for help in the design of spacecraft fire suppression systems

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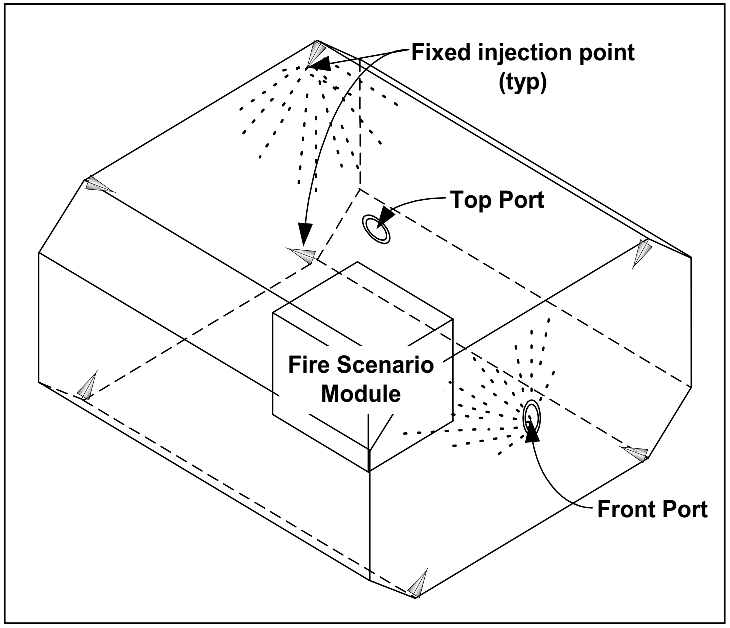
EXPERIMENTAL APPROACH



III. SUPPRESSION METHODS

- No agent (baseline)
- Single injection port
- Multiple injection ports (dispersion)

IV. EXPERIMENTAL CONFIGURATIONS

- Forced ventilation
- Obstructions
- Applied Voltage (24 VDC and 120 VDC)
- Micro, partial, and normal gravity

I. FIRE SCENARIOS

- Single Cable
- Cable bundle
- Circuit board
- Cloth and paper

II. SUPPRESSION AGENTS

- Water mist
- Carbon dioxide (CO_2)
- Nitrogen (N_2)
- Dual-fluid

V. MEASUREMENTS

- Temperature
- Gas analysis
- Suppressant transport
- Fire extinction

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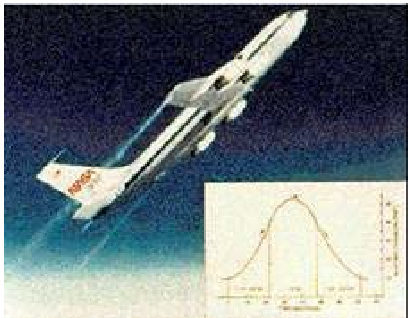
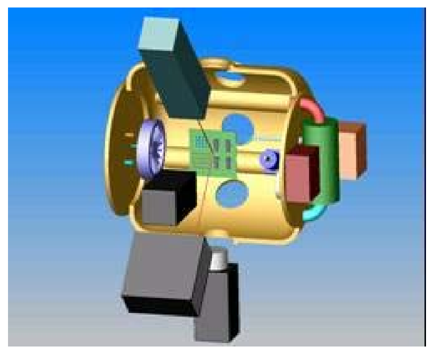
PARTIAL GRAVITY TESTING

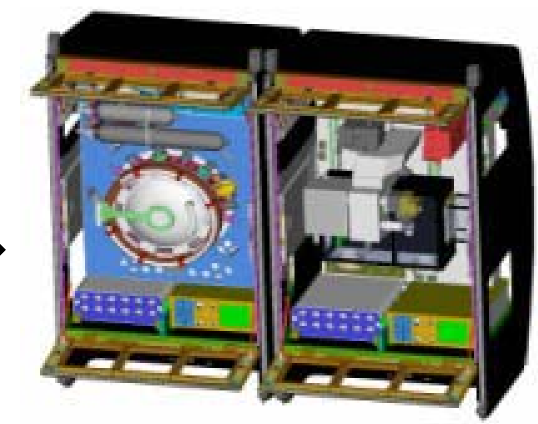


CURRENT TESTING:
KC-135 Parabolic flights
(0.01, 0.16, 0.38 *g*)

FUTURE PLANS:
Microgravity tests on
ISS (10^{-6} *g*)



Fire Suppression Insert



Combustion Integrated Rack (CIR)

RESEARCH POTENTIAL

- Current Low-Gravity Testing Facility could be used as prototype for a Fire Suppression Insert in the Combustion Integrated Rack (CIR) onboard the ISS
- Testing under long durations of μg could provide a demonstration of a fire-suppression system prototype under spaceflight conditions (Technology Readiness Level, TRL 6)

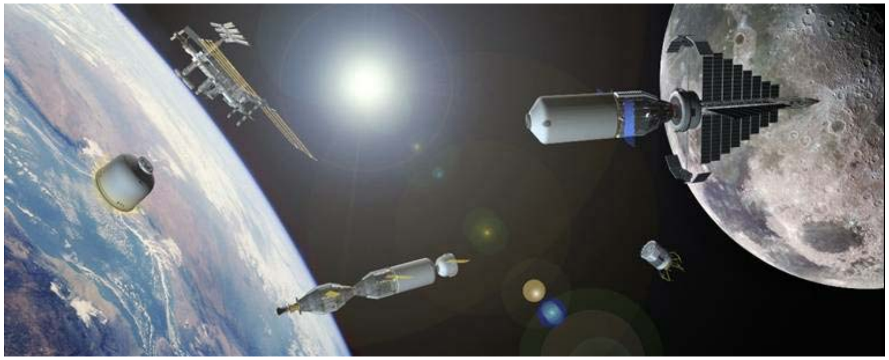
CONTRIBUTION TO NASA'S EXPLORATION MISSION

DELIVERABLE

- Evaluation and practical demonstration of the most effective fire extinguishing system to put out a fire inside an equipment rack, spacecraft module, or planetary habitat

EVALUATION TOOLS

- Numerical modeling
- Ground testing (normal gravity)
- Validation of scaling methods
- Partial-gravity testing
- Human Factors Engineering
- Risk analysis assessment



TIMETABLE

- Fire-suppression system prototype ready by 2008 for use in the design of fire extinguisher for Crew Exploration Vehicle (1st Manned Mission: 2014)

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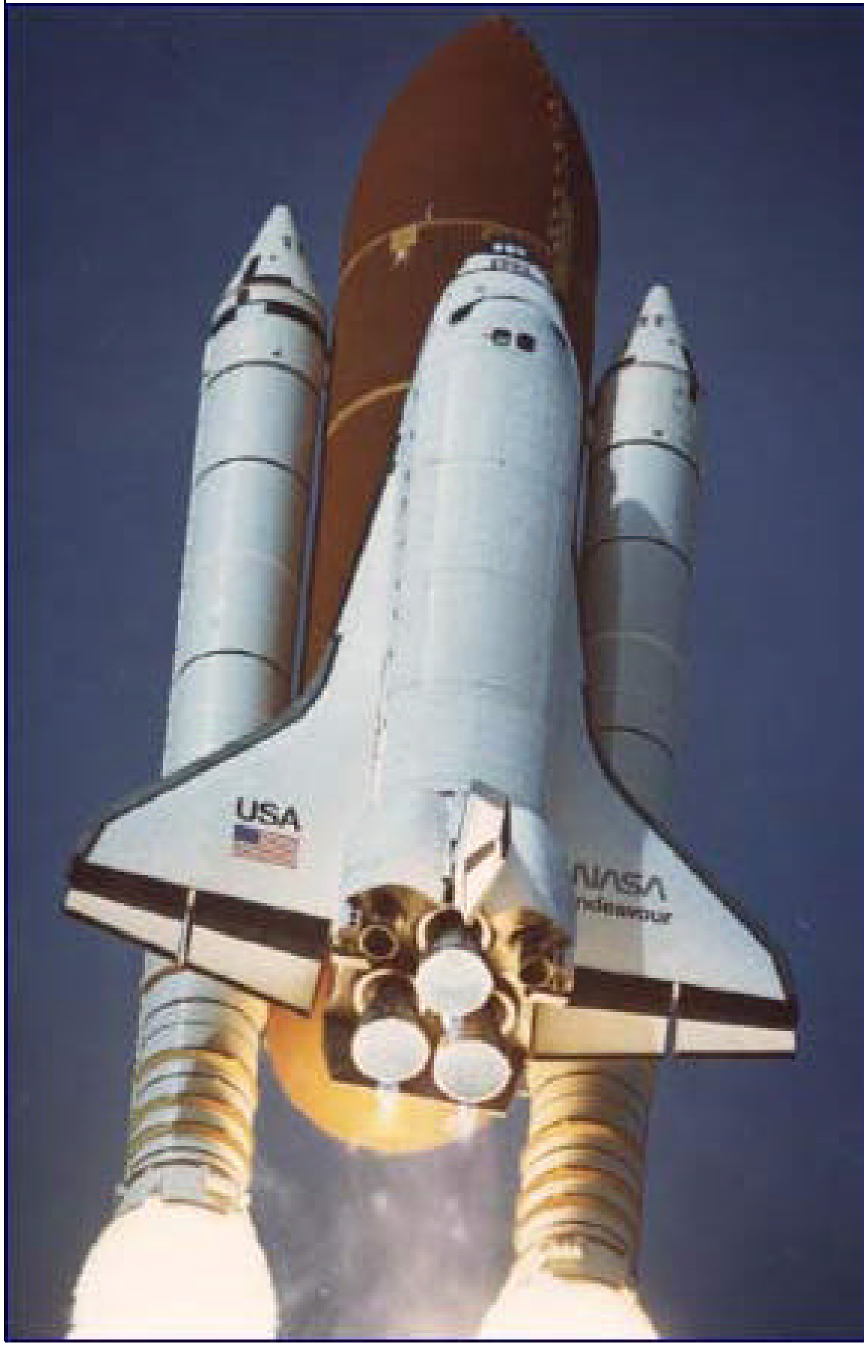
ORBITER VEHICLE (SPACE SHUTTLE)



SPACECRAFT DIMENSIONS, WEIGHT, & CLEARANCES

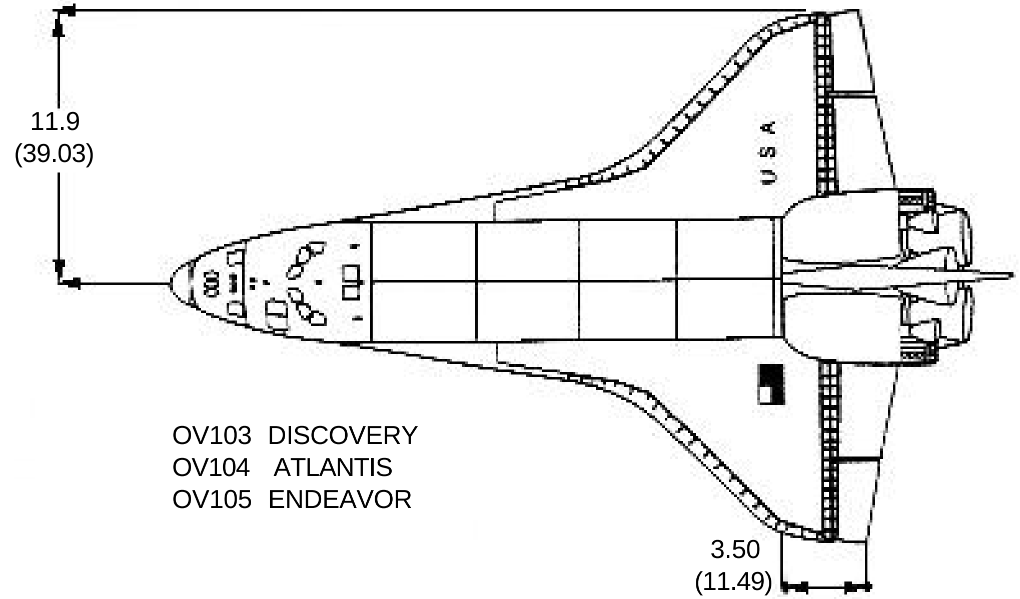
*DIMENSIONS IN METERS (FEET)

DIMENSIONS AND WEIGHT

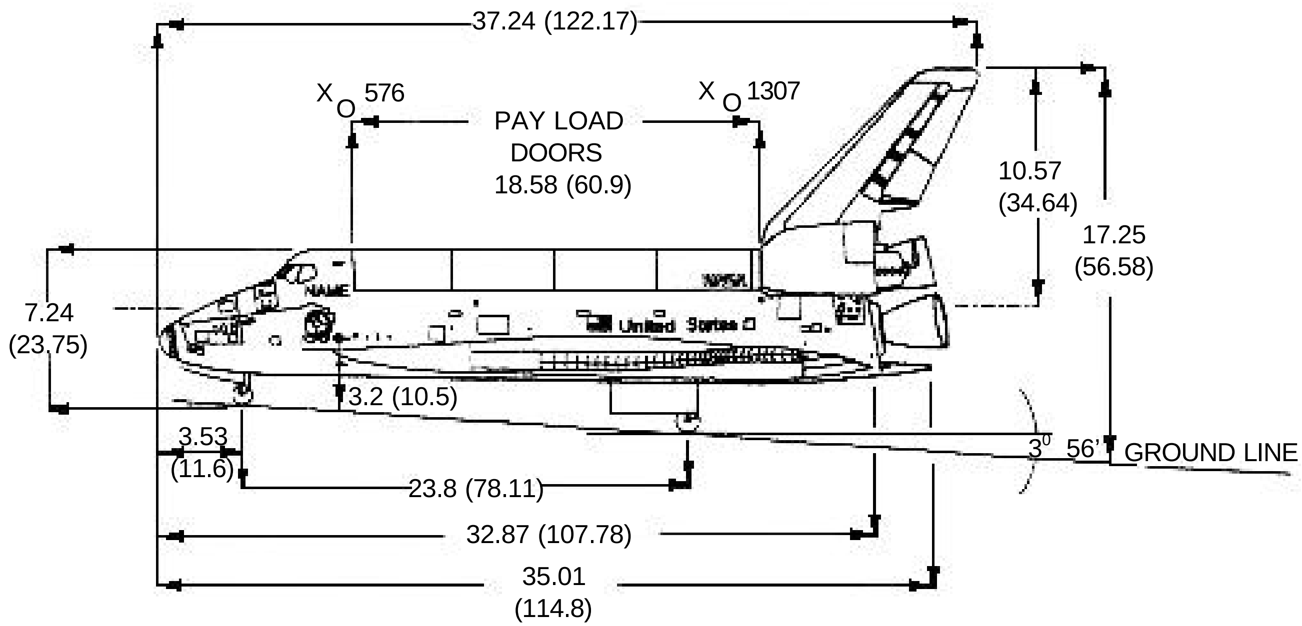
WING SPAN	23.79 m	(78.06 ft)
LENGTH	37.24 m	(122.17ft)
HEIGHT	17.25 m	(56.58 ft)
TREAD WIDTH	6.91 m	(22.67 ft)
GROSS TAKEOFF WEIGHT		VARIABLE
GROSS LANDING WEIGHT		VARIABLE
INERT WEIGHT (APPROX.)	74 844 kg	(165000 lb)

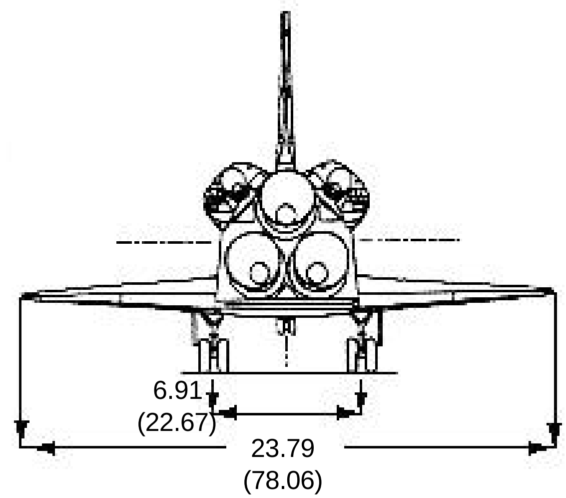
MINIMUM GROUND CLEARANCES

BODY FLAP (AFT END)	3.68 m	(12.07 ft)
MAIN GEAR (DOOR)	0.87 m	(2.85 ft)
NOSE GEAR (DOOR)	0.90 m	(2.95 ft)
WINGTIP	3.63 m	(11.92 ft)



OV103 DISCOVERY
OV104 ATLANTIS
OV105 ENDEAVOR





TYPES OF HAZARDS AND SAFETY PRECAUTIONS

The types of hazards associated with all fluids and gases onboard the Orbiter and the safety precautions that should be taken with each are addressed here. Potential Orbiter hazards include exposure to gases (ammonia, helium, nitrogen, oxygen), raw propellants (hydrazine, monomethlhydrazine, nitrogen tetroxide, liquid hydrogen, liquid oxygen), and toxic vapors (ammonia. hydrazine, monomethlhydrazine, nitrogen tetroxide). Flash fires, high pressures, hot brakes and wheels, propellant fires, steam/ hot water , and unexpected pyrotechnic devices are elements which contribute to flammability and toxic hazards. Fluid/gas storage tank locations are provided on page OV.15.

Fluid/gas specifications, locations, associated systems, approximate total tank capacities, lower explosive limits (LEL), upper explosive limits (UEL), threshold limit values (TVL), and descriptions are included on pages OV.9 and OV.10.

The ranking officer/supervisor at the landing site will determine the acceptable level of protection to be used by the crash/rescue personnel under his supervision before exposure to any Orbiter hazards. Acceptable levels of protection will be predetermined, based on worst case contingency as specified in program approved safety and health documents, and will not be restricted by the minimal levels described in the manual. This may include additional or higher-rated protective equipment.

Classifications of Hazardous Fluids/Gases

Pages OV.11 through OV.14 classifies Orbiter hazardous fluids/gases into three classifications (toxic, flammable, hypergolic). Toxic substances produce harmful effects on biological systems. In general, the toxicity of a specific substance depends on a number of factors: (1) quantity required to produce harmful effects (2) the rate and extent to which a chemical is absorbed by biological systems (inhalation, ingestion, injection), (3) the rate and extent of chemical breakdown, and (4) the rate and extent of excretion.

In dealing with average, healthy humans, it is useful to quantify the limit to which people may be repeatedly exposed on an all-day, everyday basis without suffering adverse effects. This is known as TLV. It is usually expressed as parts per million (ppm) for gases in air or milligrams per cubic meter $(mg/m)^3$ for fumes and dusts. The lower TLV's, the more toxic the substance. For common substances, TLV's vary from 0.1 ppm to 1000 ppm. The higher the TLV, the less likelihood of harmful effects from similar exposures.

The flammability of a substance is generally defined as the ability to easily ignite and burn. More precise definitions are given in the Code of Federal Regulations (CFR)- Transportation, Title 49, which governs the transport of hazardous materials, and the National Fire Protection Association (NFPA), which generates regulations for the storage and use of hazardous materials.

The hazard associated with these substances is that they ignite quite readily when they are mixed with air or an oxidizer and are exposed to a source of ignition. The minimum concentration of gas or vapor in air below which a substance does not burn when exposed to an ignition source is called the LEL (too lean). The maximum concentration of the substance in air above which ignition does not occur when exposed to an ignition source is called the UEL (too rich). The lower and upper explosive limits are expressed in percent by volume of vapor in air. The flammability range of a substance is the numerical difference between the lower and upper explosive limits.

Orbiter hypergolic propellants (hydrazine, monomethylhydrazine) are self-igniting upon contact with the oxidizer (nitrogen tetroxide) and are considered extremely hazardous.

Onboard Quantities at Landing

Quantities of the hazardous fluids/gases onboard the Orbiters following emergency landings [return to launch site (RTLS), transoceanic abort landing (TAL), abort once around (AOA)] and normal end-of-mission landings are provided on pages OV.16 and OV.17 for worst case landings.

Pyrotechnic Devices

Pyrotechnic devices are used for: (1) landing gear release, (2) crew compartment fire suppression, (3) emergency egress window jettison, (4) remote manipulator arm emergency jettison, (5) Ku-band antenna emergency jettison, (6) crew module emergency depressurization, (7) side hatch jettison, (8) Orbiter/external tank separation and (9) drag chute deployment and jettison. Pyrotechnic devices are normally safed by NASA or U.S. Air Force contractor personnel, but crash/rescue personnel should be familiar with their locations, exterior markings, access panels and component locations.

HAZARDOUS FLUIDS AND GASES

SYSTEM COLOR CODING

FLUID/GAS	TOXIC	FLAMMABLE	HYPERGOLIC
1. AMMONIA	X	X	X
2. BREATHING OXYGEN	NA	OXY	NA
3. FLUORINERT FC-40	NA	NA	NA
4. FREON-21	LOW	NA	NA
5. HALON 1301	LOW	NA	NA
6. HELIUM	NA	NA	NA
7. HYDRAULIC FLUID	NA	NA	NA
8. HYDRAZINE	X	X	X
9. LUBE OIL	NA	NA	NA
10. LIQUID HYDROGEN	NA	X	NA
11. LIQUID OXYGEN	NA	OXY	NA
12. MONOMETHYLHYDRAZINE	X	X	X
13. NITROGEN	NA	NA	NA
14. NITROGEN TETROXIDE	X	OXY	NA

HAZARDOUS FLUIDS AND GASES

NOTE: Reference page OV.8 number codes except items 15 and 16.

# Code	Fluid/gas	Specification	Location	System	Approx. total tank capacities kg (lbs)	Lower explosive limit (LEL)	Upper explosive limit (UEL)	Threshold limit valve (TLV) ppm	Description $m^3(ft^3)$
1	Ammonia	MIL-P-27406	Aft fuselage	ECLSS	44.45	16%	25%	50	Two tanks 0.051 (1.8)
2	Breathing oxygen (GO^2)	MIL-O-0272210D amendment 1	Mid fuselage	ECLSS (LSS)	32.21 (71)	(a)		(b)	One tank 0.143 (4.73) (mission kit only)
3	Freon-21 Dichloromono-fluoromethane ($CHCl^2F$)	BB-F-1421A type 21	Mid and aft fuselage	ECLSS	272.16 (600)	(a)		1000 (TWA)	System
4	Halon 1301 Bromotri-fluoromethane	MIL-M-12218B	Crew module fire extinguishers	Fixed	5.17 (11.4)	(a)		1000 (TWA)	Three tanks
				Portable	3.6 (8.4)			1000 (TWA)	Three bottles
5	Fluorinert FC-40	SE-S-0073 (MB0110-012)	Mid fuselage	EPS	35.11 (77)	(a)		(c)	Fuel cell coolant loops
6	Helium (HE)	MIL-P-27407 amendment 1	Fwd RCS module	Fwd RCS	3.63 (8)	(a)		(d)	Two tanks 0.049 (1.73)
			OMS/RCS modules	OMS	44.91 (99)				Two tanks 0.490 (17.3)
				Aft RCS	7.26 (16)				Four tanks 0.049 (1.73)
			Aft fuselage	MPS	22.68 (50)				Four tanks 0.134 (4.73) Two tanks 0.008 (0.29)
			Mid fuselage	MPS	77.56 (171)				Three tanks 0.049 (17.3) Three tanks 0.134 (4.73)
7	Hydrazine (N_2H_4)	MIL-P-26536C amendment 1	Aft fuselage	APU	476.28 (1050)	4.7%	100% @ 212^0 F	0.1	Three tanks 0.187 (6.6)
8	Hydraulic	MIL-H-83282A	Fwd, mid and aft fuselage, and wings	Hydraulic	382.3(e) (101)	204^0C (400^0F)		(c)	Three systems
		MIL-P-27201C	Landing gear struts	Landing gear	13.6 (30)	110^0C (230^0F)		(c)	Nose & main gear
9	Liquid hydrogen (LH_2)	MIL-P-27201B type II	Aft fuselage	MPS	169.19 (373)	4%	75% @ 68^0	(d)	Feedlines & SSME
		MIL-P-27201C grade A type I or II	Mid fuselage	EPS	166.92 (368)			(d)	Four tanks 0.606 (21.4)
		MIL-P-27201C grade A type I or II	Mid fuselage EDO Cryo Kit	EPS	166.92 (368)			(d)	Four tanks 0.606 (21.4)

HAZARDOUS FLUIDS AND GASES-Continued

NOTE: Reference page OV.8 number codes except items 15 and 16.

# Code	Fluid/gas	Specification	Location	System	Approx. total tank capacities kg (lbs)	Lower explosive limit (LEL)	Upper explosive limit (UEL)	Threshold limit valve (TLV) ppm	Description m^3(ft^3)
10	Liquid Oxygen (LO_2)	MIL-P-25508E type II grade F	Aft fuselage	MPS	222.8 (4896)			(a)	Feedlines & SSME
		MIL-P-255O8E type II grade F	Mid fuselage	EPS & LSS	1417.05 (3124)			(b)	Four tanks 0.318 (11.24)
		MIL-P-25508E type II grade F	Mid fuselage EDO Cryo Kit	EPS	1417.05 (3124)			(b)	Four tanks 0.318 (11.24)
11	Lube oil	MIL-L-23699C	Aft fuselage	APU	8.16 (18)	246^{0} C 475^{0} F		(c)	Three systems (cooling loops)
12	Monomethyl-hydrazine (CH_3NHN_2)	MIL-P-27404A amendment 2	Fwd RCS module	Fwd RCS	428.2 (944)	2.5%	98% @ 1 atmosphere	0.2	One tank 0.506 (17.88)
			OMS/RCS modules	Aft RCS	872.73 (1924)				Two tanks 0.506 (17.88)
				OMS	4297.86 (9475)				Two tanks 2.547 (90)
13	Nitrogen (N_2)	MIL-P-27401C grade B	Mid fuselage	ECLSS	103.42 (228)	(a)		(d)	Four tanks (base-line) 0.134 (4.73)
14	Nitrogen tetroxide N_2O_4	MIL-P-26539C amendment	Fwd RCS module	Fwd RCS	664.25 (1464)	(a)		2.5	One tank 0.506 (17.88)
			OMS/RCS modules	Aft RCS	1329/40 (2928)				Two tanks 0.506 (17.88)
				OMS	7071.17 (15589)				Two tanks 2.547 (0.24)
15	Wate (deionized)	JSC-SPEC-C-20	Crew module	ECLSS	60.33 (133)	(a)		None	Two cooling loops
			Aft fuselage	Hydraulic	192.33 (424)				Three water spray boilers
				APU	4.3 (9.5)	Injector			One tank 0.007 (0.24)
16	Water (portable and waste)		Lower Equipment bay, crew module	LSS	381.0 (840)	(a)		None	Five tanks 0.761 (2.69)

(a) Does not apply
(b) No TLV, however, limits are 100% for 48 hour at 101 kN (1 atm) (upper limit, lower limit + 14%)
(c) No TLV, because of low vapor pressure, inhalation of vapors not encountered in normal use
(d) Simple asphyxiant, no TLV
(e) Measurement in litres (gallons) for hydraulic fluid

HAZARDOUS FLUIDS AND GASES-Continued

Anhydrous ammonia (NH3) - 99.5% (by weight) basic ammonia. This gas is normally a pungent, colorless vapor.

Pg OV.8 # Code	Health Hazard	First Aid	Protective Clothing	Respiratory Protection	Fire Hazard	Fire Control
1	Liquid anhydrous ammonia produces severe burns on contact. Gaseous anhydrous ammonia is a strong irritant and can damage the respiratory tract. Since ammonia vapor can be smelled at concentrations of 5.0 ppm in air, the odor normally provides adequate warning. Anhydrous ammonia gas in concentration of 1% by by volume can cause death in a few minutes. Concentrations of 0.05 to 0.1 can cause irritations to the eyes, respiratory tract and throat. TLV of anhydrous ammonia is given on page OV.9.	Remove the victim from the contaminated atmosphere. Apply artificial respiration if breathing has stopped. Provide positive pressure or mouth-to-mouth resuscitation if the victim is gasping for breath. If ammonia has contacted the eyes, flush with a gentle stream of water for at least 15 minutes and place in the care of a physician. If ammonia has contacted the skin, flush the area of contact with large amounts of water.	Standard firefighting protection clothing; a fire fighting crash hood or and a protective face/eye mask.	Entry into an ammonia atmosphere is extremely hazardous and is warranted only in extreme emergency conditions. Approved respiratory protection equipment will be worn at all times when working in an area where the potential for exposure exists.	Has a narrow flammability range i.e. 16.1 to 26.8 % by volume in air. Normally, the fire hazard is insignicant unless a large spill occurs.	Use water as a spray or fog to remove vapor and combat fires.

Oxygen (LO2, GO2)-A powerful oxidizer in both the liquid and gaseous states. The gas is colorless, orderless, and slightly heavier than air. The liquid is pale blue and is slightly more dense than water.

WARNING

When liquid oxygen is trapped in a closed system and refrigeration is not maintained, rupture of the system can occur. Liquid oxygen at a temperature above -83 ^{0}C (-181 ^{0}F) at an atmospheric pressure of 101kN (17.7 psi) expands to about 860 times its liquid volume. Liquid oxygen cannot be held in a liquid state at a temperature above -83^{0} C (-181^{0} F) regarless of the confining pressure.

Pg OV.8 # Code	Health Hazard	First Aid	Protective Clothing	Respiratory Protection	Fire Hazard	Fire Control
2, 10	An oxygen-rich atmosphere can be ignited by a spark. Liquid oxygen is generally less dangerous than oxygen stored as a high-pressure gas. Liquid oxygen bolts (vaporized) at -147 ^{0} C (-297 ^{0} F) and instantly freezes any object that contacts it. **WARNING** Oxygen permeation of clothing is extremely dangerous if an ignition source is present.	If liquid oxygen contacts the skin, flush the affected area with water. If extensive burns result, contact a physician. **WARNING** Do not use fire blanket to cover personnel whose clothing is oxygen saturated.	Standard firefighting protection clothing; a firefighting crash hood or equivalent; and a protective face/eye mask.	Not required. However, approved respiratory protection will be worn when working in an atmosphere where there is a potential vapors. **WARNING** Do not enter areas with less than 18% oxygen unless self-contained respiratory equipment is immediately available.	Oxygen is nonflammable in normal concentrations. However, in high concentrations, oxygen reacts rapidly with flammable materials to form a shock-sensitive gel. **WARNING** Do not expose organic or flammable substances (oil, grease, liquid hydrogen, cloth, wood, paint, tar) to liquid oxygen. Areas having more than 20% oxygen are considered to be oxygen enriched and and the fire hazard greatly increased.	Use water to help prevent pure oxygen pockets, which result from LO2, or GO2 leaks. The fog should be directed into the gaseous oxygen. **WARNING** Direct water fog so that it will not blow back on fire fighting personnel. Combination of LO2 and any hydrocarbons impacted with 40 pounds of water pressure could detonate shock sensitive gels.

HAZARDOUS FLUIDS AND GASES-Continued

Freon-21 (Dichloromonofluoromethane (CHDL2F)) - A colorless, ordorless, nonflammable gas at standard temperature and pressure.

Pg OV.8 # Code	Health Hazard	First Aid	Protective Clothing	Respiratory Protection	Fire Hazard	Fire Control
3	The TLV of Freon-21 is given on page OV.9. Moderate concentrations can cause lightheadedness, shortness of breath and narcosis. Concentrations above 1000 ppm can cause arrhythmia (irregularity of the heart and pulse.	Remove the victim from the contaminated area and administer breathing oxygen. Apply artificial respiration if breathing has stopped. If Freon-21 has contacted the eyes. Flush with a gentle stream of water for at least 15 minutes. **WARNING** If the victim is unconscious or is having difficulty breathing. Do not administer adrenaline or a similar drug (can cause irregular heartbeat).	Standard firefighting protection clothing; a firefighting crash hood or equivalent; and a protective face/eye mask.	Approved respiratory protection equipment will be worn at all times when working in an area where the potential for exposure exists.	Nonflammable	

Halon 1301 (Bromotriflouromethane (CBrF3)) - A colorless, ordorless, nonflammable gas at ambient temperature and pressure. Used as fire-extinguishing agent in Orbiter fixed and portable fire extinguishers.

4	The TVL of Halon 1301 is given on page OV.9. Moderate concentrations of 10 to 20% by volumn for 20 minutes can cause a general decrease in judgement ability and alertness.	Remove the victim from the contaminated area and administer breathing oxygen.	Standard firefighting protection clothing; a firefighting crash hood or equivalent; and a protective face/eye mask.	Approved respiratory protection equipment will be worn at all times when working in an area where the potential for exposure exists.	Nonflammable	

Florinert FC-40 (Florocarbon) - A fluorinated liquid used as a dielectric coolant in the fuel cells of the electrical power system (EPS). FC-40 is a stable liquid that is chemically inert, clear, colorless, ordorless, nonflammable, practically nontoxic at ambient temperature and pressure.

5	None defined at normal ground temperature and pressures. Exposure to temperatures of 315 ^{0}C (600 ^{0}F) may produce toxic products.	If FC-40 has contacted the eyes, flush with a gentle stream of water. If irritation develops, seek medical attention. Provide fresh air for excessive inhalation of vapors.	Standard firefighting protection clothing; a firefighting crash hood or equivalent; and a protective face/eye mask.	Approved respiratory protection equipment will be worn at all times when working in an area where the potential for exposure exists.	Nonflammable	

Helium (He) - An inert nonflammable, nontoxic, colorless, ordorless gas at ambient temperatures.

6	Acts as a simple asphyxiant in concentrations where the oxygen level is reduced to less than 15%.	Move the victim to well-ventilated area. Use self-contained breathing apparatus, if necessary, apply artificial respiration and then obtain medical aid.	Standard firefighting protection clothing; a firefighting crash hood or equivalent; and a protective face/eye mask.	Approved respiratory protection equipment will be worn at all times when working in an area where the potential for exposure exists.	Nonflammable	

HAZARDOUS FLUIDS AND GASES-Continued

Hydrazine (N2H4) and monomethylhydrazine(CH3NHNH2) - At room temperature, a clear, oily, water-white liquid with an ordor similar to ammonia.

Pg OV.8 # Code	Health Hazard	First Aid	Protective Clothing	Respiratory Protection	Fire Hazard	Fire Control
7, 12	In contact with skin or eyes, liquid hydrazine can cause severe local damage or burns. It can penetrate skin to cause systemic effects similar to those produced when swallowed or inhaled. If inhaled, the vapor causes local irritation of the eyes and the respiratory tract. On short exposure, systemic effects involve the central nervous system with symtoms including tremors. On exposure to higher concentrations, convulsions and possible death follow. Repeated or prolonged exposure may cause toxic damage to the liver (fatty liver) and kidney (interstitial nephritis), and anemia. Do not exceed the exposure ceiling of the TVL for monoethylhydrazine. **WARNING** N2H4 and CH3NHNH2 are suspect carcinogens. CH3NHNH2 is a suspect teratogen. The hydrazine odor threshold is much greater than the TVL. Do not, therefore, depend on the sense of smell to provide sufficient warning of hazardous levels.	Remove the victim from the contaminated environment. Remove all contaminated clothing. Wash propellant from the skin with water. If eyes have been exposed, flush gently with water for at least 15 minutes. Obtain immediate medical attention.	Standard firefighting protection clothing; a firefighting crash hood or equivalent; and a protective face/eye mask. **WARNING** Avoid skin contact.	Entry into a hydrazine atmosphere is extremely hazardous and is warranted only in extreme emergency conditions. Under such conditions, self-contained breathing equipment that uses oxygen should be of the rebreathing type to minimize release of oxygen to the atmosphere. If demand-type equipment is used, compressed air rather than oxygen must be used.	Hydrazine is a strong reducing agent. It is hypergolic with oxidizers such as nitrogen tetroxide (N2O4) and metal oxides of iron, copper, lead, etc.	In all cases involving a major leak, blanket the area with water fog. Water is the most effective agent for completely extinguishing air supported hydrazine fires. Water fog can be used for combating spill-type fires. Effective use of water minimizes the reignition and flashback hazard.

Hydraulic fluid - Two types: (1) used in landing gear struts (MIL-H-5606) and (2) used in the hydraulic system (MIL-H-83282). Both are red in color.

Pg OV.8 # Code	Health Hazard	First Aid	Protective Clothing	Respiratory Protection	Fire Hazard	Fire Control
8	None defined at standard temperature and pressure.	If eyes are affected, flush with a gentle stream of water.	Standard firefighting protection clothing; a firefighting crash hood or equivalent; and a protective face/eye mask.	Approved respiratory protection equipment will be worn at all times when working in an area where the potential for exposure exists.	None defined at standard temperature and pressure. High-pressure leaks present a fire hazard.	Use standard techniques.

HAZARDOUS FLUIDS AND GASES-Continued

Liquid hydrogen (LH2) - A low viscosity liquid that is nontoxic, transparent, colorless, and odorless.

Pg OV.8 # Code	Health Hazard	First Aid	Protective Clothing	Respiratory Protection	Fire Hazard	Fire Control
9	As a cryogenic liquid (low temperature), will cause a serious burn (frostbite) if it contacts the skin. Gaseous hydrogen (GH2) acts as simple asphyxiant. High concentrations will not produce systemic effects, but if high enough, can reduce atmospheric oxygen, causing oxygen deprivation.	Remove the victim to a well ventilated area. If breathing has stopped, apply artificial respiration and obtain medical aid. If liquid hydrogen contacts the skin, flush the affected area with water. Extensive burns (frostbite) require prompt medical attention.	Standard firefighting protection clothing; a firefighting crash hood or equivalent; and a protective face/eye mask. **WARNING** Liquid hydrogen will saturate normal clothing rendering it extremely flammable.	Entry into a hydrogen atmosphere is extremely dangerous and is warranted only in an extreme emergency. Under such conditions self contained breathing equipment that use oxygen should be of the rebreathing type to minimize release of oxygen into the atmosphere. If demand-type equipment is used, compressed air rather than oxygen must be used.	Hydrogen gas is highly combustible with air over a wide range of mixtures. Hydrogen burns in air with an invisible flame if there are no impurities. Liquid hydrogen fires are of short duration because liquid hydrogen evaporates rapidly. Detonation does not result as long as mixtures formed from liquid hydrogen evaporating into the atmosphere are not confined. **WARNING** In enclosed spaces, evacuate all personnel when the hydrogen atmospheric concentrations exceeds 0.8 % by volume; this amount is 20% of the lower flammability limit of 4 % by volume.	Allow controlled burning of a hydrogen fire until the flow can be shut off. Fires can also be controlled effectively by using very high concentrations of water. If possible, spray large quantities of water to cool adjacent surfaces. **WARNING** Eliminate all ignition sources. If hydrogen continues to leak after hydrogen flames are extinguished, an explosive cloud of combustible gas may be formed. Static electricity from clothing can cause ignition.

Nitrogen (N2) - A gas at ambient temperature and pressure that is inert, nontoxic, colorless, and nonflammable.

Pg OV.8 # Code	Health Hazard	First Aid	Protective Clothing	Respiratory Protection	Fire Hazard	Fire Control
13	Acts a simple asphyxiant where the oxygen level has been reduced to less than 15%.	Move the victim to a well ventilated area. Use self contain breathing apparatus if necessary. If required, apply artificial respiration and obtain medical aid.	Standard firefighting protection clothing; a firefighting crash hood or equivalent; and a protective face/eye mask.	Approved respiratory protection equipment will be worn at all times when working in an area where the potential for exposure exists.	Nonflammable.	

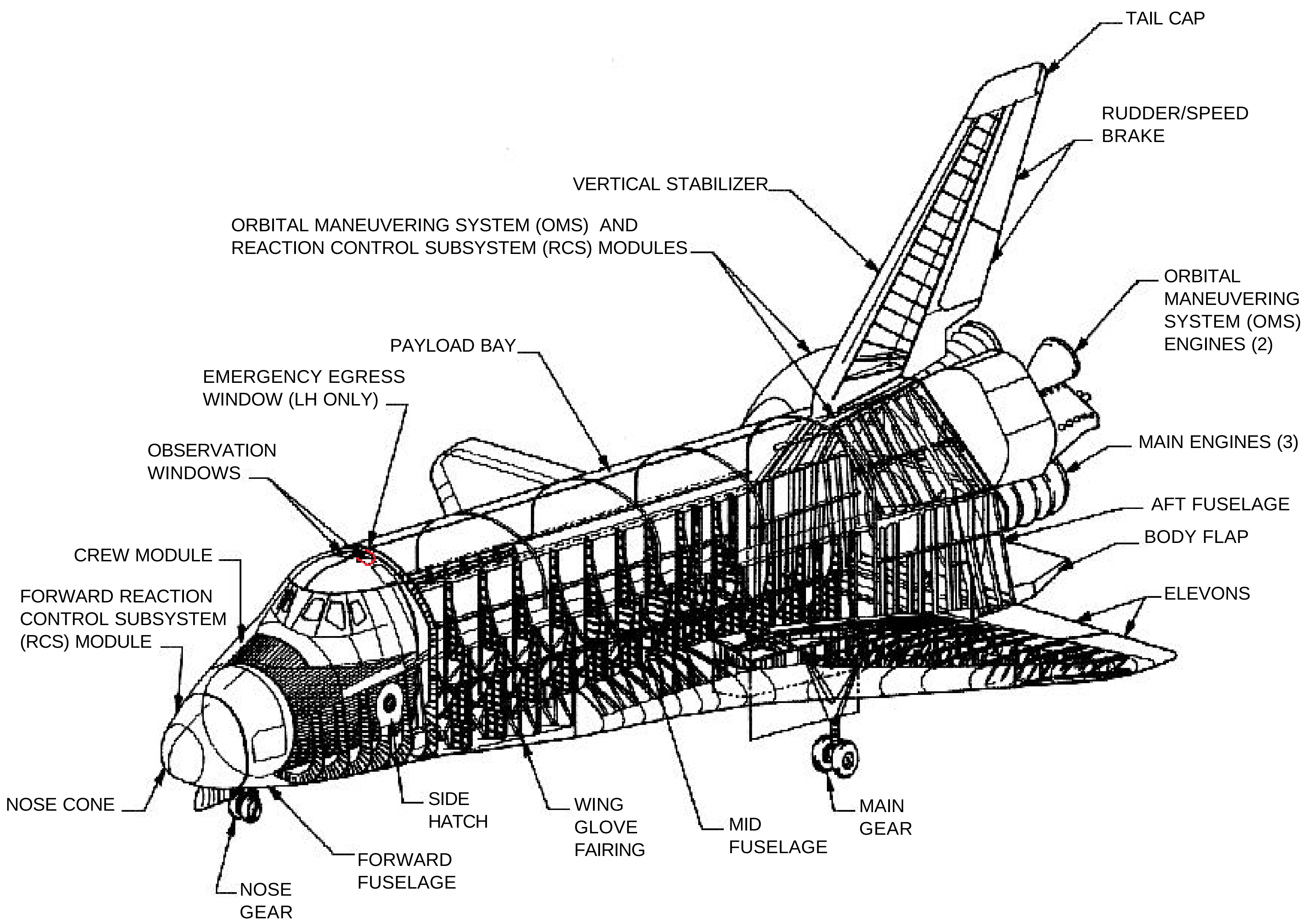
Nitrogen textroxide (N2O4) - Fumes vary in color from light orange to reddish brown to blue or green at low temperature.

Pg OV.8 # Code	Health Hazard	First Aid	Protective Clothing	Respiratory Protection	Fire Hazard	Fire Control
14	Skin contact with liquid nitrogen tetroxide will cause burns similar to nitric acid. Brief contact results in a yellow stain. If contact is more than momentary, a severe chemical burn will result. Liquid nitrogen tetroxide in the eyes will cause blindness. If swallowed, it will cause death from severe internal burns. Prolonged inhalation of the fumes will result in irritation of respiratory track and may cause pulmonary edema (lungs fill with water).	Remove the victim from the contaminated area. Remove all contaminated clothes and wash the victim with liberal amounts of water. If eyes have been exposed, flush with water for at least 15 minutes and obtain immediate medical attention.	Standard firefighting protection clothing; a firefighting crash hood or equivalent; and a protective face/eye mask. CAUTION Do not use Type A and Type B canister gas masks (with soda lime or soda lime-activated carbon fills). Those masks do not provide adequate protection.	Entry into a nitrogen tetroxide atmosphere is extremely hazardous and is warranted only in an extreme emergency. Approved respiratory equipment will be worn at all times when working in an area where the potential for exposure exists. **WARNING** Fires involving N2O4 burn vigorously and emit toxic fumes. N2O4 containers exposed to fire should be kept cool by applications of water (if possible).	Nonflammable, but will actively support combustion when mixed with a fuel. The oxygen content of N2O4 is about 70% by weight. Nitrogen tetroxide is hypergolic with a number of fuels, including hydrazine. Smoke and fumes from these fires are toxic and should be approached from the upwind side.	For a major leak, blanket the area with water fog. Water is the most effective agent for completely extinguishing air-supported fires. Water can be used for combating spill-type fires. Effective use of water minimizes the reignition and flashback hazard.

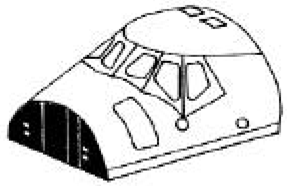
DANGER AREAS/SAFETY PRECAUTIONS HAZARDOUS MATERIALS, FLUIDS & GASES

DANGER AREA	PERSONNEL ACTION
CAUTION Monomethylhydrazine (CH3NHNH2) in contact with metallic oxides or other oxidizing agents can ignite. NOTE: Nitrogen tetroxide (N2O4) and monomethylhydrazine may be venting through the relief valves unless each system has been safed.	Do not park vehicles over metal drains. Stay upwind of venting gas. Wear protective clothing and recommended air breathing device.
Forward and aft reaction control subsystem (RCS) thruster nozzles and relief valve vent ports.	Stand clear.
Main landing gear/tires/wheels could explode. Peak temperatures may not be reached for 45 minutes.	Do not approach from the sides.
Main landing gear tire fire. Peak temperatures may be reached 45 minutes after a hard-braking landing which could ignite the rubber tires.	Approach upwind and apply large amounts of water to cool the brakes and to extinguish the burning tires.
Metals (composites) Berylium: windshield frames, ET doors, and brake structure Aluminum boron: truss members in the wing feed-through section Epoxy boron: truss members of the main propulsion system thrust structure, aft fuselage Although not easily ignited, these metals will burn at elevated temperatures and produce toxic compounds that are hazardous to health.	MET-L-X may be used on brake fires. Exercise caution. Although small amounts of water accelerate these types of metal fires, rapid application of large amounts of water is effective in extinguishing these fires because of the cooling effect of water. If water or foam is used, wear complete protective clothing and NIOSH-approved positive pressure breathing equipment.
Fluids/gases are flammable and hazardous.	Exercise caution to prevent exposure.
External surfaces will be at elevated temperature.	Wear proper clothing to prevent injury.
Hydrogen overboard vents, 8-in. fill and drain, and 17-in. Orbiter/external tank (ET) disconnects. Autoignition may result from high surface temperatures. Note that the flame of pure hydrogen is invisible.	Exercise caution.
Switches.	Do not operate any switch other than those specifically identified.
Emergency egress window that is to be jettisoned (all vehicles).	Move to position out of range of debris.
Emergency jettison of the side entry/egress hatch (all vehicles).	Move to position out of range of jettisoned hatch.
Inadvertant deployment of drag chute after rollout (all vehicles).	Avoid area 10 degrees left and 47 degrees right of Orbiter centerline and 100 feet aft until pyrotechnic circuits are safed.

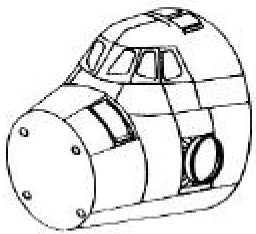
ORBITER STRUCTURE



ORBITER STRUCTURE-Continued

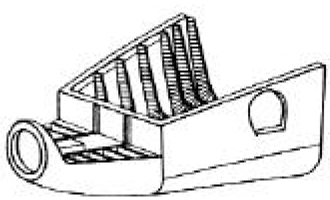


UPPER FORWARD FUSELAGE
- Skin and Stringer

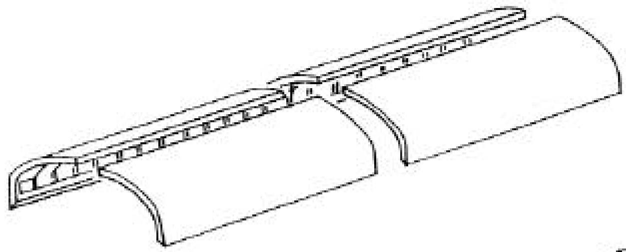


CREW MODULE (CABIN)
- Floating
- Welded Skin

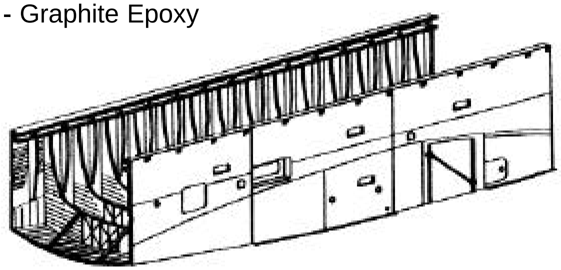
FORWARD REACTION CONTROL SUBSYSTEM (RCS) MODULE
- Skin and Stringer



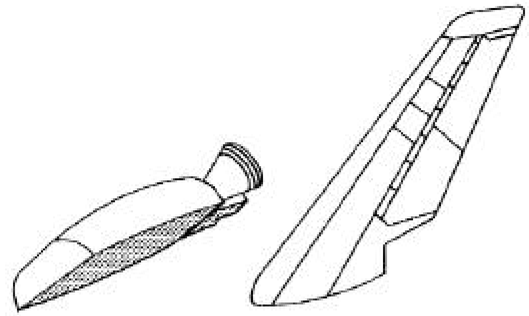
LOWER FORWARD FUSELAGE
- Riveted Skin and Stringer



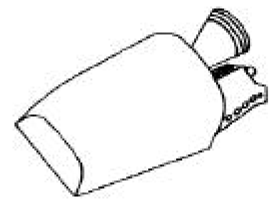
PAYLOAD BAY DOORS
- Two Doors split at vertical
- Graphite Epoxy



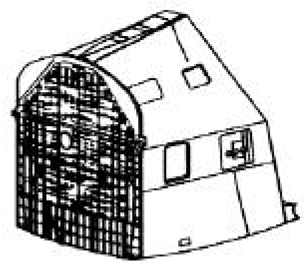
MID FORWARD FUSELAGE
- Skin and Stringer
  Honeycomb Panels



VERTICAL STABILIZER
- Skin and Stringer Fin Covers
- Honeycomb Rudder Cover
- Machined Spars
- Sheet Metal Ribs

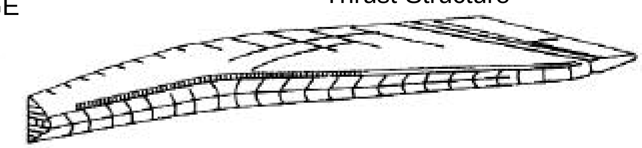


ORBITAL MANEUVERING SYSTEM (OMS)/REACTION CONTROL SUBSYSTEM (RCS) MODULE (TYPICAL)
- Skin and Stringer
- Graphite Epoxy and Milled Skin
- Titanium Thermal Barrier



AFT FUSELAGE
- Integrally Machined Skin/ Stiffner Shell
- Titanium/Boron Epoxy Thrust Structure

BODY FLAP



WING
- Skin and Stringer
- Web and Truss Spars

ORBITER STRUCTURE AND SURFACE TEMPERATURES FOR OV 103 DISCOVERY, OV 104 ATLANTIS, AND OV 105 ENDEAVOUR

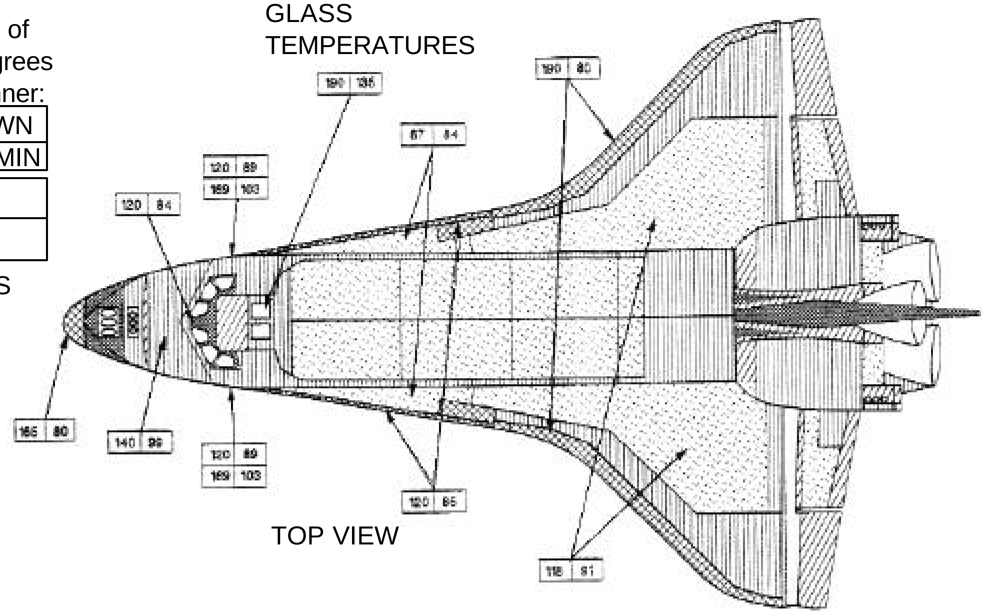
- RCC- REINFORCED CARBON-CARBON
- HRSI- HIGH TEMPERTURE REUSABLE SURFACE INSULATION
- LRSI- LOW TEMPERATURE REUSABLE SURFACE INSULATION
- FRSI- FELT REUSABLE SURFACE INSULATION (NOMEX FELT)
- METAL OR GLASS
- AFRSI- ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION (QUILTED)

NOTE:

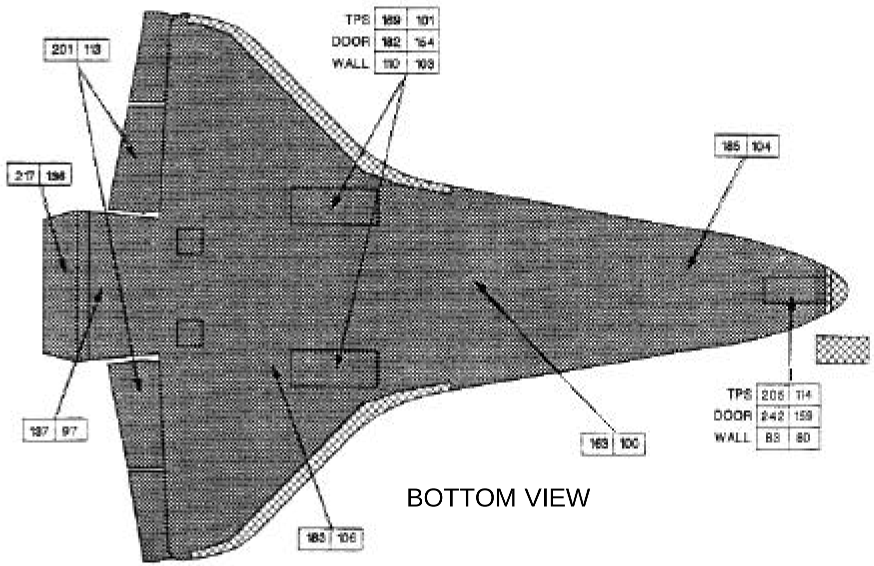
- Post touchdown temperatures of the orbiter are indicated in degrees fahrenheit in the following manner:

COMPONENT MEASURED	TOUCHDOWN +4 MIN	TOUCHDOWN +30 MIN
THERMAL PROTECTION SYSTEM (TPS) -		
STRUCTURE -		

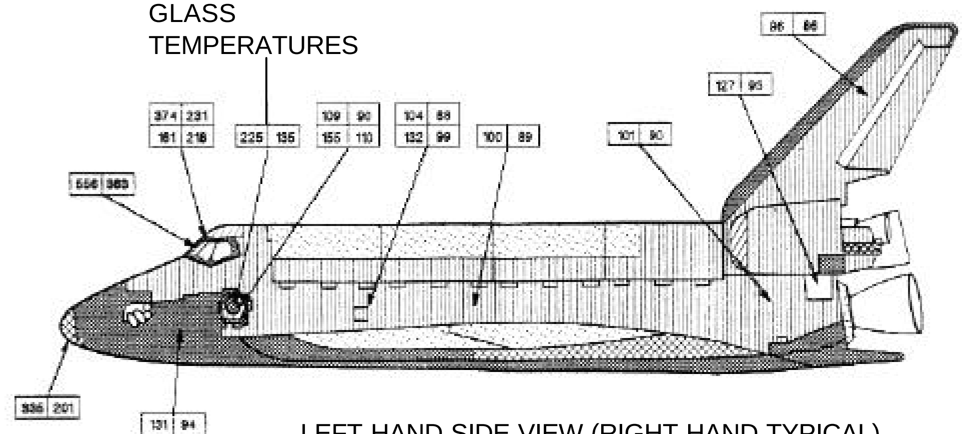
- Single-level boxes indicate TPS temperature only.



TOP VIEW



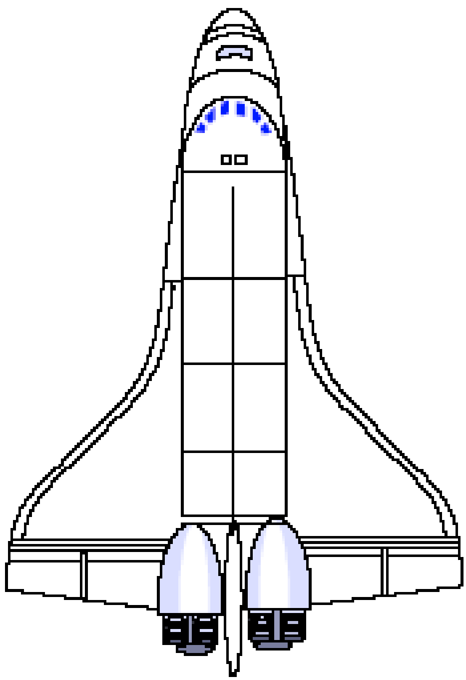
BOTTOM VIEW



LEFT-HAND SIDE VIEW (RIGHT HAND TYPICAL)

Department of Defense Manager's

SPACE SHUTTLE



PROCEDURES DOCUMENT

INTRODUCTION TO RESPONSE AND EGRESS PROCEDURES

Procedures listed within are the result of combined NASA and DOD test and evaluation utilizing high-fidelity mockups of the orbiter crew compartment. These procedures are recommendations and by no means should be regarded as mandatory. On-Scene Commanders, Senior Fire Officers, and Rescue Team Leaders should not be restricted from making real-time decisions to effect the safe recovery of the astronauts. Response and egress procedures are based primarily on the NASA Procedures Manual. DOD standards are applied as needed and content is condensed to highlight pertinent information useful to DOD emergency responders. For more detailed information regarding these recommended Space Shuttle emergency response procedures, contact DDMS-T at Patrick AFB, Florida.

NOMINAL (NORMAL) RESPONSE PROCEDURES

1. Response Actions. The response to a landing of the Orbiter Vehicle (OV) should be similar to any other response to an emergency landing of a large frame aircraft except for the following considerations:

a. The OV is like a glider and, therefore, will make only one attempt to land.
b. The OV carries extremely toxic chemicals not found on other military/civilian aircraft.
c. The OV may carry astronauts who've been in a weightless environment for an extended duration and, therefore, may not physically be able to egress the vehicle without assistance from the responding forces.

2. Initial Positioning. Once the OV stops, the Contingency Response Force (CRF) should move into an initial support position at 1,350 feet upwind of the OV. The DOD On-Scene Commander (OSC) should then establish a 1,250 foot "blast hazard zone" in a 360 degree arc around the OV. An initial positioning sample is provided in Figure 1.

Convoy Deployment Initial Approach

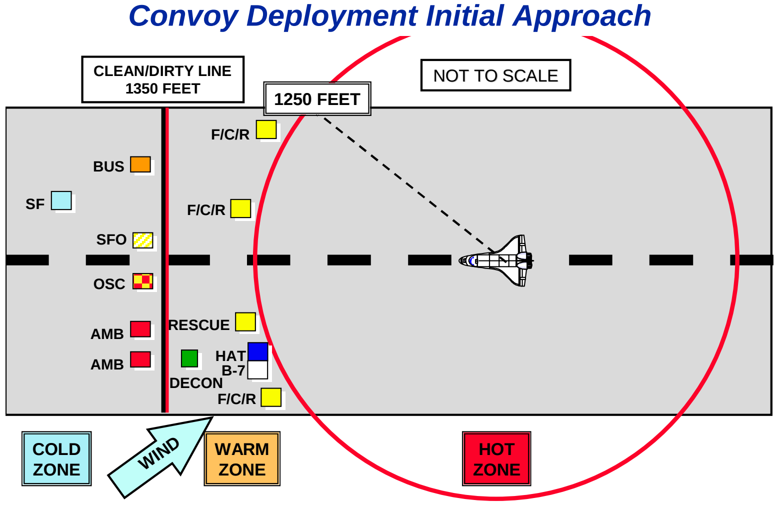


Figure 1

NOTE: At any time during a nominal response, an emergency condition (referred to by NASA as a MODE) may be declared by the OSC, SFO, Flt Dir or flight crew.

WARNING

At any time during a nominal response or declared emergency response (MODE), if a catastrophic event (i.e. an explosion or massive toxic release) occurs or is perceived to be imminent, an "Egress Condition Red" should be declared and all response forces should evacuate the danger area.

WARNING

The 1,250-foot blast hazard zone is primarily designed to protect personnel and equipment from an explosive hazard, however, the 1,250-foot zone will also provide protection from a toxic hazard if the OV remains intact after landing. **Under no circumstance will personnel enter the 1,250-foot hazard zone without the permission of the OSC and access to personal protective equipment (PPE) to include self-contained breathing apparatus (SCBA). All personnel proceeding inside the 700-foot perimeter must use PPE/SCBA.**

3. Clean/dirty Line. The OSC should establish a clean/dirty line at 1,350 feet upwind of the OV to clearly delineate the dividing line between the known clean environment and the potentially contaminated area inside of 1,350 feet. The intent of the clean/dirty line is to create a zone for contamination reduction between the 1,250-foot hazard zone and the 1,350 clean/dirty line. If decontamination of astronaut crew or CRF members is required, it should be accomplished in the decontamination zone.

NOTE: If there is a known emergency condition with the flight crew or OV, the flight crew and OSC may communicate directly via UHF 259.7 MHz or 296.8 MHz after landing.

4. Equipment Requirements. The following is the recommended equipment to support a rescue operation on an intact OV. This list does not include equipment which may be needed in support of an off-base or off-runway scenario. This is a generic list and most items can be local-purchased. However, some items cannot be substituted due to their uniqueness and importance. Those items will be identified with an asterisk (*). The list below reflects equipment needed to support the extraction of up to 11 astronauts due to the remote possibility of an orbiter returning to earth during or following a rescue or "launch on need" (LON) mission.

Quantity	Description
1	Electronic Combustible Gas Indicator (CGI) capable of monitoring for lower explosive limits of combustibles and oxygen enriched atmospheres
1	35 ft extension ladder
1	12-14 ft roof ladder
11	High-Intensity Cyalume Light Sticks (Night only)
2	Extraction Ropes or Straps (minimum 40 ft each)
1	Descent Strap (minimum 20 ft)
11	Arm straps
11	Leg Straps
1	B-1 or B-7 Stand
1	Hatch Entry Tool (5/8" drive)
1	# 10 Torque Head Screwdriver
4	Emergency Breathing Air (EBA) Bottles (if applicable) *
2	Anchor straps (minimum 6ft)
1	Aircraft chocks
2	Class III Life Safety Harness
1	Binoculars

NOTE: NASA may provide funding/reimbursement for some Space Shuttle-unique equipment.

5. Three Key Communications. Communications from the flight crew will drive the response scenario. The OSC should focus on listening for the following calls:

a. Crew Okay
b. Reaction Jet Driver (RJD) powered down and side hatch is safe
c. APU shutdown and vehicle fuel cells powered down.

6. Hazard Assessment of the OV. The Hazardous Assessment Team (HAT) normally consists of a minimum of two persons. They should be wearing full PPE including a self contained breathing apparatus (SCBA) and be equipped with a combustible gas indicator. They are tasked with testing the

atmosphere around the orbiter for the presence of combustible gases and also inspecting the exterior of the OV for possible leaks, the presence of smoke/fire, or any other damage or hazardous condition. The HAT should relay pertinent information to the OSC and inform him/her when the hazard assessment is complete. The HAT vehicle will normally tow a B-1/B-7 stand into the 200 foot mark (minimum safe distance for a combustible engine) and then proceed to the OV on foot.

Once the OSC confirms receipt of the first and second communications described above, he/she should direct the Hazard Assessment Team (HAT) to proceed into the 1,250 foot hazard zone to conduct a ground-level hazard assessment of the OV. The HAT will:

a. Proceed to approximately 200 feet off the nose of the OV at a 45 degree angle.
b. Chock the nose gear of the OV.
c. Unhook the B-1 or B-7 stair stand (towed in with them) and position it within 20 feet of the side hatch (not inline).
d. Utilizing their CGI's, they will proceed from the side hatch (not inline), around the nose, to about the same position on the opposite side of the OV.
e. They will return to their vehicle and radio results of the assessment to the OSC.

NOTE: If the HAT detects a hazardous atmosphere or condition, they will immediately pass that information to the OSC for appropriate action. If an emergency is declared or the side hatch is opened at any time during the hazard assessment, the HAT will cease the assessment and the OSC/SFO will initiate the appropriate response. Once the astronaut crew has exited the vehicle, FCR will transport them out of the 1,250 hazard zone through the DECON corridor.

7. FCR Downgrade. Once the HAT completes the hazard assessment and reports "all clear," the OSC should declare an FCR "downgrade," allowing the SFO to move FCR vehicles from 1,250 foot to 700 foot at their discretion.

8. OV Power Down and Crew Egress. Approximately 30 minutes after landing, the astronaut crew will power down the OV and begin to egress. Following power down, the crew will communicate with the OSC, if required, on UHF 259.7 MHz or UHF 296.8 MHz using a PRC-112 survival radio possessed by each of the astronauts. Once all crew members are out of the vehicle, they should be quickly transported out of the 1,250-foot hazard zone and processed through the DECON corridor. Medical personnel should be prepared to receive the flight crew on the clean side of the clean/dirty line at 1,350 feet.

WARNING

The flight crew will activate their Emergency Oxygen System (EOS) prior to exiting the OV. The EOS supplies crew members with approximately 10 minutes of pure oxygen and protects them from a potentially contaminated atmosphere. After this oxygen supply is depleted, an anti-suffocation valve built into the helmet will activate, allowing the astronaut to breathe ambient air. It is imperative to minimize the astronaut's exposure by expediting their transport away from the OV through the decontamination corridor to the clean/dirty line at 1,350 feet.

9. Positioning the B-1/B-7 Stand at the Side Hatch. Once the hazard assessment of the OV is complete, and the flight crew powers down the OV, FCR personnel wearing full PPE will proceed to the side hatch with a B-1 or B-7 stand. Because the side hatch is approximately 10 feet off the ground, the B-1/B-7 stand is required to provide safe egress for the crew. Once the flight crew opens the side hatch, the B-1/B-7 stand will be positioned to enable crew egress.

10. Crew Escorted to Transport Vehicle at 200 Feet. As the flight crew exits the vehicle, FCR personnel will escort them on foot to a transport vehicle parked at 200 feet off the nose (assumes upwind position) of the OV.

11. Crew Transported to DECON. Once placed in the transport vehicle, the flight crew will then be transported to the DECON corridor beginning at the 1,250 foot hazard zone. DECON personnel will evaluate and decontaminate the crew if required.

12. Crew Turned Over to Medical. After clearing DECON, the crew will be turned over to medical personnel on the clean side of the clean/dirty line for medical assessment and treatment, if required.

13. Fire Watch. At least one piece of major fire fighting apparatus should maintain a fire watch over the OV until the arrival of the NASA Rapid Response Team (RRT).

WARNING

The OV will remain on the runway for an extended period awaiting the arrival of the RRT. During this time, the vehicle will probably leak and vent small amounts of hydrogen, oxygen, and ammonia; and may vent hypergolic chemicals. Fire watch personnel should maintain vigilance at all times in order to respond quickly in the event of an emergency.

CONTINGENCY (EMERGENCY) RESPONSE PROCEDURES.

1. Initial Support Position. An emergency condition, also referred to by NASA as a MODE, may be declared at any time following the landing of the OV. If the OV lands safely on the runway and remains intact through wheels stop, the initial positioning of emergency vehicles should be similar to the positioning of the Contingency Response Force (CRF) for a nominal response.

2. Emergency MODEs. NASA has adopted the term MODE to describe various emergencies and specific response actions associated with Space Shuttle operations. MODEs I-IV are associated with launch pad emergencies and are not applicable to ELS support. MODEs V-VIII are described below and, as applicable, response forces will initiate the proper actions to affect astronaut recovery.

a. MODE V - Unaided egress/aided escape from the OV. A landing mishap and/or a post-landing emergency occurs on or near the runway and the OV is accessible to ground emergency responders. The flight crew egresses the OV and FCR personnel assists them in escaping the immediate area. In this situation, the crew will expeditiously power down the orbiter, open the side hatch, and deploy the emergency escape slide. FCR personnel will meet the crew at the base of the slide and transport them out of the 1,250 foot hazard zone to DECON.

b. MODE VI - Aided egress/aided escape from the OV. A landing mishap and/or a post-landing emergency occurs on or near the runway and the OV is accessible to ground emergency responders. The rescue team enters the OV to assist the flight crew in their egress from the vehicle and escape from the immediate area. In this situation, FCR personnel will enter and power down the orbiter (if required), seal the astronauts (face shield/bailer bar), activate their emergency oxygen system, extricate and transport them out of the 1,250 foot hazard zone to DECON.

NOTE: MODEs V/VI may be declared by any of the following: OSC, SFO, Flt Dir or the flight crew. The OSC and SFO have the advantage of observing the vehicle externally, while the flight crew has the advantage of observing the vehicle internally. The Flt Dir has access to telemetry data (as long as the OV is powered) and is able to monitor critical orbiter systems. If a MODE V/VI is declared, the OSC should transfer command and control duties to the SFO until the astronauts have been safely transported out of the 1,250 foot hazard zone.

c. MODE VII - Aided egress/aided escape from the OV after a landing mishap occurs off the runway and the OV is not immediately accessible to ground emergency responders. FCR personnel are transported by helicopter or other means to the scene and, if able, enter the OV to assist the flight crew in their egress from the vehicle and escape from the immediate area.

WARNING

If FCR forces are able to reach the OV, they may proceed with rescue operations following MODE VI procedures. Due to the chemical and explosive hazards associated with the OV, emergency responders should use extreme caution when approaching the vehicle.

d. MODE VIII (Bailout). Bailout of the flight crew during controlled, gliding flight. A bailout may occur over the ocean or land, during the launch or landing phases of a mission.

3. Rescue Team Complement. Flight crew rescue/egress concept is designed to be performed by a team consisting of nine personnel, designated as Rescuemen 1-9. The rescue team leader should be assigned as Rescueman 1. Up to four rescue personnel will enter the orbiter, while the other five personnel remain outside the OV to receive and transport the astronauts out of the 1,250-foot hazard zone.

4. Equipment Requirements. Although the probable means of entry will be through the side hatch, rescue personnel must have all required equipment necessary to execute a top hatch entry/egress.

5. OV Seating Configuration. The number of astronauts on board the OV may range between 4 and 11 astronauts. There will always be four astronauts on the flight deck and up to seven on the mid-deck. To facilitate rescue operations, the seats are numbered as identified in Figure 2.

NOTE: Astronaut number and configuration can vary depending on each mission profile. The possibilities include up to eleven astronauts on board with as many as seven in the recumbent (laying down) position.

6. Vehicle Positioning (MODE V/VI). When directed by the OSC/SFO after a MODE is declared, the FCR will position as required to conduct emergency operations. Firefighting apparatus should attempt to maintain a 200 foot distance from the OV if no fire or chemical hazard is present.

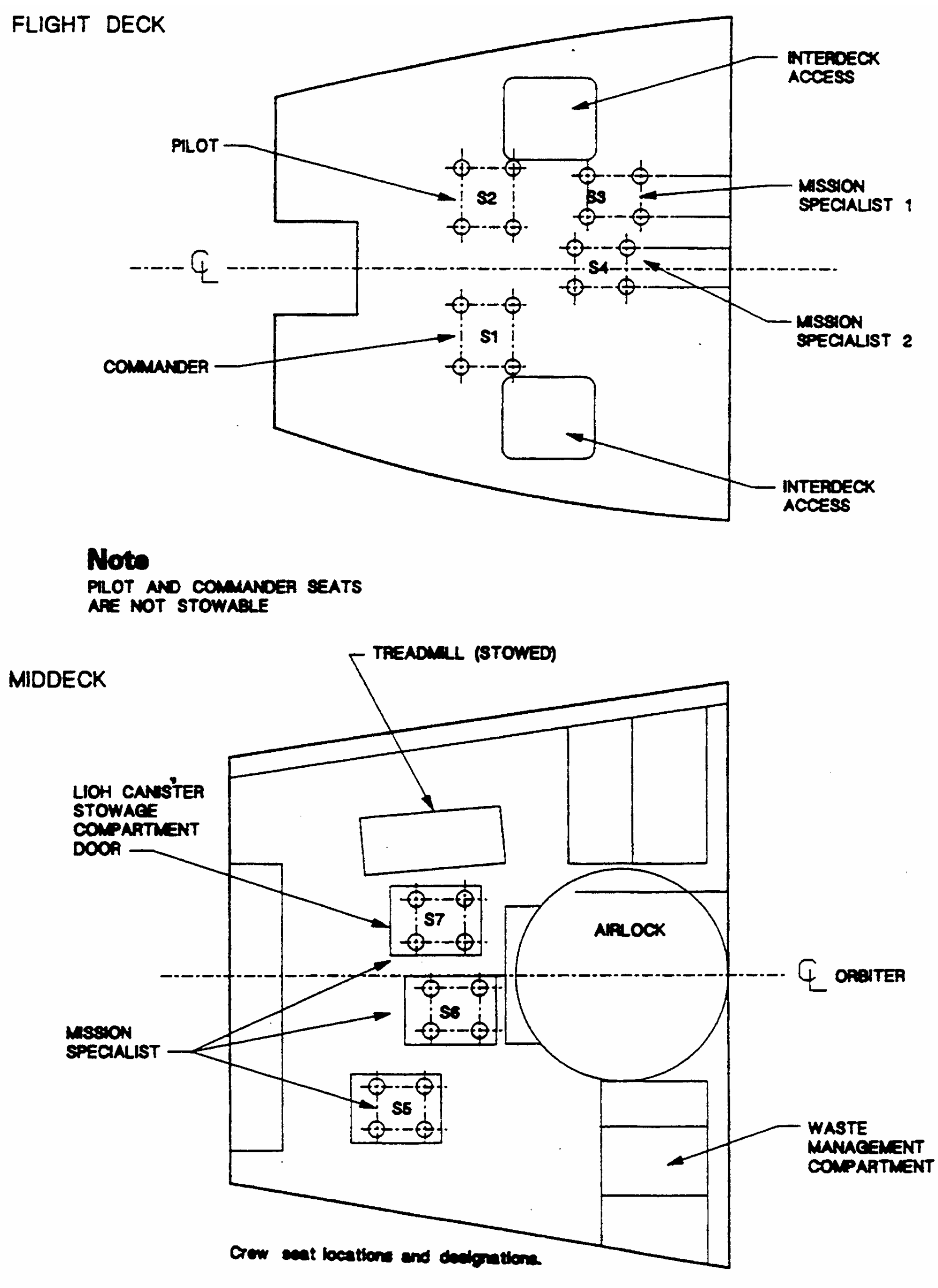
WARNING

The atmosphere around the orbiter should be assumed to be combustible and/or toxic. Unless responding to a declared MODE V/VI, do not operate a vehicle within 200 feet of the OV with an internal combustion engine or potential ignition source. If fire is already present, the SFO will ensure FCR vehicles are positioned to extinguish the fire and/or to protect the rescue crew egress path.

7. Rescue Operations. Upon declaration of a MODE, the OSC/SFO will direct offensive operations to negate the hazard(s) and to rescue and transport the astronaut crew out of the 1,250 foot hazard zone. When operating within the hazard zone, FCR personnel should have a hand-line available for fire or chemical suppression in the vicinity of the ingress/egress path. For a MODE V egress, the rescue team will proceed to the bottom of the emergency escape slide at the side hatch to assist and transport the astronauts away from the orbiter and out of the hazard zone to DECON. For a MODE VI egress, the rescue team may be required to ingress the OV either via the side or the top hatch.

NOTE: Emergency Breathing Apparatus (EBA) bottles are not required and are not available at most DOD sites; therefore, the use of EBAs is not detailed in the following MODE VI procedures. At sites that do employ EBAs, rescue team members will ensure the last four astronauts leaving the orbiter are equipped with EBAs.

NOTE: Although there is an emergency "cut in" location identified on the exterior of the OV, cutting into the orbiter has been determined to be NOT feasible.



FLIGHT DECK
INTERDECK ACCESS
PILOT
S2
S3
MISSION SPECIALIST 1
S4
MISSION SPECIALIST 2
S1
COMMANDER
INTERDECK ACCESS
Note
PILOT AND COMMANDER SEATS ARE NOT STOWABLE
MIDDECK
TREADMILL (STOWED)
LIOH CANISTER STOWAGE COMPARTMENT DOOR
S7
AIRLOCK
ORBITER
S6
MISSION SPECIALIST
S5
WASTE MANAGEMENT COMPARTMENT
Crew seat locations and designations.

Figure 2

SPACE SHUTTLE HAZARDS / TOXIC HAZARD CORRIDOR

1. Toxic Leaks and Vapors Corridor.

a. Following an OV landing, the potential exists for toxic leaks, fires or spills. The most likely scenario is a minor leak or drip following a nominal landing.

b. Potential OV hazards include exposure to gases (ammonia, helium, nitrogen, oxygen), raw propellants (hydrazine, monomethylhydrazine, nitrogen tetroxide, liquid hydrogen, liquid oxygen) and other toxic vapors (ammonia, hydrazine, monomethylhydrazine, nitrogen tetroxide, and Freon 21). Flash fires, high pressures, hot brakes and wheels, propellant fires, steam/hot water and unexpended pyrotechnic devices are elements, which contribute to flammability and toxic/explosive hazards. OV hypergolic fuels (hydrazine, monomethylhydrazine) are self-igniting upon contact with the oxidizer (nitrogen tetroxide) and are considered extremely hazardous.

c. During an emergency landing, OV thrusters may leak or drip toxics. Stainless steel containers or 55 gallon drums may be placed under the thrusters to contain the leak. These containers should be one-third full of water because the hypergolic fuels are water soluble. If hydrazine leaks on asphalt, it may start a fire before a container can be placed under the leak. The leak and resultant fire may be controlled with water. The primary objective in this case would be to control the fire to protect the OV. Normally, the oxidizer will vaporize.

d. At most DOD installations, the fire department is normally responsible for initial response and containment of toxic spills. Your Local Emergency Response Plan (LERP) should indicate the entity responsible for cleanup and recovery. As a minimum, personnel performing these operations are required to wear self-contained breathing apparatus (SCBA) and fire fighter protective clothing. If at all possible, emergency responders should not come in contact with substances leaking from the OV. If this is impossible, as a result of responders trying to contain a leak, responders should wear a liquid splash (non-encapsulated) or acid suit (encapsulated).

2. Toxic Hazard Corridor/Perimeter. For OV emergency landing operations, a toxic corridor/perimeter should be plotted by disaster preparedness/bioenvironmental personnel and provided to the OSC prior to landing. The following toxic hazard release containment rules have been developed in coordination with the NASA KSC Launch & Landing Office and with the NASA KSC Safety Office; however, if time permits, DOD commanders should use applicable DOD disaster preparedness/bioenvironmental directives and resources in determining toxic chemical dispersion and modeling. Questions concerning toxic hazard should be referred to the appropriate entity at your installation.

a. Intact OV after landing (no damage to orbiter systems): Maintain 1,250 foot perimeter (upwind and downwind). This minimum distance is based on a hypergolic spill of 3.0 lbs (1.3 lbs MMH plus 1.7 lbs N_2O_4).

b. Damaged OV after landing (suspected or known damage to orbiter systems) and surface winds are **greater than three (3) knots**: Maintain 1,250 feet upwind and 5,000 feet downwind. These minimum distances are based on a spill of N_2O_4 of 80 lbs/min, over 8 minutes, in an 800 square foot spill area.

c. Damaged OV after landing (suspected or known damage to orbiter systems) and surface winds are **three (3) knots or less**: Maintain 5,000 foot perimeter (upwind and downwind). This minimum distance is based on a spill of N_2O_4 of 80 lbs/min, over 8 minutes, in an 800 square foot spill area.

3. Post-Landing Hazards. After landing, DOD personnel will respond to recover the astronaut crew and to provide security for the OV until the NASA RRT arrives. Ground support personnel must be aware of potential hazards during these operations.

4. Explosive / Blast Hazards. The blast hazard zone is a 1,250-foot safety perimeter around the OV. This perimeter will remain intact until NASA RRT personnel arrive and provide additional guidance to the

OSC. Explosive hazard protection should be established in accordance with applicable military service directives. Refer to Figures 3 and 4 for explosives / blast locations.

5. Gases / Fluids. Figure 5 provides quantities of hazardous fluids and gases that are estimated to be on board the OV during landing. Standard fire protection clothing and breathing apparatus provide protection from minimal exposure to hazardous fluids and gases when appropriate wash down procedures are used. Establish a clear zone downwind of the OV and approach from upwind.

6. OV Surface Temperature / Heat Hazard. The re-entry process causes extreme heating of the OV and surfaces may remain super-heated for up to 30 minutes post-landing. The nose section and leading edges of the wings may reach temperatures in excess of 500 deg F and should be avoided. All personnel should avoid touching glass or exposed metal areas. In addition to the temperature hazard, personnel should refrain from touching OV thermal protective system tiles to avoid damaging the tiles. These tiles are extremely fragile and, to prevent damage, should not be touched.

7. Hot Brakes. A hot brake hazard is always present post-landing for up to 45 minutes. A safety zone of 60 feet around the brakes should be established. If hot brakes results in a tire fire, water should be used to extinguish or control the fire. FCR crews should be prepared for re-ignition because the brakes could remain hot for extended periods. Refer to Figures 5 and 6 for hazard zones.

NOTE: The HAT and FCR will avoid the hot brake/fragmentation hazards when operating within the 1,250-foot hazard zone. The tires currently used on the OV have fusible plugs installed. These plugs are designed to vent and relieve pressure caused by excessive heating and prevent tire fragmentation.

8. Pyrotechnics. The following systems can operate pyrotechnically and present both a blast hazard and possible ignition source if activated:

a. Side Hatch. The side hatch is approximately four feet in diameter, weighs approximately 300 pounds and can only be jettisoned by the crew. The hatch can jettison horizontally out to 100 feet in 2 seconds. It is imperative that the OSC has received communication from the flight crew, Flt Dir or DDMS SOC confirming that the side hatch has been safed (2nd key communication) prior to clearing emergency responders into the 1,250-foot hazard zone.

b. Top Hatch. The top hatch is approximately two feet square and weighs around 40 pounds. It can be jettisoned by the flight crew from inside the OV or from the outside by FCR personnel. The top hatch is designed to jettison up and aft to the left side of the OV. The exterior jettison mechanism is located on the right side of the OV, opposite the designed jettison direction. Refer to Figures 3 and 4 for the jettison hazard zones of both the side and top hatch.

NOTE: If FCR personnel elect to jettison the top hatch or request the crew jettison the side hatch, a water fog may be directed over the selected hatch to suppress the flames and minimize potential ignition of flammable chemicals.

c. Drag Chute. The drag chute presents two possible hazards to rescue forces. First, it is possible that the chute does not deploy resulting in live pyrotechnics in the aft of the OV. Second, when the chute does deploy, there is a potential for debris to be scattered behind the OV on the runway. Responders approaching from the rear should avoid this debris. Do not pick up any of this debris. The Mishap Investigation Team (MIT) will perform this task when they arrive with the RRT.

d. Landing Gear. The landing is hydraulically actuated with a pyrotechnic backup. If the landing gear does not deploy within one second of activation, pyrotechnics will fire to unlock the gear up locks. There may be live pyrotechnic devices present in the main landing gear wheel wells if the gear was lowered normally (one each uplock release thruster cartridge “Class C” explosive). Do not transmit on any radios while standing in the wheel wells.

9. Chemical. The hypergolic fuels (Hypergols) are the most hazardous chemicals on board the OV. In addition to the hypergols, there are several other hazardous chemicals of which emergency responders must be aware.

a. Hypergolic Fuels. The two hypergolic fuels are monomethylhydrazine (MMH) and nitrogen tetroxide (N2O4). A hypergolic reaction occurs when these two chemicals come in contact with each other in the right concentration. It is characterized by explosive ignition.

(1) MMH is a colorless, highly reactive, corrosive, flammable and highly toxic liquid that has a fishy, ammonia-like odor. It is used as rocket fuel. MMH is heavier than air and water-soluble. It has a flammable range of roughly 2-99%. In the event of an MMH leak, FCR personnel can use a water fog to protect the rescue path to dilute the chemical and suppress off-gassing.

(2) N2O4 is a yellowish to dark brown, nonflammable, highly volatile and extremely poisonous liquid. Vapors will be yellowish-brown, reddish-brown, or dark brown and are heavier than air. N2O4 is used as an oxidizer. In the event of an N2O4 leak, use the same water fog procedure as for MMH.

WARNING

If both MMH and N2O4 are leaking simultaneously, immediately declare an egress condition red and notify the flight crew. If FCR personnel are in the middle of executing a MODE V/VI, a water fog can be used to protect the egress path much like controlling a running fuel fire. A hypergolic fire cannot be extinguished (unless one of the two chemicals stops leaking), but it can be controlled to protect flight crew and FCR personnel.

b. Hydrogen and Oxygen. The OV uses hydrogen and oxygen to create drinking water and generate electricity for OV systems. These chemicals could leak post-landing from the vent locations indicated in Figure 5. Hydrogen is a clear, flammable gas. Oxygen is a clear gas that will intensify fire or flammable atmospheres.

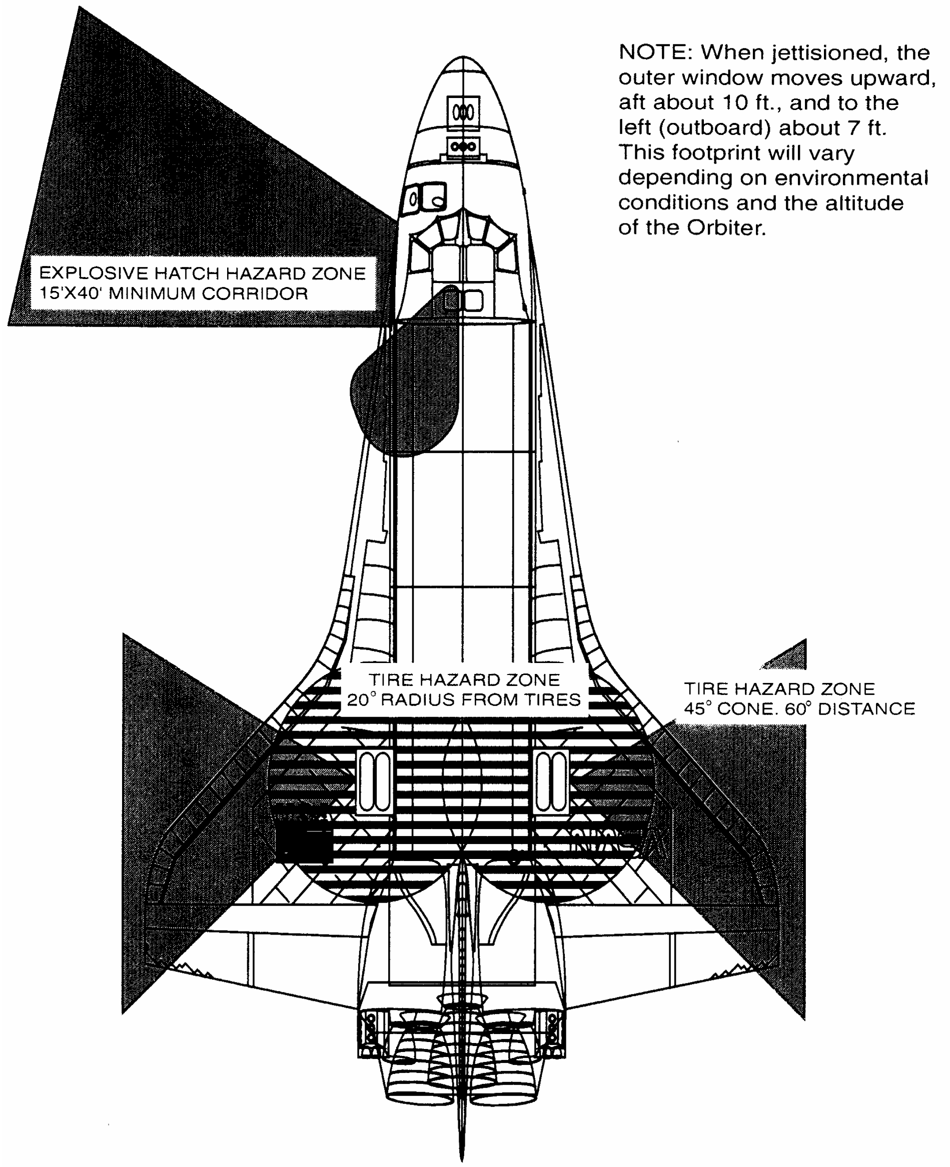
WARNING

During an emergency landing, if the crew was unable to perform a main propulsion system dump, the OV will release hydrogen gas from a vent near the forward left part of the vertical stabilizer. The vented hydrogen will most likely be ignited. If ignition is evident, under no circumstances will the OV be approached by other than crew rescue. The crew should egress the OV without assistance, if able. If not, initiate a MODE VI. This venting may continue for approximately 12 hours.

NOTE: Some of the hydrogen and oxygen is stored cryogenically. Cryogenics are stored at extremely cold temperatures and present a cold hazard in addition to the chemical hazard. High temperatures at DOD landing sites may cause the cryogenics to vent.

c. Ammonia. Ammonia is a corrosive, combustible and toxic colorless liquid. Ammonia venting will normally occur for 20-45 minutes post-landing. Ammonia venting during nominal operations is limited and dissipates readily. If a more severe ammonia spill occurs, declare a MODE V or VI, protect the egress path with a water fog and evacuate the 1,250 foot hazard area.

d. Hydrazine (N2H4). Hydrazine is used as the fuel for the three auxiliary power units (APU). When in operation, the APUs vent hydrazine flames upward by the vertical stabilizer at the aft of the OV. A chugging sound may be heard.



Orbiter Escape Hatch and Panel Jettison Danger Areas

Figure 3

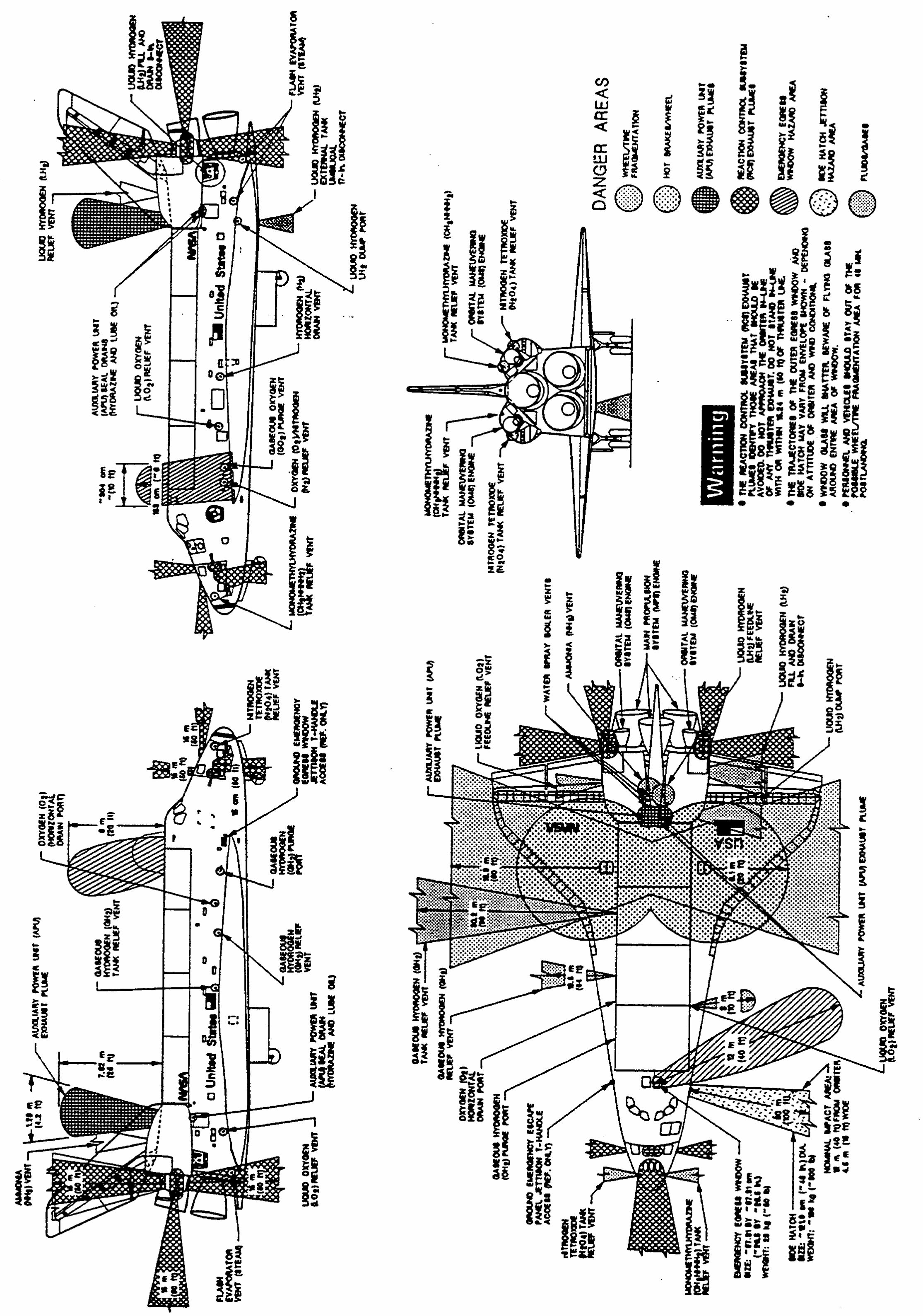


Figure 4

SPACE SHUTTLE ORBITER VEHICLE
HAZARDOUS FLUIDS AND GASES ALL VEHICLES

PRINCIPAL HAZARDOUS FLUIDS AND GASES					
CHEMICAL	CHARACTERISTIC	USE	NUMBER OF TANKS	LANDING QUANTITY LB	LANDING QUANTITY GAL.
MONOMETHYL-HYDRAZINE (CH_3NHNH_2)	FLAMMABLE TOXIC	PROPELLANT (OMS-RCS)	5	1796	213.4
NITROGEN TETROXIDE N_2O_4	ACID FORMING TOXIC	PROPELLANT (OMS-RCS)	5	2945	350.6
HYDRAZINE (N_2H_4)	FLAMMABLE TOXIC	AUXILIARY POWER UNIT	3	490	58.3
ANHYDROUS AMMONIA (NH_3)	CAUSTIC TOXIC	COOLANT	2	98	17.2
LIQUID HYDROGEN (LH_2)	CRYOGENIC FLAMMABLE	FUEL CELLS (ELECTRICAL POWER)	3	160	19.0
LIQUID OXYGEN (LO_2)	CRYOGENIC OXIDIZER	FUEL CELLS (ELECTRICAL POWER)	3	1376	163.8

Warning

- ORBITER CRASH OR EMERGENCY LANDING MAY RESULT IN TOXIC MATERIAL SPILL AND/OR VAPORS. RESCUE AND GROUND HANDLING PERSONNEL MUST WEAR PROTECTIVE CLOTHING WITHIN A 200-FT RADIUS OF THE ORBITER VEHICLE. THE DOWNWIND AREA MUST REMAIN CLEAR OF UNPROTECTED PERSONNEL UNTIL VERIFIED SAFE.

Note

- Quantities shown are estimated maximums following a nominal 5-day mission.
- Quantities may vary depending on extent of mission completion prior to landing.
- Payloads, if present, may contain additional hazardous fluids and gases.
- Gaseous oxygen is a mission kit and may not fly always.

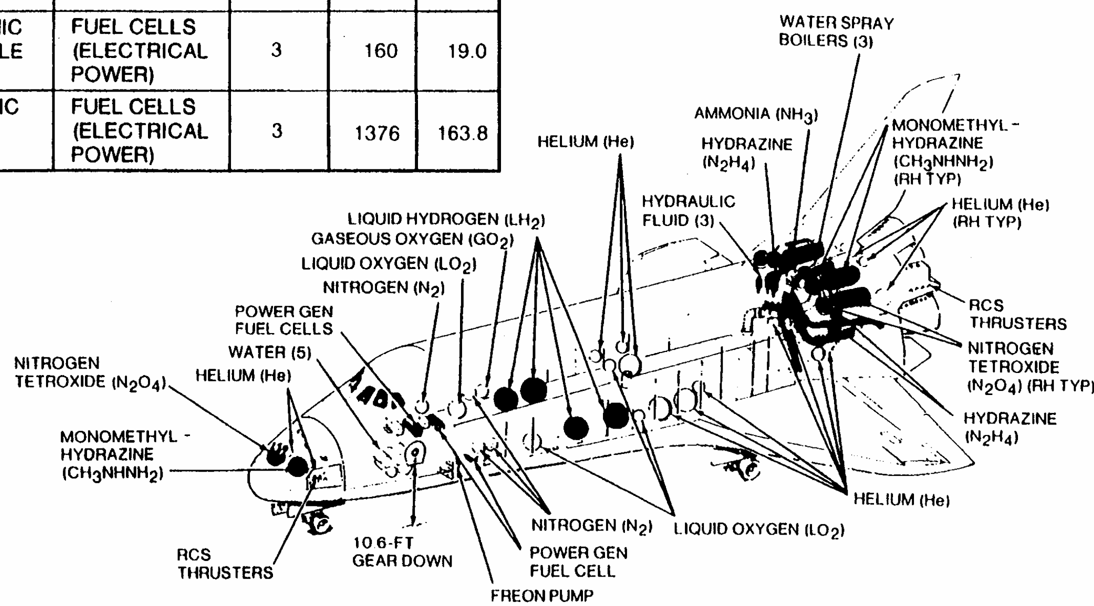


Figure 5

MODE VI RESCUE PROCEDURES

General. The provides specific recommended procedures that may be followed by the Senior Fire Official (SFO) and Fire/Crash/Rescue (FCR) personnel in the event an interior rescue operation (MODE VI) is declared.

NOTE: Interior procedures may be applied by rescue forces at all NASA-designated sites at which the Space Shuttle may land. These recommended procedures, to include the order of removal of the astronauts from the Orbiter Vehicle (OV), are the result of combined NASA and DOD test and evaluation using a high-fidelity mockup of the OV crew compartment. **While strongly recommended, these procedures will not restrict a rescue team leader or SFO from making real-time decisions to effect the safe recovery of the astronauts**.

NOTE: Because Emergency Breathing Apparatus' (EBA) are not available at most DOD sites, its use is not detailed in the following MODE VI procedures. At sites that do employ EBAs, rescue team members will ensure the last four astronauts leaving the OV are equipped with EBAs.

NOTE: Although there is an emergency "cut in" location identified on the exterior of the OV, cutting into the OV is NOT feasible.

SECTION I - SIDE HATCH EGRESS

Rescue Crew Member	Step	Action
4	1	Chock nose gear of OV. (Conditions permitting)

NOTE: The OV does not have a parking brake.

WARNING
The OSC/SFO will ensure the side hatch is safed prior to approaching the OV. If unable to confirm condition of the side hatch, F/C/R personnel will make entry through the top hatch.

Rescue Crew Member	Step	Action
1	2	Position ladder near OV side hatch. Ladder should rest on OV, forward of the hatch. If hatch is not accessible, proceed to Section II, Top Hatch Egress.
1	3	Climb ladder and break thermal protection system (TPS) tile over hatch actuator using the emergency hatch opening tool.
1	4	Insert tool into latching mechanism receptacle. (Figure 6)
1	5	Hit tool with heel of hand to drive tool in and release internal lock (approximately 30 pounds of force required).
1	6	Rotate tool clockwise to vent detent. Wait 30 seconds for pressure to equalize, and then continue to rotate clockwise to hard stop.

WARNING
Internal pressure differential may cause an explosive opening if not properly equalized.

WARNING
When opening hatch, stand clear of hatch opening path. Hatch weighs approximately 300 pounds.

NOTE: The 2 minutes (noted on side hatch opening instructions) is for normal operations. Only 30 seconds of depressurization is required during emergencies.

Rescue Crew Member	**Step**	**Action**
1	7	Pull hatch open. (Should be parallel with the ground when fully open)
1/2/3/4/5	8	Enter OV in the following order:
		a. Rescueman no. 1 proceed to flight deck
		b. Rescueman no. 3 proceed to mid-deck.
		c. Rescueman no. 2 proceed to flight deck.
		d. Rescueman no. 4 proceed to mid-deck.
		e. Rescueman no. 5 proceed to top of side hatch.

NOTE: If side hatch has been jettisoned, rescueman no. 5 will position at bottom of escape slide to help remove astronauts from the 1,250’ hazard zone.

NOTE: Use caution when entering the mid-deck from the side hatch. The bailout bar housing is located directly to the left (upon entering) of the side hatch and should be avoided to prevent injury. (Figure 7)

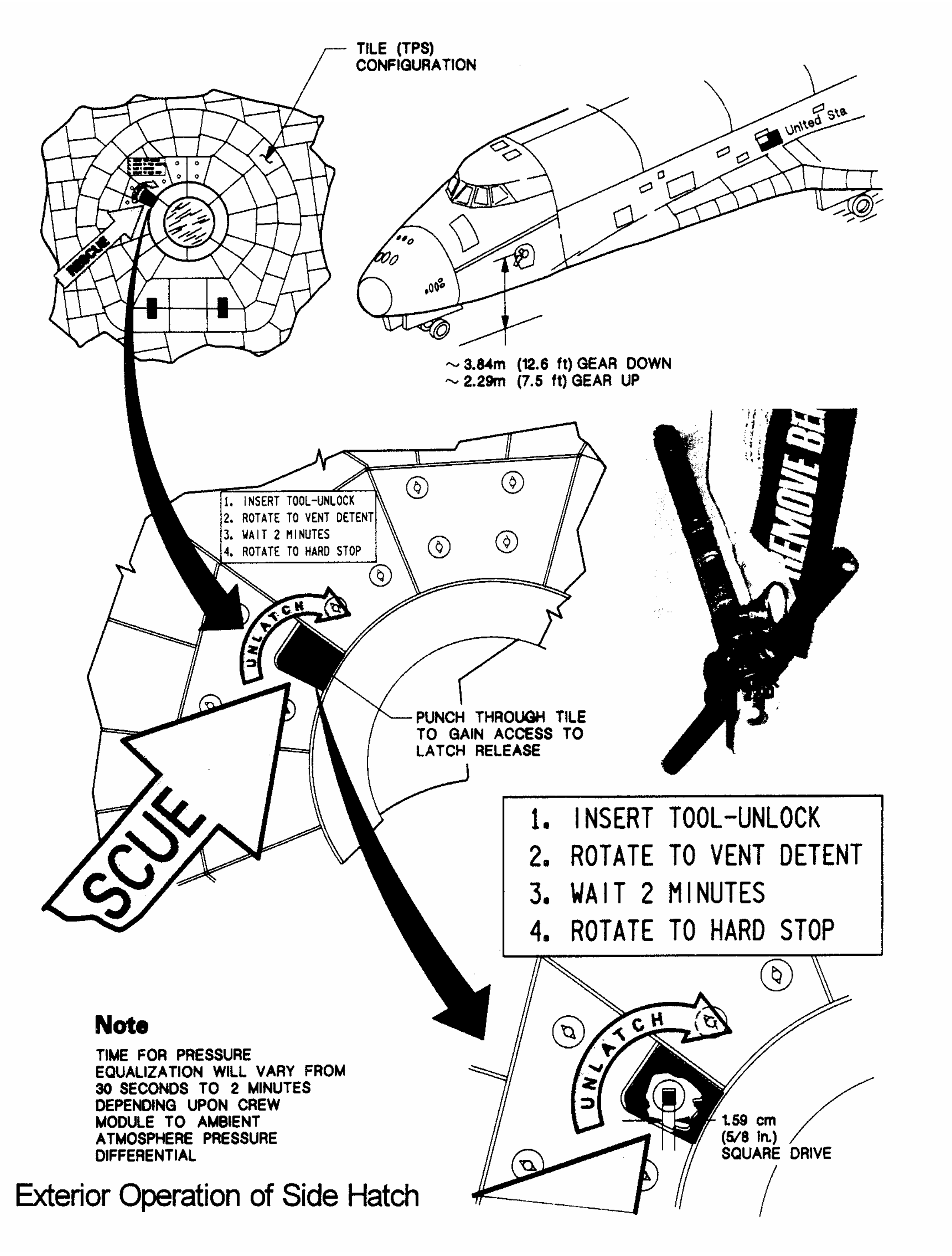

TILE (TPS) CONFIGURATION
~ 3.84m (12.6 ft) GEAR DOWN
~ 2.29m (7.5 ft) GEAR UP
1. INSERT TOOL-UNLOCK
2. ROTATE TO VENT DETENT
3. WAIT 2 MINUTES
4. ROTATE TO HARD STOP
UNLATCH
PUNCH THROUGH TILE TO GAIN ACCESS TO LATCH RELEASE
SCUE
Note
TIME FOR PRESSURE EQUALIZATION WILL VARY FROM 30 SECONDS TO 2 MINUTES DEPENDING UPON CREW MODULE TO AMBIENT ATMOSPHERE PRESSURE DIFFERENTIAL
1.59 cm (5/8 in.) SQUARE DRIVE
Exterior Operation of Side Hatch

Figure 6

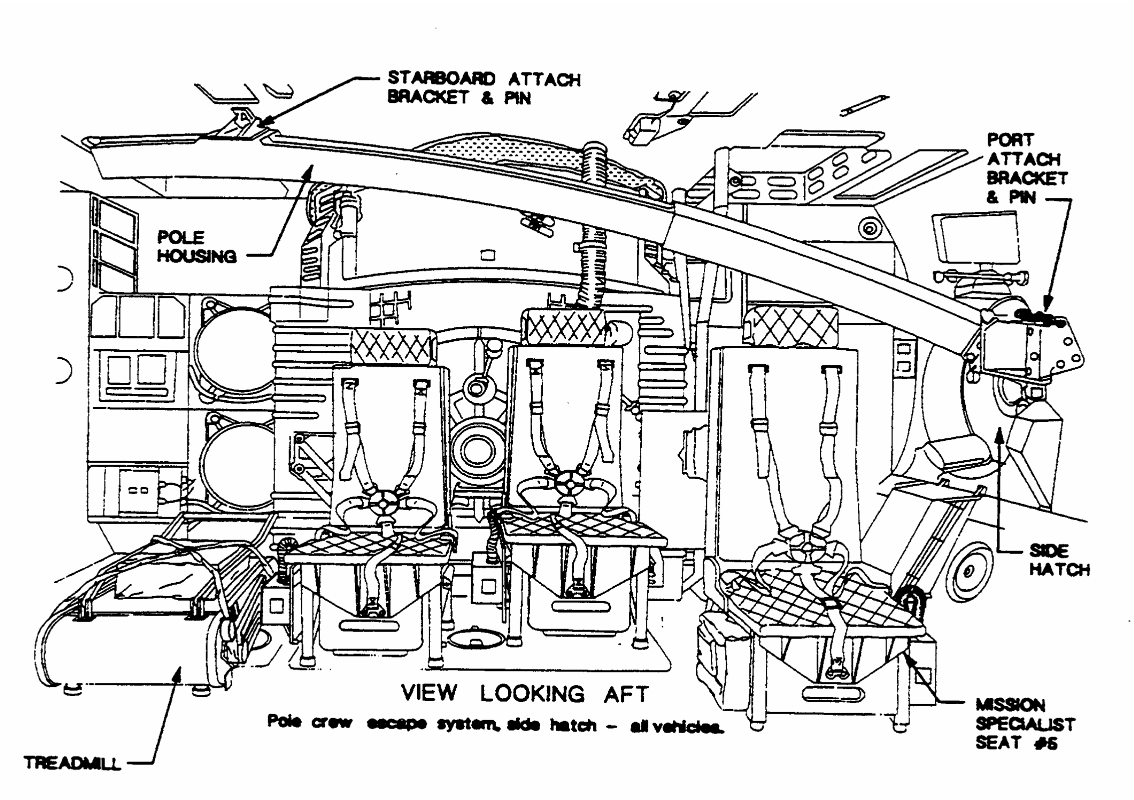


Figure 7

Rescue Crew Member	**Step**	**Action**
1/3	9	Close face plate, lock bailor bar, ensure O2 manifold is in the ON position, pull lanyard disengaging G-suit clip and pull green apple on all FCMs. (Figures 8 through 12)
1	10	Arm on-board halon fire suppression system by positioning the 3 arming switches on fire suppression panel to the up, armed position. (Figures 13 through 16)

To close faceplate, rotate clear faceplates downward.

Figure 8

Rotate bailor bar to down and locked position.

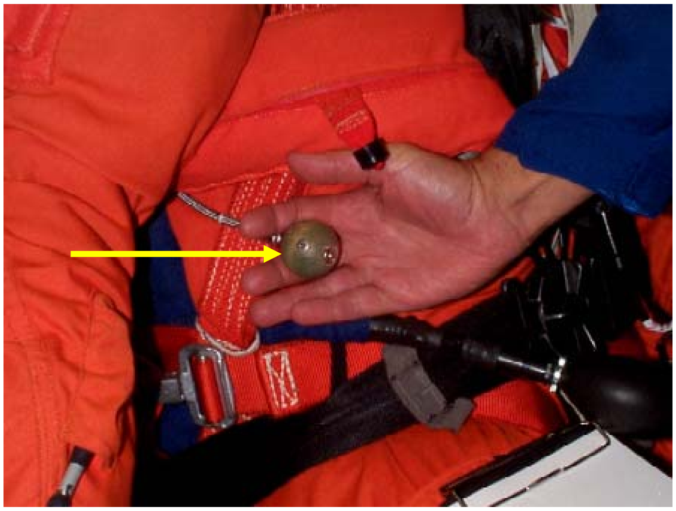
Figure 9

Ensure O2 manifold is in the ON position.

Figure 10

G-Suit controller clip disconnect.

Figure 11



Pull Green Apple out firmly.

Figure 12

NOTE: Fire suppression switches may be located by following the top forward instrument panel below the glare shield in front of the commander, across to the left. The switches are under the end of this panel. (Figures 13 through 16)

WARNING

The fire suppression system cannot be activated if OV has been powered down.

NOTE: For fire in OV crew module use on-board portable fire extinguishers.

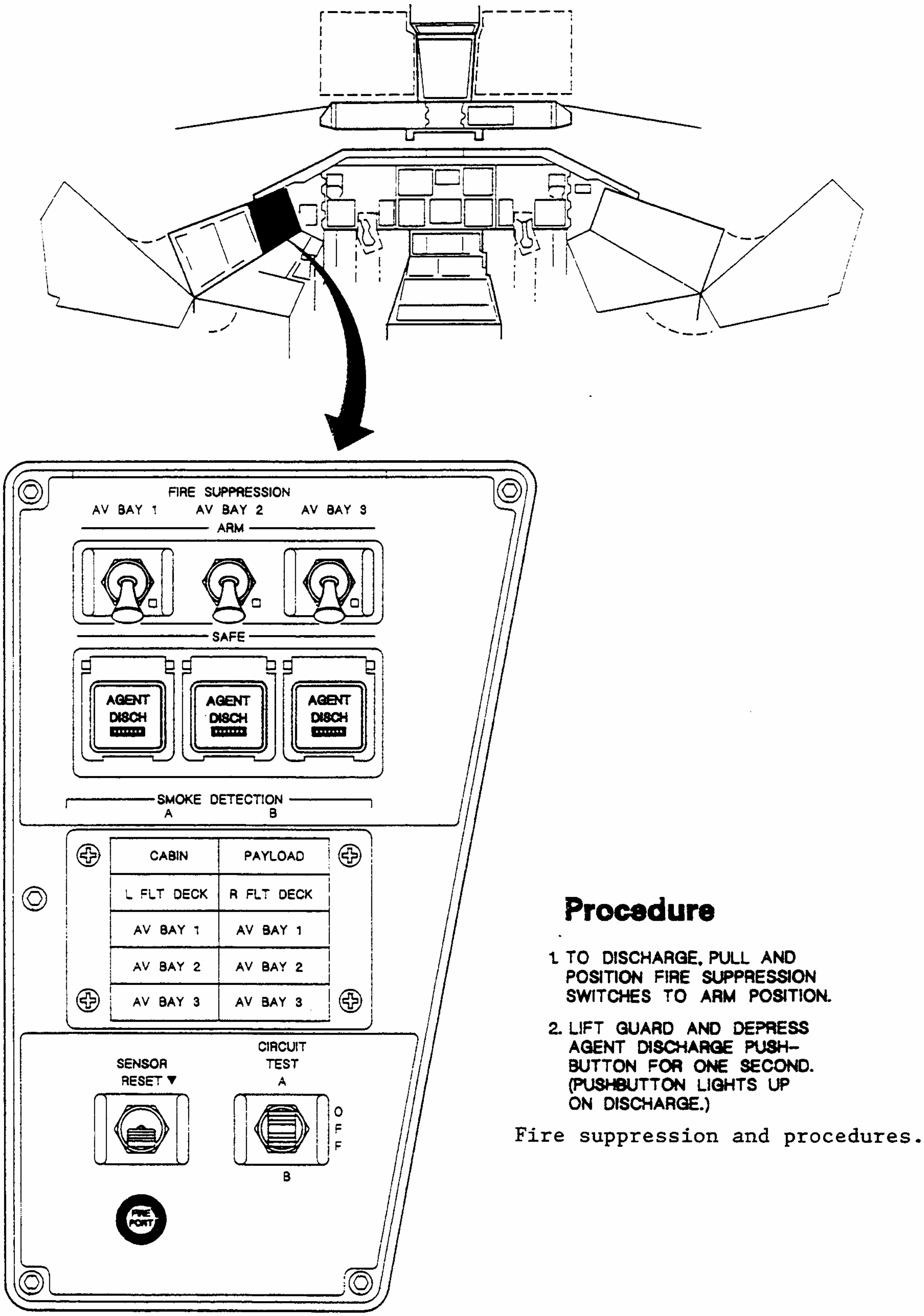
Rescue Crew Member	Step	Action
1	11	Lift safety guards and depress agent discharge buttons for 1 second. Button should light up after discharge. (Figure 16)
1	12	Position 3 FC/ Main Bus A, B, and C switches on power distribution panel to off (down) position. (Figure 17 and 18)

NOTE: Switches may be located by following the top forward instrument panel below the glare shield, across to the right in front of the pilot. The 3 FC/Main Bus and ESS switches are directly under the end of this panel. (Figures 19 and 20)

WARNING

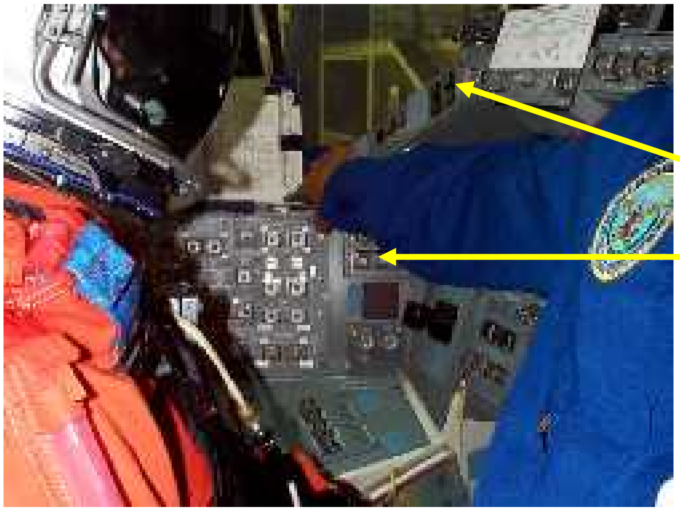
FC/Main Bus Switches A, B, and C are both lever lock and momentary, therefore these switches must be pulled out before they can be positioned down to "OFF". They must be held in the "OFF" position for 2 seconds.

Rescue Crew Member	Step	Action
1	13	Position 3 ESS FC 1, 2, and 3 switches to the "OFF" (down) position, (switches immediately to the left of FC/Main Bus A, B, and C). (Figure 20)



Fire suppression and procedures.

Figure 13



Glare Shield

Fire Suppression Panel

Figure 14

Figure 15

Pull 3 Fire Suppression Arming Switches "out" and "up" to the armed position.

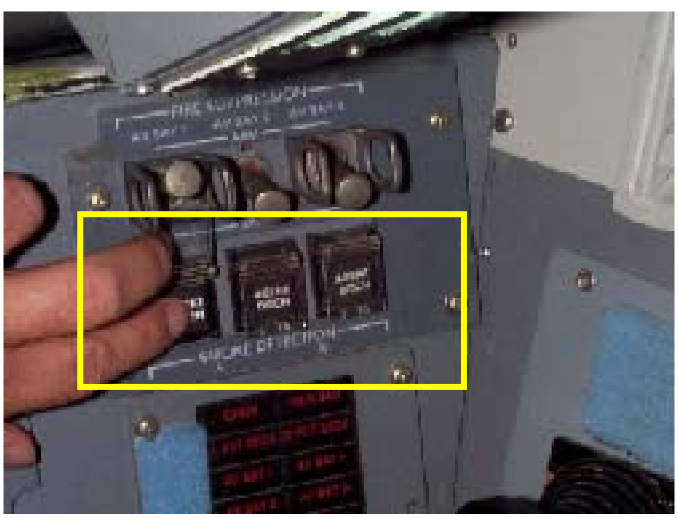


Figure 16

Lift safety guards and depress "Agent Discharge Buttons". Hold for 1 second and release.

Warning

- **Do not deviate from the powerdown procedures given. Positioning of any other switches/circuit breakers other than those specified may jeopardize the safety of the flightcrew and rescue personnel.**

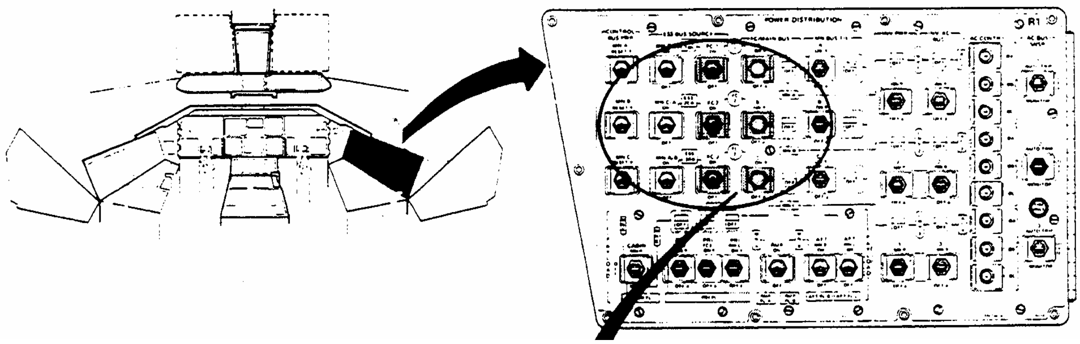


Figure 17

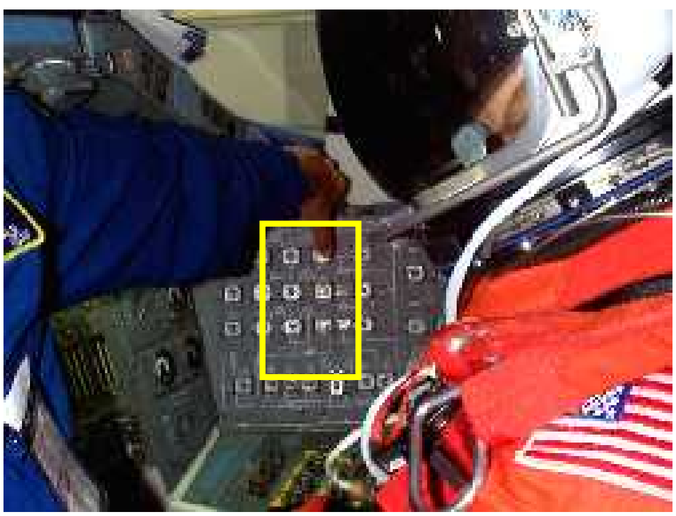


Figure 18

FC/Main Bus Switches A, B, and C (4th row from left to right).

ESS FC Switches 1, 2, and 3 (3rd row from left to right).

FC/Main Bus Switches A, B, and C must be pulled "out" and to the "down" position. Hold for 2 seconds and release.

Figure 19

ESS FC Switches 1, 2, and 3 are to be flipped to the "down" position.

Figure 20

<u>WARNING</u>

OV oxygen system flow is terminated upon OV power down.

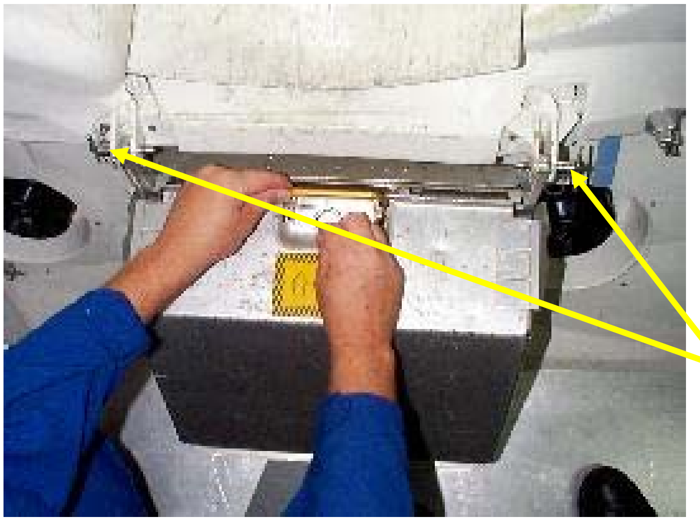
<u>WARNING</u>

Do not deviate from these procedures. Positioning of the switches/circuit breakers other than specified can jeopardize the flight crew and rescue personnel.

Rescue Crew Member	**Step**	**Action**
4/5	14	Deploy slide package.
		a. Remove locking pin from slide package cover. Remove slide cover and discard. (Figure 21)
		b. Remove slide package hinge pins. (Figure 21)
		c. Rotate slide package and assembly into the hatch opening. (Figure 22)

d. Pass slide package out to rescueman no. 5, who will connect it to the face of the side-hatch. (Figure 23)

e. Flip slide package overboard and pull inflation handle to inflate the slide. (Figure 24)



Remove slide-cover cotter pin, and discard slide cover. Remove slide hinge pins on left and right side.

(Hinge Pins)

Figure 21

Rotate slide package into side-hatch entry.

Figure 22

Figure 23

Pass entire slide package out to Rescueman no. 5. He/she then clips the slide package into top of hatch door.

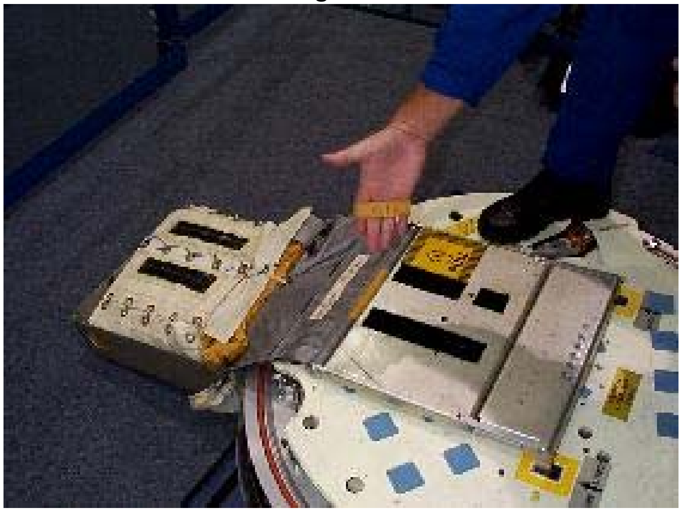


Figure 24

Flip slide package completely over and pull charging handle.

NOTE: If side hatch has been jettisoned, remove hinge pins and rotate the slide package into the hatch opening. Re-install hinge pins and flip slide package overboard, and pull the inflation handle. (Figures 25 and 26) Rescueman no. 5 will position at the base of the slide and join the exterior rescue team.

Rescue Crew Member	Step	Action
1/2/3/4	15	Perform **Seat Removal Procedures** on astronauts in seats 4 and 6.

a. Remove and discard kneeboard. (Figure 27)

b. Disconnect five-point harness. (Figure 28)

c. Disconnect upper and lower parachute fittings. (Figures 29 and 30)

d. Disconnect liquid cooled undergarment connection. (Figure 31)

e. Disconnect communication cord. (Figure 32)

f. Disconnect OV oxygen supply hose. (Figure 33)

NOTE: Procedures 15 a - f must be accomplished on every astronaut in the OV. As a result, we'll refer to steps 15 a - f throughout the remaining portion of this section as **"Seat Removal Procedures"**.

NOTE: Using the "5, 4, 3-method" helps rescue team members remember disconnect procedures. **Five** stands for 5-point harness, there are **four** parachute fittings, and **three** external connections.

NOTE: The g-suit controller clip must be pulled prior to EBA attachment to prevent loss of emergency air into the g-suit.

Rotate slide package into side-hatch entry.

Figure 25

Flip completely over, and pull charging handle.

Figure 26

Remove thigh mounted knee-board.

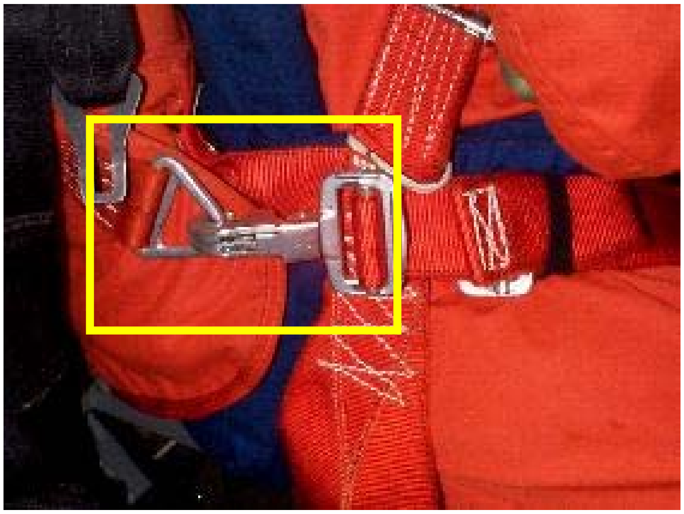
Figure 27

Turn 5-point harness disconnect 1/4 turn in either direction to release.

Figure 28

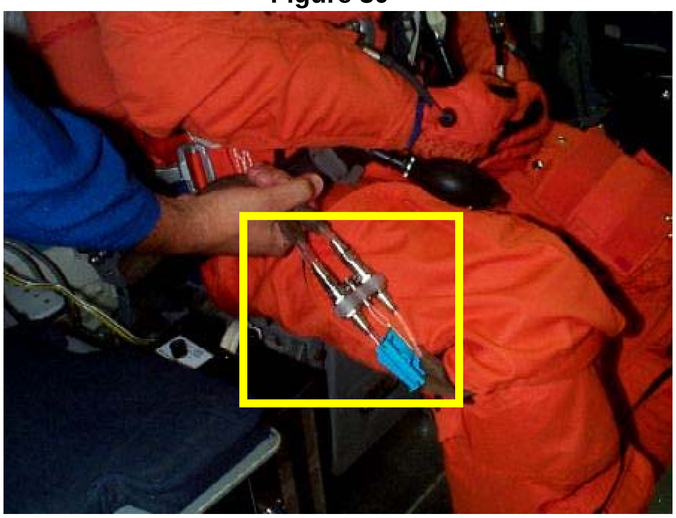
Disconnect upper (frost) parachute fittings by squeezing mechanism together.

Figure 29



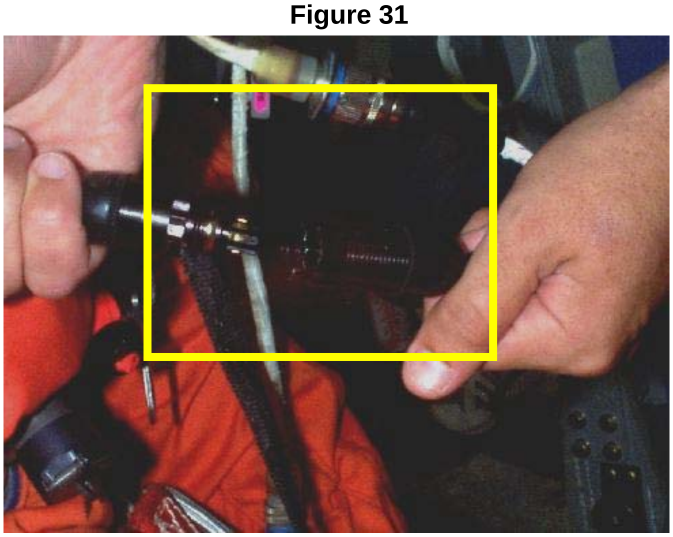
Disconnect lower winged ejector clips.

Figure 30



Disconnect liquid cooling undergarment supply hose.

Figure 31



Disconnect Communication Cord.

Figure 32

Quick disconnect on O2 Manifold.

Figure 33

Rescue Crew Member	**Step**	**Action**
3	16	Apply leg and wrist straps to FCM in seat 6.
3/4	17	Lift and place FCM in front of hatch opening.
4	18	Lift and rest FCM through side hatch head first.
4	19	Attach descent strap to FCM's ankles.
4/5	20	Slowly lower FCM's down escape slide using the descent strap.
1/2	21	Apply leg and wrist straps to FCM in seat 4.
2	22	Lift FCM from seat 4 to inner deck access and place feet in inner deck access.
2	23	Lower FCM using the survival harness to rescueman no. 4 on mid-deck.

NOTE: The survival harness is the only load bearing part of the astronaut suit and must be used during the lowering process.

NOTE: Effective communication between rescuemen nos. 2 and 4 is imperative to safely lowering FCMs from the flight deck to the mid-deck for extrication.

4	24	Lift and rest FCM through side hatch head first.
4	25	Attach descent strap to FCM's ankles.
4/5	26	Slowly lower FCM down escape slide using the descent strap.

NOTE: After the FCM in seat No. 4 is removed, this seat should be used as a staging seat for preparing the remaining FCMs on the flight deck for removal.

NOTE: After the FCM in seat 6 is removed, this seat should be used as a staging seat for preparing the remaining FCMs on the mid-deck for removal.

Rescue Crew Member	**Step**	**Action**
3	27	Perform **Seat Removal Procedures** on FCM in seat 5.
3/4/5	28	Move FCM in seat 5 to seat 6 and repeat steps 16-20.
2	29	Perform **Seat Removal Procedures** on FCM in seat 3.
1/2/4/5	30	Move FCM in seat 3 to seat 4 and repeat steps 21-26.
3	31	Perform **Seat Removal Procedures** on FCM in seat 7.
3/4/5	32	Move FCM in seat 7 to seat 6 and repeat steps 16-20.

NOTE: Once you have removed the FCM from seat 5, it is advisable to lower the lumbar portion of seat 5 to make the removal of the remaining FCM's more efficient.

1	33	Perform **Seat Removal Procedures** on FCM in seat 2.
1/2	34	Move FCM in seat 2 to seat 4 via the center console.

NOTE: Lowering the control stick may make this step easier (Figure 34).

Figure 34

1/2/4/5	35	Repeat steps 21-26.
1	36	Perform **Seat Removal Procedures** on FCM in seat 1.
1/2	37	Move FCM in seat 1 to seat 4 via the center console.
1/2/4/5	38	Repeat steps 21-26.
1	39	When all FCM's have been removed, account for all rescue crewmembers and exit OV via the side hatch.

Rescue Crew Member	**Step**	**Action**
	40	Exit the 1,250 ft. Hazard zone and report to Decon for evaluation.
Exterior Rescueman	41	Disconnect descent strap from FCM's ankles.
	42	Ensure FCM's 02 manifold is still in the ON position (if EBA is attached).
	43	Place FCM in litter, and transport to DECON to be checked for contamination.
	44	Deliver FCM to medical personnel.

SECTION II – TOP HATCH ENTRY

Rescue Crew Member	**Step**	**Action**
4	1	Chock OV nose gear (conditions permitting)
ALL	2	Proceed to right side of OV.
ALL	3	Position ladder to side of emergency egress window jettison t-handle access door. (Figure 35).
1	4	Climb ladder, use #10 Torq-head screwdriver to remove fasteners, punch out red tile and open access door by pressing release button. (Figure 35)

WARNING

Before jettisoning the emergency egress window, advise ground support personnel and flight crew of intentions.

WARNING

Ensure areas aft and to the sides of the OV are clear of all personnel prior to jettisoning the top hatch.

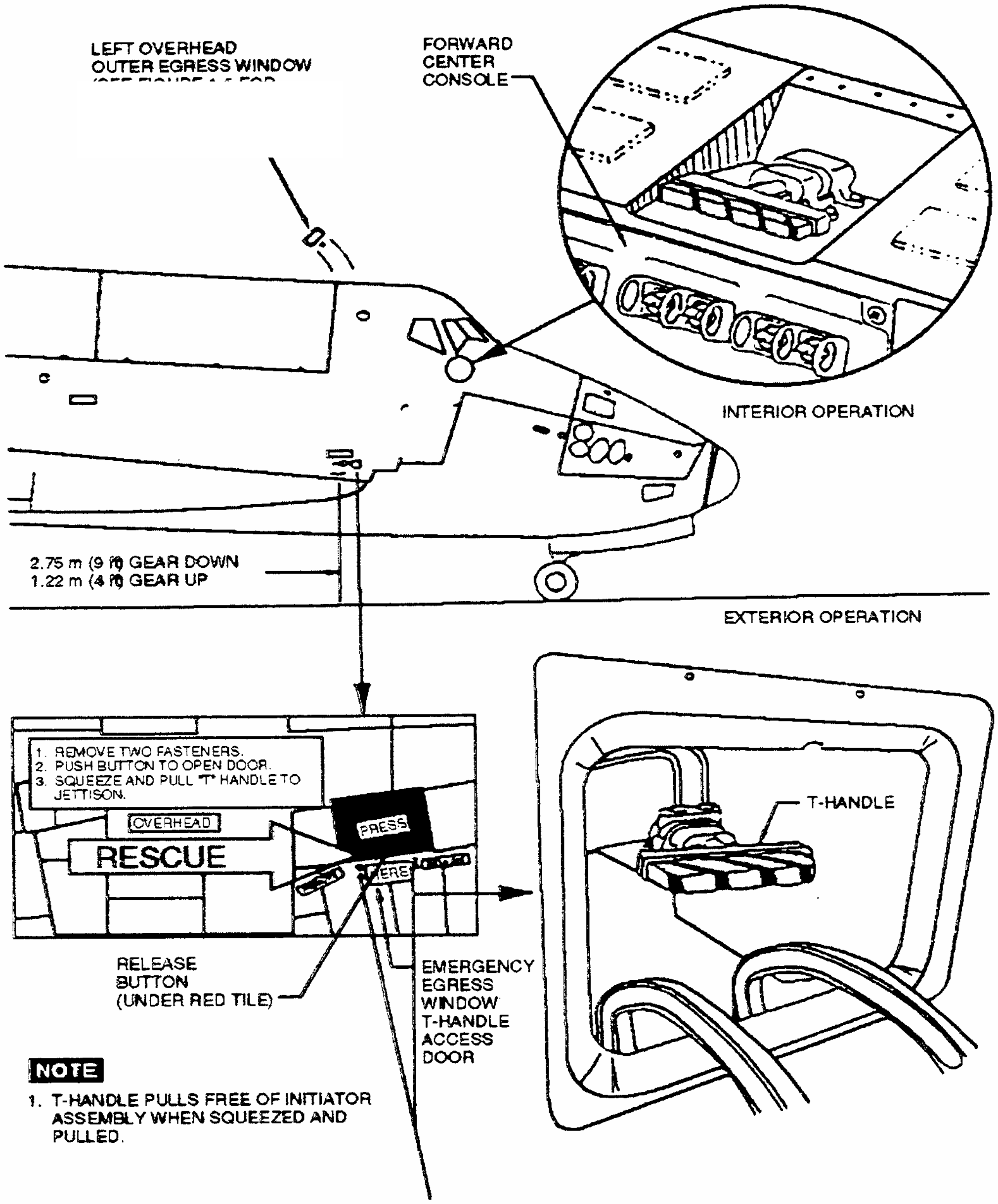
WARNING

Personnel should be aware that any flammable/explosive atmosphere in the immediate area of the emergency egress window could be ignited when the window is jettisoned. At the SFO's discretion, fire fighters can direct water fog in the immediate area of the top hatch to reduce the chance of flash fire.

WARNING

Rescue personnel should be aware that following jettison of the top hatch, large quantities of glass may be on top of the OV and in the crew compartment.

1	5	Squeeze and pull t-handle outward to jettison emergency egress window. The t-handle will pull free of initiator.
1	6	Descend ladder.
ALL	7	Position extension ladder (minimum 35-foot) against right side of OV or maximum stability and hold ladder in place.



TORQ-SET SCREW LOCATIONS

Interior/Exterior Operation Of Jettison T-Handle (All Vehicles)

Figure 35

Rescue Crew Member	**Step**	**Action**
1/2/3/4	8	Climb ladder to top of OV.

NOTE: Rescueman no. 5 remains at the bottom of the ladder until requested on top of the OV.

NOTE: Should the emergency egress window fail to jettison, firefighters may use a pry bar to dislodge the window by prying down. The window may fail to open due to the pressure inside the OV.

3	9	Enter through top hatch and proceed to mid-deck.
1	10	Enter through top hatch and remain on flight deck.
4	11	Enter through top hatch and proceed to mid-deck.
1/3	12	Close face plate, lock bailor bar, ensure O2 manifold is ON, and pull green apple on all FCM's. (Figures 8 through 10)
4	13	Unlock side hatch and attempt to open manually. (Figures 36 and 37)

NOTE: If the side hatch opens, rescueman no.5 proceeds to the side hatch, rescueman no. 2 proceeds to the flight deck, and the rescue team performs side hatch extrication procedures starting with SECTION I, Step 10. If side hatch does not open, continue to the next step of this section.

4	14	If side hatch will not open manually, signal Rescueman no. 3 to perform side hatch jettison.

WARNING

All personnel should be aware that any flammable/explosive atmosphere in the immediate area of the side hatch could be ignited when the hatch is jettisoned. At the SFO's discretion, firefighters may direct a water fog across the side of the OV to reduce the chance of a flash fire.

NOTE: The hatch jettison handle is located in a protective metal housing forward and left of seat 5 on the mid-deck. Directions for actuation are listed on the mechanism housing.
(Figure 38)

WARNING

Before pulling the jettison handle, all rescuemen in the interior, and all forces on the exterior should be warned to prevent injury or death.

3	15	a. Squeeze latch pins together to gain access to side hatch jettison handle. (Figure 39)
		b. Remove safety cover. (Figure 40)
		c. Pull safety pin (Figure 41)
		d. Pull the right handle upward. (Figure 42)

NOTE: If the side hatch jettisons, rescueman no. 5 proceeds to the side hatch, rescueman no. 2 proceeds to the flight deck, and the rescue team performs side hatch extrication procedures starting with SECTION I, Step 10.

NOTE: If the side hatch does NOT open, rescueman no. 5 proceeds to the top of the OV and assists no. 2 with removing FCMs through the top hatch.

Rescue Crew Member	**Step**	**Action**
1	16	Perform OV shutdown procedures. (Section I, Steps 10-13)
2/5	17	Attach safety lines to bar inside the top hatch.
1	18	Perform **Seat Removal Procedures** on FCM in seat 4.

NOTE: Because seat 4 is directly below the top hatch, the FCM in seat 4 will be removed first. Then, all FCMs will be removed from the mid-deck. This frees up either rescueman no. 3 or 4 to assist no. 1 with extrication operations on the flight deck.

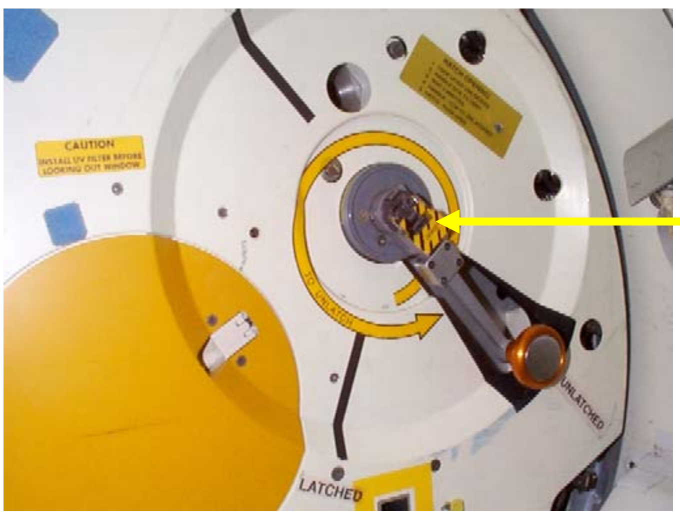
1	19	Apply leg strap to FCM in seat 4.

NOTE: For top hatch extrication, wrist straps should NOT be used. This allows the FCM's arms to hang straight down and fit more easily through the top hatch.

2/5	20	Lower extraction straps/ropes to rescueman no. 1.
1	21	Attach extraction straps/ropes to survival harness of FCM in seat 4.

NOTE: Ascent straps should be marked in a fashion that they are readily identifiable to all rescue team members as to which one is for the right and which one is for the left.

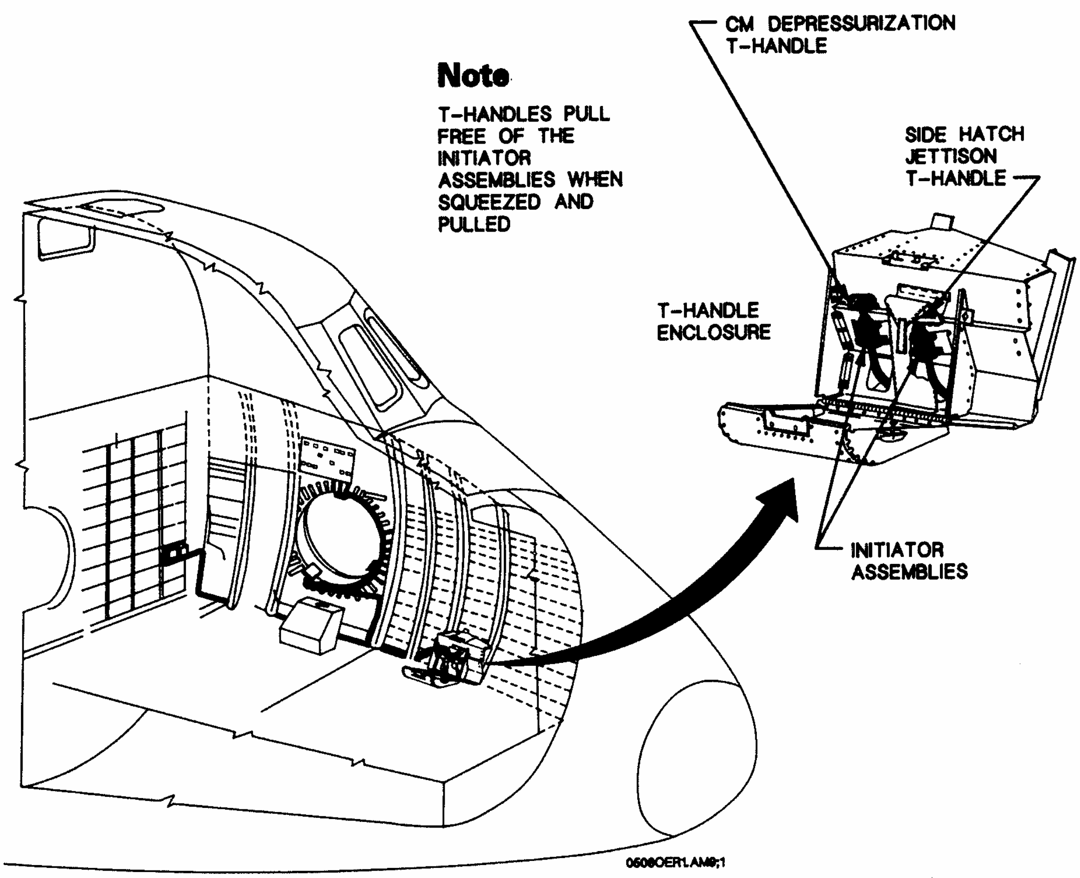
2/5	22	Hoist FCM through the top hatch.



Mechanism to unlock side-hatch from interior of OV.

Figure 36

Figure 37



Emergency Crew Module Depressurization and Side Hatch Jettison T-Handles (All Vehicles)

Figure 38

Figure 39

Squeeze latch pins together to gain access to Side-Hatch Jettison Handle.

Figure 40

Remove protective cover from jettison handle.

Figure 41

Remove ground safety pin.

Pull jettison handle upward.

Figure 42

Rescue Crew <u>Member</u>	**<u>Step</u>**	**<u>Action</u>**
1	23	As rescuemen nos. 2 and 5 hoist, guide FCM through hatch.

NOTE: Guiding astronauts through the top hatch is paramount to safely performing crew extrication. The top hatch is a very small opening and the FCMs may have to be guided through with their shoulders at a diagonal to fit through the hatch.

2/5	24	Lower FCM off right side of the OV.

NOTE: Astronauts should be lowered off the right side of the OV to avoid rescue crews and FCMs operating near the side hatch. The side hatch is still an explosive hazard and will be avoided.

Exterior	25	Disconnect extraction straps and place FCM in litter.
Exterior	26	Ensure 02 manifold is ON (if EBA is attached).
Exterior	27	Transport crew member(s) to DECON for evaluation.
Exterior	28	Repeat steps 25-27 on all FCMs as lowered.
2/5	29	Hoist extraction straps and lower to mid-deck.
3/4	30	Perform **Seat Removal Procedures** on FCM in seat 6 and attach leg strap.
3/4	31	Lift and place FCM at bottom of stairs.
3/4	32	Connect extraction straps to shoulder harness.
2/5	33	Hoist FCM through hatch and lower on right side of the OV.
1/3/4	34	Help guide FCM through inner deck access and hatch during hoist.
3/4	35	Repeat steps 30-34 on remaining FCMs on the mid-deck.

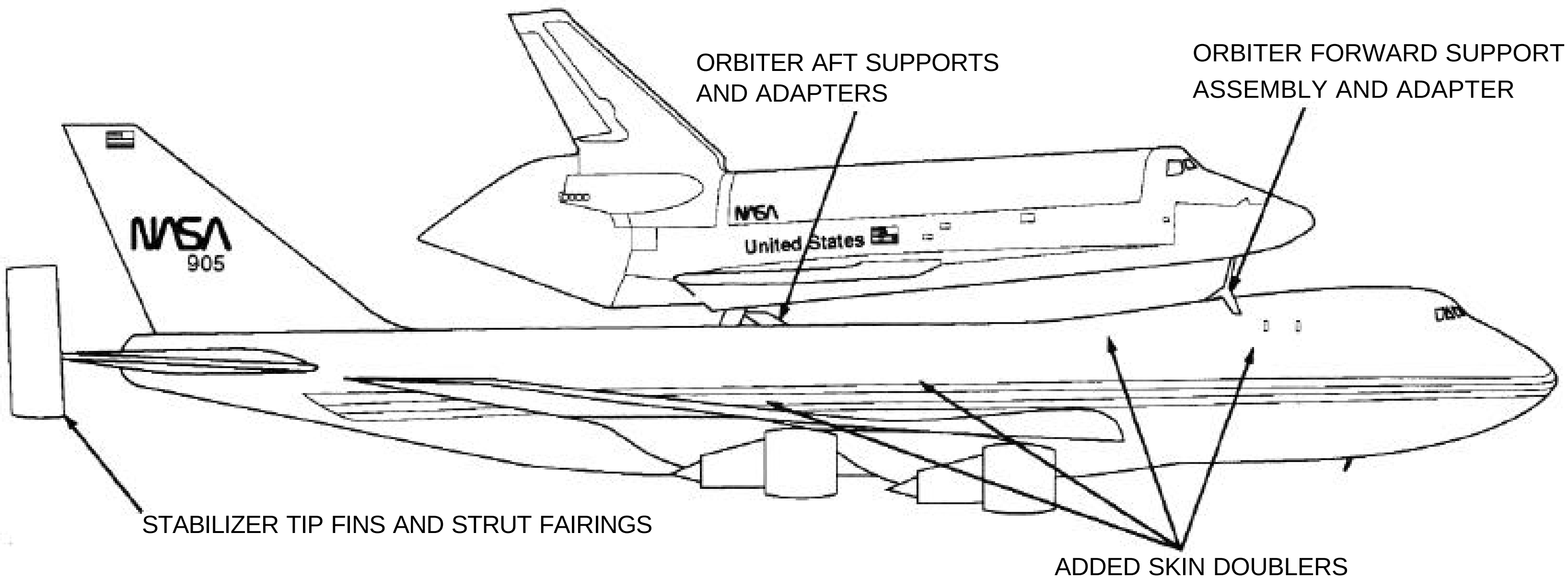
Rescue Crew <u>Member</u>	**<u>Step</u>**	**<u>Action</u>**
3/4	36	After all FCM's on the mid-deck have been removed, Rescueman no.3 or 4 will proceed to flight deck and assist no.1.
1/3 or 4	37	Move FCM in seat 3 to seat 4, apply leg strap and attach extraction straps/ropes.
2/5	38	Hoist FCM through hatch and lower on right side of OV.
1/3 or 4	39	Help guide FCM through hatch opening.
1/3 or 4	40	Perform **Seat Removal Procedures** on FCMs in seats 1 and 2, transfer to seat 4, apply leg strap and attach extraction straps/ropes.
2/5	41	Hoist FCMs through hatch and lower on right side of OV.
1/3 or 4	42	Help guide FCMs through hatch opening.
ALL	43	Once all FCMs have been extricated, exit the OV, evacuate the 1,250-foot hazard zone and report to DECON for evaluation.

ORBITER CARRIER (OC) INFORMATION

747-200B AIRFRAME

NOTE:

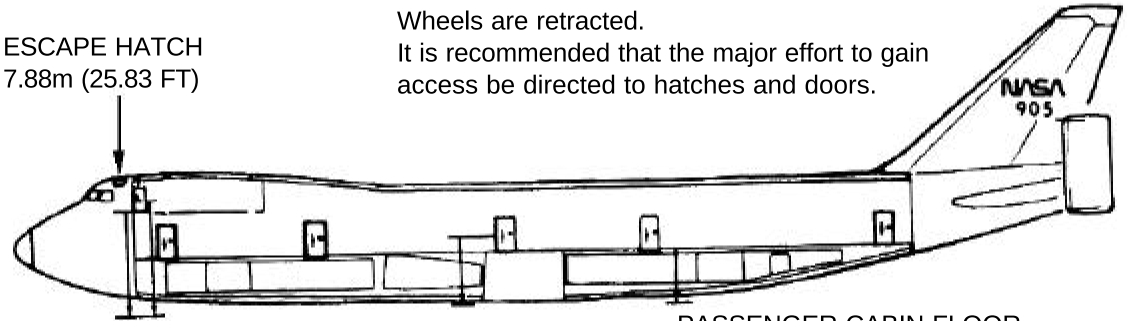
- All passengers seating and galley provisions removed aft of no. 1 doors
- Added bulkheads
- Modified adjacent frames
- Increased skin gage
- Revised tip ribs
- Added tip fin attach fingers
- Wheels equipped with fusible plugs
- Added skin doublers

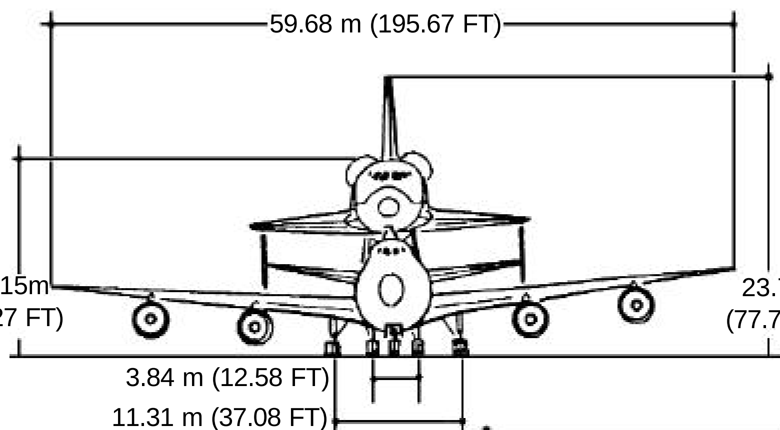


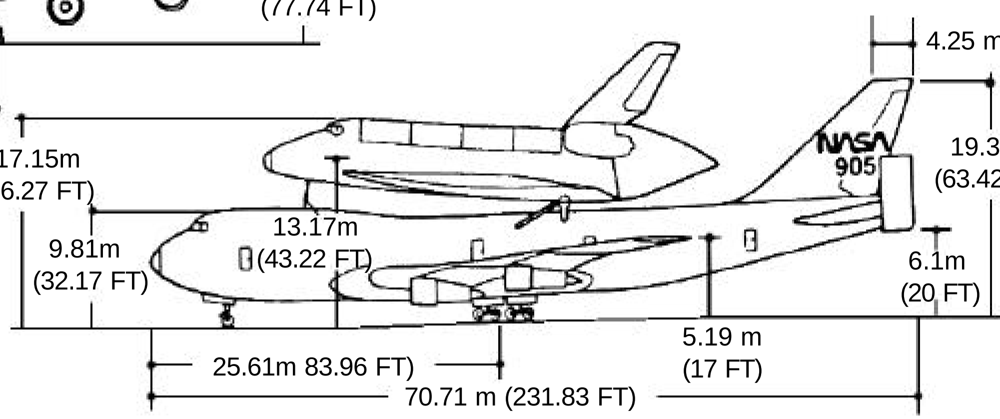
ORBITER CARRIER DIMENSIONS

WEIGHTS (MATED)
MAXIMUM TAXI GROSS WEIGHT: 323,410 kg (713,000 LB)
DESIGN LANDING WEIGHT: 272,154 kg (600.000 LB)

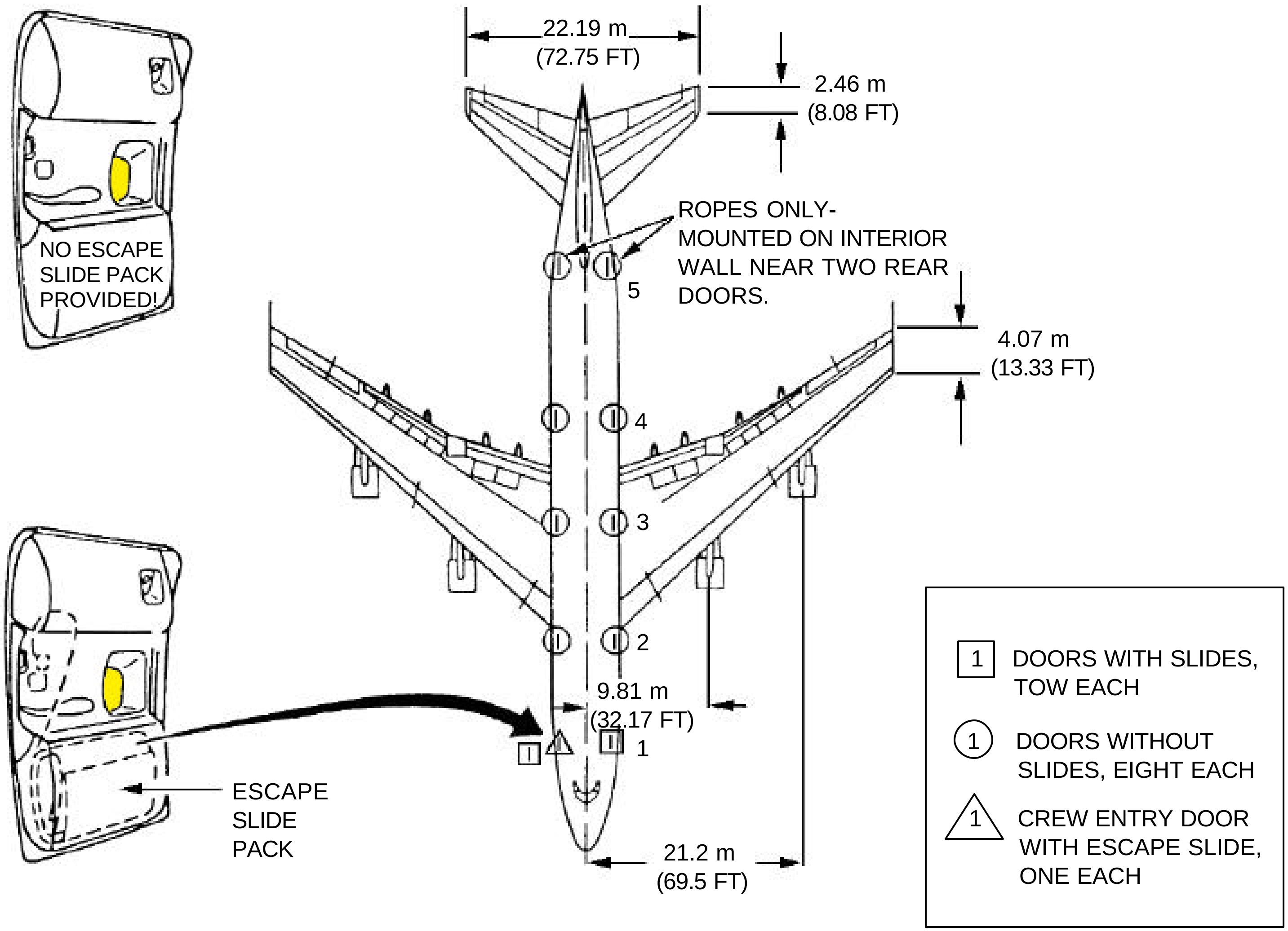
NOTE:
Wheels are retracted.
It is recommended that the major effort to gain access be directed to hatches and doors.







ORBITER CARRIER DIMENSIONS-Continued

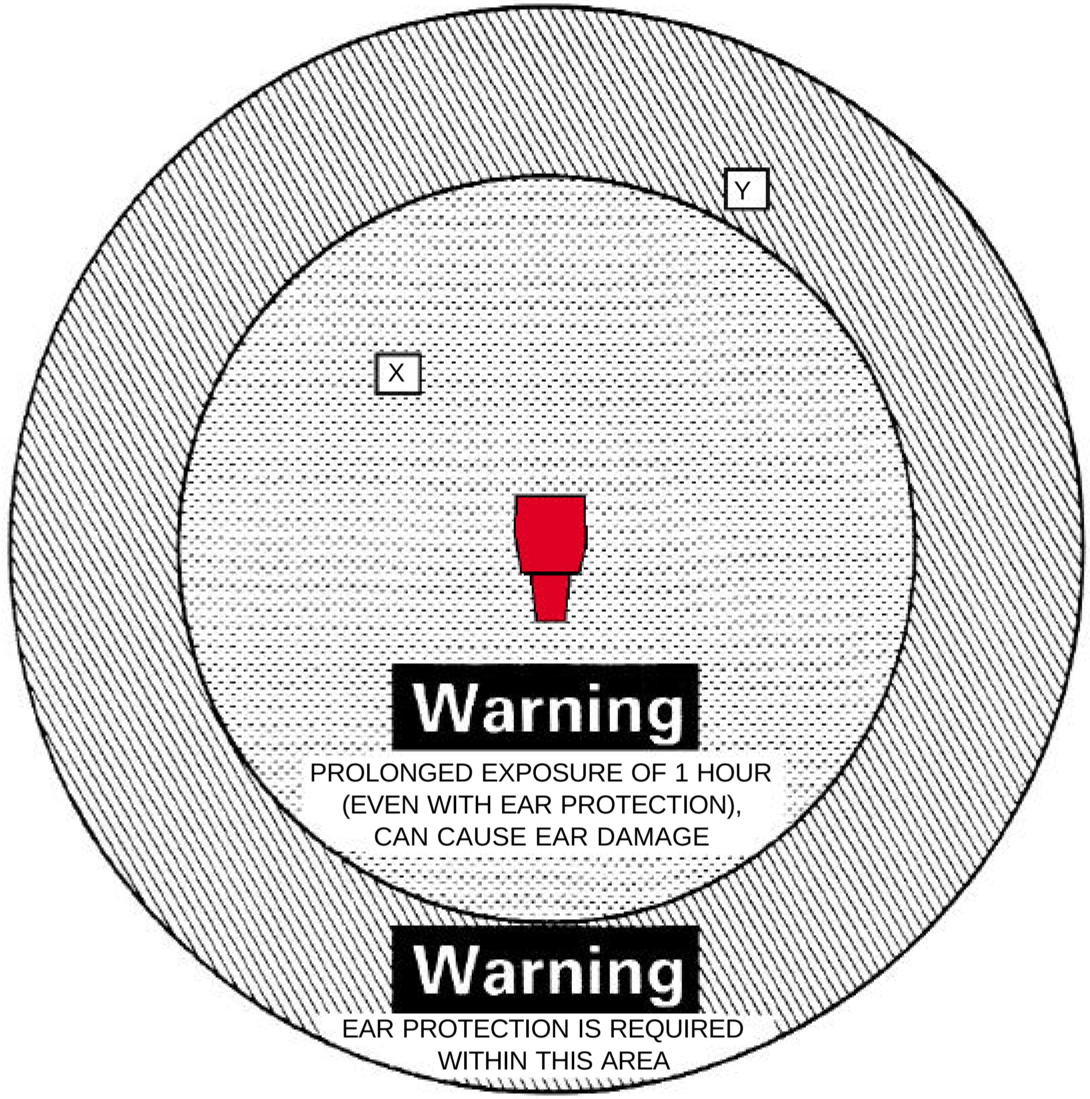


ORBITER CARRIER HAZARDS

Jet Engine Noise Hazard Areas

NOTE:
Shuttle carrier and Orbiter are mated.

SCA POWER SETTING	RADIUS X m (FT)	RADIUS Y m (FT)
GROUND IDLE	22.88 (75)	30.5 (100)
BREAKAWAY THRUST (N_1 -1800 RPM)	30.5 (100)	45.75 (150)
TAKEOFF THRUST	30.5 (100)	61 (200)



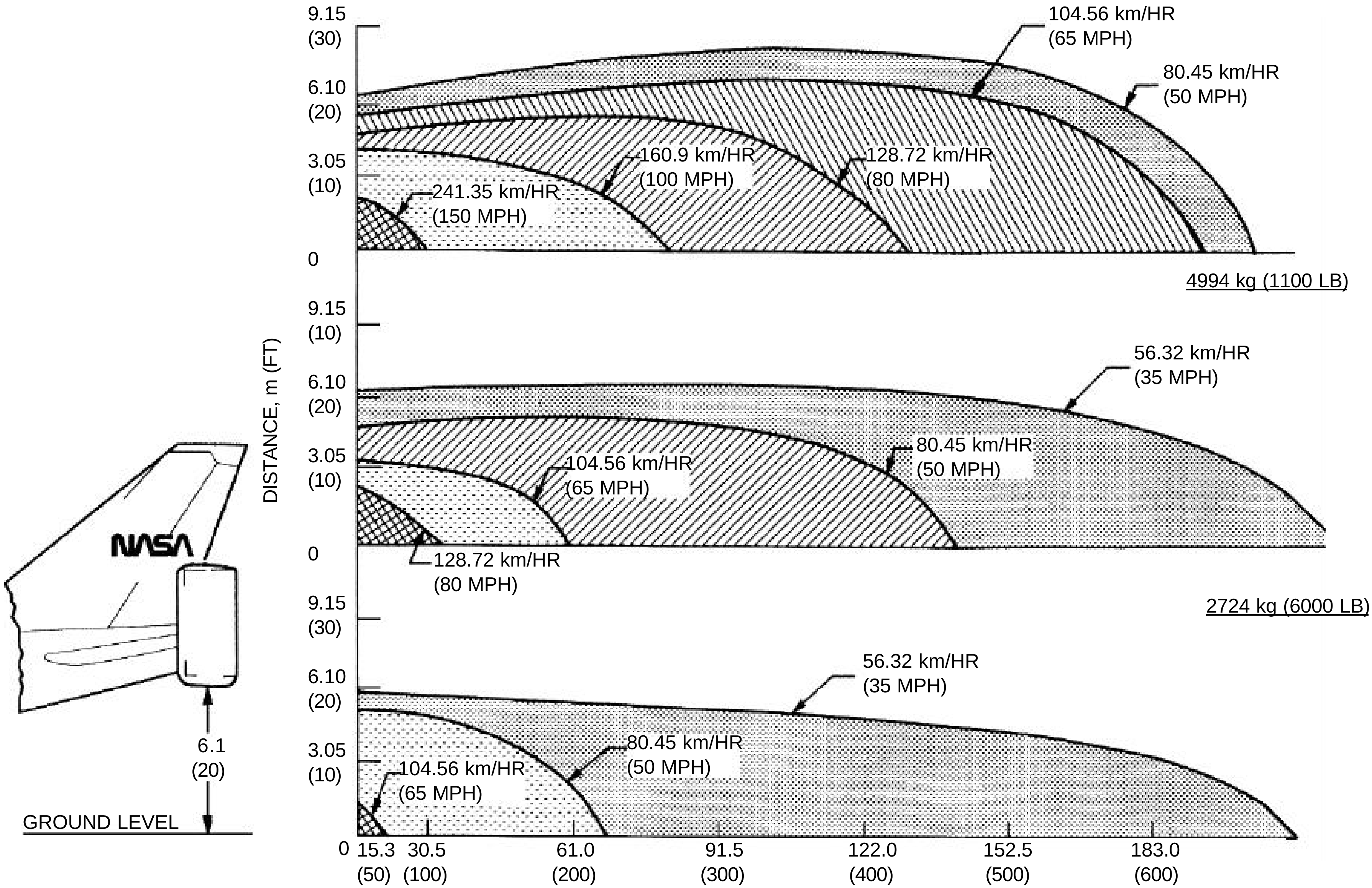
ORBITER CARRIER HAZARDS-Continued

Jet Engine Exhaust Wake/Velocity

Distance: meters (FEET)
Weight: kilograms (POUNDS (LB))
Speed: kilometers/Hour (Miles Per Hour)

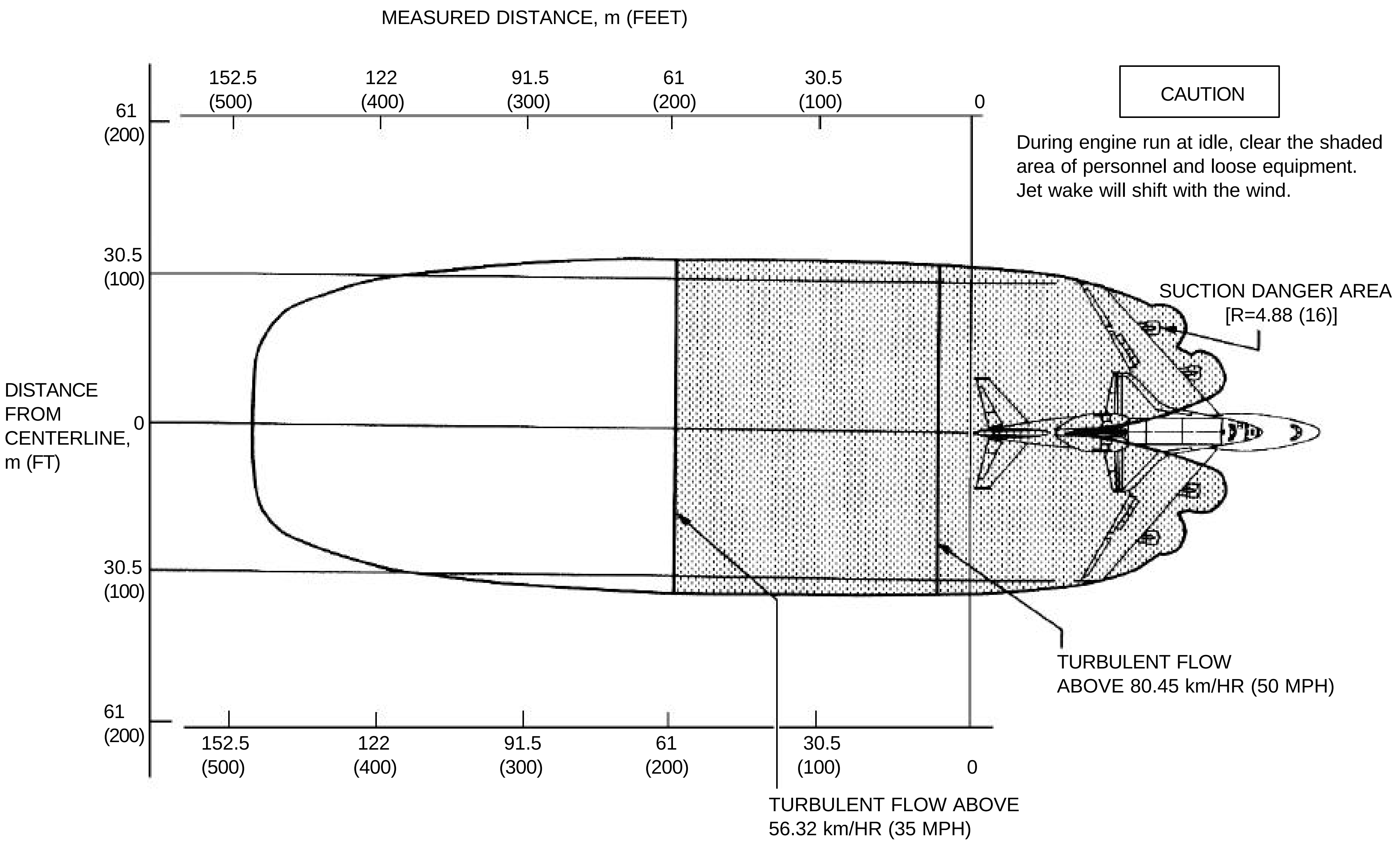
THRUST

TAKEOFF



ORBITER CARRIER HAZARDS-Continued

Jet Engine Exhaust Velocity - Idle Thrust

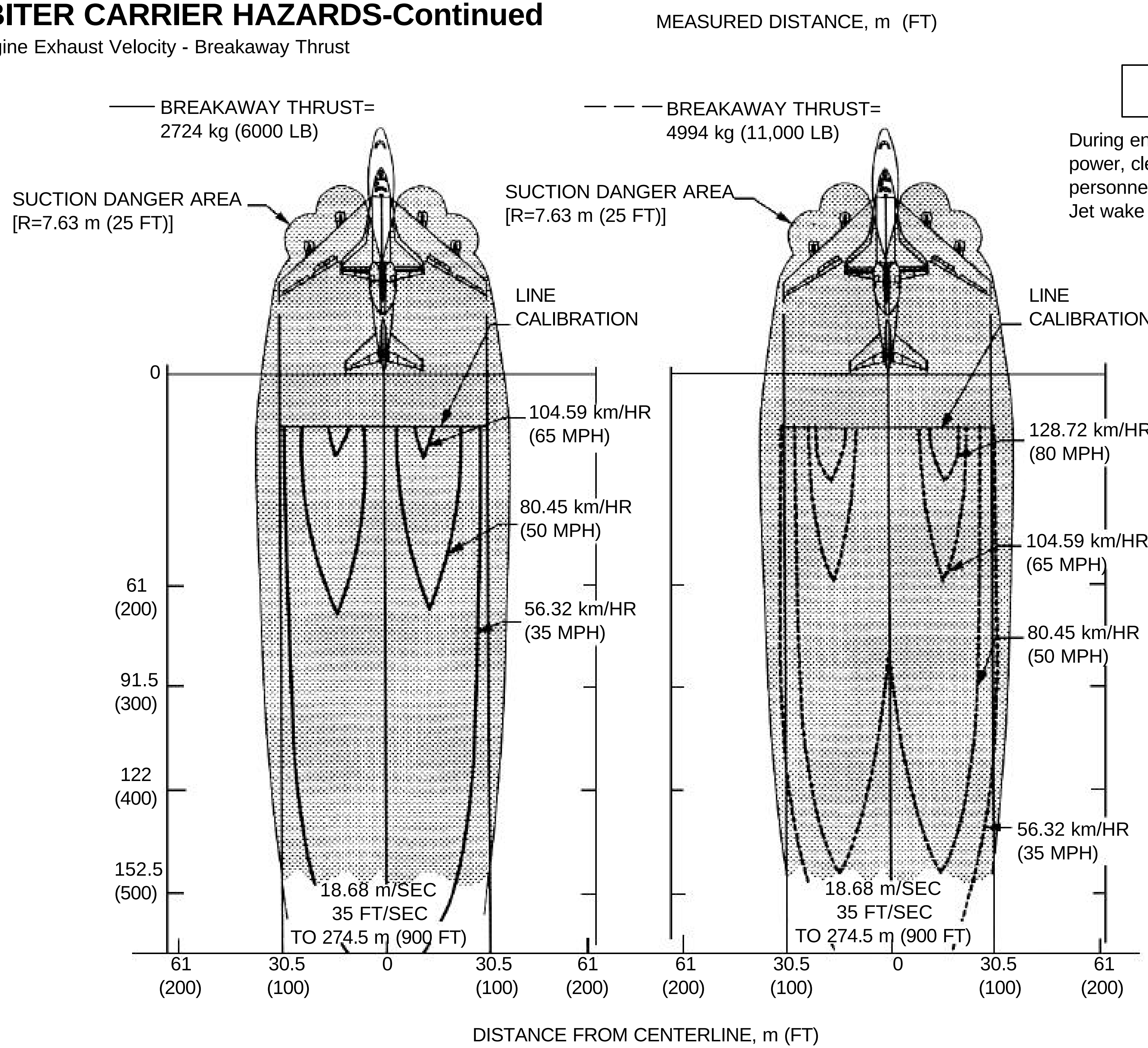


ORBITER CARRIER HAZARDS-Continued

Jet Engine Exhaust Velocity - Breakaway Thrust

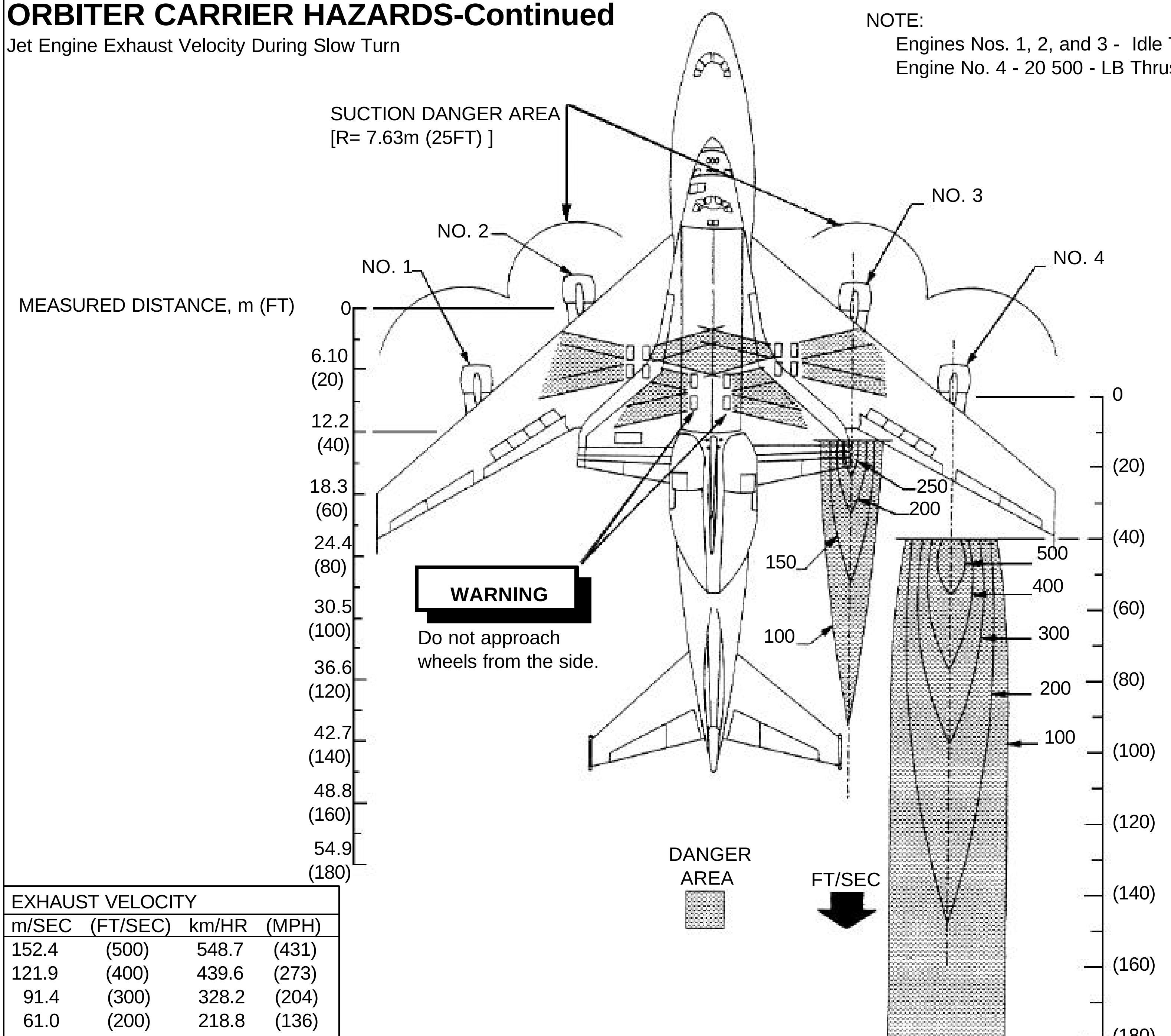
CAUTION

During engine run at breakaway power, clear the shaded area of personnel and loose equipment. Jet wake will shift with the wind.



ORBITER CARRIER HAZARDS-Continued

Jet Engine Exhaust Velocity During Slow Turn



EXHAUST VELOCITY			
m/SEC	(FT/SEC)	km/HR	(MPH)
152.4	(500)	548.7	(431)
121.9	(400)	439.6	(273)
91.4	(300)	328.2	(204)
61.0	(200)	218.8	(136)
30.5	(100)	109.4	(68)

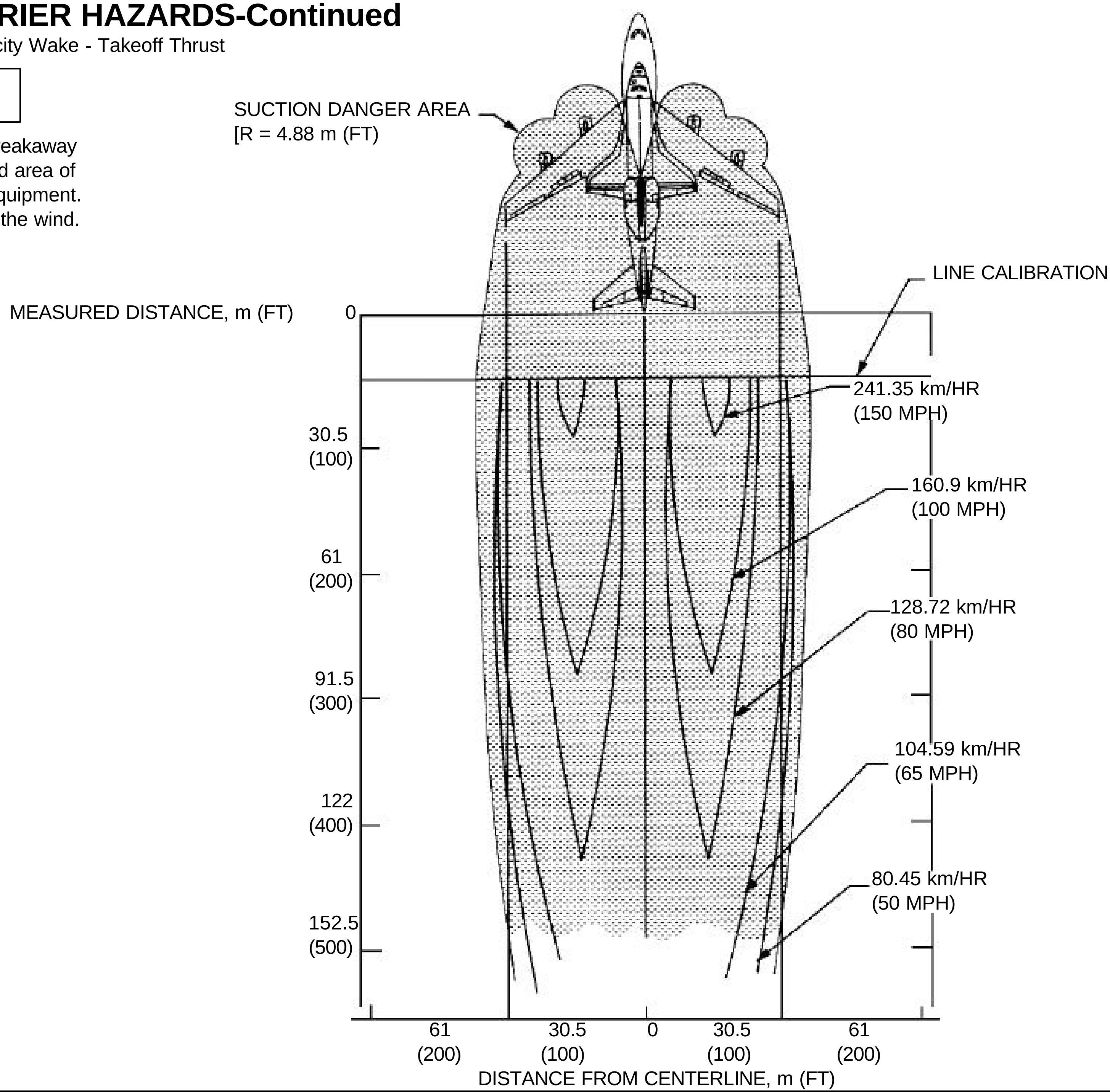
FT/SEC = MPH x 1.467

ORBITER CARRIER HAZARDS-Continued

Jet Engine Exhaust Velocity Wake - Takeoff Thrust

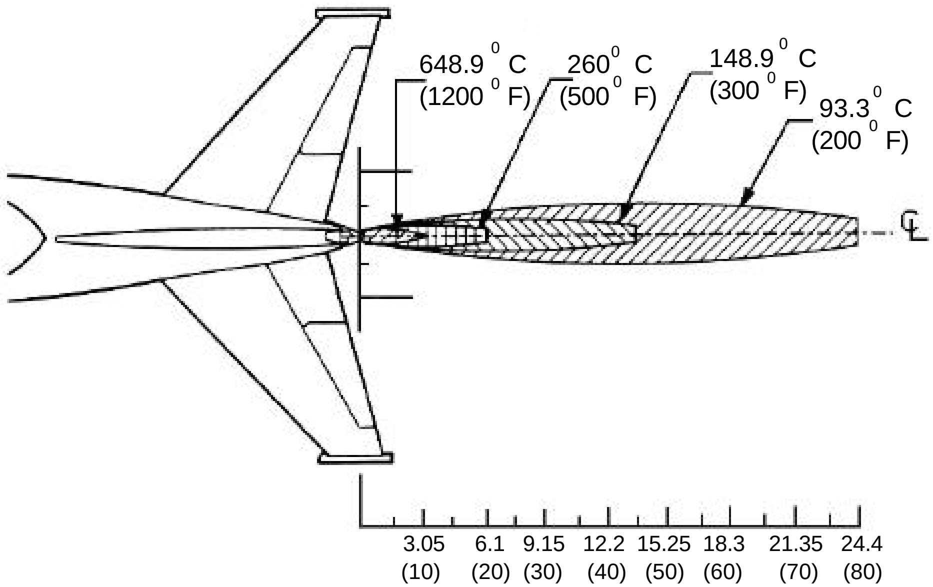
CAUTION

During engine run at breakaway power, clear the shaded area of personnel and loose equipment. Jet wake will shift with the wind.

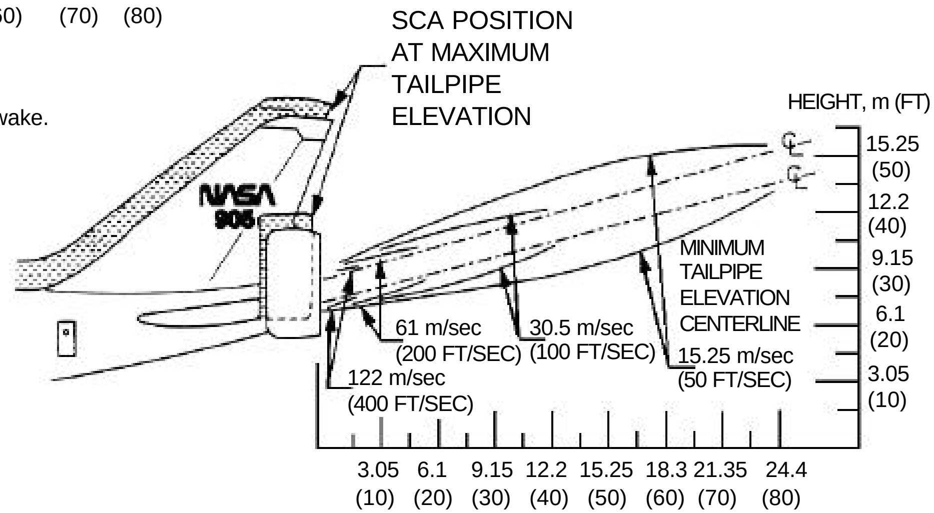


ORBITER CARRIER HAZARDS-Continued

Orbiter Carrier APU Exhaust Velocity/Wake



(h) SCA APU exhaust temperature/wake.



SPECIAL TOOLS/EQUIPMENT
Power Rescue Saw
SPAAT/Fire Drill II
35 Foot Ladder

NOTE:
Besides the flight crew on the flightdeck, approximately nine (9) personnel are located in the forward main deck.

AIRCRAFT ENTRY

1. NORMAL/EMERGENCY ENTRY

a. Pull entry door handles from recess position and rotate 180 degress clockwise for entry doors located on far left side and counter-clockwise for entry doors on right side.

NOTE:
All eleven entry doors open outward except crew entry door which slides aft.

b. Press release button on crew escape hatch, located top forward center of crew compartment,and rotate escape hatch 180 degrees clockwise. Push escape handle inward.

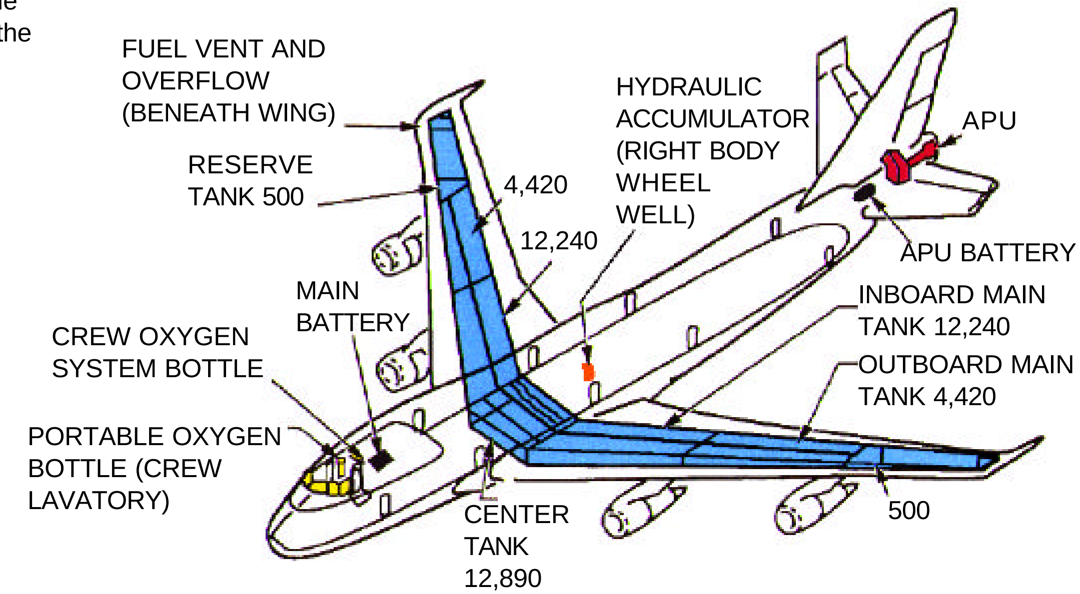
c. Pull handle, located on crew door, and rotate 180 degrees counterclockwise. Push door inward until slide tracks are engaged, then slide door aft.

NOTE:
Only the two forward entry doors contain emergency escape chutes and are deployed only from inside the aircraft. Opening either door from the outside disengages the emergency evacuation system and the escape slide will not deploy. The other doors are blocked.

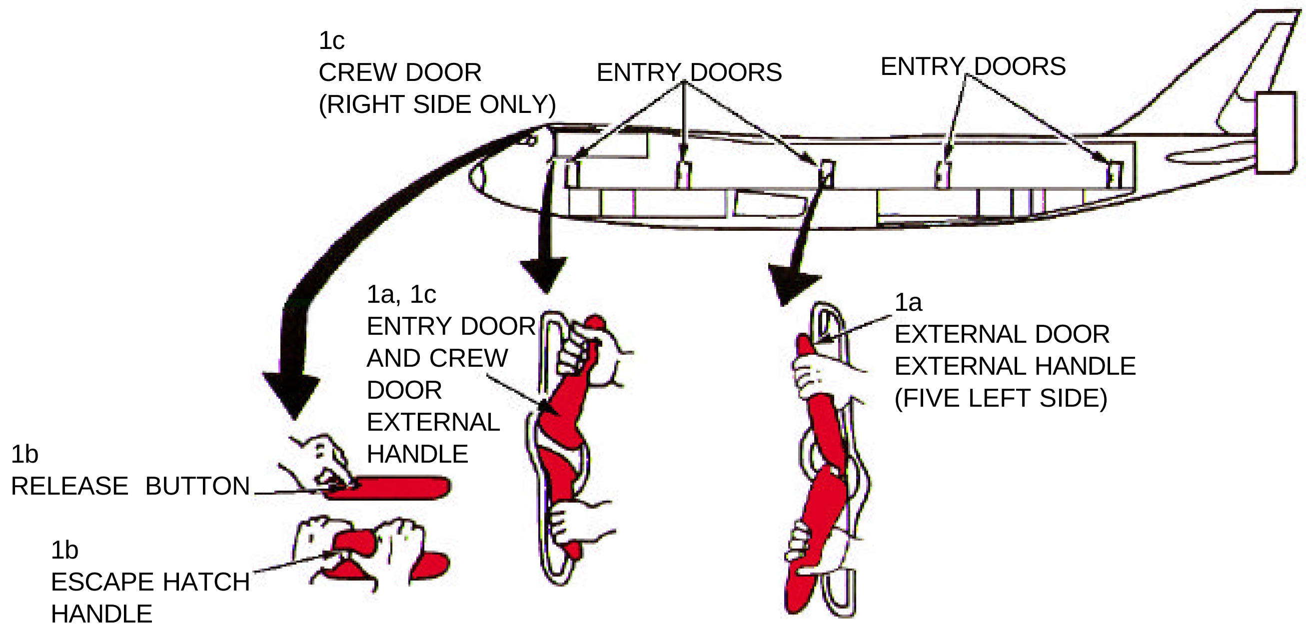
2. CUT-IN

a. Cut areas along the window lines as a last resort.

FUEL TANK QUANTITES STATED IN GALLONS



NOTE:
2 inch band of contrasting color around all doors and hatches that are operable from outside of the aircraft.



ENGINE SHUTDOWN AND AIRCREW EXTRACTION

1. EMERGENCY SHUTDOWN
a. Pull emergency fire T-handle, located on pilot's overhead panel.
b. Place battery switch, located on flight engineer's center panel, to OFF position.
c. Pull APU fire shutdown T-handle, located on flight engineer's upper left panel.

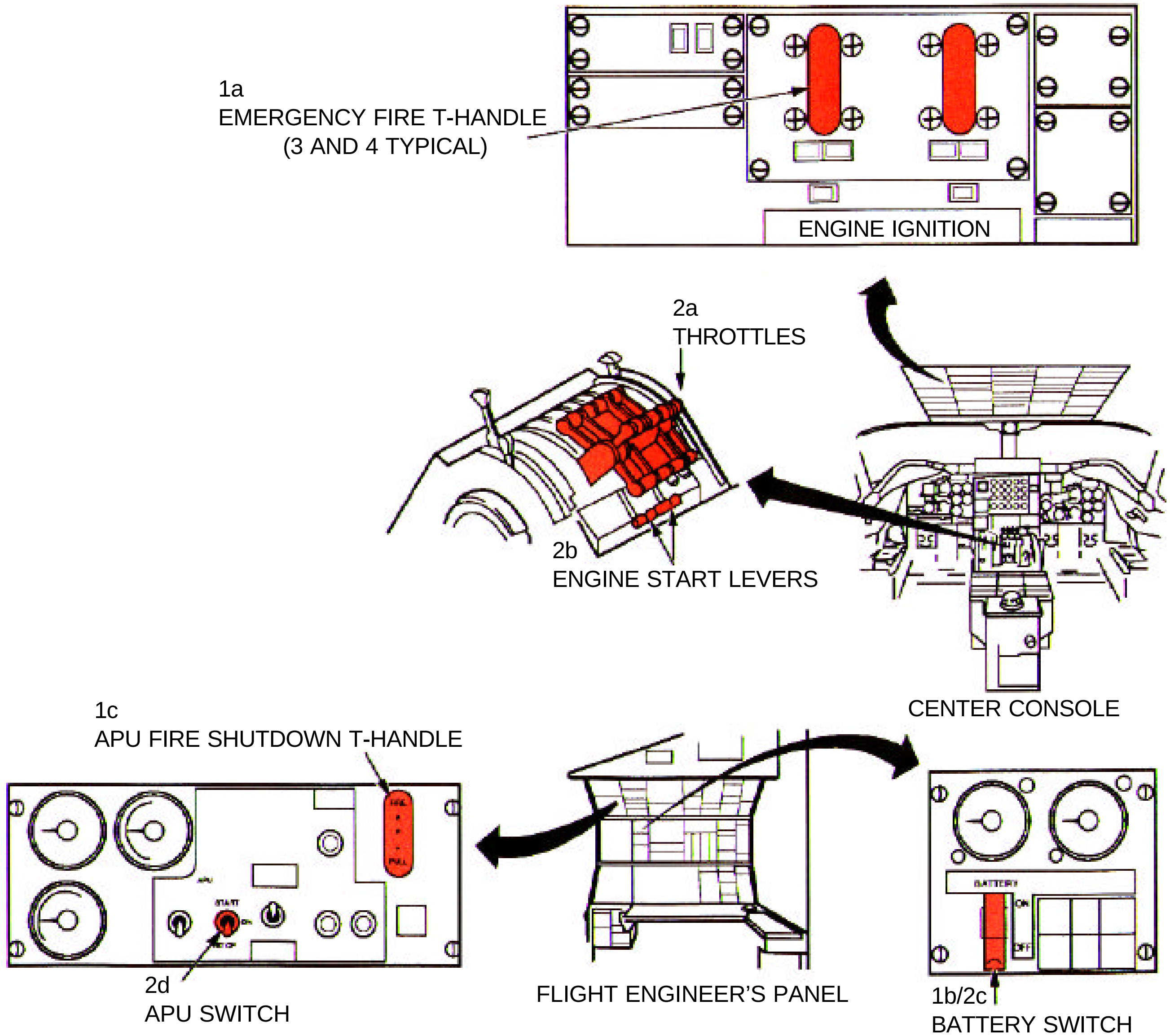
2. NORMAL SHUTDOWN
a. Retard throttles, located on pilot's center console, to IDLE position.
b. Place engine start levers, located on pilot's center console, to CUTOFF position.

NOTE:
If engines fail to shutdown, pull emergency fire T-handle, located on pilot's overhead panel.

c. Place battery switch, located on flight engineer's center panel, to OFF position.
d. Place APU switch, located on flight engineer's upper left panel, to STOP position.

NOTE:
If APU fails to shutdown, pull emergency T-handle located on flight engineer's overhead panel.

3. AIRCREW EXTRACTION
a. Unlatch lap belts and remove shoulder harness from crewmembers.
b. Depress control handles and rotate flight engineer's seat from left to right.
c. Passenger seats are equipped with lap belts only.



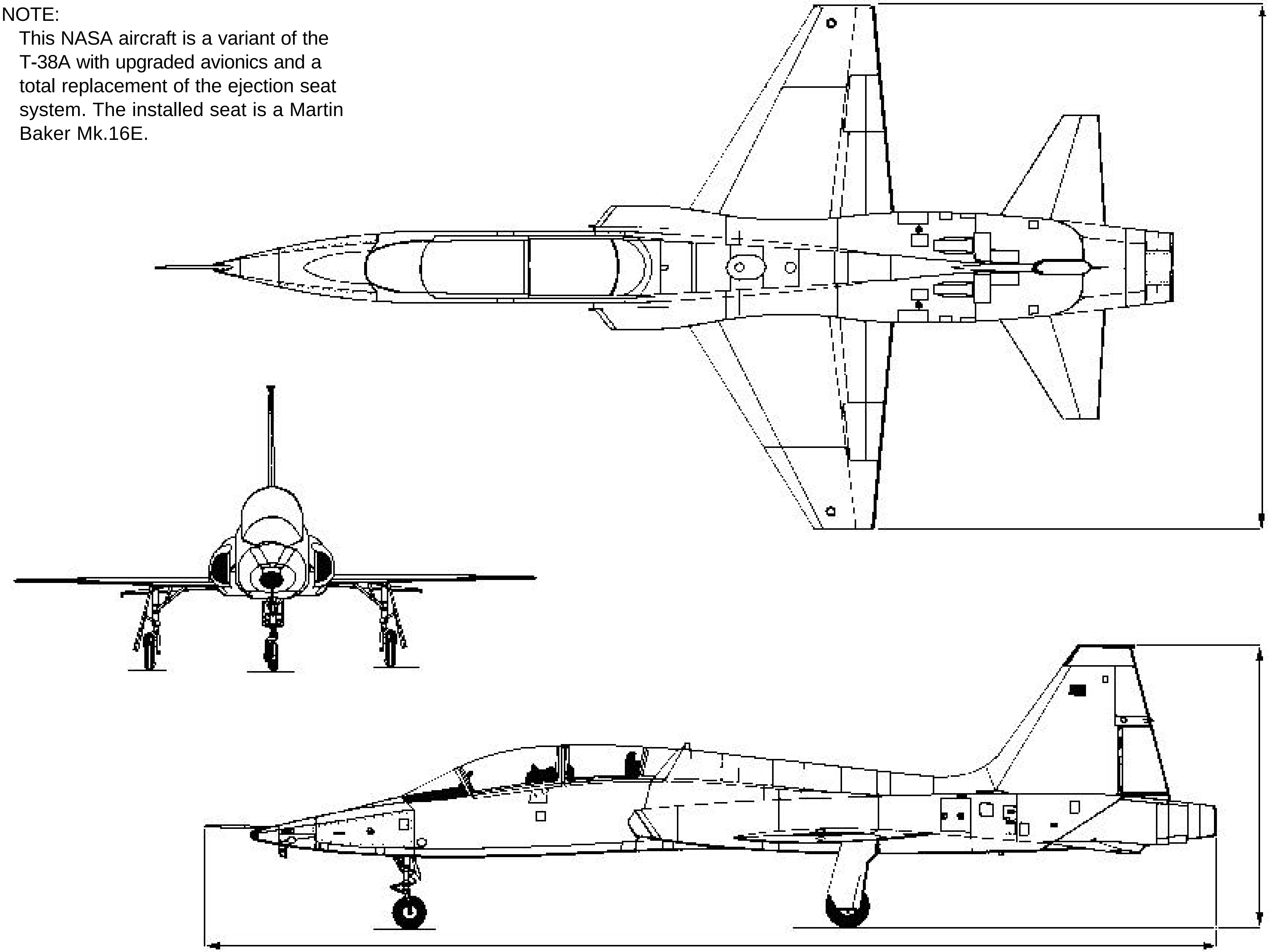
AIRCRAFT PAINT SCHEME

AIRCRAFT DIMENSIONS

T-38N

NOTE:

This NASA aircraft is a variant of the T-38A with upgraded avionics and a total replacement of the ejection seat system. The installed seat is a Martin Baker Mk.16E.



AIRCRAFT SKIN PENETRATION POINTS, MATERIALS, FIRE ACCESS DOOR AND HAZARD AREAS

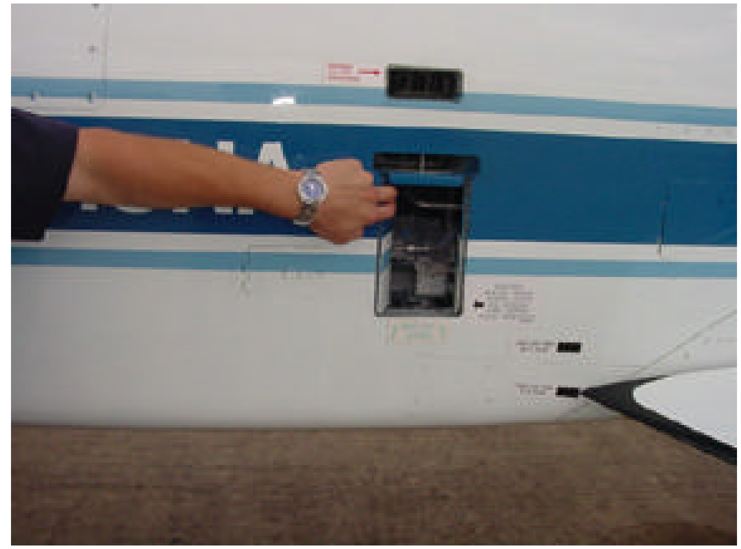
T-38N

WARNING

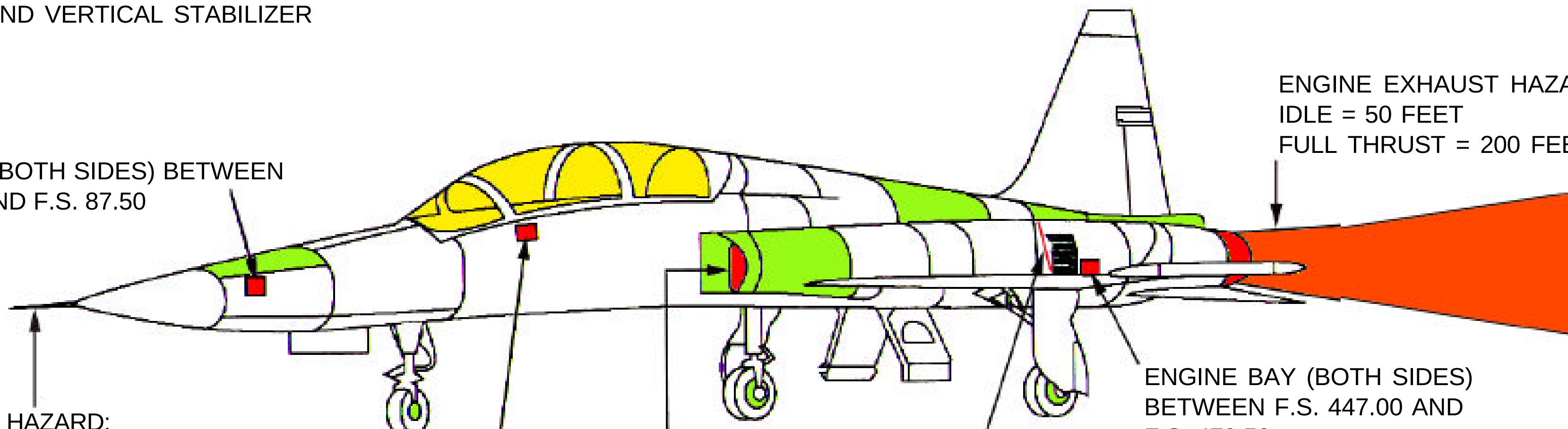
Magnezium fires should be fought with dry chemical and not water. Water usage will spread fire.

PLEXIGLASS
- WINDSHIELD AND CANOPIES

MAGNEZIUM
- WHEELS
- AFT OF NOSE CONE
- COCKPIT
- INTAKE COVERINGS
- CENTER OF FUSLAGE
- FORWARD ENGINE AREA
- AREA AROUND VERTICAL STABILIZER



FIRE ACCESS DOOR



ENGINE EXHAUST HAZARDS:
IDLE = 50 FEET
FULL THRUST = 200 FEET

GUN BAYS (BOTH SIDES) BETWEEN F.S. 47.50 AND F.S. 87.50

ENGINE BAY (BOTH SIDES) BETWEEN F.S. 447.00 AND F.S. 479.50

PITOT TUBE HAZARD: UNPAINTED AREA COULD BE HOT AND CAN PUNCTURE

COCKPIT (BOTH SIDES) BETWEEN F.S. 220.76 AND F.S. 235.50. ABOVE H.L.R. AND BELOW LONGERON

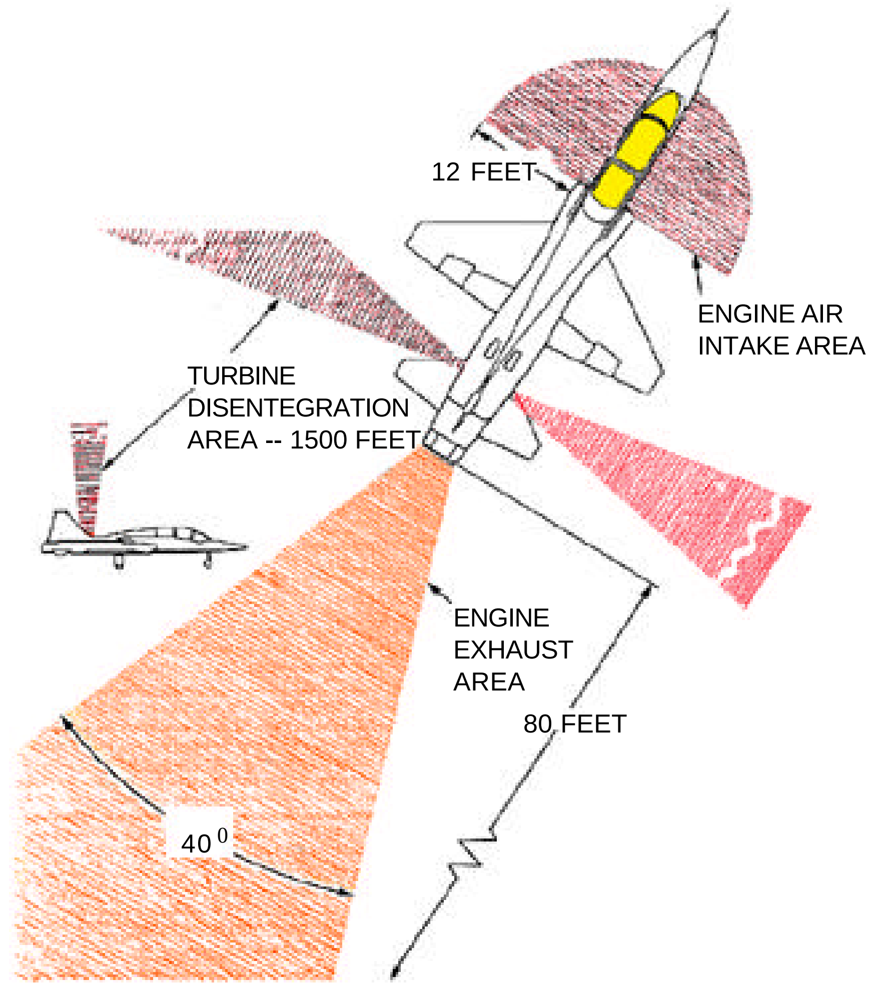
ENGINE INTAKE HAZARD: 25 FEET

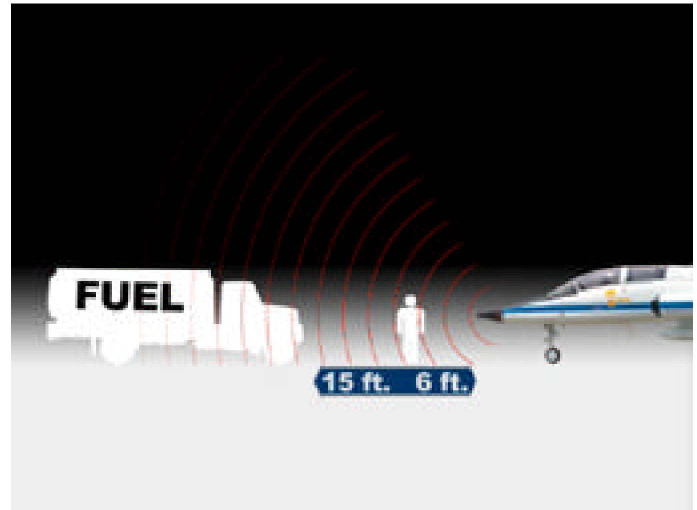
TURBINE HAZARD AREA EXTENDS TO 1500 FEET

AIRCRAFT HAZARD AREAS

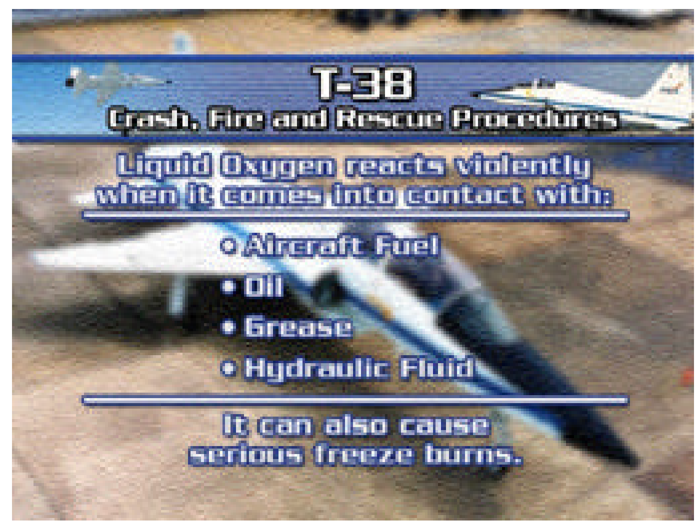
T-38N

	DISTANCE IN FEET	EXHAUST VELOCITY	EXHAUST TEMPERATURE
MAXIMUM THRUST	80	NEGLIGIBLE	150°F (66°C)
	60	34 MPH	250°F (121°C)
	30	260 MPH	600°F (316°C)
	20	500 MPH	900°F (482°C)
TAXI THRUST (IDLE)	35	NEGLIGIBLE	150°F (66°C)
	30	20 MPH	175°F (80°C)
	20	85 MPH	275°F (135°C)





FUEL TRUCK DISTANCE AND RADAR EMISSION AREA



LIQUID OXYGEN HAZARDS

LANDING GEAR PINS AND FUEL SERVICING PORT

NOSE LANDING GEAR PIN LOCATION

MAIN LANDING GEAR PIN LOCATION

FUEL SERVICING PORT

FUEL SERVICING PORT

T-38N

SPECIAL TOOLS/EQUIPMENT
Power Rescue Saw
Safety Pins
Fire Drill II

AIRCRAFT ENTRY

1. NORMAL ENTRY
a. Push latches to open door, located on left side of fuselage.

CAUTION

Opening canopy under windy conditions could cause inadvertant canopy separation from aircraft.

b. Pull handle(s) out until engaged and rotate clockwise to unlock and raise canopy, give canopy assistance while rotating handle.

NOTE:
Canopies are secure when raised to full open position.

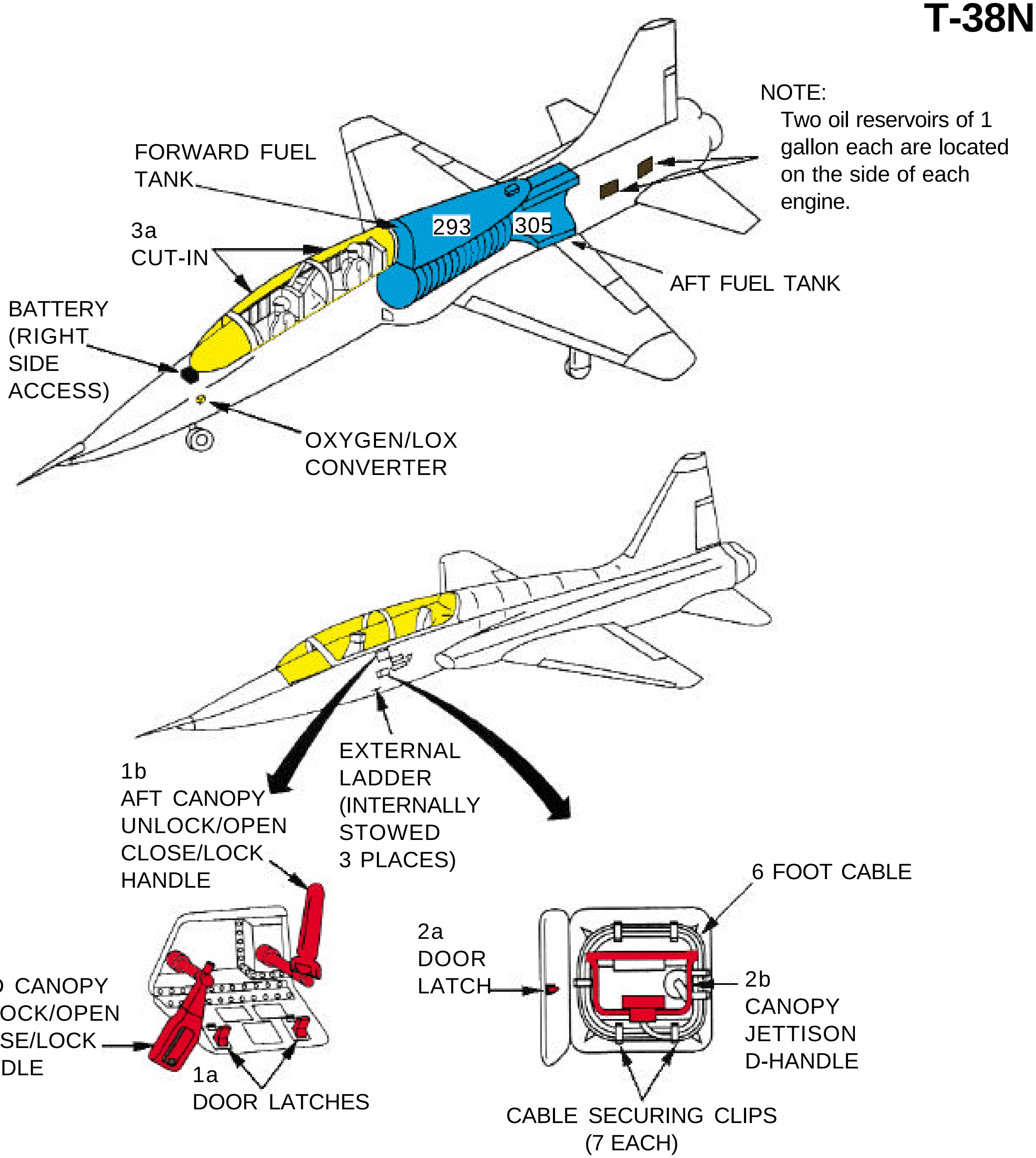
2. EMERGENCY ENTRY

WARNING

Forward canopy fracturing system only operates during forward seat ejection. Insure both canopies are closed and locked before jettisoning or injury to personnel can occur. Insure no fuel is in vicinity.

a. Push latch on canopy jettison access door to open, located on left and right side of forward fuselage.
b. Pull canopy jettison D-handle, approximately 6 feet to jettison both canopies.

3. CUT-IN
a. Cut canopy along canopy frame on all 4 sides. When using an axe, a CO2 treatment can make the cut-in easier by making the canopy brittle.



AIRCRAFT ENTRY AND CANOPY JETTISON CONTROLS

T-38N

1a, 1b
CANOPY ENTRY CONTROLS

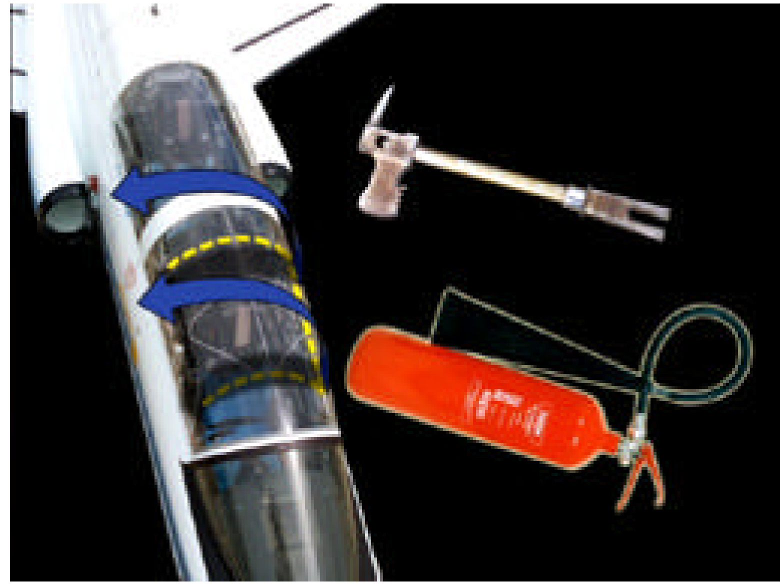
2a
EXTERNAL CANOPY JETTISON DOOR (BOTH SIDES)

2b
CANOPY JETTISON T-HANDLE

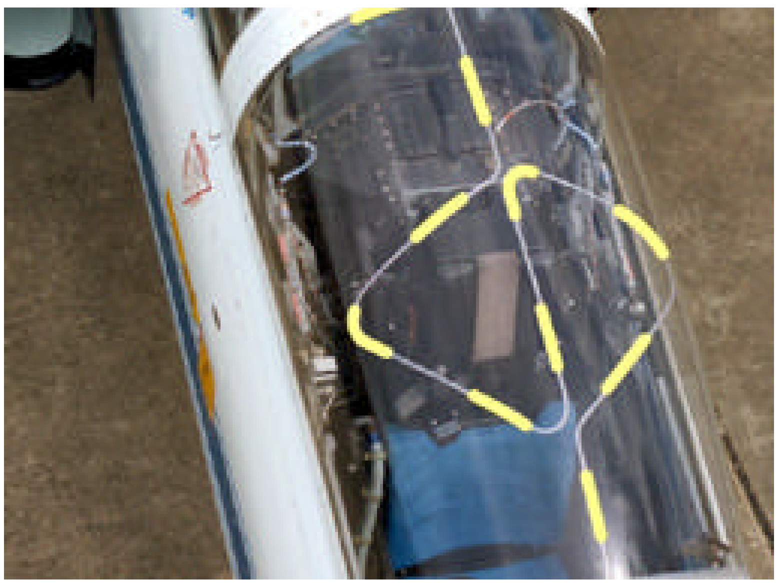
2b
CANOPY JETTISON T-HANDLE OPERATION

CANOPY CUT-IN

3a
CANOPY CUT-IN WITH POWER SAW



3a
CANOPY CUT-IN DEVICES



FORWARD CANOPY FRACTURING SYSTEM (HI-LITED)
(CUT-IN IS SAFE WITH DETONATING CORD)

AFT CANOPY (NO FRACTURING SYSTEM)

ENGINE SHUTDOWN

1. ENGINE SHUTDOWN (FWD COCKPIT ONLY)

NOTE:

Shutdown is accomplished only from the forward cockpit. This aircraft has a throttle gate installed on the aft portion of the throttle console in the forward cockpit. The throttle gate must be disengaged prior to proceeding.

a. Disengage throttle gate by pushing the red release arm inboard (toward ejection seat).

b. Raise finger lifts and retard throttles, located on left console panel, to full aft OFF position.

c. Push red guards down and place the two fuel shutoff switches, located on the left forward vertical control panel, to the CLOSED (off) position. Wait 10 seconds for fuel valve to operate.

d. Place battery switch, located on right vertical control panel, down to OFF position.

e. If weather radar switch is ON, located under the fuel shutoff switches, place switch in OFF position.

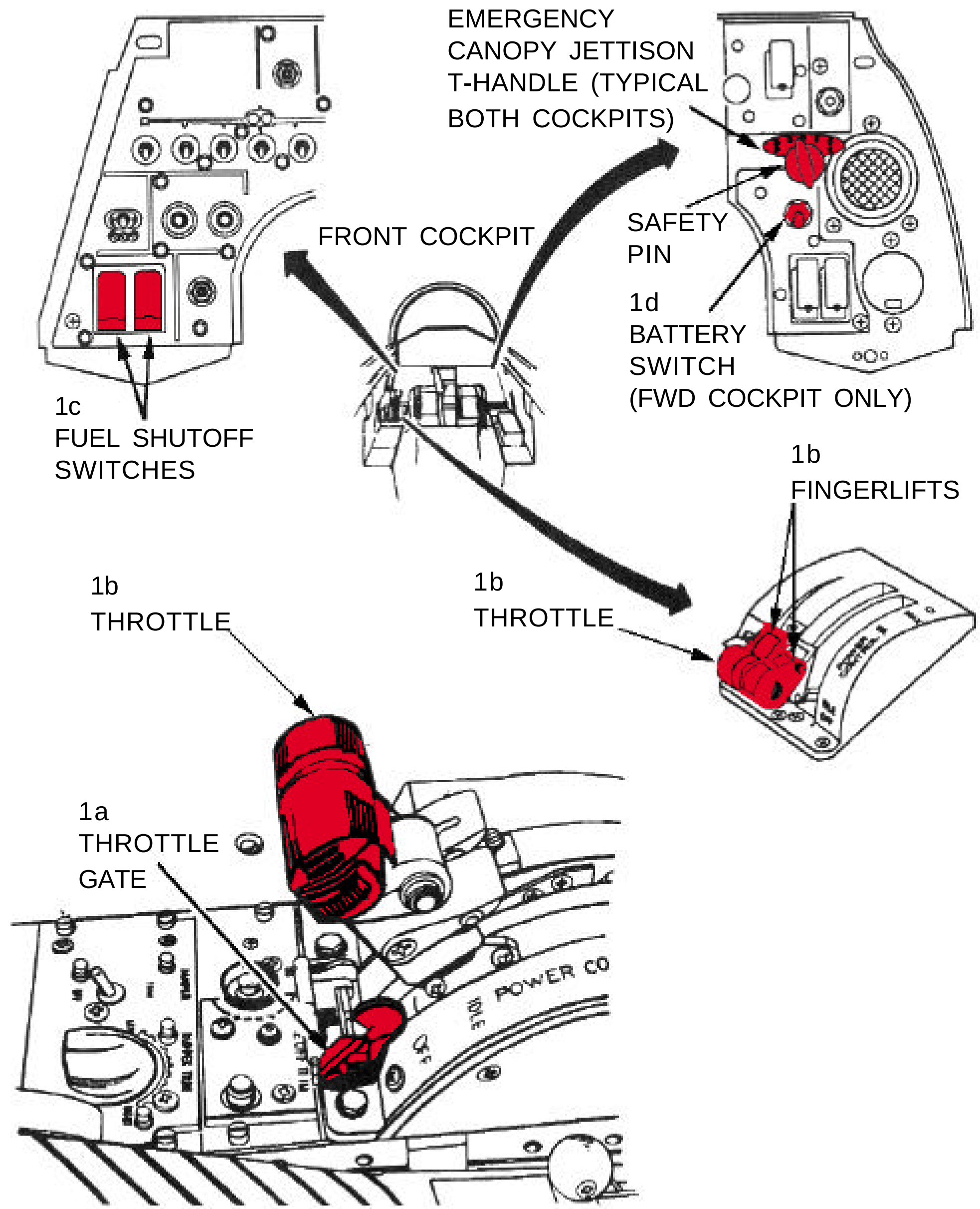
NOTE:

· Engines can be throttled to idle from rear cockpit.

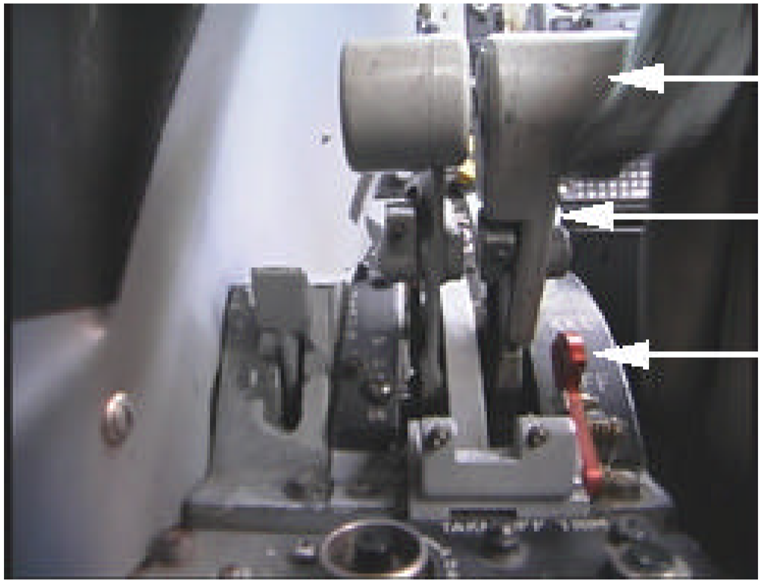
· If engines fail to shutdown, turn battery switch ON and place fuel shutoff switches, located on left vertical panel, to CLOSED position. Place battery switch to OFF position.

WARNING

If emergency canopy jettisonT-handle has been actuated, but canopy has not jettisoned, cut canopy hose at top aft of seat structure to prevent inadvertant canopy jettison.



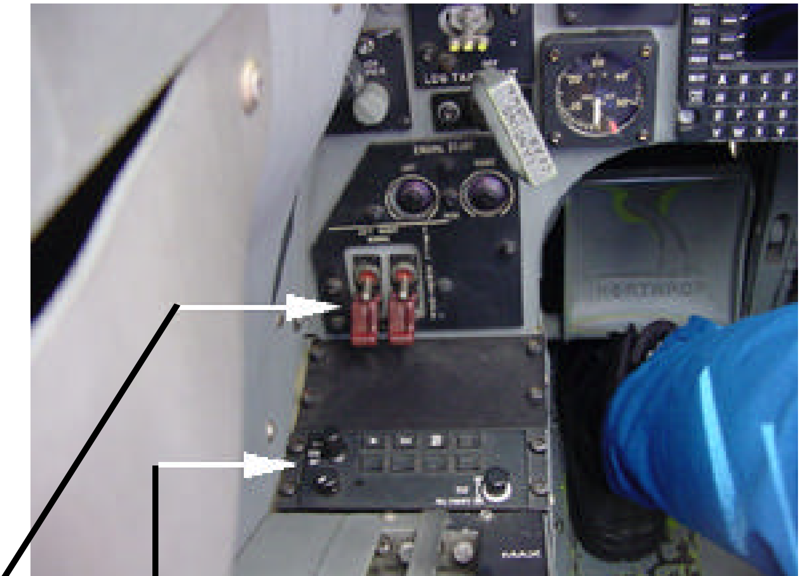
ENGINE SHUTDOWN COMPONENTS



1b
ENGINE
THROTTLES

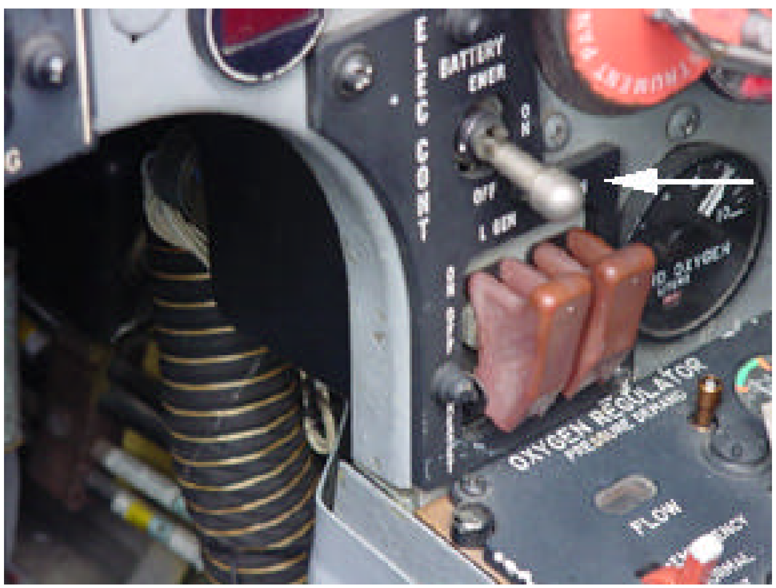
1b
FINGER
LIFTS

1a
THROTTLE
GATE

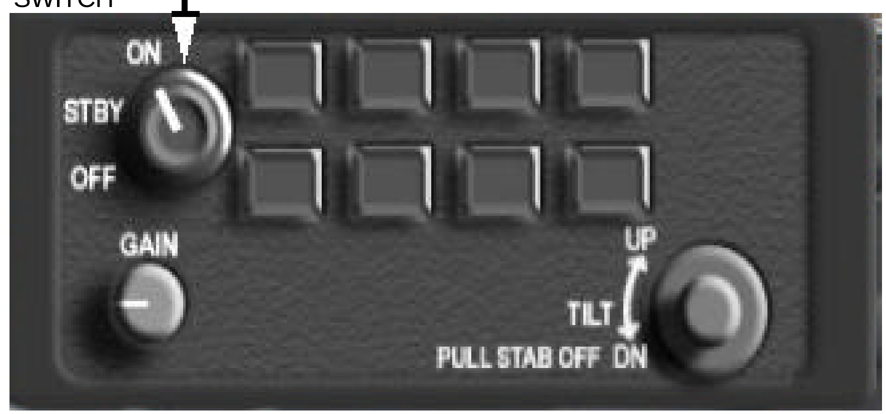


1c
FUEL SHUTOFF
SWITCHES

1e
WEATHER RADAR
SWITCH



1d
BATTERY
SWITCH



SAFETYING EJECTION SYSTEM AND AIRCREW EXTRACTION

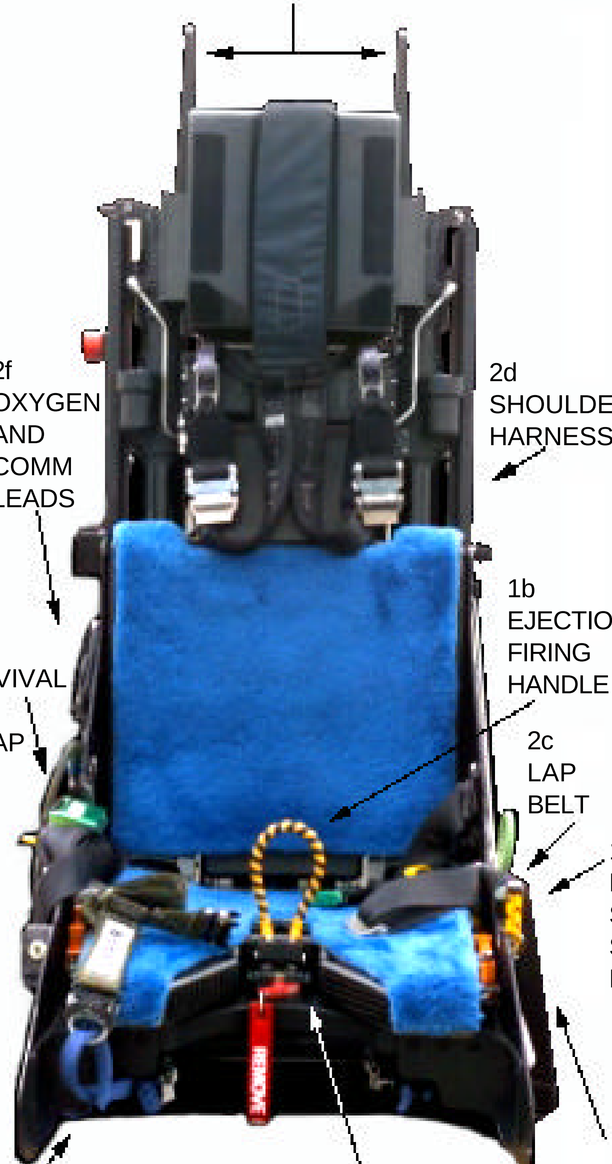
1. NORMAL SAFETYING

NOTE:
Flight status safety pins are normally stored in the right forward console.

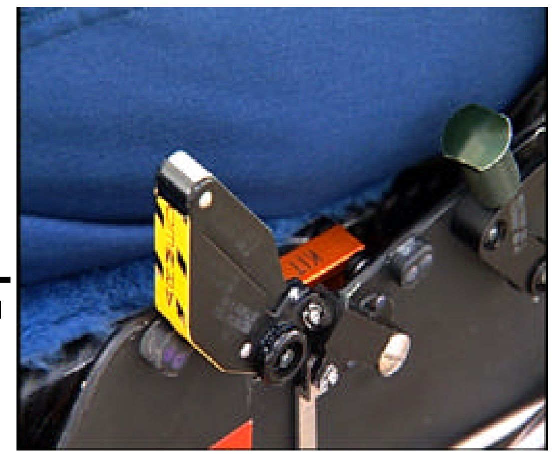
a. Rotate ejection seat safing lever forward, located on left side of seat, to the SAFE position.
b. Insert seat safety pin in firing handle, located forward center of seat.
c. Insert internal canopy jettison safety pin over canopy jettison handle located on forward right console.
d. Place the interseat sequencing handle, located at the left side console, in the SOLO mode.

2. AIRCREW EXTRACTION

a. Release tab on helmet to release oxygen mask allowing crewmember to breathe.
b. Pull leg line release lever, located on lower left side of seat to release leg restraints. Thigh and ankle garter buckles may have to be operated to prevent leg restraint entanglement during extraction process.
c. Unlatch the lap belt at the center release mechanism.
d. Unlatch each shoulder harness strap using release buckle.
e. Disconnect the survival kit on each side by depressing the button located in each buckle.
f. The oxygen hose and communication lead will automatically disconnect and fall away as the crewmember is extracted.

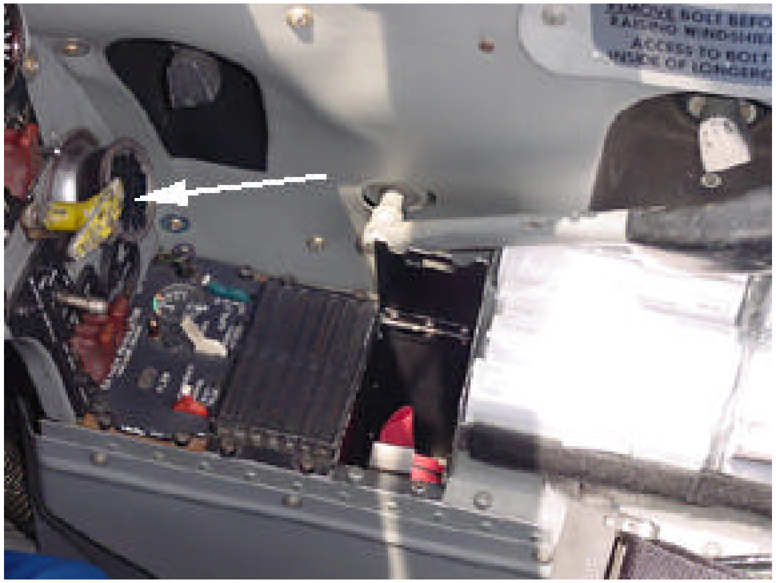


1b
EJECTION SEAT SAFING LEVER (ARMED)



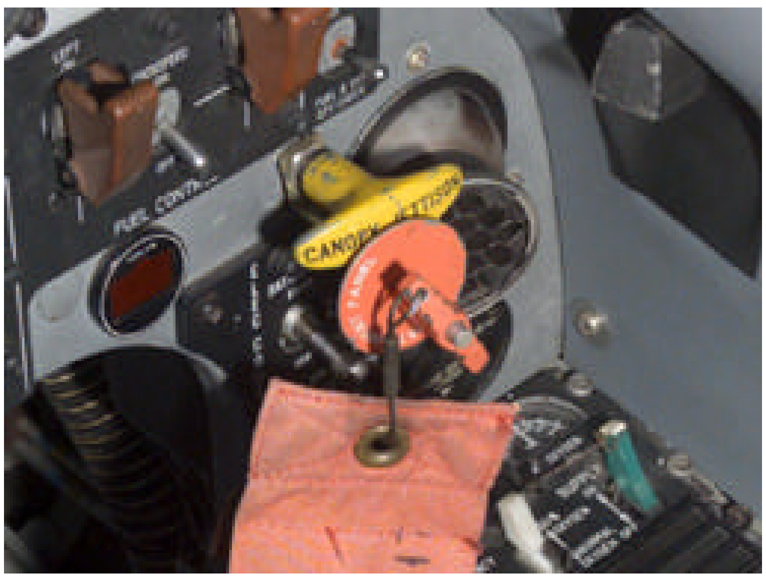
1b
EJECTION SEAT SAFING LEVER (SAFED)

CANOPY SAFETYING AND EJECT MODE SELECTOR

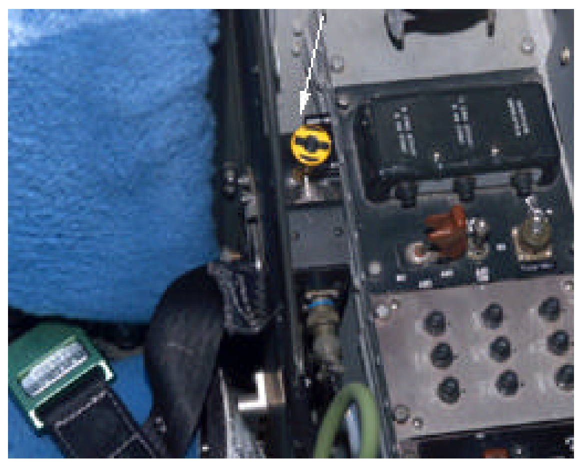


1c
INTERNAL CANOPY JETTISON T-HANDLE (ARMED)

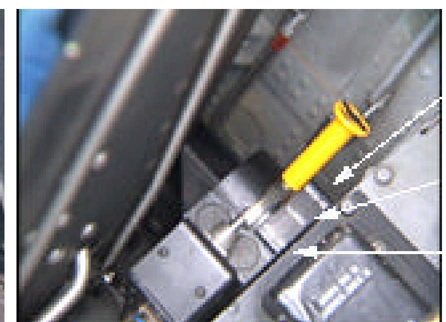
EJECTION SEAT AND CANOPY JETTISON SAFETY PINS



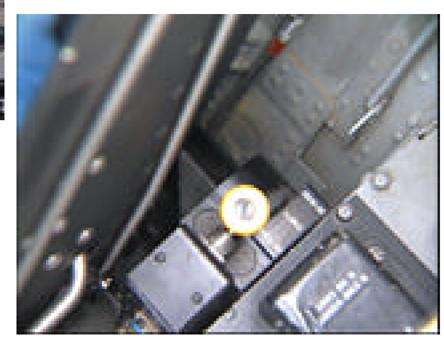
1c
INTERNAL CANOPY JETTISON T-HANDLE (SAFETIED)



1d
INTERSEAT SEQUENCING HANDLE
EJECTION MODES:
BOTH--BOTH SEATS EJECT
FWD--FWD SEAT EJECTS
SOLO--SEATS EJECT SEPARATELY



BOTH
FWD
SOLO

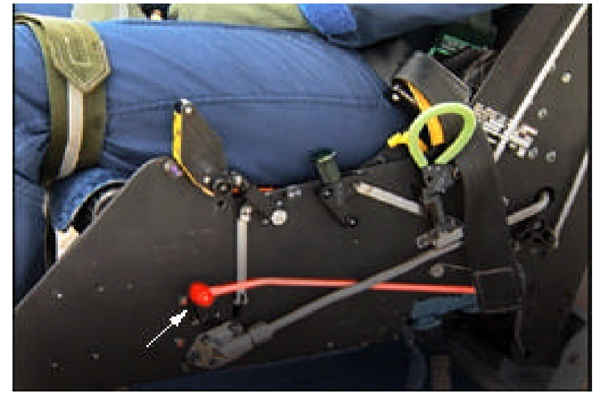


1d
SOLO
MODE

AIRCREW EXTRACTION

T-38N

2a
RELEASING OXYGEN MASK



2b
RELEASING LEG LINE RELEASE LEVER

2c
MANUALLY RELEASING LEG GARTER

2d
RELEASING LAP BELT

2e
RELEASING SHOULDER HARNESS

2f
RELEASING SURVIVAL KIT BELT

2g
OXYGEN AND COMM LEAD CONNECTIONS

OXYGEN SHUTDOWN AND BATTERY REMOVAL

1. OXYGEN SHUTDOWN

NOTE:
Use this procedure only if time permits.

a. After the crewmember(s) have been extracted, the oxygen system should be shutdown.

b. Place the red and white oxygen switches, located on the forward right console, to the EMERGENCY position.

1b
OXYGEN CONTROL PANEL

2. BATTERY REMOVAL

NOTE:
If battery removal is necessary to remove power or the hazards a battery would cause if left installed, remove the battery from the aircraft.

a. Locate the aircraft battery in the forward aircraft compartment just aft of the nose.

b. Disconnect the battery terminals.

c. Disconnect the battery strap.

d. Remove the battery to safe distance.

2b
BATTERY TERMINALS

2c
BATTERY STRAP

AIRCRAFT TOWING WITH TOW BAR

1. AIRCRAFT TOWING WITH TOW BAR

a. Install safety pins in all wheel gears.

b. Install tow bar to nose wheel gear.

c. Install tow bar to tow vehicle.

d. Place tow person in cockpit in case braking is required during towing process.

e. Place wing walkers on each wing during towing operation.

f. Tow aircraft forward to designated location.

AIRCRAFT TOWING WITH TOW CABLE

1. AIRCRAFT TOWING WITH TOW CABLE

a. Install safety pin in all wheel gears.

b. Install tow cable to main wheel gears.

c. Install tow cable to tow vehicle.

d. Place tow person in cockpit in case braking is required during towing process.

e. Place wing walkers on each wing and one nose walker during towing operation.

f. Tow aircraft backward to designated location.