Round Trip to Orbit: Human Spaceflight Alternatives

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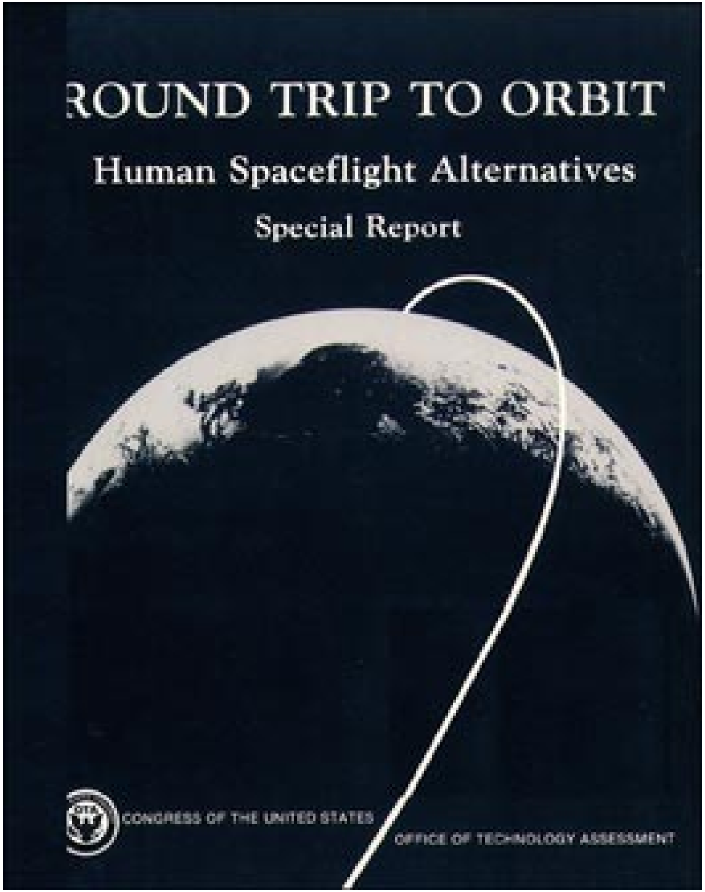

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Foreword

In the 20 years since the first Apollo moon landing, the Nation has moved well beyond the Saturn 5 expendable launch vehicle that put men on the moon. First launched in 1981, the Space Shuttle, the world's first partially reusable launch system, has made possible an array of space achievements, including the recovery and repair of ailing satellites, and shirtsleeve research in Spacelab. However, the tragic loss of the orbiter *Challenger* and its crew three and a half years ago reminded us that space travel also carries with it a high element of risk-both to spacecraft and to people.

Continued human exploration and exploitation of space will depend on a fleet of versatile and reliable launch vehicles. As this special report points out, the United States can look forward to continued improvements in safety, reliability, and performance of the Shuttle system. Yet, early in the next century, the Nation will need a replacement for the Shuttle. To prepare for that eventuality, NASA and the Air Force have begun to explore the potential for advanced launch systems, such as the Advanced Manned Launch System and the National Aerospace Plane, which could revolutionize human access to space. Decisions taken now will affect the future of spaceflight in the 21st century.

This special report examines a wide range of potential improvements to the Space Shuttle, explores the future of space transportation for humans, and presents policy options for congressional consideration. It is one of a series of products from abroad assessment of space transportation technologies undertaken by OTA, requested by the Senate Committee on Commerce, Science, and Transportation, and the House Committee on Science, Space, and Technology. In the past year, OTA has published a special report, *Launch Options for the Future: A Buyer's Guide,* a technical memorandum, *Reducing Launch Operations Costs: New Technologies and Practices,* and a background paper, *Big Dumb Boosters: A Low-Cost Space Transportation Option?*

In undertaking this effort, OTA sought the contributions of a wide spectrum of knowledgeable individuals and organizations. Some provided information, others reviewed drafts. OTA gratefully acknowledges their contributions of time and intellectual effort. OTA also appreciates the help and cooperation of NASA and the Air Force. As with all OTA reports, the content of this special report is the sole responsibility of the Office of Technology Assessment and does not necessarily represent the views of our advisors or reviewers.

John H Gibbons

JOHN H. GIBBONS
Director

Advisory Panel on Round Trip to Orbit: Human Spaceflight Alternatives

M. Granger Morgan, *Chairman*
Head, Department of Engineering and Public Policy
Camegie-Mellon University

I.M. Bernstein
Provost and Academic Vice President
Illinois Institute of Technology

Michael A. Berta
Assistant Division Manager
Space and Communications Group
Hughes Aircraft Company

Richard E. Brackeen
President & CEO
Matra Aero Space, Inc.

Preston Craig
Chief Scientist
United Technologies Space Flight Systems

Edward T. Gerry
President
W. J. Schafer Associates, Inc.

Jerry Grey
Director, Science and Technology Policy
American Institute of Aeronautics and Astronautics

William H. Heiser
Consultant

Otto W. Hoemig, Jr.
Vice President
Contel/American Satellite Corporation

Donald B. Jacobs
Vice President, Space Systems Division
Boeing Aerospace Company

John Logsdon
Director, Graduate Program in Science, Technology and Public Policy
George Washington University

Hugh F. Loweth
Consultant

Anthony J. Macina
Program Manager
IBM Federal Systems Division

George B. Merrick
Vice President
North American Space Operations
Rockwell International Corporation

Alan Parker
Consultant

Gerard Piel
Chairman Emeritus
Scientific American

Bryce Poe, II
General, USAF (retired)
Consultant

Ben R. Rich
Vice President and General Manager
Lockheed Corporation

Sally K. Ride
Professor, Center for International Security and Arms Control
Stanford University

Tom Rogers
President
The Sophron Foundation

Richard G. Smith
Senior Vice President
JLC Aerospace Corporation

William Zersen
Consultant

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OTA Project Staff on Round Trip to Orbit: Alternatives for Human Spaceflight

Lionel S. Johns, *Assistant Director, OTA*
Energy, Materials, and International Security Division

Alan Shaw, *International Security and Commerce Program Manager (from March 1989)*

Peter Sharfman, *International Security and Commerce Program Manager (through February 1989)*

Ray A. Williamson, *Project Director (from January 1989)*

Richard DalBello, *Project Director (until January 1989)*

Eric O. Basques

Michael B. Callaham

Arthur Charo

Gordon Law

Contractor

Leonard David

Administrative *Staff*

Jannie Home (through November 1988)

Cecile Parker (through March 1989)

Jackie Robinson

Louise Staley

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James Bain
NASA

Paul Bialla
General Dynamics

Robert Barthelemy
NASP Joint Program Office

Darrell Branscome
NASA

Benjamin Buchbinder
NASA

Wallace Burnett
Rockwell International

Jerry Craig
NASA

Charles Darwin
NASA

John Gaines
General Dynamics

Daniel Gregory
Boeing Aerospace Company

Charles Gunn
NASA

Ron Harris
NASA

Capt. David Hart
US. Navy
NASP Interagency Office

Daniel Herman
NASA

Clay Hicks
Rockwell International

William J. Huffstetler
NASA

Ned Hughes
NASA

Robert A. Jones
NASA

David Kennison
Pratt & Whitney

Jack Kerrebrock
Massachusetts Institute of Technology

C. V. Lewis
Rockwell International

David Moore
Congressional Budget Office

Wally McClure
Rockwell International Corporation

Scott Pace
The Rand Corporation

Maj. Robert Preston
U.S. Air Force

Bill Rock
NASA

Robert Rosen
NASA

Thaddeus Shore
Strategic Defense Initiative Organization

W. H. Siegfried
McDonnell Douglas

Maj. Jess Sponable
U.S. Air Force
NASP Joint Program Office

William Strobl
General Dynamics

Ted Talay
NASA

Charles Teixeira
NASA

Lowell Zoeller
NASA

Related OTA Reports

Civilian Space

Advanced Space Transportation Technologies Assessment

- *Launch Options for the Future: A Buyer's Guide.* OTA-ISC-383, July 1988. GPO stock #052-003-01117-4; $5.00.
- *Reducing Launch Operations Costs: New Technologies and Practices.* OTA-TM-ISC-28, September 1988. GPO stock number #052-003-01118-2; $4.50.
- *Big Dumb Boosters: A Low-Cost Space Transportation Option?:* OTA Background Paper, February 1989.
- *Commercial Newsgathering From Space:* OTA-TM-ISC-40, May 1987. GPO stock #052-003-01066-6; $3.00.
- *Space Stations and the Law: Selected Legal Issues.* OTA-BP-ISC-41, September 1986. GPO stock #052-003-01047-0; $3.75.
- *International Cooperation and Competition in Civilian Space Activities.* OTA-ISC-239, July 1985. NTIS order #PB 87-136 842/AS.
- *U.S.-Soviet Cooperation in Space:* OTA-TM-STI-27, July 1985. GPO stock #052-003-01004-6; $4.50.
- *Civilian Space Stations and the U.S. Future in Space:* OTA-STI-241, November 1984. GPO stock #052-003-00969-2; $7.50.
- *Remote Sensing and the Private Sector: Issues for Discussion.* OTA-TM-ISC-20, March 1984. NTIS order #PB 84-180 777.
- *Salyut: Soviet Steps Toward Permanent Human Presence in Space:* OTA-TM-STI-14, December 1983. GPO stock #052-003-00937-4; $4.50.
- *UNISPACE '82: A Context for International Cooperation and Competition:* OTA-TM-ISC-26, March 1983. NTIS order #PB 83-201 848.
- *Space Science Research in the United States:* OTA-TM-STI-19, September 1982. NTIS order #PB 83-166 512.
- *Civilian Space Policy and Applications:* OTA-STI-177, June 1982. NTIS order #PB 82-234 444.
- *Radiofrequency Use and Management: Impacts From the World Administrative Radio Conference of 1979. OTA-CIT-163, January 1982. NTIS order #PB 82-177 536.*
- *Solar Power Satellite Systems and Issues:* OTA-E-144, August 1981. NTIS order #PB 82-108 846.

Military Space

- *SDI: Technology, Survivability, and Software:* OTA-ISC-353, May 1988. GPO stock #052-003-01084-4; $12.00.
- *Anti-Satellite Weapons, Countermeasures, and Arms Control:* OTA-ISC-281, September 1985. GPO stock #052-003-01009-7; $6.00.
- *Ballistic Missile Defense Technologies:* OTA-ISC-254, September, 1985. GPO stock #052-003-01008-9; $12.00.
- *Arms Control in Space.* OTA-BP-ISC-28, May 1984: GPO stock #052-003-00952-8; $3.00.
- *Directed Energy Missile Defense in Space:* OTA-BP-ISC-26, April 1984. GPO stock #052-003-00948-0; $4.50.

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Congressional Alternatives for Crew-Carrying Launch Systems

If Congress wishes to continue to improve the safety, reliability, performance, and/or economy of crew-carrying launch systems, it has a number of alternatives from which to choose. Several are listed below; they are not mutually exclusive, nor is the list exhaustive. Congress could decide to proceed with one or more from each list of options.

Because of the long lead times for the development of space transportation systems, some decisions will have to be made in the next year or two. Others can wait until the middle of the next decade or later.

Near-Term Decisions

If Congress wishes to:	*Then it could:*
Improve Shuttle system safety and reliability: *(See ch. 3.)*	• *Fund development of Liquid-fueled Rocket Boosters (LRBs).* • *Fund continued development and improvement of Advanced Solid Rocket Motors (ASRMs) and alternate turbopumps for the Space Shuttle Main Engines* • *Fund continued gradual improvement of Redesigned Solid Rocket Motors (RSRMs).* • *Fund installation of built-in test equipment in the Shuttle and more automated test equipment in launch facilities.* *High confidence* in the safety or reliability of LRBs, ASRMs or other new systems would require many flight tests.
Improve Shuttle system performance (payload carried per flight): *(See ch. 3.)*	• *Fund development of LRBs.* • *Fund continued development of ASRMs.* • *Fund improvement of RSRM thrust.* • *Fund development of lighter External Tanks.* • *Fund procurement of a new orbiter made of new, lightweight materials,* • *Fund procurement of a new orbiter capable of flying unpiloted.* LRBs offer the greatest performance increase. In principle they could lead to improved mission safety.
Maintain a sustainable Shuttle launch rate of 9 to 11 launches per year: *(See ch. 3.)*	• *Fund the purchase of at least one additional orbiter to be delivered as soon as possible (1996), and direct NASA to minimize the number of Shuttle flights flown per year. NASA could reduce Shuttle flights by:* *a. postponing or canceling some planned Shuttle launches; or* *b. relying more on expendable launch vehicles, such as Titan IVs.*

A four-orbiter fleet is required to sustain a Shuttle launch rate of 9-11 launches per year. Shuttle reliability is uncertain but may lie between 97% and 9990. If it is 98%, there is a 50% probability of losing one orbiter about every three years assuming a launch rate of 11 per year. Higher launch rates would require additional launch facilities.

Purchasing an additional orbiter would provide a hedge against attrition. Minimizing the number of flights per year would reduce the probability of attrition before *Endeavour* enters service.

Reduce risks to fleet capabilities during Space Station assembly:

(See *ch.* 3.)

- *Direct NASA to buy and use Titan IV launch vehicles, or develop and use Shuttle-C launch vehicles, to carry some Space Station elements to orbit.*
- *Fund immediate procurement of one or more additional orbiters.*

The first option would reduce the number of Shuttle flights required for assembly (from 21 to 10, if Shuttle-C is used) and the risk to the Shuttle and Shuttle crews. The second option would hedge against the effects of attrition.

Reduce risks to successful Space Station assembly:

(See *ch.* 3.)

- *Direct NASA to develop and use Shuttle-C to carry some Space Station elements to orbit. (This would reduce the total number of flights required and might reduce the risk of losing an element.)*

Develop the technology base for building new crew-carrying launch systems:

(See *chs. 4 & 5.)*

- *Continue to fund technology development and test efforts such as:*
  a. the National Aero-Space Plane program; or
  b. the Advanced Launch System program.

ALS or NASP technology could be used in the Personnel Launch System or the Advanced Manned Launch System proposed by

Provide for emergency crew return from the Space Station:

(See *ch. 6.)*

- *Fund a program to develop:*
  a. a capsule for Space Station escape; or
  b. a glider for Space Station escape.

However, the improvement to Space Station crew safety that a crew emergency return vehicle might provide is highly uncertain.

Far-Term Decisions

If Congress wishes to: — ***Then it could:***

Build safer, more reliable crew; carrying launch systems:

(See chs. 4 & 5)

- *Fund development of safer, more reliable launch systems to augment or succeed the Shuttle. These might include:*
  a. a Personnel launch system (PLS), or
  b. an Advanced Manned Launch System (AMLS), or
  c. vehicles derived from the National Aero-Space Plane program.

These systems are being designed to survive some types of engine failure and could have crew escape systems. However, designs have not been chosen, nor have detailed safety assessments been performed.

Improve launch system reliability:

(See *chs.* 3,4, 5)

- *Fund development of launch vehicles or systems (e.g. Space Transportation Main Engines) that could be manufactured, integrated, and launched by highly automated methods with improved process control. Fault-tolerant system design may be useful if critical components are not sufficiently reliable.*

Lower launch cost:

(See *chs.* 4&5)

- *Fund development of vehicles designed for quick turn-around, such as those being considered for an Advanced Manned Launch System or as possible successors to the proposed National Aero-Space Plane test vehicle (X-30).*

Vehicles derived from the NASP X-30 may have greater potential to reduce launch costs compared with two-stage AMLS configurations. However, they would be more risky to develop and would likely be available later.

Selected Options for Improving the Space Shuttle System

The following options were selected from a wide range of possible improvements to the Space Shuttle System. The effectiveness of each option represents OTA'S considered judgement. However, each may be more or less effective depending upon other improvements chosen and the pace at which they are implemented.

Options	Improve Shuttle safety and/or reliability	Increase Shuttle system performance (payload per flight)	Maintain capability to sustain Shuttle launch rate of 9-11 p--	Extend the life of the current orbiter fleet	Increase the probability of assembling Space Station on schedule	Provide for emergency crew return from space	Prepare for the development of future launch systems
Major investment							
1. Continue to develop the Advanced Solid Rocket Motors (ASRMs)	★★	★★			★★		
2. Fund development of Liquid Rocket Boosters (LRBs)	★★★	★★★		★	★		★★★
3. Develop Shuttle-C				★★	★★★		★
4. Fund purchase of one or more additional orbiters			★★★	★	★★★		
5. Fund development of capsule or glider for Space Station escape						★★★	★
6. Institute integrated long-term program to improve reliability, safety, and performance of Space Shuttle system	★★★	★★★		★★	★★★		★
Supporting improvements							
1. Continue to improve the Redesigned Solid Rocket Motors (RSRMs)	★	★	★		★		
2. Incorporate built-in test equipment in existing launch vehicles and develop additional automated test equipment for launch facilities	★		★★	★			★★★
3. Develop lighter weight External Tank (ET)		★★					★
4, Develop lightweight structures for Shuttle orbiter		★★					★
5. Modify orbiter for automatic flight capability	★	★				★	★
6. Fund technology development and test efforts	★★★	★		★★	★		★★★
7. Shift all payloads not requiring crews from Shuttle to expendable launch vehicles to reduce Shuttle flight rate			★★	★★	★★		

KEY: ★★★ . Very effective
★★ . Moderately effective
★ . Somewhat effective