

# Nondestructive Evaluation Education, Experiences and Career at NASA

Brazosport College

August 2017

Part 1

**Ajay M. Koshti, D.Sc. PE  
ASNT Level III (UT,RT, ET, PT, MT)  
NDE Lead Engineer**



**NASA Johnson Space Center**

# Agenda

- Education and Experiences
- Publications/Patents
- NASA Programs with NDE Involvement

# Publications/Patents

## – Areas

- Ultrasonic stress/preload measurements: Modeling and measurement
- Residual stress measurement
- Thermal NDE, Temperature measurement: modeling, analysis, measurement, data processing
- Eddy current flaw detection
- Computed Tomography: POD Analysis
- POD data analysis
- X-ray Flaw detection: Modeling and analysis

## – Publication Sites

- NASA Tech Briefs, Materials Evaluation, SPIE, Experimental Mechanics, Experimental Techniques, U.S. Patent, and NDE Proceedings.

## – U.S. Patent

- Thermal NDE, two patents for NASA
- Citation in Patent: 1 (used by Boeing for bolt assembly of critical joints on commercial planes)

# Publications

- 1 Preload measurement in sleeve bolts using an ultrasonic technique, A Koshti - Materials evaluation, 1996 - proceedings.spiedigitallibrary.org
- 2 Effect of bending on ultrasonic preload measurements in bolts, AM Koshti - ... on NDE for Health Monitoring and ..., 2001 - proceedings.spiedigitallibrary.org
- 3 Simulation of ultrasonic measurement on a bolt in a shear joint, Proc. SPIE 4702, A M Koshti, Smart Nondestructive Evaluation for Health Monitoring of Structural and Biological Systems, 411 (June 11, 2002); doi:10.1117/12.469903
- 4 Simulation of effect of bending stress on the ultrasonic beam, A M Koshti, Proc. SPIE 4702, Smart Nondestructive Evaluation for Health Monitoring of Structural and Biological Systems, 148 (June 11, 2002); doi:10.1117/12.469874
- 5 Simulation of ultrasonic preload measurement on a bolt in an interference fit joint, A M Koshti - NDE For Health Monitoring and ..., 2002 - proceedings.spiedigitallibrary.org
- 6 Estimation of accuracy in ultrasonic preload measurements, A M Koshti, Proc. SPIE 4335, Advanced Nondestructive Evaluation for Structural and Biological Health Monitoring, 300 (July 24, 2001); doi:10.1117/12.434186
- 7 Ultrasonic measurement of the bending of a bolt in a shear joint, A M Koshti - Experimental mechanics, 1998 - Springer
- 8 Stress measurement via the acoustoelastic effect and water-coupled ultrasonic waves, A M Koshti, D M Egle - NDT and E International, 1995 - ingentaconnect.com
- 9 Estimating temperature rise in pulsed thermography using irreversible temperature indicators, A M Koshti, Proc. SPIE 4702, Smart Nondestructive Evaluation for Health Monitoring of Structural and Biological Systems, 191 (June 11, 2002); doi:10.1117/12.469878
- 10 Measuring and Estimating Normalized Contrast in Infrared Flash Thermography, Koshti, Ajay M. NASA Technical Reports Server (NTRS), Collection, Johnson Space Center, February 2013, Document ID: 20130009802.
- 11 Applicability of a Conservative Margin Approach for Assessing NDE Flaw Detectability, A M Koshti, NASA Technical Reports Server (NTRS, Johnson Space Center, Apr. 16, 2007, Document ID: 20070016672
- 12 Nondestructive Crack Detection in a Fuel System Component, A M Koshti, NASA Technical Reports Server (NTRS)Johnson Space Center; Kennedy Space Center; Langley Research Center; Marshall Space Flight Center, May 10, 2010, Document ID: 20100020162
- 13 X-Ray Computed Tomography Inspection of the Stardust Heat Shield, NASA Technical Reports Server (NTRS), Ames Research Center; Goddard Space Flight Center; Johnson Space Center, June 14, 2010, Document ID: 20100027549, Subject Category: SPACECRAFT DESIGN, TESTING AND PERFORMANCE, Report:ARC-E-DAA-TN1350
- 14 An Alternate Technique for Implementing Center-Hole Drilling/Residual-Stress Measurements A M KOSHTI, D M EGLER - Experimental Techniques, 1985 - Wiley Online Library
- 15 Exploration of COTS Ultrasonic NDE Methods for ISS MMOD Impact Analysis, Daniel P Violette, University of Connecticut, Storrs, CT, 06798, Ajay M Koshti, Johnson Space Center, Houston, TX, 77058, and David Stanley Johnson Space Center, Houston, TX, 77058, NASA MUST – Internship Final Report, NASA Technical Reports Server (NTRS), Johnson Space Center, 2012 Document ID: 20120013518, Report/Patent Number: JSC-CN-26785
- 16 IR Thermography of International Space Station Radiator Panels, Koshti, Ajay; Winfree, William; Morton, Richard; Howell, Patricia, NASA Technical Reports Server (NTRS), NASA Johnson Space Center; Langley Research Center, 2010, Document ID: 20100035740
- 17 Eddy-Current Detection Of Cracks In Reinforced Carbon/Carbon, Christensen, Scott V.; Koshti, Ajay M., Johnson Space Center, NASA Technical Reports Server (NTRS), Nov 1, 1995, Document ID: 19950070376
- 18 Wedge Heat-Flux Indicators for Flash Thermography, Koshti, Ajay M., NASA Technical Reports Server (NTRS), NASA Johnson Space Center, November 2003, Publication Year: 2003, Document ID: 20110023942
- 19 Modeling the X-ray Process, and X-ray Flaw Size Parameter for POD Studies, Ajay M. Koshti, NASA Johnson Space Center, SPIE Smart Structures and NDE, San Diego, CA, March 2014
- 20 Methods and Systems for Characterization of an Anomaly Using Infrared Flash Thermography, US Patent 8,577,120 B1, Nov. 5, 2013, Ajay Koshti, Assigned to NASA.
- 21 The Critical Role of High Resolution X-ray Micro-computed Tomography for Ultra-thin Wall Space Component Characterization, D. J. Roth, R. W. Rauser, R.R. Bowman, R.E. Martin, A. M. Koshti, and D. S. Morgan, Materials Evaluation, March 2014, page 383.

# Internet Sites with Profile and Publications

<http://spie.org/profile/Ajay.Koshti-153499>

<https://www.linkedin.com/>

<http://scholar.google.com/>

**Ajay Koshti**  
 NASA Johnson Space Center  
 ultrasonic testing, infrared, x-ray, eddy current  
 Verified email at nasa.gov - Homepage

Citation indices	All	Since 2012
Citations	115	55
h-index	6	4
i10-index	4	0

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Title 1-20 Cited by Year

**SPIE.**  
 CONNECTING MINDS. ADVANCING LIGHT.

Dr. Ajay Koshti  
 Nondestructive Evaluation Lead Engineer  
 NASA Johnson Space Ctr  
 Regular Member

**Profile Summary**  
 Dr. Ajay Koshti holds B.S., M.S., and D. Sc. degrees, and Professional Engineer (PE) certification in Mechanical Engineering. He also holds ASNT level III certification in five Nondestructive Evaluation (NDE) methods. He worked as an NDE engineer on NASA Space Shuttle Program (SSP) for 23 years at different locations including Rockwell Facility in Downey and Palmdale, California, NASA KSC and NASA JSC. Post Columbia accident, he led the project of developing and implementing infrared nondestructive testing of Space Shuttle wing leading edge and nose cone for pre-flight ground processing. He chaired NASA Orbiter NDE Working Group and contributed to development and implementation of nondestructive methods used on Orbiter hardware such as vertical tail lug joints, main propulsion system (MPS) flowlines, MPS valve poppets, composite pressure vessels, midpody boron-aluminum struts, payload bay doors, laminated and honeycomb composite structures. He also worked as Orbiter Ground Support Equipment (GSE), including Orbiter Handling Equipment (OHE), Engineer for six years. He led the implementation of ultrasonic preload measurements on some Space Shuttle critical joints such as Orbiter to ET umbilical disconnect bolts, Orbiter to Boeing 747 attachment bolts and Orbiter vertical tail forward attachment bolts. He helped in resolution of issues of Orbiter GSE such as the Orbiter mate/demate slings, jacks, tow bars, and orbiter transporter. Since 2004, he has been working as lead NDE engineer at NASA JSC. Since the end of SSP, he has been supporting the International Space Station (ISS) program, Orion MPCV Program, and Commercial Cargo & Crew Program (CCCP). He co-chairs the NASA Orion MPCV NDE Working Group. He authored or coauthored many NDE papers and reports, some of which have been cited in other research papers and patents. He has two patents in infrared thermography.

**Publications** Most recent | Show all (48)  
 A method to measure and estimate normalized contrast in infrared flash thermography (Conference Proceedings)  
 Authors: Ajay Koshti  
 Published: 22 Apr 2016  
 show citation  
 Methods and Systems for Measurement and estimation of Normalized Contrast in Infrared Thermography (Conference paper)

- Status of thermal NDT of space shuttle materials at NASA  
 KE Cramer, WP Winfree, K Hodges, A Koshti, D Ryan, WW Reinhardt  
 Defense and Security Symposium, 62051B-62051B-9
- Ultrasonic measurement of the bending of a bolt in a shear joint  
 A Koshti  
 Experimental Mechanics 38 (4), 270-277
- Preload measurement in sleeve bolts using an ultrasonic technique  
 A Koshti  
 Materials evaluation 54 (2), 308-313
- Preload measurement in sleeve bolts using an ultrasonic technique  
 AM Koshti  
 Nondestructive Evaluation of Aging Infrastructure, 406-418
- Methods and systems for characterization of an anomaly using infrared thermography

**Ajay Koshti**  
 NDE Lead Engineer at NASA Johnson Space Center  
 Houston, Texas Area | Aviation & Aerospace

Previous: Boeing, Rockwell Aerospace  
 Education: University of Mumbai

88 connections

View profile as [dropdown]

Add a section to your profile - be discovered for your next career step.

Language: Add language  
 Volunteering Experience: Add volunteering experience

Summary

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# Education and Experience

1974-1976: Junior College, University of Bombay (Mumbai)

1976-1981: **Bachelor of Technology (Mechanical Engineering)**

Indian Institute of Technology, Bombay

1981-1982: Union Carbide India Ltd. (Bombay)

Maintenance Engineer

1983- 1985: **M.S. (Mechanical Engineering)**

University of Oklahoma

1985-1987: Pace Setter Inc. Manufacturing Engineer

**ASNT Level III (UT)**

1988-1993: Rockwell International, Downey, CA

NDE/Quality Engineer, Space Shuttle Orbiter Program

**ASNT Level III (PT, MT, RT, ET)**

**PE (Mechanical Engineering)**

1993-2003: Rockwell International and Boeing North American

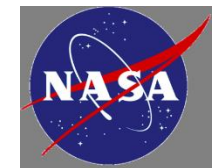
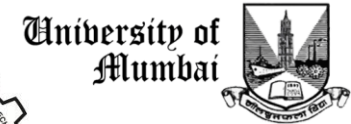
Kennedy Space Center

NDE, Ground Support Engineering and Orbiter Handling Engineering

2002: **Doctor of Science in Mechanical Engineering**, University of Mumbai

2004-Current: NASA Johnson Space Center

**Lead NDE Engineer**



# University of Mumbai (Bombay)

University of  
Mumbai



Established 1857

Established by British Rulers in India



University is Ranked 5<sup>th</sup> in India

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available on the internet

# Indian Institute of Technology, Bombay



Main Building



Established in 1958  
Ranked 39th in Asia  
IIT Undergraduate Brand  
is Recognized worldwide  
as IIT Engineers have emigrated to  
most developed countries and  
done very well.



Sports Field



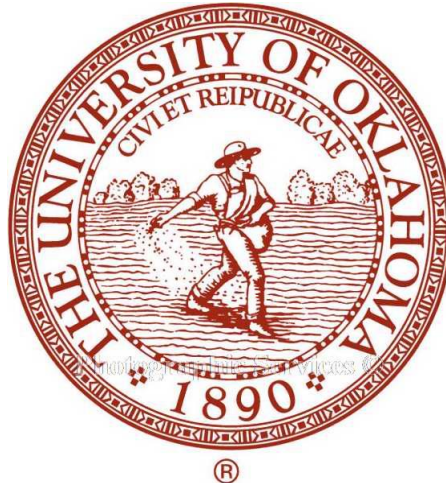
Mechanical Eng. Side View



Mechanical Eng. Entrance



# University of Oklahoma



Well known in College Football  
7 national **championships**,  
44 conference **championships**  
**#88 in Mechanical Eng. by U.S. News**



Mechanical Engineering

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# Space Shuttle Program

## Rockwell Intl., Downey and Palmdale CA

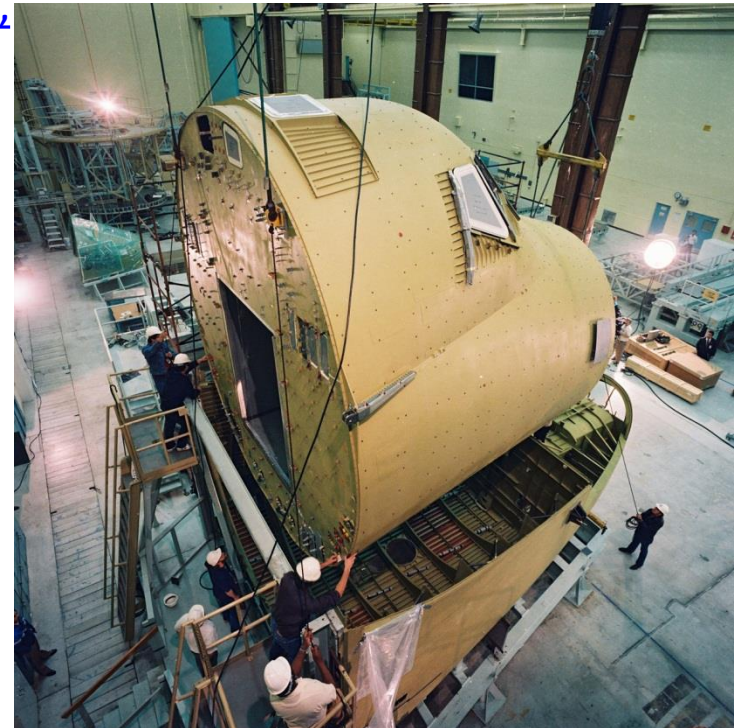
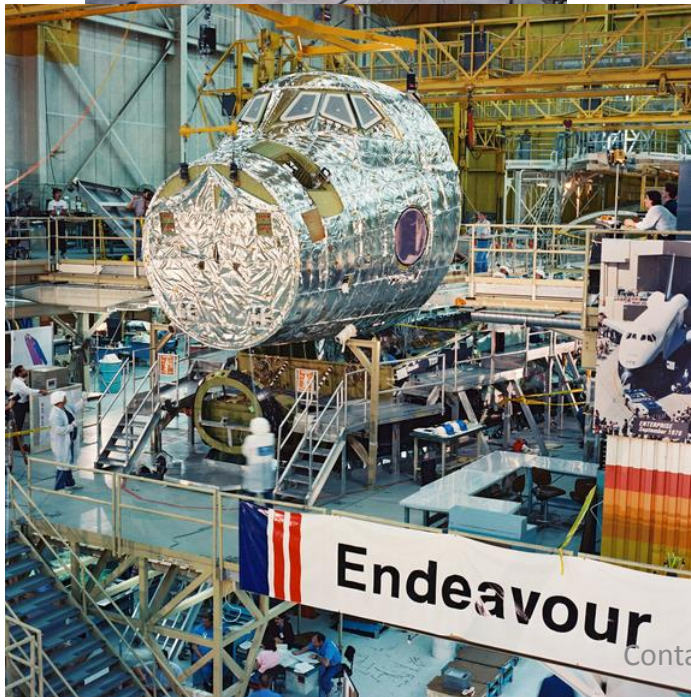
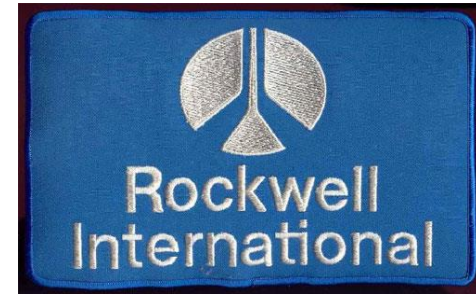


Space  
Shuttle  
First  
flight

April  
12,  
1981

Last  
flight

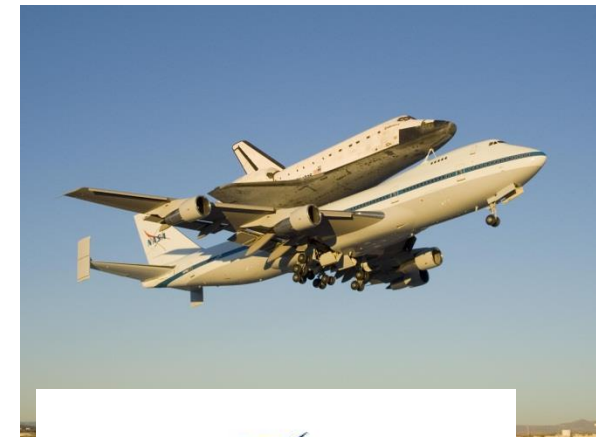
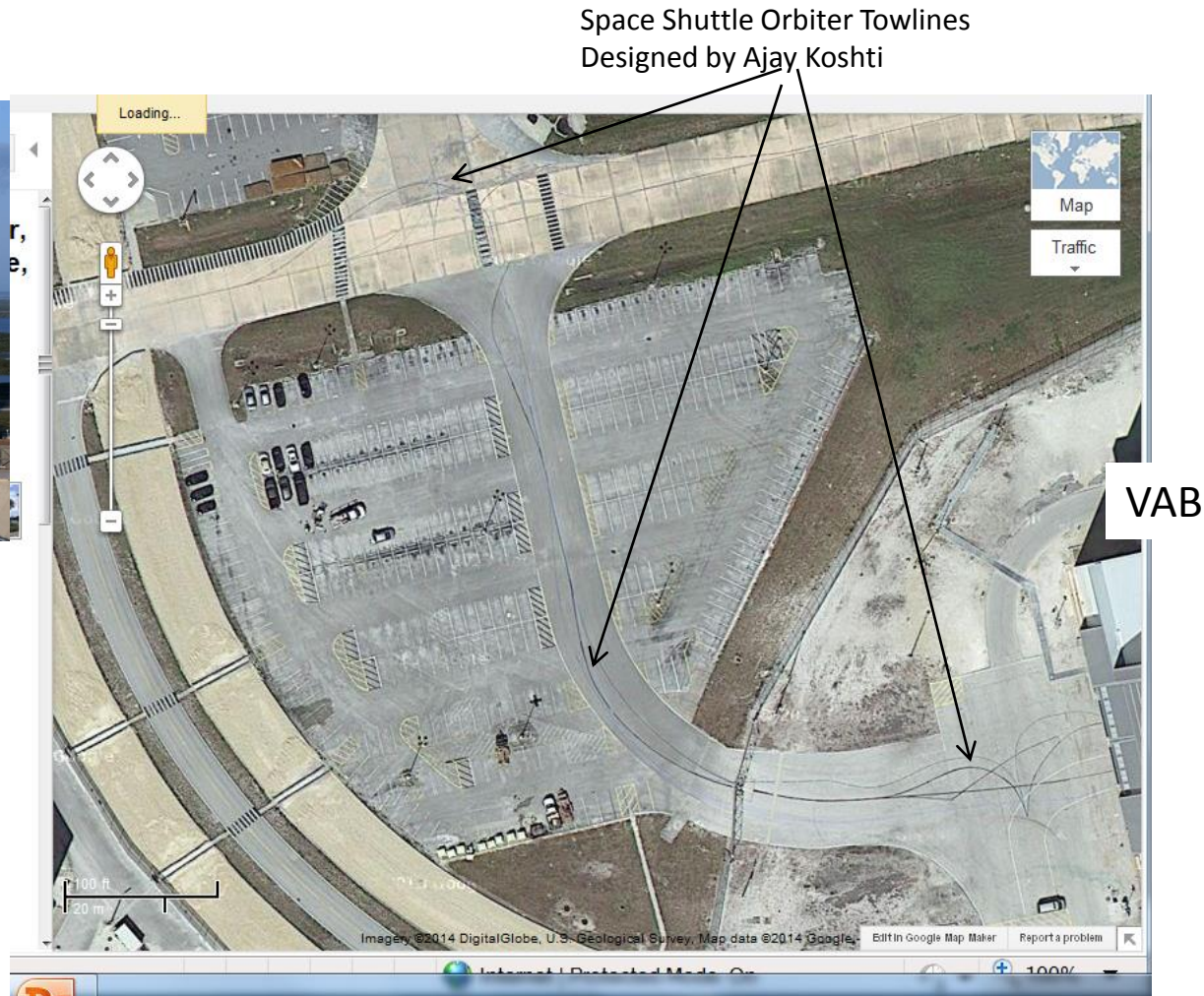
July 21,  
2011



Worked in Downey plant from 1988 to 1993

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available on the internet

# Kennedy Space Center Space Shuttle Launch Pad & VAB Area

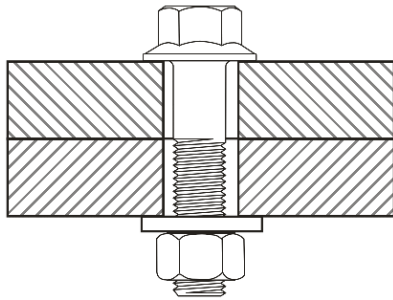


Google Map of Vehicle Assembly Building Area

Worked at Kennedy Space Center for Boeing from 1993 to 2003  
content is shared to the public  
available on the internet

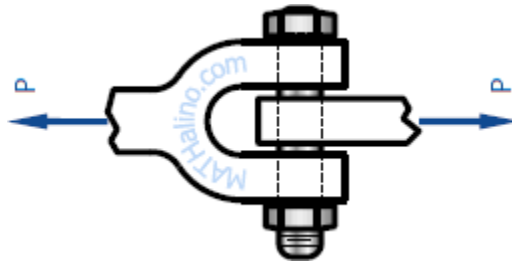
# Ultrasonic Preload Measurement Applications

## Case 1: Clamp Joint (Shank in Clearance)



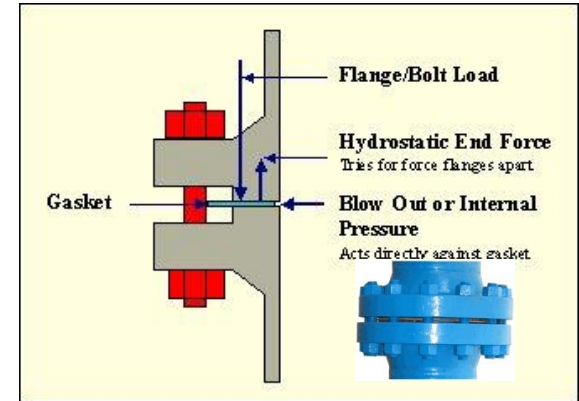
Measure bolt preload

## Case 2: Double Shear Joint



Measure Load P

## Case 3: Flange Joint



Measure bolt preload

Figure 1-11b

## Case 4: Clamp Joint with Interference

### SLEEVbolt® INTERFERENCE FASTENING SYSTEM

#### SLEEVbolt INSTALLATION

This drawing shows examples of two SLEEVbolt assemblies ready for installation.

The required counterbored nut is then installed to desired torque level. Installation technique is similar to description below.



1 Drill straight diameter hole with countersink. 2 Insert critical clearance-fit SLEEVbolt assembly (tapered bolt in tapered inside diameter sleeve.) 3 Pull or load bolt into interference fit with counterbore nut. 4 Install counterbore nut to desired torque level.

PATENT NUMBERS

- Ultrasonic transducer contacts on bolt head or tail
- Measures ultrasonic wave return trip
- transit time through the length of the bolt

See papers 1 through 7 by Ajay Koshti for applications of four cases. Covers modeling and experimental results.

Measure preload and shank pressure

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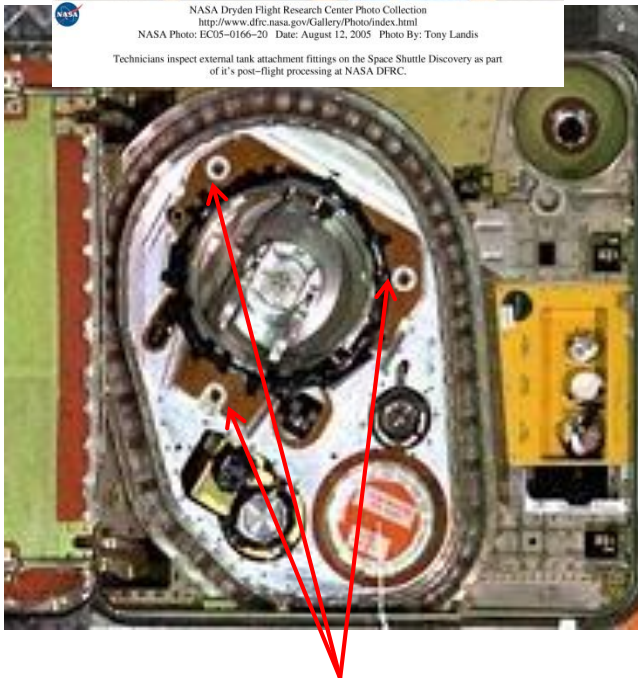
# Space Shuttle Ultrasonic Preload Applications



NASA Dryden Flight Research Center Photo Collection  
<http://www.dfrc.nasa.gov/Gallery/Photo/index.html>  
 NASA Photo: ECI05-0166-20 Date: August 12, 2005 Photo By: Tony Landis  
 Technicians inspect external tank attachment fittings on the Space Shuttle Discovery as part of it's post-flight processing at NASA DFR.



Two 2" Dia. Orbiter to Aircraft attachment bolts in Clamped Joint



Three bolt (0.7" Dia) locations in a Flange Joint in the 17" Orbiter/ET Disconnect

Figure 5

**1 Orbital Maneuvering System**

Two engines  
 Thrust level = 6,000 pounds each

Propellants  
 Monomethyl hydrazine (fuel) and nitrogen tetroxide (oxidizer)

**2 Reaction Control System**

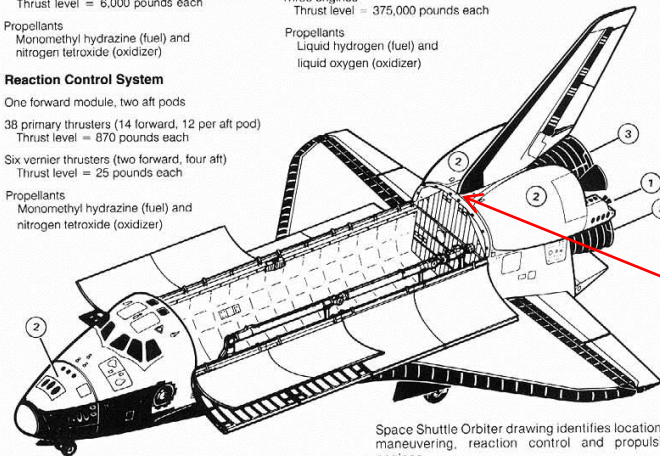
One forward module, two aft pods  
 38 primary thrusters (14 forward, 12 per aft pod)  
 Thrust level = 870 pounds each  
 Six vernier thrusters (two forward, four aft)  
 Thrust level = 25 pounds each

Propellants  
 Monomethyl hydrazine (fuel) and nitrogen tetroxide (oxidizer)

**3 Main Propulsion**

Three engines  
 Thrust level = 375,000 pounds each

Propellants  
 Liquid hydrogen (fuel) and liquid oxygen (oxidizer)



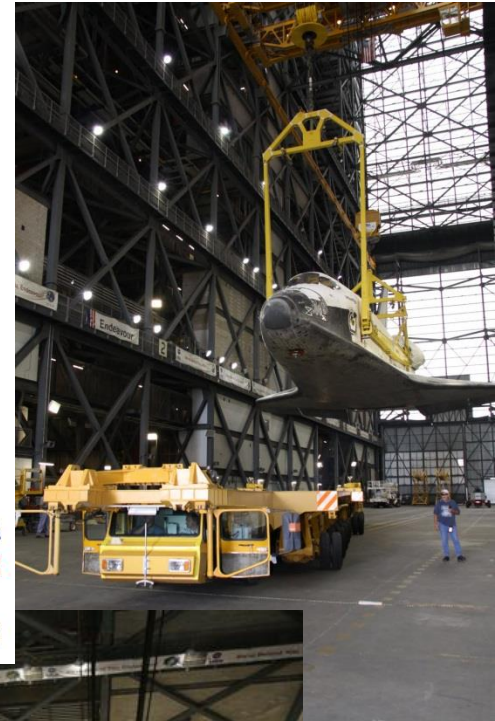
Two Vertical Tail attachment sleeve bolts in Interference Joint

Space Shuttle Orbiter drawing identifies location of principal maneuvering, reaction control and propulsion system engines.

Led development of above ultrasonic preload applications.

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# Vehicle Assembly Building



*United Space Alliance*



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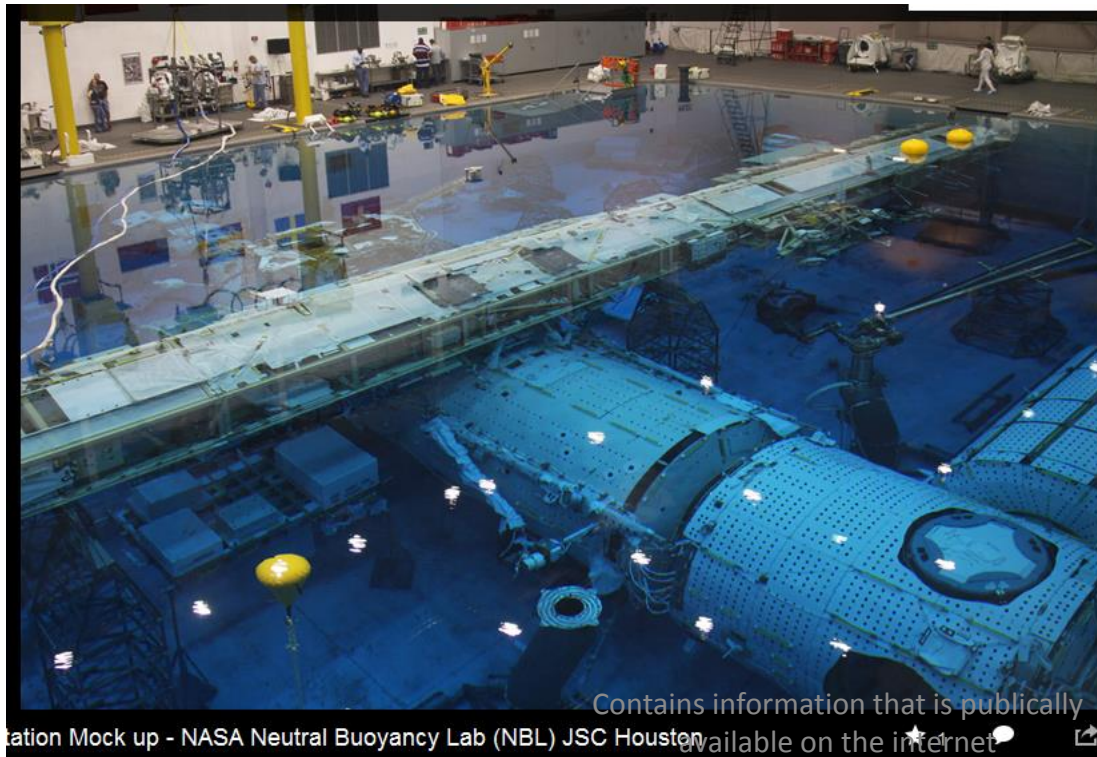
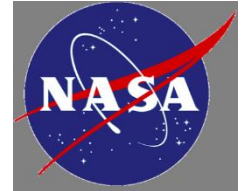
# Orbiter to Carrier Aircraft Mate/Demate Facility and Launch Pad



Tailcone is the only hardware built by Boeing before acquiring Rockwell Aerospace and McDonnell Douglas. Tailcone was used for a ferry flight atop Boeing 747.

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# NASA Johnson Space Center



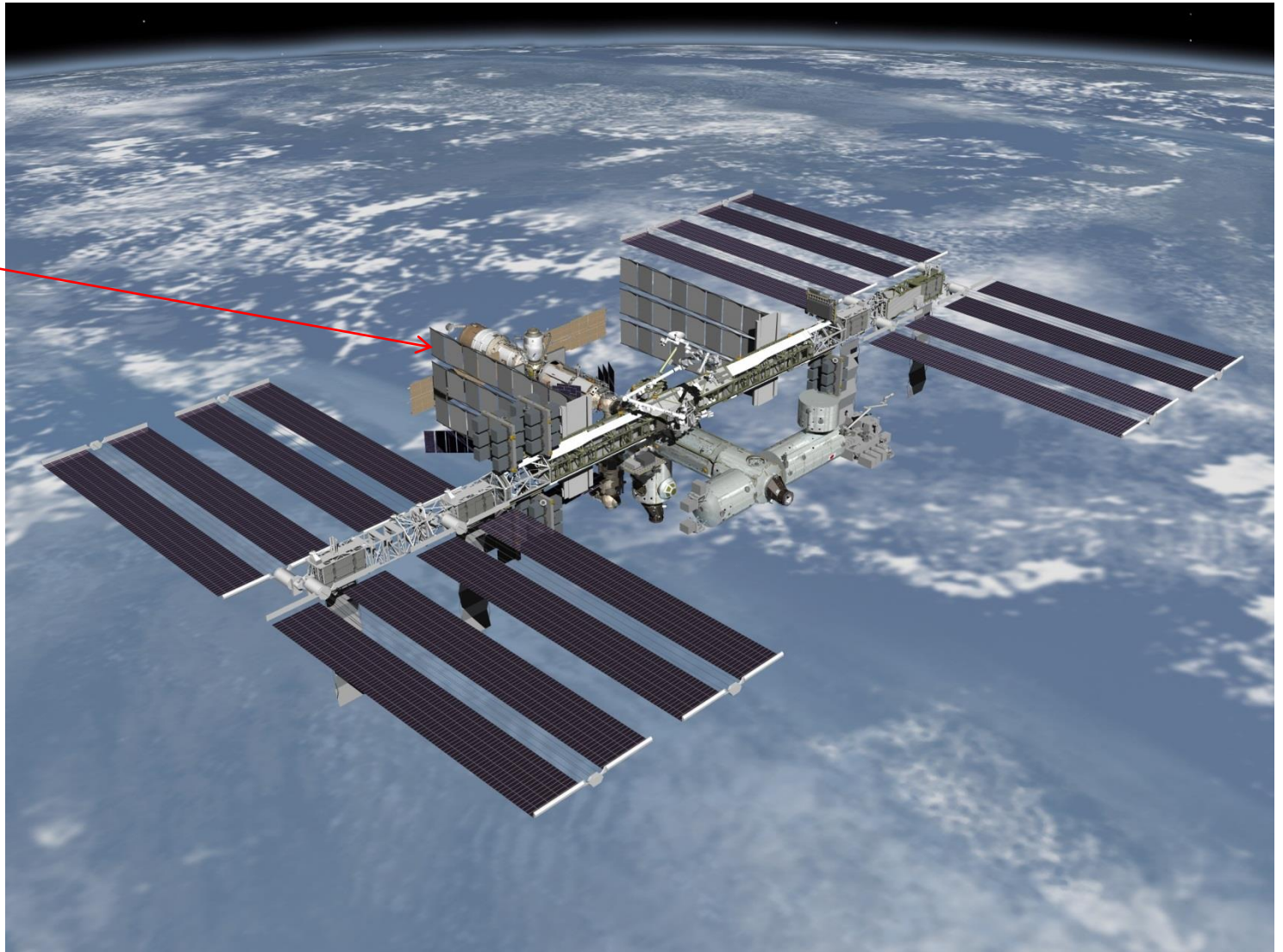
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ation Mock up - NASA Neutral Buoyancy Lab (NBL) JSC Houston



Robonaut R2 above ISS



# International Space Station



EVA Infrared  
Imaging NDE  
of radiators

Currently ISS is the largest program for NASA Johnson space Center

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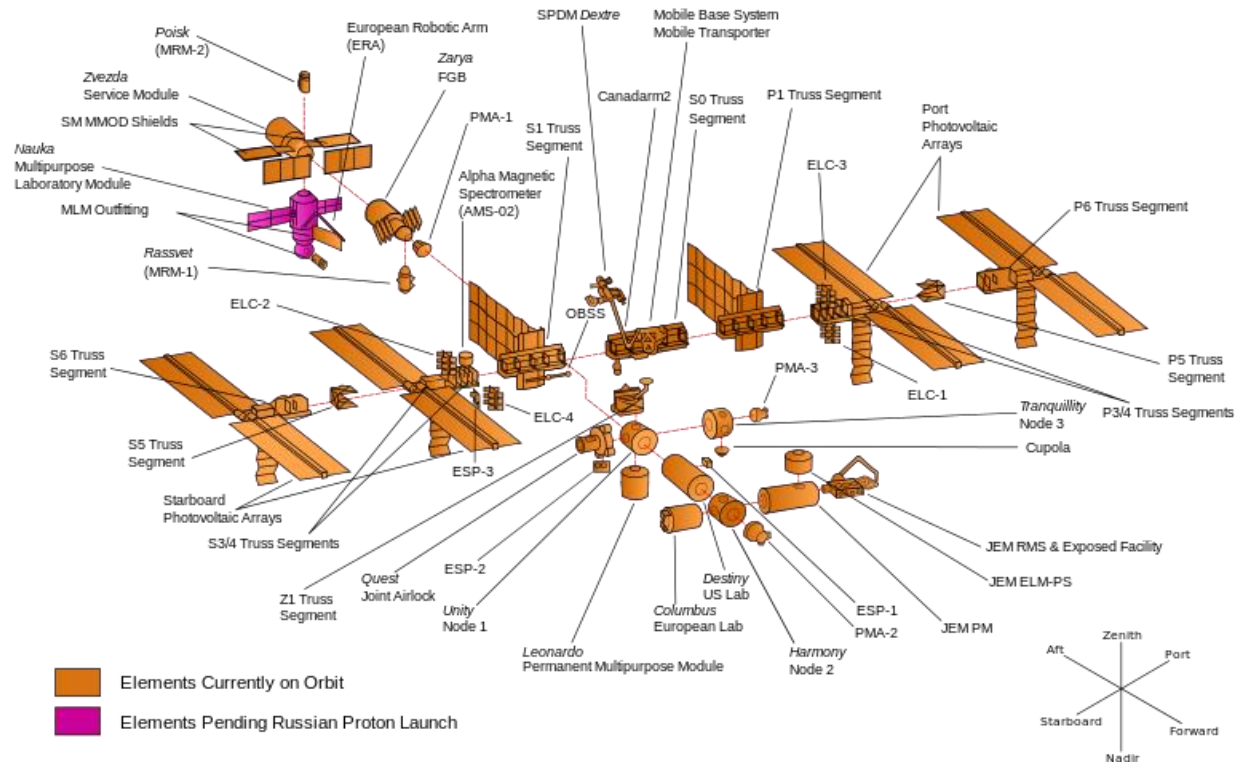
# International Space Station

## Station statistics

<a href="#">COSPAR ID</a>	1998-067A
<a href="#">Call sign</a>	<i>Alpha</i>
Crew	Fully crewed 6 Currently aboard 6 ( <a href="#">Expedition 38</a> )
<a href="#">Launch</a>	1998
<a href="#">Launch pad</a>	<a href="#">Baikonur 1/5</a> and <a href="#">81/23 Kennedy LC-39</a>
<a href="#">Mass</a>	approximately 450,000 kg (990,000 lb)
Length	72.8 m (239 ft)
Width	108.5 m (356 ft)
Height	c. 20 m (c. 66 ft) nadir–zenith, arrays forward–aft (27 November 2009) <a href="#">[cited info]</a>
Pressurised <a href="#">volume</a>	837 m <sup>3</sup> (29,600 cu ft) (21 March 2011)
<a href="#">Atmospheric pressure</a>	101.3 kPa (29.91 inHg, 1 atm)
<a href="#">Perigee</a>	417 km (259 mi) <a href="#">AMSL</a> <sup>[1]</sup>
<a href="#">Apogee</a>	422 km (262 mi) <a href="#">AMSL</a> <sup>[1]</sup>
Orbital <a href="#">inclination</a>	51.65 <a href="#">degrees</a> <sup>[1]</sup>
Average speed	7.66 kilometres per second (27,600 km/h; 17,100 mph) <sup>[1]</sup>
<a href="#">Orbital period</a>	92.83 minutes <sup>[1]</sup>
Orbit epoch	8 March 2014 <sup>[1]</sup>
Days in orbit	5587 (8 March)
Days occupied	4874 (8 March)
Number of orbits	87564 <sup>[1]</sup>
<a href="#">Orbital decay</a>	2 km/month
Statistics as of 9 March 2011	

## ISS Configuration

As of May 2011 (ULF6 - STS-134)



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# NASA Ellington Field, Houston



Contains information that is publicly available on the internet

# Project Morpheus



USA

Designer [NASA](#)

Manufacturer [NASA/JSC](#)

Application Planetary and lunar lander

Status In development

Propellant [Liquid-fuel engine](#)  
[liquid oxygen](#) / [methane](#)<sup>[1]</sup>

Performance

Thrust 22000 N <sup>[2]</sup>

[Specific impulse](#) 321 s <sup>[3]</sup>

Burn time tested: 123 s <sup>[4]</sup>

Used in  
Morpheus Lander



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# Astronaut Suits



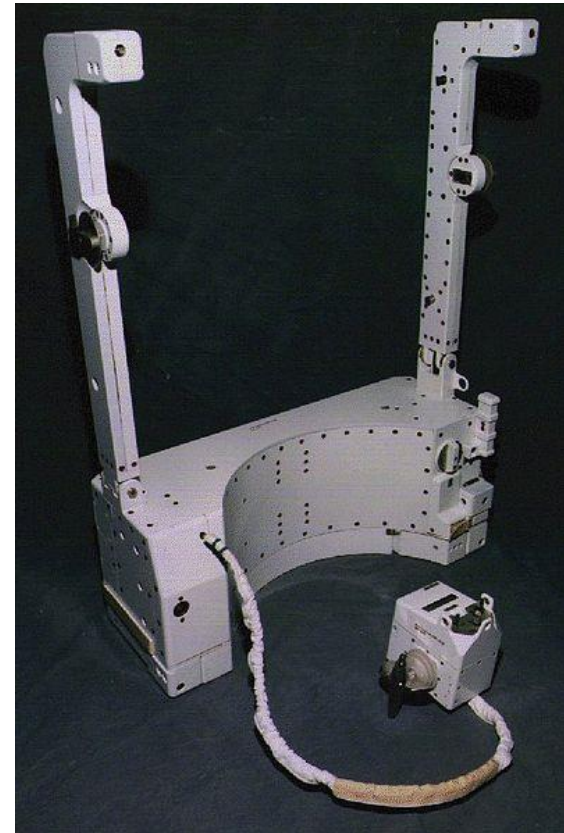
Mark III Suit



ISS EMU Suit

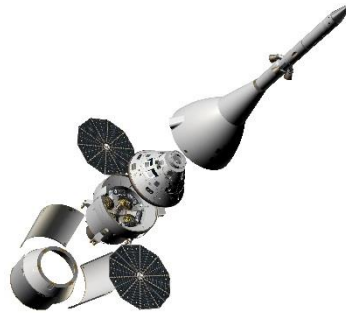
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# NASA Simplified Aid for EVA Rescue (SAFER)



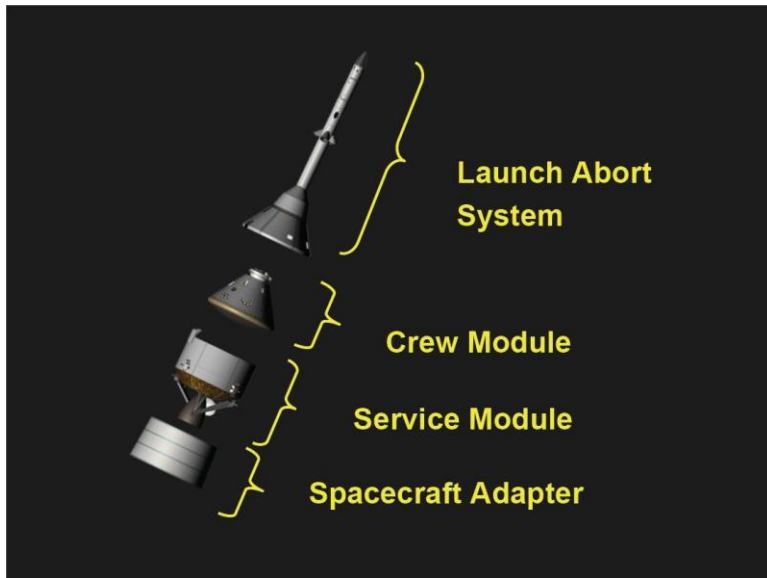
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# NASA Orion Spacecraft



- The **Orion Multi-Purpose Crew Vehicle (Orion MPCV)** is an American [spacecraft](#) intended to carry a crew of four astronauts to destinations at or beyond [low Earth orbit](#) (LEO). Currently under development by [NASA](#) for launch on the [Space Launch System](#), Orion is intended to facilitate human exploration of [asteroids](#) and of [Mars](#) and to retrieve crew or supplies from the [ISS](#) if needed.
- The MPCV's first test flight (uncrewed), known as [Exploration Flight Test 1](#) (EFT-1), was launched atop a [Delta IV Heavy](#) rocket on December 5, 2014, on a flight lasting 4 hours and 24 minutes, landing at its target in the [Pacific Ocean](#) at 10:29 Central . The first mission to carry astronauts is not expected to take place until 2023 at the earliest, although NASA officials have said that their staff is working toward an "aggressive internal goal" of 2021.

# NASA Orion Spacecraft



## Description

**Role:**

Beyond LEO, back-up for commercial cargo and crew to the ISS<sup>[1]</sup>

**Crew:**

2–6<sup>[2]</sup>

**Carrier rocket:**

[Space Launch System](#) (planned-deep space), [Delta IV](#) (test flight), [Ares I](#) (cancelled)

**Launch date:**

**December 5, 2014** (uncrewed test launch)<sup>[3]</sup>

## Dimensions

**Height:**

**Diameter:**

5 m (16.5 ft.)

**Pressurized volume:**

19.56 m<sup>3</sup> (691 cu ft) <sup>[4]</sup>

**Habitable volume:**

8.95 m<sup>3</sup> (316 cu ft) <sup>[4]</sup>

**Capsule mass:**

8,913 kg (19,650 lb.)

**Service Module mass:**

12,337 kg (27,198 lb.)

**Total mass:**

21,250 kg (46,848 lb.)

**Service Module propellant mass:**

7,907 kg (17,433 lb.)

## Performance

**Total delta-v:**

1,595 m/s

**Endurance:**

21.1 days<sup>[2][4]</sup>

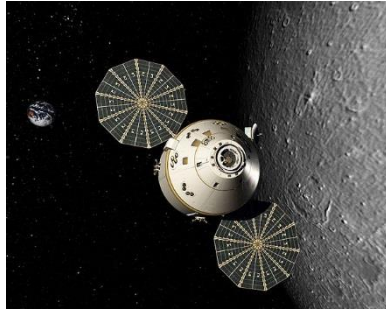
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# Orion Spacecraft

- NASA's Orion spacecraft will carry astronauts further into space than ever before using a module based on Europe's Automated Transfer Vehicles (ATV).
- The ATV-derived service module, sitting directly below Orion's crew capsule, will provide propulsion, power, thermal control, as well as supplying water and gas to the astronauts in the habitable module.
- The first Orion mission will be an uncrewed lunar flyby in 2018, returning to Earth's atmosphere at 11 km/s – the fastest reentry ever.

# Orion Spacecraft



EFT-1 Orion after final weld on June 22, 2012.



Exploration Flight Test 1 Recovery on December 5, 2014



Interior of the Orion mock-up, October 2014.



Exploration Flight Test 1 Recovery on December 5, 2014

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Engineers successfully tested the parachutes for NASA's Orion spacecraft at the U.S. Army Yuma Proving Ground in Arizona Wednesday, March 8, 2017

# Orion Spacecraft



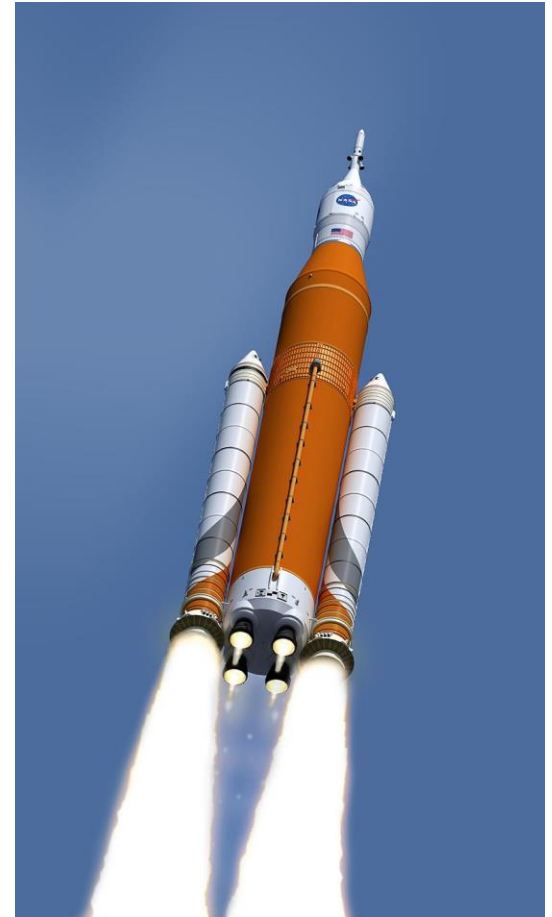
Orion Lifting off on top of a Delta IV Heavy on December 5, 2014

Assembly operation to prepare Orion EFT 1 for its first flight in December 2014.

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# Space Launch System (SLS)

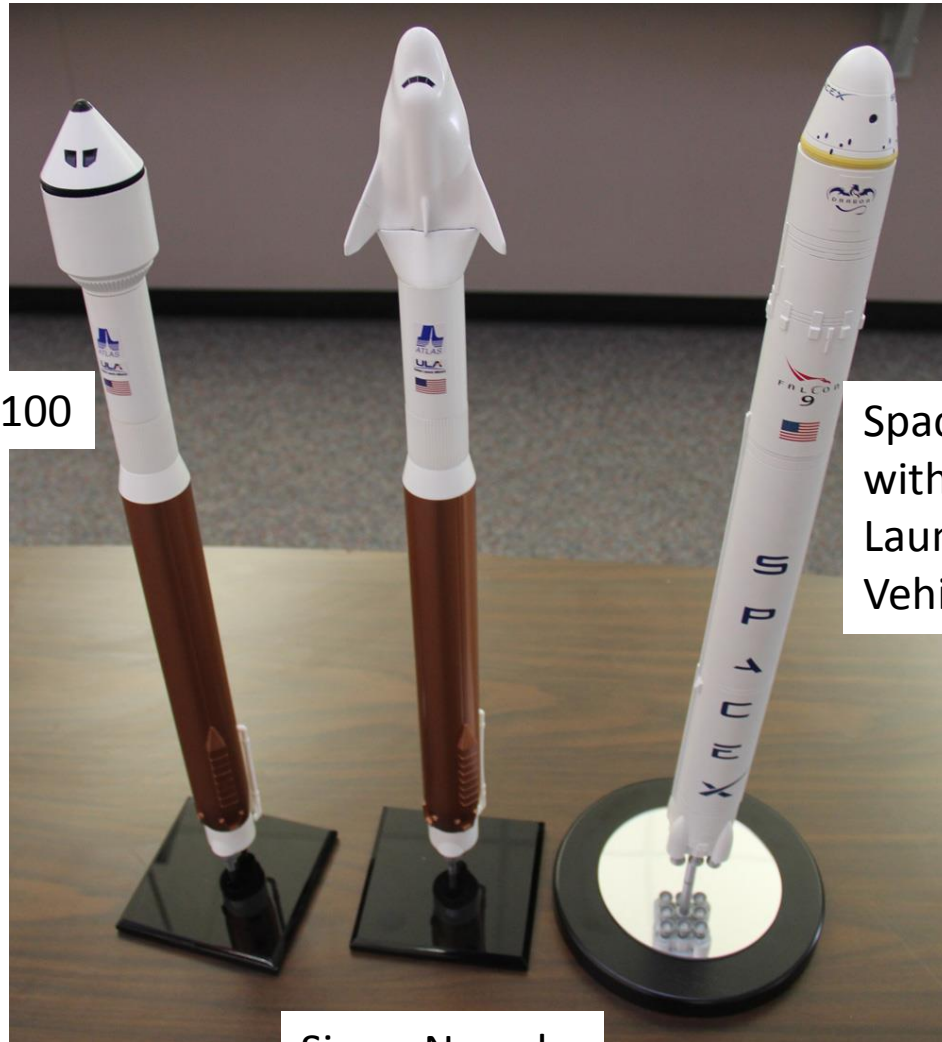
- The **Space Launch System (SLS)** is an American [Space Shuttle-derived](#) heavy [expendable launch vehicle](#) being designed by [NASA](#). It is to replace the retired [Space Shuttle](#). The SLS will be the most powerful rocket ever built, with about 20% more thrust than the [Saturn V](#) and a comparable payload capacity, putting the SLS into the [super heavy-lift launch vehicle](#) class of rockets.
- The SLS launch vehicle is to be upgraded over time with more powerful versions. Its initial Block 1 version is to lift a [payload](#) of 70 [metric tons](#) to [low Earth orbit](#) (LEO), which will be increased with the debut of Block 1B and the [Exploration Upper Stage](#).
- Block 2 will replace the initial Shuttle-derived boosters with advanced boosters and is planned to have a LEO capability of more than 130 metric tons to meet the congressional requirement. These upgrades will allow the SLS to lift astronauts and hardware to various beyond-LEO destinations: on a [circumlunar trajectory](#) as part of [Exploration Mission 1](#) with Block 1, to a near-Earth asteroid in [Exploration Mission 2](#) with Block 1B, and to [Mars](#) with Block 2. The SLS will launch the [Orion Crew and Service Module](#) and may support trips to the [International Space Station](#) if necessary. SLS will use the ground operations and launch facilities at NASA's [Kennedy Space Center](#), Florida.



# NASA Commercial Crew



Boeing CST 100



SpaceX Dragon with Falcon 9 Launch Vehicle

Sierra Nevada Dream Chaser With Atlas

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# SpaceX Dragon Spacecraft

- **Dragon** is a [spacecraft](#) developed by [SpaceX](#), an American [private space transportation](#) company based in [Hawthorne, California](#). Dragon is launched into space by the SpaceX [Falcon 9 two-stage-to-orbit launch vehicle](#), and SpaceX is developing a crewed version called the [Dragon 2](#).
- During its maiden flight in December 2010, Dragon became the first commercially built and operated spacecraft to be recovered successfully from orbit. On 25 May 2012, a cargo variant of Dragon [became the first commercial spacecraft](#) to successfully [rendezvous](#) with and attach to the [International Space Station](#) (ISS). SpaceX is contracted to deliver cargo to the ISS under [NASA's Commercial Resupply Services](#) program, and Dragon began regular cargo flights in October 2012. With the Dragon spacecraft and the [Orbital ATK Cygnus](#), NASA seeks to increase its partnerships with domestic commercial aviation and aeronautics industry.



Dragon

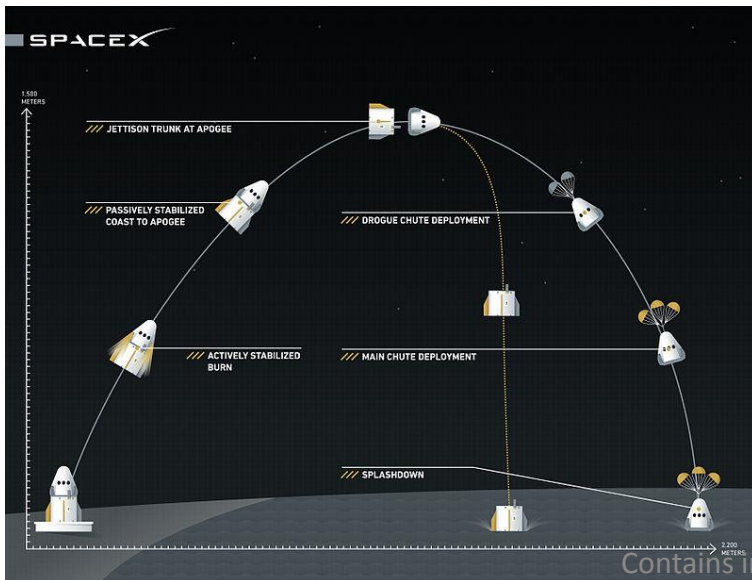
# Dragon 2 Manned Spacecraft



Dragon 2 spacecraft conducting a propulsive hover test, Nov. 2015



Crew Dragon Pad Abort Test Launch, May 6, 2015



An infographic of the SpaceX Dragon 2 Pad Abort Test for the May 2015 test, produced by SpaceX

Contains information that is publicly available on the internet

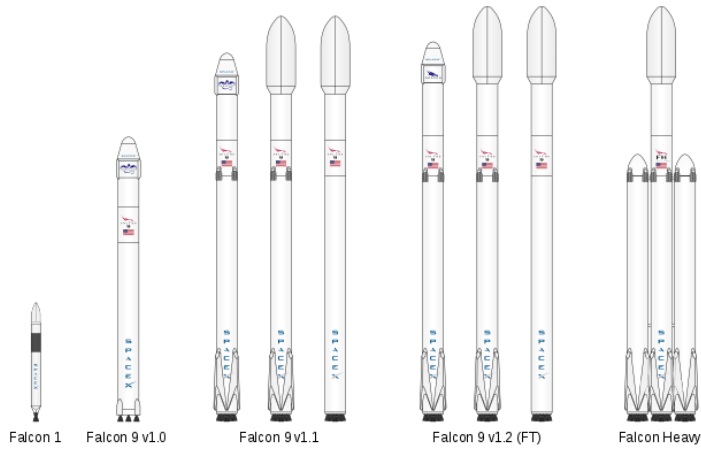
# SpaceX Falcon 9

The **Falcon rocket family** is an American family of multi-use rocket [launch vehicles](#) developed and operated by Space Exploration Technologies ([SpaceX](#)). The vehicles in this family include the flight-tested [Falcon 1](#) and [Falcon 9](#). The Falcon 1 made its first successful flight on 28 September 2008, after several failures on the initial attempts. The larger [Evolved Expendable Launch Vehicle](#) (EELV)-class Falcon 9 flew successfully into orbit on its maiden launch on 4 June 2010. The Falcon 9 is eventually intended to be a reusable vehicle. SpaceX is currently in production of the first [Falcon Heavy](#) launch system. Other designs for boosters with even larger payload lifting capabilities are currently being researched, but not yet confirmed.





# SpaceX Falcon



Conceptual rendering of Falcon Heavy at Pad 39A, Cape Canaveral



Falcon 9 first stage on an ASDS barge after the first successful landing at sea, CRS-8 Mission. April 2016

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# Boeing CST-100 Starliner



## General information

Manufacturer	<a href="#">Boeing</a>
Country of origin	<a href="#">United States</a>
Applications	Crew Transfer Vehicle
Orbit regimes	<a href="#">Low Earth</a>
Operator	<a href="#">Boeing</a> <a href="#">Bigelow Aerospace</a>
Lifetime	210 days (docked to ISS) <sup>[1]</sup>

## Production

Status	In development
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## Typical spacecraft

Average mass	≈10 tonnes <sup>[1]</sup>
Power	4 x 26300 Kg <sup>[1]</sup> <sup>[clarification needed]</sup>

## Dimensions

4.56 m
CM+SM: 5.03 m
CM: 3.14 m <sup>[1]</sup>

Contains information that is publically available on the internet

# NASA Commercial Crew: Dream Chaser by Sierra Nevada



Size Comparison to Space Shuttle



## Description

### Role:

Part of NASA's Commercial Crew Program to supply crew and cargo to the International Space Station

### Crew:

Up to 7<sup>[1][2]</sup>

### Dimensions<sup>[3]</sup>

#### Length:

9.0 m

29.5 ft.

#### Wing Span:

7.0 m

22.9 ft.

#### Volume:

16.0 m<sup>3</sup>

565 cu ft.

#### Mass:

11,300 kg

25,000 lb.<sup>[4]</sup>

## Performance

### Endurance:

At least 210 days<sup>[5]</sup>

### Re-entry:

Less than 1.5



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# Bigelow Expandable Activity Module



Full-scale mock-up of BEAM, January 16, 2013

## Station statistics

<a href="#">Launch date:</a>	2015
<a href="#">Launch vehicle:</a>	<a href="#">Falcon 9</a>
<a href="#">Mass:</a>	3,000 lb (1,360 kg) <sup>[1]</sup>
Length:	13 ft. (4 m) <sup>[1]</sup>
Diameter:	10.5 ft. (3.2 m) <sup>[1]</sup>
Living <a href="#">volume:</a>	565 cu ft (16 m <sup>3</sup> ) <sup>[2]</sup>



# Blue Origin



## Incremental Development

BLUE ORIGIN

- Suborbital program in flight testing stage
  - *Goddard* subscale demonstrator flown 2006-2007
  - *New Shepard* system in development
    - Propulsion Module
      - 2011 testing demonstrated boost, landing and flight to 45,000 feet/Mach 1.2
      - Development of next vehicle underway
    - Crew Capsule – successful pad escape test October 2012
- Orbital Transportation System
  - Reusable orbital Space Vehicle (SV)
    - Transport to LEO or ISS for up to seven people
    - ~22,000 lbm with crew at launch
  - Two-stage Orbital Launch Vehicle (OLV)
    - Expendable upper stage
    - Reusable first stage



# Blue Origin



New Shepard Launch on April 29, 2015.



New Shepard landing with parachutes on April 29, 2015.