1.0 UdSSR – Russian Systems
   • Vostok
   • Voskhod
   • Soyuz
   • Soyuz Derivative Systems
   • Additional Systems

2.0 Chinese Systems
   • Shenzhou

3.0 European Systems
   • ATV
   • ATV Evolution

4.0 Japanese Systems
   • HTV
   • HTV-R

5.0 US Systems
   • Mercury
   • Gemini
   • Apollo
   • Space Shuttle
   • Constellation Programm
   • COTS Programm
UdSSR and Russian Systems

First man-rated space craft in history
1.0 UdSSR - Russian Systems

1.1 Vostok

1. TV-camera
2. Life support system equipment
3. Descent module
4. Instrument panel
5. Attitude control handle
6. Commanding radio system antennas
7. Pilot in catapulting chair
8. ACS and spacesuits ventilation system tanks
9. Voice communication radio system (Zarya) antennas
10. Signal system antennas
11. Breaking propulsion system
12. Telemetric system antennas
13. Shutter of thermal control system
14. Sun tracker
15. Attitude control optical system (Vzor)
1.0 UdSSR - Russian Systems

1.1 Vostok

- Spacecraft of the first human spaceflight with Yuri Gagarin (April 12th 1961)
- Single crew cockpit for shortterm flights (max. 10 days)
- Vostok carrier rocket as launch vehicle of the vostok spacecraft
- Unreated versions for photographic spy applications (Zenit)
1.0 UdSSR - Russian Systems

1.2 Voskhod

- Second human spaceflight programm of the UdSSR
- Rated with a crew of two up to three cosmonauts
- First spacewalk, Alexey Leonov (March 18th 1965)
1.3 Soyuz

- The Soyuz space transportation system consists of two main elements: the Soyuz U launcher and the Soyuz TMA spacecraft
- Launcher: Soyuz U is derived from the Soviet R-7 rocket design; Soyuz U by now has over 1000 launches; 7000 kg payload to LEO
- Soyuz spacecraft design dates back to 1960s; TMA version is capable of transporting 3 crew to a space station and back
- Soyuz landing module was originally design for lunar missions (capsule outer moldline supports hyperbolic lifting entry)
1.4 Soyuz Derivative Systems: Progress

- The Progress spacecraft is an un-crewed resupply vessel for space stations derived from the Soyuz spacecraft
  - The utility and instrument modules are very similar to those of the Soyuz
  - The utility module holds pressurized supplies for the space station crew
  - The landing module is substituted with a structure for storing fluid supplies
- It is launched on the same launch vehicle as a Soyuz (Soyuz U launcher)
- The Progress spacecraft is designed to burn up during Earth entry after completion of its mission (space station trash disposal)
- A small reentry capsule can be flown with the Progress spacecraft in order to return small amounts of payload to Earth
1.0 UdSSR - Russian Systems

1.4 Soyuz Derivative Systems: Zond

- The Zond system was developed by the Soviet Union for unmanned and manned circumlunar flights
- The Zond spacecraft was based on the Soyuz spacecraft without a utility module
  - For manned circumlunar flights, a single crew members would have inhabited the landing module for the ~7 day mission
- The Zond spacecraft was designed to be launched into LEO by a Proton rocket and injected towards the Moon using a Block D upper stage
- 5 unmanned Zond missions were flown, some of them (2) would have been survivable for a human crew
  - One had a turtle as crew (the turtle survived)
1.4 Soyuz Derivative Systems: Lunar Orbiter (+ Lander)

- In addition to the Zond circumlunar program, the Soviet Union pursued a manned lunar landing program
  - The mission architecture was similar to the Apollo architecture: single launch (N1 rocket), with lunar orbit rendezvous (LOR), i.e. a lander spacecraft and an orbiter spacecraft
- The orbiter spacecraft was derived from the Soyuz spacecraft
  - Modified utility and instrument modules; modified heat shield and avionics for the landing module
- 1 cosmonaut would have remained in the orbiter while another cosmonaut landed on the Moon onboard LK (*Lunnyi Korabl*)
- All four N1 launches attempted were unsuccessful; there never was a manned lunar mission
1.4 Additional Systems: Energia-Buran

- Soviet orbiter program (1976-1993)
- One autonomous spaceflight (November 15th 1988)
- Program cancelled due to budget issues
1.0 UdSSR - Russian Systems

1.5 Additional Systems: KLIPER

- Russian concept for a reusable spacecraft
- Lifting body concept to replace Soyuz
- Crew capability up to six cosmonauts
- Program period 2000-2007
- Cancelled due to budget issues
2.0 Chinese Systems

Chinese Systems

First taikonaut in space: Oct. 2003
2.0 Chinese Systems

2.1 Shenzhou

- Chinese Shenzhou spacecraft is a derivative of the Russian Soyuz s/c
  - Spacecraft consists of service, reentry, and orbital modules; however their design is different from the Russian Soyuz design
  - The orbital module can be customized according to mission objectives
  - The orbital module remains operational after separation from the descent module

- Shenzhou spacecraft are launched on a Long March CZ-2F rocket from the Jiuquan Satellite Launch Center
  - 1st unmanned flight (Shenzhou 1): winter 1999 / 2000
  - 1st manned flight (Shenzhou 5): October 2003, taikonaut Yang Liwei
  - Shenzhou 6: October 2005; 2-person crew
  - Shenzhou 7: 3-person crew; EVA
European Systems

First autonomously flying and docking spacecraft to a man-rated habitat
3.0 European Systems

3.1 ATV
Automated Transfer Vehicle

- When Russia decided in 1994 to participate in the International Space Station (ISS) program, ESA made the decision to start the development of a re-supply vehicle for the ISS – the Automated Transfer Vehicle (ATV)

- The ATV development and production is being carried out by a consortium of companies in 10 countries under the leadership of EADS Astrium

- The ATV program took 13 years and cost ~ Euro 1.3 billion for ATV development, testing, and first flight

- Four more ATV flights to the ISS are planned over the next 4 years; ATV re-supply flights are one of the key contributions of ESA to the ISS program
  - Jules Verne: March 9th 2008
  - Johannes Kepler: February 16th 2011
  - Edoardo Amaldi: March 23rd 2012

- Currently, the ATV is only capable of transporting pressurized supplies and propellant to the ISS; however, ATV evolution options which could return cargo as well as transport crew to and from the ISS are under consideration
3.0 European Systems
3.0 European Systems
### 3.1 ATV: Mission Scenario

- **ATV docks autonomously to ISS**
- **ISS crew transfers supplies and waste, as well as propellant; ATV raises ISS orbit (reboost)**
- **ATV LEO free flight**
- **ATV launch on Ariane 5**
- **ATV LEO free flight**
- **ATV destructive Earth entry**
3.0 European Systems

3.2 ATV Evolution

- Advanced Reentry Vehicle (ARV) for payload return as no large payload returns are possible after the space shuttle retirement
- Crew Transportation Vehicle (CTV) for European astronauts to compete US and Russian spacecrafts

In 2011 a cooperation with NASA was announced to focus on more cost-effective programs due to budget issues. A proposal is expected for 2012.
Japanese Systems

H-II Transfer Vehicle
4.1 HTV

- The HTV is one of the Japanese Space Agency’s (JAXA) key contributions to the ISS
- The HTV is launched on an H-IIIB rocket, flies autonomously to ISS vicinity, is captured by the station’s robotic arm, and is then berthed to Node 2 (where it stays for 30 days)
- HTV can transport pressurized supplies as well as unpressurized spare parts up to the ISS; Earth entry is destructive
- The 1st HTV has successfully carried out its mission (Sept. 10th 2009); six more flights are planned as part of the ISS program (last flight Jan. 22nd 2011, next flight July 21st 2012)
4.0 Japanese Systems

4.2 HTV-R

- In 2010 JAXA proposed a return capsule option for HTV
- The pressurized compartment will be replaced with an reentry vehicle with a cargo capability of 1.6 t from ISS to Earth
- First launch is expected in 2017/18
US American Systems

First man on moon – First reusable orbiter
5.0 US Systems

5.1 Mercury

- First US man-rated spacecraft
- Single crew cockpit
- First suborbital ballistic flight with Alan Shepard (May 5th 1961 with Redstone)
- First orbital flight with John Glenn (Feb. 20th 1962 with Atlas)
5.0 US Systems

5.2 Gemini

- Second US spaceflight program
- Two crew cockpit
- First US spacewalk with Edward White (June 4th 1965)
- First in-orbit rendezvous of a spacecraft with station-keeping orbits
5.0 US Systems

5.3 Apollo

• US-Moonlanding program
• Crew of three into lunar orbit
• Crew of two on lunar surface
• First man on the moon (July 20th-21st 1968)
5.0 US Systems

5.3 Apollo

- SM – Service Module with propellant and supplies
- CM – Command Module (also return vehicle)
- LM – Lunar Module (LEM Lunar Excursion Module) for landing on surface and return to lunar orbit
5.0 US Systems

5.4 Space Shuttle

- First reusable spacecraft (orbiter, booster)
- Crew of two up to eight (twelve possible)
- About 13t payload to orbit and return
- Maximum of 17d mission duration
- 5 crafts, 135 total flights, 2 losses
5.4 Space Shuttle: Main Components Space Transportation System (STS)

**SRB**
Solid Rocket Booster (solid propellant)

**ET**
External Tank
LOX/LH2 (liquid propellant)

**Orbiter**
with crew compartment and cargo bay
5.0 US Systems

5.4 Space Shuttle: Orbiter

3-Deck crew compartment

Reusable Orbiter
5.0 US Systems

5.4 Space Shuttle: Orbiter Propulsion Systems

- **OMS**
  Orbital Maneuvering System
  (liquid propulsion for orbital maneuvers)

- **RCS**
  Reaction Control System
  (liquid propulsion for in-orbit maneuvers: pitch, jaw, roll)

- **SSME**
  Space Shuttle Main Engine
  (liquid propulsion for launch only)

Images: nose section, nose section, aft section
5.0 US Systems

5.4 Constellation Program

- **December 1998**: Start of ISS assembly
- **October 2000**: Expedition 1 arrives on ISS
- **February 2003**: Loss of space shuttle Columbia on mission STS-107
- **August 2003**: Columbia Accident Investigation Board releases report calling for a redirection of US human spaceflight policy
- **January 2004**: President George W. Bush presents the Vision for Space Exploration (VSE)
- **July 2005**: shuttle flights resume with mission STS-114
- **November 2005**: the Exploration Systems Architecture Study (ESAS) final report is published outlining a new space transportation architecture
- **August 2006**: CEV contract awarded to Lockheed Martin
- **June 2009**: the Augustine Commission starts work on a comprehensive review of US human spaceflight plans requested by the Obama administration
- **October 2009**: the final report of the Augustine Commission review of US human spaceflight plans is published
5.0 US Systems

5.4 Constellation Program: Roadmap
5.0 US Systems

5.4 Constellation Program: Launch Vehicle
### 5.0 US Systems

#### 5.4 Constellation Program: Crew Vehicle (ORION)

<table>
<thead>
<tr>
<th>ESAS Concept</th>
<th>Characteristic</th>
<th>Current Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOX / methane</td>
<td>RCS and SM propellants</td>
<td>NTO / MMH</td>
</tr>
<tr>
<td>5.5 m</td>
<td>Capsule base diameter</td>
<td>5 m</td>
</tr>
<tr>
<td>Blunt body, 32.5 deg. side-wall angle</td>
<td>Shape</td>
<td>Blunt body, 32.5 deg. side-wall angle</td>
</tr>
<tr>
<td>6</td>
<td>Crew transportation to ISS</td>
<td>4</td>
</tr>
<tr>
<td>2, linear</td>
<td>Solar arrays</td>
<td>2, circular</td>
</tr>
<tr>
<td>LIDS</td>
<td>Docking system</td>
<td>LIDS</td>
</tr>
<tr>
<td>At bottom of SM</td>
<td>Spacecraft adapter attachment</td>
<td>At top of SM</td>
</tr>
</tbody>
</table>
### 5.4 Constellation Program: Crew Launch Vehicle (ARES I)

<table>
<thead>
<tr>
<th>ESAS Concept</th>
<th>Characteristic</th>
<th>Current Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-segment RSRB</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; stage</td>
<td>5-segment RSRB</td>
</tr>
<tr>
<td>Polybutadiene acrylonitrile (PBAN)</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; stage fuel</td>
<td>Polybutadiene acrylonitrile (PBAN)</td>
</tr>
<tr>
<td>2 separate tanks</td>
<td>Upper stage type</td>
<td>Common bulkhead</td>
</tr>
<tr>
<td>Air-startable SSME</td>
<td>Upper stage engine</td>
<td>J-2X (same as Ares V)</td>
</tr>
<tr>
<td>5.5 m</td>
<td>Upper stage diameter</td>
<td>5 m</td>
</tr>
<tr>
<td>LOX / LH&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Upper stage propellants</td>
<td>LOX / LH&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
</tbody>
</table>

**Orion & spacecraft adapter**

**Ares I upper stage & interstage**

**Ares I 1<sup>st</sup> stage**
### 5.0 US Systems

#### 5.4 Constellation Program: Payload Launch Vehicle (ARES V)

<table>
<thead>
<tr>
<th>ESAS Concept</th>
<th>Characteristic</th>
<th>Current Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 SSME engines</td>
<td>Core stage engines</td>
<td>5 or 6 RS-68 engines</td>
</tr>
<tr>
<td>8.4 m (same as shuttle external tank)</td>
<td>Core stage diameter</td>
<td>10 m</td>
</tr>
<tr>
<td>2 x 5-segment RSRBs (PBAN)</td>
<td>Boosters</td>
<td>2 x 5.5-segment RSRBs (PBAN)</td>
</tr>
<tr>
<td>2 x J-2X</td>
<td>Upper stage engines</td>
<td>1 x J-2X</td>
</tr>
<tr>
<td>2 separate tanks</td>
<td>Upper stage type</td>
<td>Common bulkhead</td>
</tr>
<tr>
<td>8.4 m</td>
<td>Upper stage diameter</td>
<td>10 m</td>
</tr>
<tr>
<td>8.4 m</td>
<td>Fairing external diameter</td>
<td>10 m</td>
</tr>
</tbody>
</table>
## 5.0 US Systems

### 5.4 Constellation Program: Lunar Lander (ALTAIR)

<table>
<thead>
<tr>
<th>ESAS Concept</th>
<th>Characteristic</th>
<th>Current Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integral airlock</td>
<td>Ascent stage airlock</td>
<td>Separate airlock</td>
</tr>
<tr>
<td>Horizontal cylinder</td>
<td>Ascent stage geometry</td>
<td>Vertical cylinder</td>
</tr>
<tr>
<td>LOX / methane (same as ESAS CEV)</td>
<td>Ascent stage propulsion</td>
<td>NTO / MMH (same as shuttle OMS)</td>
</tr>
<tr>
<td>7.5 m</td>
<td>Descent stage diameter</td>
<td>8.4 m</td>
</tr>
<tr>
<td>4, derived from RL-10</td>
<td>Descent stage engines</td>
<td>1, derived from RL-10</td>
</tr>
<tr>
<td>8 identical tanks, 2 LOX, 2 LH₂</td>
<td>Descent stage tanks</td>
<td>Custom tanks for LOX and LH₂</td>
</tr>
<tr>
<td>With descent stage</td>
<td>LOI maneuver</td>
<td>With descent stage</td>
</tr>
</tbody>
</table>

[Image of Lunar Lander (ALTAIR)]

**Sources:**
- [ESAS Concept](https://www.nasa.gov/mission_pages/cesi/development_concepts.html)
5.0 US Systems

5.4 Constellation Program: Augustine Commission

- After being sworn in, the Obama Administration conducted comprehensive analyses and reviews of all US government agencies and programs
- In June 2009, a commission lead by former Lockheed Martin CEO Norman R. Augustine was appointed by the President’s Science Advisor to carry out a comprehensive review of US human spaceflight plans
- In October 2009, the commission’s final report was released with the following major findings/recommendations:
  - The current human spaceflight plan is on an unsustainable trajectory (funding, timeline)
  - All remaining flights in the shuttle program should be flown without schedule pressure
  - The US participation in the ISS program should be extended to the year 2020
  - Orion and Ares I will likely not be operational before the year 2017 (resulting in a potential 7-year delay in US human spaceflight capability); Ares V may not be ready before the late 2020s
  - Serious consideration should be given to purchasing crew transportation services from the US commercial sector (for example as part of the COTS program: COTS-D)
  - With increased funding (+ $3 billion / year), interesting program options with exploration missions beyond LEO in the early 2020s are available, in particular the Flexible Path option
5.4 Constellation Program: Alternatives (Shuttle-Derived Heavy Lift Launch Vehicle)

- **Ares V “Lite”**
  - 140 mt to 28,5 deg. LEO
  - 2 5-segment RSRBs, 5 RS-68 engines
  - Upper stage (EDS) with one J-2X

- **Shuttle-derived sidemount launcher**
  - Shuttle orbiter substituted with payload shroud and thrust structure with 3 SSMEs
  - 100 – 110 mt to 28,5 deg. LEO

- **Shuttle-derived inline launcher**
  - Launcher with re-designed external tank (3 SSMEs below), 2 4-segment RSRBs
  - J-2X-based upper stage (single engine)
  - 100 – 110 mt to 28,5 deg. LEO
5.0 US Systems

5.5 COTS

Commercial Orbital Transportation Services

- COTS program was created in January 2006 in order to address the anticipated gap in US cargo capability to the ISS after shuttle retirement.

- Requirements for 4 COTS capability levels were defined:
  - Capability level A: External unpressurized cargo delivery and disposal
  - Capability level B: Internal pressurized cargo delivery and disposal
  - Capability level C: Internal pressurized cargo delivery, return and recovery
  - Capability level D: Crew transportation

- 2 commercial partners are currently developing COTS systems as part of funded Space-Act-Agreements:
  - Space Exploration Technologies (SpaceX): Dragon spacecraft and Falcon 9 launch vehicle
  - Orbital Space Sciences Corporation (Orbital): Cygnus spacecraft and Taurus II launch vehicle

- In December 2008, NASA awarded SpaceX and Orbital contracts for Commercial Resupply Services (CRS) to the ISS
  - 8 Flights from Orbital (worth ~$1.9 billion) and 12 flights from SpaceX (worth ~$1.6 billion)
5.0 US Systems

5.5 COTS
5.0 US Systems

5.5 COTS: SpaceX (Falcon9 – Dragon)

- **Payload Fairing or Dragon spacecraft**
- **2nd stage:**
  - LOX / kerosene propulsion
  - 1 Merlin engine
- **Interstage**
- **1st stage:**
  - LOX / kerosene propulsion
  - 9 Merlin engines (developed in-house at Space X)

Falcon 9 Launch Vehicle
(10450 kg to 28.5 deg LEO from KSC)

Capsule (pressurized cargo stored here)
ISS berthing adapter
Draco thrusters (MMH / NTO)
Solar panel (batteries located in trunk and in capsule)
“Trunk” (unpressurized cargo stored here)

Dragon interior arrangement for cargo transportation
Dragon interior arrangement for crew transportation

Space Transportation Systems
5.5 COTS: SpaceX (Falcon9 – Dragon)

- Dragon free flight
- Dragon berthing ops
- Dragon berthed to ISS Node 2
- Dragon un-berthing ops
- Falcon 9 2nd stage flight
- Dragon launch on Falcon 9 (KSC)
- Dragon free flight
- Dragon Earth entry and splashdown
5.0 US Systems

5.5 COTS: Orbital (Taurus II – Cygnus)

- Cygnus spacecraft
  - Service module: based on STAR bus; dual-mode N$_2$H$_4$/MON-3 or N$_2$H$_4$ propulsion
  - Pressurized cargo module is based on ISS Multi-Purpose Logistics Module (MPLM) heritage and the ISS berthing mechanism
  - Supply capability to ISS berthing adapter: 2,000 kg (standard), 2,700 kg (enhanced)

- Taurus II launch vehicle
  - 2-stage launch vehicle
  - Stage 1: LOX / kerosene propellants; derived from Zenit vehicle
  - Stage 2: ATK Castor 30 solid rocket motor
  - Initial launch site: Wallops Flight Facility (compatible with other launch sites)
  - Payload capability: ~5000 kg to LEO
Summary

Short summary and comparison of most important space crafts
## Summary

### Current operating space crafts

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Shuttle orbiter</td>
<td>Retired</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Soyuz</td>
<td>Operational</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes, with modifications</td>
<td>Yes (small amount)</td>
<td>?</td>
</tr>
<tr>
<td>Progress</td>
<td>Operational</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td>?</td>
</tr>
<tr>
<td>ATV</td>
<td>Operational</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td>?</td>
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<tr>
<td>HTV</td>
<td>Operational</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Shenzhou</td>
<td>Operational</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes, with modifications</td>
<td>Yes (small amount)</td>
<td>?</td>
</tr>
<tr>
<td>Dragon</td>
<td>Ready for test</td>
<td>With modifications</td>
<td>Yes</td>
<td>With modifications</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cygnus</td>
<td>Under dev.</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Orion</td>
<td>Under dev.</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>?</td>
</tr>
</tbody>
</table>
Summary

Size comparison of different space crafts

- Pressurized
- Unpressurized
- Fuel

comparable scale of all vehicle sizes

Mercury

Command Module (Apollo)  Orion  Space Shuttle Orbiter (3-Deck crew compartment)

Progress  Automated Transfer Vehicle  H-II Transfer Vehicle  Dragon  Dragon Extended  Cygnus  Cygnus Extended

Space Transportation Systems
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