ISRO Advances Gaganyaan Mission Through Crew Module Validation to Strengthen India's Human Spaceflight Capability and Re-entry Safety

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Recent Developments:

- **ISRO** has successfully completed major qualification tests of the **Gaganyaan Crew Module** systems, including the **Crew Module Up-righting System (CMUS)**, **Crew Module–Service Module Connect and Disconnect System (CS-CDS)** and **Crew Module structural qualification** for apex cover separation.
- **The successful tests** validate critical technologies related to crew safety during **module separation, atmospheric re-entry, parachute deployment and sea recovery**, bringing India closer to its first human spaceflight mission.

Gaganyaan Mission:

About:

- **Gaganyaan** is India's first indigenous **human spaceflight programme**, formally announced in **2018**.
- **The mission** aims to demonstrate India's capability to send **three astronauts** into a **400 km Low Earth Orbit (LEO)** for nearly **three days** and safely recover them through **sea splashdown** in Indian waters.
- **Successful execution** will make India the **fourth country**, after the **United States, Russia and China**, to independently develop and execute a human spaceflight mission.
- **The Human-rated Launch Vehicle Mark-3 (HLVM3)** will place the **Orbital Module (OM)** into the designated orbit.
- **Before the crewed mission**, ISRO is conducting multiple **uncrewed qualification missions** to validate the performance, reliability and safety of all mission-critical systems.

Mission Objectives:

- **Demonstrate** indigenous human spaceflight capability.
- **Validate** crew safety technologies under actual flight conditions.
- **Develop** advanced technologies required for long-duration human space missions.
- **Strengthen** India's strategic and technological capabilities in space exploration.

Crew Training and Human Spaceflight Programme:

Astronaut-Designates:

- **Group Captain Prasanth Balakrishnan Nair**
- **Group Captain Ajit Krishnan**
- **Group Captain Angad Pratap**
- **Wing Commander ShubhanshShukla**

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Training Features:

- **Astronauts** undergo training in spacecraft operations, survival techniques, emergency procedures, microgravity adaptation and physical conditioning.
- **Training** also includes simulation exercises for launch, orbital operations, re-entry and recovery.

Orbital Module (OM):

Overview:

- **The Gaganyaan spacecraft** is officially known as the **Orbital Module (OM)**.
- **The Orbital Module** follows a **bi-modular configuration**, reducing structural complexity and overall launch mass compared to conventional three-module spacecraft.

Crew Module (CM):

- **The Crew Module** is a pressurised and habitable capsule designed to accommodate astronauts throughout the mission.
- **The module** incorporates an **Environmental Control and Life Support System (ECLSS)** to maintain Earth-like living conditions.
- **The Crew Module** also integrates the **Thermal Protection System (TPS)**, avionics, navigation systems and deceleration mechanisms required for safe atmospheric re-entry and splashdown.

Service Module (SM):

- **The Service Module** is an unpressurised unit providing propulsion, electrical power, thermal management, avionics support and orbital manoeuvring capability.
- **The module** separates before atmospheric re-entry and burns up completely during descent.

Comparison with Other Human Spacecraft:

- **Russia's Soyuz** and **China's Shenzhou** employ a **three-module configuration**.
- **Gaganyaan** adopts a **two-module architecture**, improving mass efficiency while retaining all essential mission functions.

Crew Module Re-entry Safety Mechanisms:

Service Module Separation, Connect & Disconnect System (CS-CDS):

- **The Service Module** must separate precisely before atmospheric re-entry begins.
- **The Connect & Disconnect System (CS-CDS)** employs redundant pyrotechnic mechanisms to ensure reliable separation.
- **Failure of separation** could alter the spacecraft's centre of gravity and compromise safe re-entry.

Sphere-Cone Aerodynamic Configuration:

- **The Crew Module** adopts a **sphere-cone design** that improves aerodynamic stability during hypersonic descent.
- **The blunt spherical base** generates a detached shock wave that deflects extreme aerodynamic heating.
- **The conical section** generates controlled aerodynamic lift, reducing deceleration loads experienced by astronauts.

Thermal Protection System (TPS):

- **The ablative heat shield** gradually chars and erodes during re-entry, carrying away intense thermal energy.
- **The Thermal Protection System** protects the Crew Module from temperatures generated during hypersonic atmospheric entry.

Active Attitude Control:

- **Reaction Control System (RCS)** thrusters continuously maintain the correct orientation of the Crew Module.
- **The attitude control system** ensures that the heat shield remains properly aligned throughout atmospheric descent.

Multi-stage Parachute Deceleration System:

- **The deceleration system** consists of **10 parachutes** belonging to **4 different categories**.
- **The deployment sequence** includes **Apex Cover Separation Parachutes, Drogue Parachutes, Pilot Parachutes and Main Parachutes**, progressively reducing descent velocity before splashdown.
- **The parachute architecture** incorporates redundancy, ensuring safe recovery even if one parachute does not perform as expected.

Crew Module Up-righting System (CMUS):

- **The Crew Module** is naturally bi-stable after splashdown because of its internal mass distribution.
- **If inversion occurs**, the **Crew Module Up-righting System (CMUS)** automatically inflates flotation bags using stored cold gas.
- **The system** restores the capsule to an upright position, protects astronaut safety and exposes communication beacons for rapid recovery by the **Indian Navy**.

Strategic and Scientific Significance:

Scientific Importance:

- **The mission** will facilitate **microgravity research** in biological sciences, material science, medicine and space technology.
- **The programme** will validate indigenous technologies such as **life-support systems, radiation protection, crew recovery and safe atmospheric re-entry**.

Strategic Importance:

- **Human spaceflight capability** enhances India's technological self-reliance.
- **The programme** strengthens India's position among major global space powers.
- **The mission** supports long-term national objectives in strategic space capability and advanced aerospace manufacturing.

Future Human Spaceflight Roadmap:

Bharatiya Antariksh Station:

- **Technologies demonstrated through Gaganyaan** will support the development of the **Bharatiya Antariksh Station (BAS)**.
- **The first module (BAS-01)** is targeted for launch by **2028**, while the complete modular space station is planned by **2035**.

Crewed Lunar Mission:

- **India** aims to undertake an indigenous **crewed lunar mission by 2040**, building upon technologies developed under the Gaganyaan programme.

Related Technologies and Institutions:

Environmental Control and Life Support System (ECLSS):

- **Maintains** breathable atmosphere, temperature, humidity, pressure and carbon dioxide removal inside the Crew Module.

Human-rated Launch Vehicle Mark-3 (HLVM3):

- **A human-rated version** of **Launch Vehicle Mark-3 (LVM3)** incorporating enhanced structural reliability, fault tolerance and crew safety features.

Crew Escape System (CES):

- **Provides** rapid separation of the Crew Module from the launch vehicle during launch emergencies, ensuring astronaut survival.

UPSC Value Addition:

Important Terms:

- **Low Earth Orbit (LEO):** An Earth orbit generally extending up to about **2,000 km**, where most human space missions operate.
- **Atmospheric Re-entry:** The controlled return of a spacecraft from orbit through Earth's atmosphere.
- **Splashdown:** Controlled landing of a spacecraft in the sea.
- **Human Rating:** Certification process ensuring that a launch vehicle or spacecraft satisfies stringent crew safety requirements.
- **Ablation:** Controlled erosion of heat-shield material to dissipate extreme thermal energy during re-entry.

Previous Human Spaceflight Milestones:

- **Vostok-1 (1961):** First human spaceflight by **Yuri Gagarin**.
- **Apollo-11 (1969):** First human landing on the Moon.
- **ShenzhoProgramme:** China's indigenous human spaceflight programme.
- **Soyuz Programme:** Russia's long-running human space transportation system.

Prelims Facts:

- **Gaganyaan** aims to place **3 astronauts** in **400 km Low Earth Orbit** for about **3 days**.
- **HLVM3** is the designated launch vehicle for the mission.
- **The Orbital Module** consists of only **2 modules**—**Crew Module** and **Service Module**.
- **The Service Module** separates before atmospheric re-entry.
- **The Crew Module** uses a **sphere-cone configuration** for aerodynamic stability.
- **The parachute deceleration system** consists of **10 parachutes** of **4 different types**.
- **The Crew Module Up-righting System (CMUS)** uses **stored cold gas** to restore capsule orientation after splashdown.
- **Gaganyaan** serves as the technological foundation for the **Bharatiya Antariksh Station** and India's proposed **crewed lunar mission**