N.O.M.A.D.: An Exploration Mission to Neptune – Mission Concept
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Introduction: Neptune is the eighth planet in our solar system and the furthest. Because of this, our knowledge about Neptune is severely limited. This report analyses a hypothetical mission to Neptune, where the spacecraft would explore the ice-giant and its moons. The goal is to design a collaborative mission between several space agencies in the name of peaceful exploration to learn more about ice giants, our solar system and the universe itself.

Based on heritage missions, a concept is created for a large scale science mission to Neptune. The necessary subsystems are developed and compiled in form of a Preliminary Design Review. This is done within the scope of the EPFL Space System Design Engineering course. I would also like to mention the EuroSpaceHub Project and the EuroMoonMars Initiative.

Mission Objectives: The mission is to explore Neptune and its moons with a variation of science instruments and to set a precedent for future long-term interplanetary missions.

The NOMAD spacecraft would be the first spacecraft to reach Neptune since Voyager 2 and a far fly-by from New Horizons. As mentioned, Neptune is one of two ice-giants in our galaxy, neither of which has been observed from up close to date. Exploring Neptune will be a crucial step in understanding the universe.

The main partners of the mission will be NASA, ESA, JAXA and technical universities across the globe. Every scientific institution shall have access to the collected data as the mission is executed in the name scientific exploration. It will be an L-class mission and the launch is planned for no earlier than 2032.

The majority of the design choices will be based on heritage missions such as Cassini, Galileo, New Horizons and BepiColombo. Additionally, inspiration is taken from the soon to be launched JUICE and Neptune Odyssey, although the latter was never realised in favour of a mission to Uranus.

The science objectives are to take images of Neptune and its moons, mainly Triton, on the visible, IR and UV spectrum. Moreover, the composition of the atmosphere will be analysed and the magnetic field will be measured.

Mission Design: The complete mission is going to span over three decades. Phases A to D, so from feasibility study to launch, will take approximately ten years, mainly in order to thoroughly test the spacecraft. The spacecraft will be launched into Earth escape orbit by the then hopefully well-established Ariane 6. The launch window will have to be calculated very carefully to ensure the shortest possible cruise. The objective is to take no more than 15 years to reach the Neptune insertion orbit. During this time, the spacecraft shall be in CRUISE mode (fig. 1), where all non-essential systems will be turned off to preserve power.

Once the spacecraft has entered its elliptical Neptune insertion orbit, the primary propulsion system will be used to slow the spacecraft down to enter a circular orbit. Then the secondary propulsion system adjusts the orbit inclination, such that the final science orbit is a circular polar orbit, which allows coverage of almost the whole planet surface.

The science mission is planned to take ten years with a possible extension of five years. After that, the spacecraft will no longer actively work to maintain its orbit, which will degrade over time until the spacecraft eventually enters Neptune's atmosphere.

Operational Modes: The spacecraft has eight modes on mission level (fig. 1). From launch until the spacecraft enters Earth escape orbit, it is in LAUNCH mode, where all systems are off. In Earth orbit, the spacecraft will go through a commissioning phase, where every system is tested (OPERATION). When the downlinked TM is satisfactory, the spacecraft will commence its cruise to Neptune.

Mode	Operations
LAUNCH	Lift-off until it reaches earth orbit
IDLE	While in orbit, only maintenance loads on (ADCS, OBC, etc.)
SAFE	Entered if spacecraft out of control, turn off non-essential systems until back in control
OPERATION	Observation of Neptune using science instruments
TELECOM	Contact to GS over DSN (TM, TC)
CRUISE	during cruise from earth to neptune (non-essential loads turned off until Neptune orbit insertion)
ECLIPSE	Only engaging in possible operations, save power
EOL	All systems are turned off

Figure 1: Operational Modes

Once it has reached its final science orbit around Neptune, the spacecraft will be in IDLE or OPERATION mode, depending on whether the science payload is gathering data. When the spacecraft is in view of the DSN, it will be in TELECOM mode, where TM and TC is downlinked and uplinked, respectively. In case control over the spacecraft is lost, it enters the SAFE mode until proper operations can be resumed. Once the spacecraft has reached the end of its mission life (after a possible extension), the spacecraft enters EOL mode.

Subsystems: A concept has been developed for the following subsystems. As this is but an executive summary, they are only briefly described.

Telecommunication Subsystem. Data is communicated via the DSN's 70 m parabolic antenna using X- and Ka-Band.

Electrical Power Subsystem. The power source will be made up of four GPHS-RTGs since it is practically infeasible to use solar power at 30 AUs from the Sun.

Structure and Configuration. The spacecraft will have a cubic structure in accordance with the fairing dimensions of Ariane 6. The EPS is placed centrally to minimize line losses and improve heat dispersion.

Command and Data Handling. Roughly 200 kbps of science data is generated which needs to be handled additionally to the house-keeping data.

ADCS. The attitude is controlled by an active, zero-momentum bias system using three reaction wheels.

Propulsion Subsystem. A liquid bipropellant propulsion system will be used to fulfil the high ΔV requirements.

Thermal Subsystem. The mean temperature of Neptune is -200°C, this makes it very important to properly heat the system. The excess power of the EPS will be distributed in the form of heat to keep the other systems operational.

Science Payload:

The science objectives are to be fulfilled by eight main science instruments (fig. 2), which are all based on heritage instruments.

Instrument	Heritage Instrument	Heritage Mission
Magnetometer	MESSENGER MAG	MESSENEGR
Imaging Science Subsystem	ISS	Cassini
Visible-Near Infrared Imaging Spectrometer	Ralph	New Horizons
Ion and Neutral Mass Spectrometer	INMS	Cassini
Laser Altimeter	Mercury Laser Altimeter	MESSENGER
Radio and Plasma Wave Science	RPWS	Cassini
UV Imaging Spectrometer	Alice	Rosetta
Ice Penetrating Radar	MARSIS	Mars Express

Figure 2: NOMAD Science Instruments

Magnetometer. A magnetometer is used to measure Neptune's magnetic field with the goal of mapping its unusual magnetosphere in three dimensions [1].

Imaging Science Subsystem. Map the surface and the atmosphere movements (i.e. storms, aurorae) of the planet by repeatedly taking images of the planet [2].

IR Imaging Spectrometer. Map the planet surface geology and temperature, and the thermal patterns of the atmosphere [3].

Mass Spectrometer. Measure composition (mass of ions) of Neptune's atmosphere and magnetosphere [4].

Laser Altimeter. Map Neptune's surface topography and morphology by continuously sending light pulses at 10-30 Hz [5].

Radio and Plasma Wave Science. The PRWS instrument is used to detect radio and plasma waves in Neptune's magnetosphere [6].

UV Imaging Spectrometer. Analyse the composition of Neptune's surface and its atmosphere [7].

RADAR. Map Neptune's surface topography by continuously sending RF pulses [8].

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Abbreviations:

- NOMAD: Neptune Observation Mission and Discovery
- PDR: Preliminary Design Review
- TM: Telemetry
- TC: Telecommand
- DSN: Deep Space Network
- EOL: End Of Life
- IR: Infrared
- UV: Ultraviolet
- EPS: Electrical Power System
- GPHS: General-Purpose Heat Source
- RTG: Radioisotope Thermoelectric Generator
- ADCS: Attitude Determination and Control System
- C&DH: Command and Data Handling
- IRIS: IR Imaging Spectrometer
- RPWS: Radio and Plasma Wave Science
- UVIS: UV Imaging Spectrometer