Integrated Breadboard 3: Rover Capability Evolution Within Sfr Mission Context And Future Planetary Technology Testing Platform, As A Service

ASTRA 2023 Oral Presentation

DEFENCE AND SPACE

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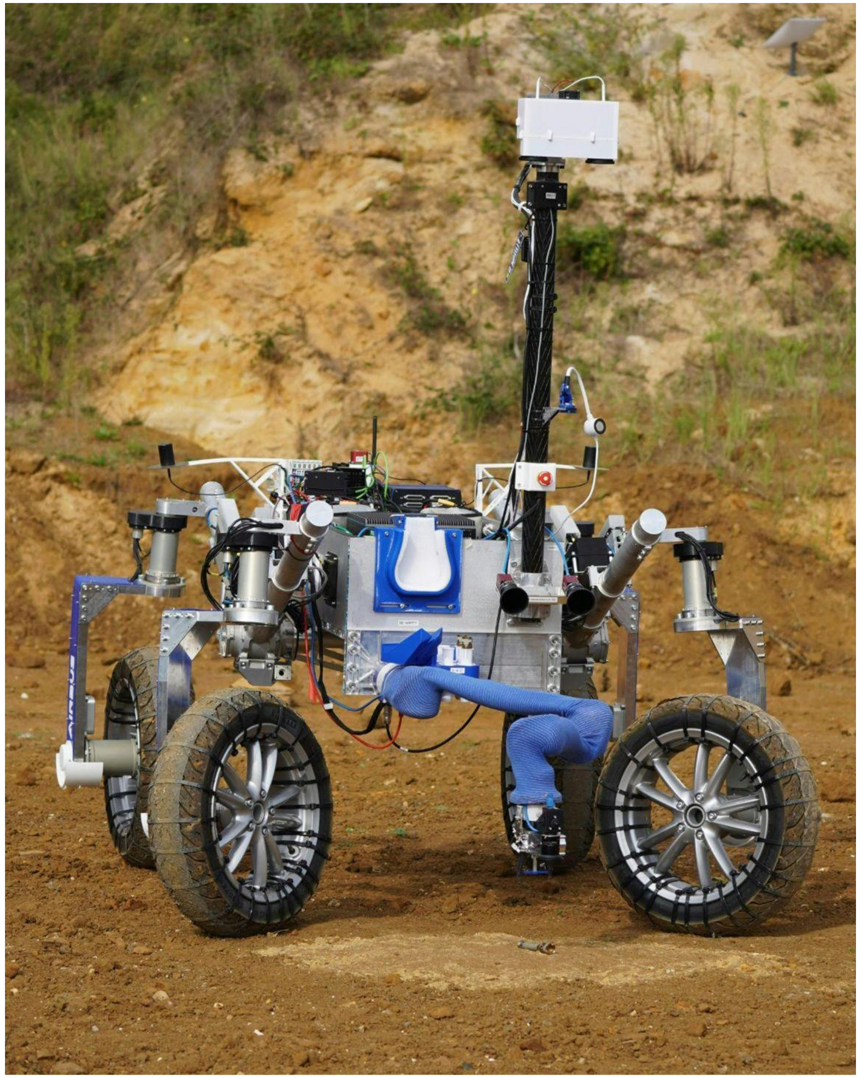
Context of the Mission

The Field Test Rover System (FTRS) was developed in the frame of **Sample Fetch Rover** mission, part of the Mars Sample Return Programme. High level requirements are:

- **Fetch autonomously** samples on the surface of Mars and bring them back to the launcher
- Do it **"As fast as possible"** (limiting human in the loop, limiting the duration of the stops, increase the drive speed)
- Develop **iterative breadboards**: Unit BBs, delta BB, IBB1, IBB2, IBB3

In the frame of IBB3 the objectives were:

- To test **Guidance, Navigation and Control (GNC)** algorithms, and traverse capabilities. For that we needed a platform that can allow mobility, relative localization, mapping, hazard detection
- To demonstrate **sample fetching** capabilities
- To use an **Operations Layer** to drive the tests
- To keep the solutions as **generic** as possible



Field Test Rover System (FTRS) know as "Codi"

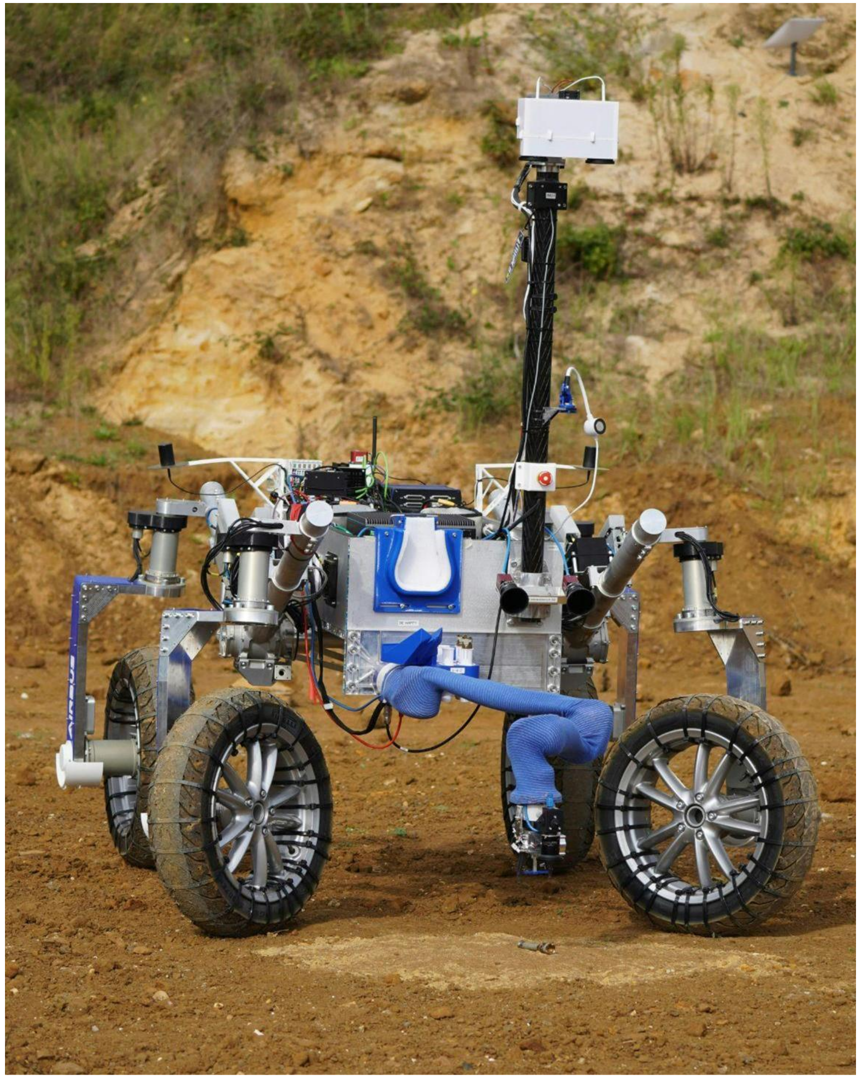
Context of the Mission

<u>Elements that are not representative of a flight model:</u>

- **Power** - use of batteries without solar panel, not representative of the flight design
- **Cooling system** - not a proper cooling system to prevent overheating of the hardware, e.g. we needed extra protection from the sun during the Field Trials
- **Rubber wheels** - not flight representative, mesh wheels would be used for the flight model
- **OBC** - IBB3 was not using Processor In the Loop, in order to increase the speed in development and testing (**ASTRA 2023 presentation by Piotr Weclewski** "TRL 6 Demonstration Of The SFR Mission Concept On A LEON4 Processor")
- **Cameras** are flight-like COTS - not flight representative optics

<u>Elements that were specific for testing:</u>

- **GNSS receiver** - used to have a ground truth and assess the position and heading estimate error
- **GNSS base station** - used to send RTK corrections to the rover
- **RTK corrections receiver** - to get below one cm ground truth precision
- **Emergency** stops



Field Test Rover System (FTRS) know as "Codi"

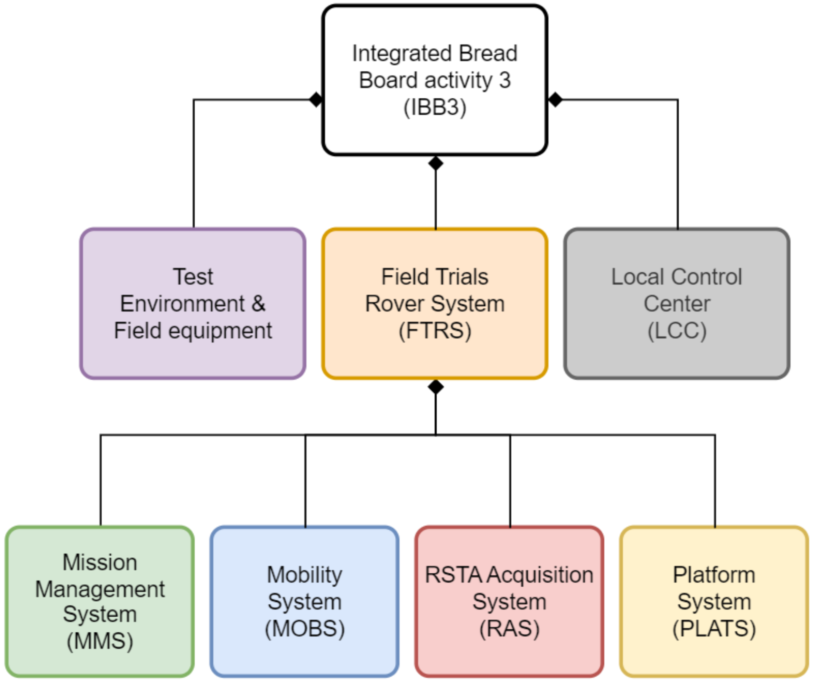
IBB3 team

The IBB3 team was composed as follow:

- **Technical Lead** - 1 person
- **Software** - 2 people
- **GNC Mobility** - 6 people
- **Robotic arm (RAS)** - 4 people
- **Platform** - 1 person
- **Mission Management System** -1 person

Our first guideline was **"1 single team"**

- Daily stand ups
- Agile development methodology
    - Fast iteration cycles



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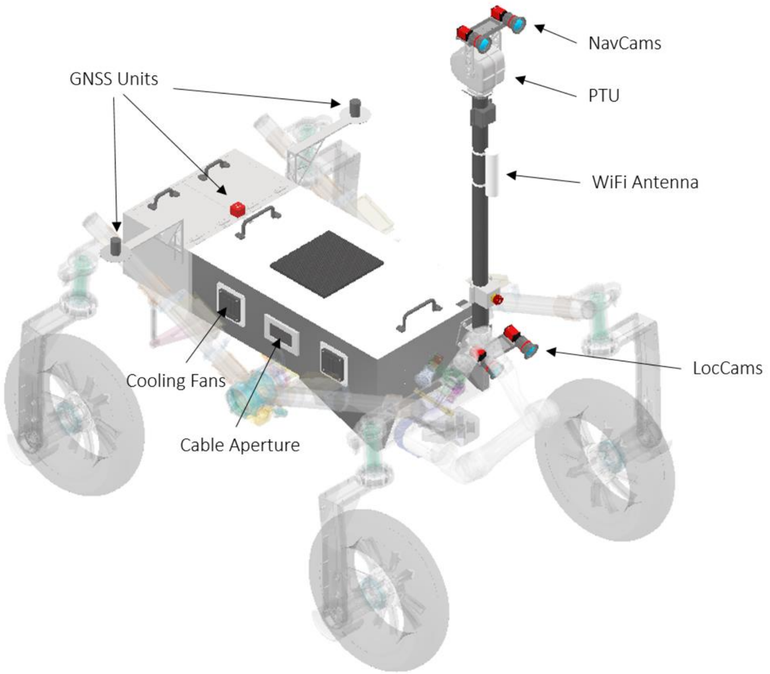
Platform

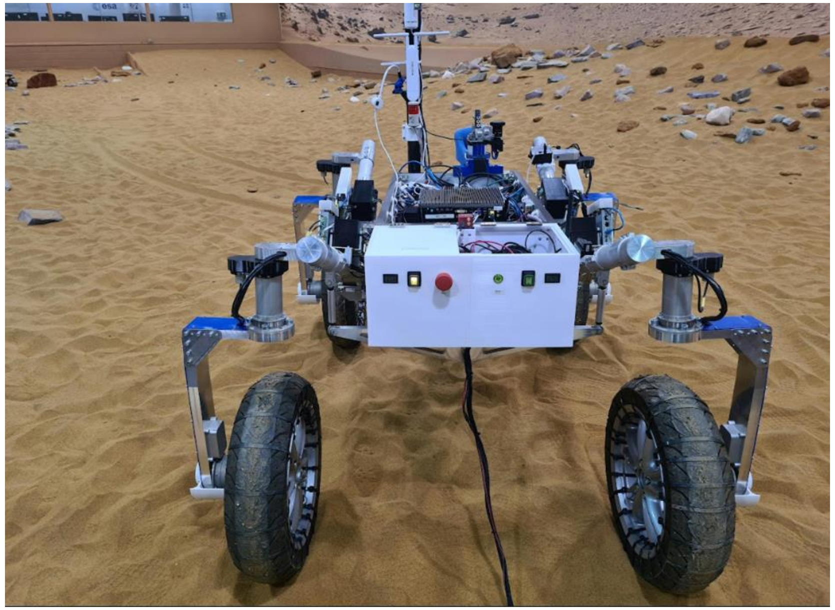
Elements of the platform that were core for IBB3 project:

- **Locomotion** subsystem - differential rocker bogie, wheels, steering actuators, drive actuators
- **Navigation** sensors/equipement - IMU, Stereo Cameras, Pan Tilt Unit
- **Fetching** subsystem - Arm, gripper, regrip bracket, stow slots
- 1 single **OBC** to run all the servers, algorithms, services

Elements that were specific for testing:

- **Ground truth** camera (for indoor GT)
- **GPS** antennas + **RTK correction** receiver - for GPS reference position and heading
- **Emergency Stops** (remote and on the rover)
- **Wifi-Network** - for command/control the rover from the control center)
- **Manual driving** capability - drive the rover with a remote control





GNC - Mobility

Main functionalities that were developed/matured in the frame of IBB3

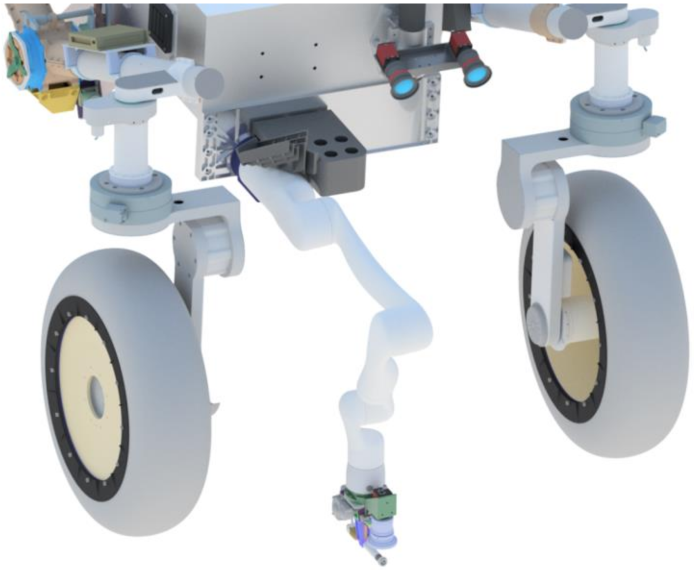
- Relative Localisation (**RelLoc**) combining Visual Odometry, Wheel Odometry and IMU - first time the full GNC stack was used in closed loop in the frame of SFR project - 0.25 % error
- Sun Sensing Heading Estimation (**SSHE**) - first time tested in the frame of SFR project - error never exceeded 0.7 degrees in the worst conditions, i.e. with a sun elevation of 60 degrees
- Autonomous Navigation (**AutoNav**) - determine autonomously the shortest safe path between waypoints - tested up to 300 meters in the IBB2 test campaign - 200 meters in the IBB3 campaign. No terrain misclassifications occurred.
- Absolute Global Localisation - Traverse (**AGL-T**) - comparison of reference images (in mission, taken by a Mars orbiter) and images taken by FTRS in situ. In the frame of testing, the reference images are taken either by the FTRS beforehand or by a drone. Reference Map resolution at 25 cm.
- Absolute Global Localisation - Depot (**AGL-D**) - comparison of images and Digital Elevation Map taken by a rover on Mars (e.g. Perseverance) with images taken by FTRS. In the frame of testing, the reference images are taken either by FTRS beforehand or by a drone. Map resolution 4cm. Total error (knowledge and control) better than 10cm.
- **In Depot path** design and driving - transition between autonomous navigation and deterministic 'in-depot' operations. In conjunction with Trasys, the capability to design depot paths using a combination of GNC processing tools & 3DROCS was developed.

Lower level control loops

- Trajectory Control (**TrajCtrl**) - provides the rover-level commands to follow a path
- Locomotion Maneuver Control (**LocoMan**) - converts the TrajControl rover-level commands into axis (drive or steer) commands

A lot of effort between IBB2 and IBB3 to **interface GNC algorithms** with the Operational layer software (3DROVS, 3DROCS from Trasys)

RSTA Acquisition Subsystem



ASTRA 2023 presentation by Chris Hackett: “Reusable Sample Tube Assembly (RSTA) Acquisition System: Pickup and Stowage System Developments in SFR Mission Context”

Fetching without human in the loop a sample on the surface of Mars

The RAS was fully integrated in the platform:

- Power
- Electronics
- Data
- Sharing hardware with other GNC functionalities (OBC, NavCam)

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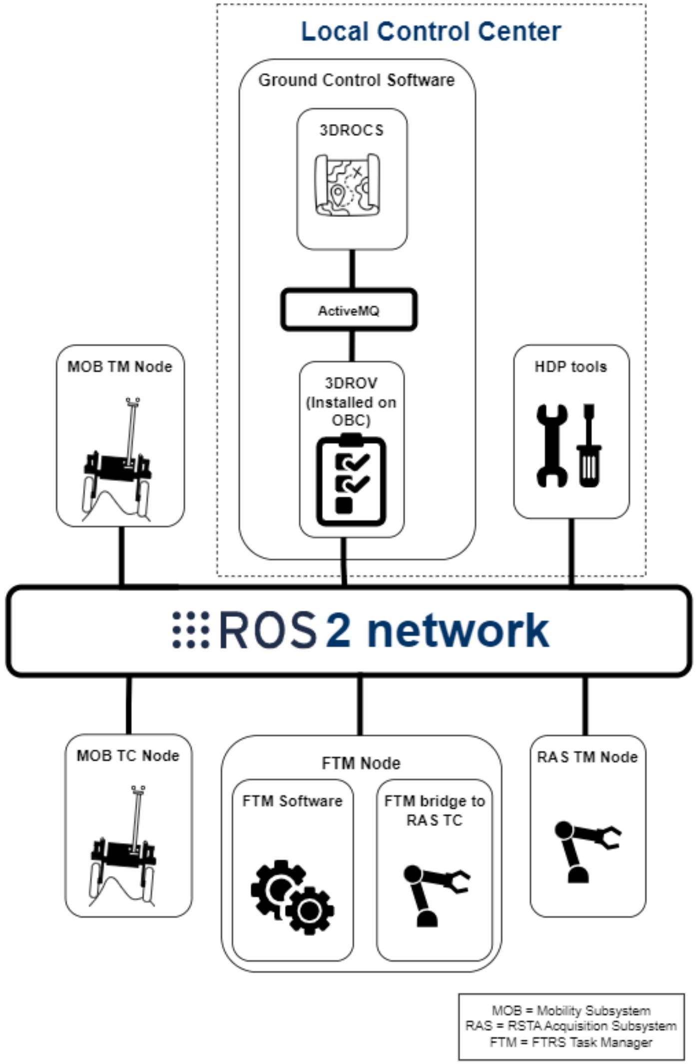
Software

The main contributions of the software team were:

- **Interface Control Document** - to well define the communication between operations, software and GNC layers throughout the ROS network
- Installation and maintenance of **3DROV** on the rover
- Installation and maintenance of the **servers and services**, e.g.:
  - Arm server
  - Gripper server
- Installation and maintenance of the **hardware interfaces** for: Visual Based Detection, Rover and Arm Locomotion, GNSS, etc.
- Installation and maintenance of the **Mesh Network with Satellite Internet Access**, essential for maintaining communications with the rover over long distances and retrieving RTK corrections

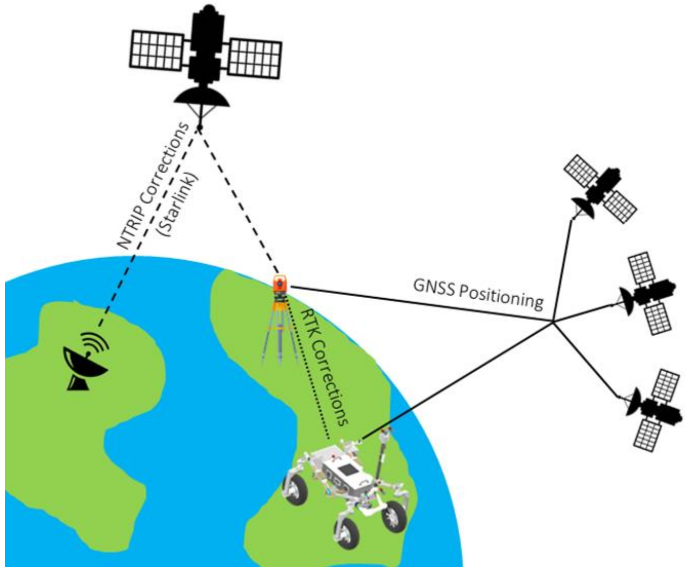


Mission Management System

3DROCS, developed by Trasys, was the main user interface tool used in the frame of the IBB3 test campaign. It was used to:

- Design tests
- Run test
- Assess the reception of Telecommands
- Assess the result of the execution of the Telecommands
- Pause/restore a test without aborting it
- 3D visualization of the terrain traversed
- Plot relative localization estimate, absolute localisation estimate and ground truth

Test environment



The test environment was designed to assess the performance of the FTRS rover capabilities. It had to do with:

- **Mapping**
  - GeoLocalized reference map for AGL-T, AGL-D and map for 3DROCS
  - Digital Elevation Maps for AGL-D imaged from the drone
- **Ground truth** - to assess the quality of RelLoc and AGL
- **Network** - to command the rover, retrieve the telemetry, get RTK corrections
- **Terrain modeling** - add features, create a rock garden and erase regular and repetitive tracks for AGL correlations

Key numbers - Generic capabilities of the FTRS

- SFR IBB platforms (IBB1, IBB2, IBB3) have driven **10 km in total without putting the rover at risk**, i.e. without driving over a dangerous area that is assessed as non-dangerous
- First successful sample **fetching end to end test in analog conditions** (in September 2023 Field Trials)
- First end to end Mobility test (Traverse, depot driving) commanded with a **Operation Layer software** (3DROCS)
- Generic solutions for test environment
  - Generic control center
  - Data management (e.g. ROS network)
  - Emergency stops (remote and on the rover)
  - Testing environment
  - Continuous integration of code base
  - Adaptive platform (e.g. Interchange mesh wheels and rubber wheels)

Further Material & Acknowledgement

Field trials:
https://www.esa.int/ESA_Multimedia/Images/2023/09/Ready_for_collection_lightsabres_for_Mars
(Credit: ESA/Airbus)

ASTRA 2023 presentation by Robert Marc: *“Design and Planning of Field Trials for the Integrated Breadboard 3 (IBB3): Towards the Demonstration of an Integrated Rover System in the SFR Mission Context”*

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THANKS FOR YOUR ATTENTION

Back Up slide - CAD model of FTRS