2nd ESA International Workshop on GNC for Interplanetary and Small-Body Missions

Program

12-13 November 2015
European Space Research and Technology Centre

Organizing Committee:

Massimo Casasco
GNC Engineer at ESA-ESTEC
Massimo.Casasco@esa.int

Cèlia Yábar Vallès
GNC Engineer at ESA-ESTEC (Moltek Consultants Ltd.)
Celia.Yabar.Valles@esa.int

Guillermo Ortega
Head of the GNC section at ESA-ESTEC
Guillermo Ortega@esa.int

Welcome

The ESA International Workshop on GNC for Interplanetary and Small-Body Missions (GNCISB) is an event organized by the European Space Agency (ESA).

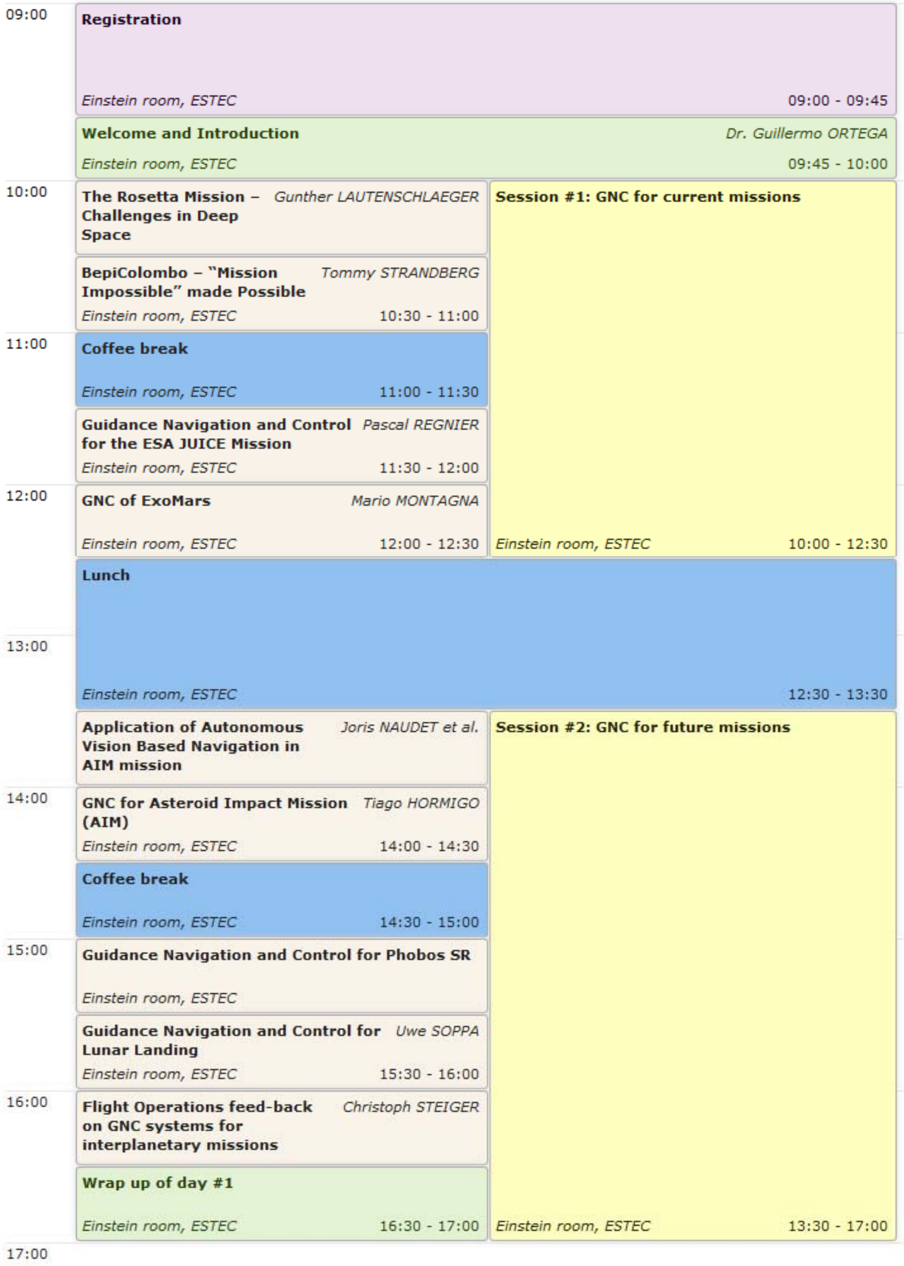
The main objective of the workshop is that of gathering world-wide experts in all Guidance, Navigation, and Control (GNC) related disciplines to review the challenges and achievements from past successful interplanetary and small body activities (missions, mission studies, research and development work, hardware developments, etc.), discuss the current needs raised by the upcoming missions to interplanetary and small body destinations, and establish shared priorities and roadmaps for future endeavours.

Based on the 1st workshop held in 2009, participation of most European space industries and other space agencies is expected.

Other key objectives of the workshop are:

- To bring together engineers, scientists, researchers from the industry, Research Institutes, Universities, Space Agencies working on the development or the use of GNC systems for interplanetary and small body missions and to share experience obtained in development, implementation and operational use.
- To provide an international forum to discuss GNC techniques and technology involved in missions to planets, asteroids or comets.
- To identify common approaches and/or differences between techniques and technologies employed in different industries or agencies and to understand the rationale lying behind the potential differences.
- To identify technological gaps where new solutions need to be developed – or where existing ones need to be extended – and to bring together the people to foster such initiatives.
- To pave the way for the success of future interplanetary and small-body missions.

Timetable 12th November



09:00

Registration
Einstein room, ESTEC 09:00 - 09:45

Welcome and Introduction *Dr. Guillermo ORTEGA*
Einstein room, ESTEC 09:45 - 10:00

10:00

The Rosetta Mission – Challenges in Deep Space *Gunther LAUTENSCHLAEGER*

BepiColombo – "Mission Impossible" made Possible *Tommy STRANDBERG*
Einstein room, ESTEC 10:30 - 11:00

11:00

Coffee break
Einstein room, ESTEC 11:00 - 11:30

Guidance Navigation and Control for the ESA JUICE Mission *Pascal REGNIER*
Einstein room, ESTEC 11:30 - 12:00

12:00

GNC of ExoMars *Mario MONTAGNA*
Einstein room, ESTEC 12:00 - 12:30

Session #1: GNC for current missions
Einstein room, ESTEC 10:00 - 12:30

Lunch

13:00

Einstein room, ESTEC 12:30 - 13:30

Application of Autonomous Vision Based Navigation in AIM mission *Joris NAUDET et al.*

14:00

GNC for Asteroid Impact Mission (AIM) *Tiago HORMIGO*
Einstein room, ESTEC 14:00 - 14:30

Coffee break
Einstein room, ESTEC 14:30 - 15:00

15:00

Guidance Navigation and Control for Phobos SR
Einstein room, ESTEC

Guidance Navigation and Control for Lunar Landing *Uwe SOPPA*
Einstein room, ESTEC 15:30 - 16:00

16:00

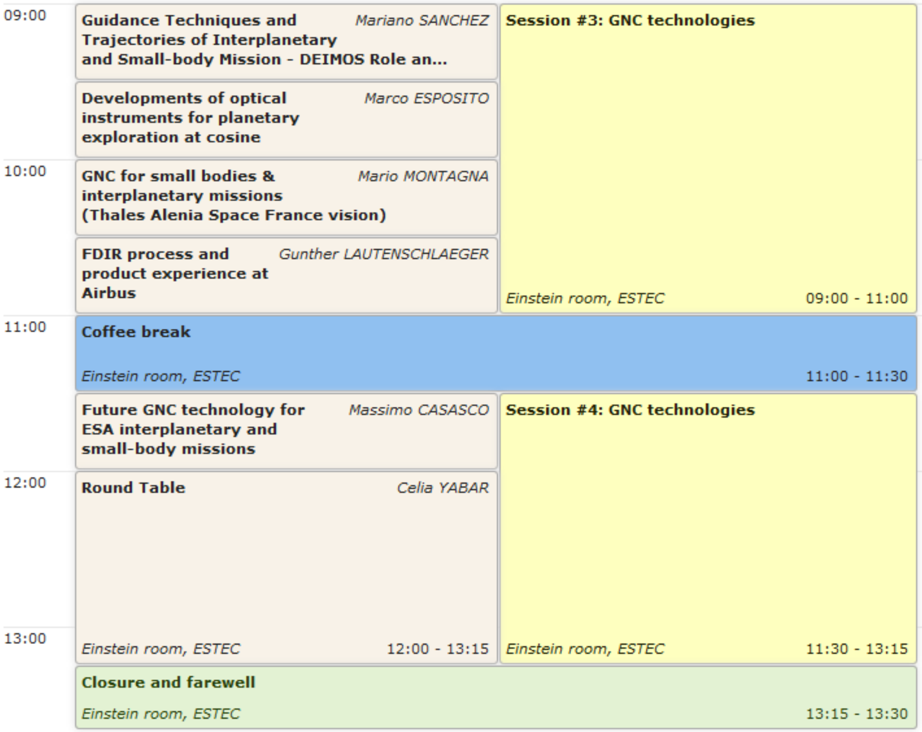
Flight Operations feed-back on GNC systems for interplanetary missions *Christoph STEIGER*

Wrap up of day #1
Einstein room, ESTEC 16:30 - 17:00

Session #2: GNC for future missions
Einstein room, ESTEC 13:30 - 17:00

17:00

Timetable 13th November



09:00	**Guidance Techniques and Trajectories of Interplanetary and Small-body Mission - DEIMOS Role an...** *Mariano SANCHEZ*	**Session #3: GNC technologies** *Einstein room, ESTEC* 09:00 - 11:00
	Developments of optical instruments for planetary exploration at cosine *Marco ESPOSITO*	
10:00	**GNC for small bodies & interplanetary missions (Thales Alenia Space France vision)** *Mario MONTAGNA*	
	FDIR process and product experience at Airbus *Gunther LAUTENSCHLAEGER*	
11:00	**Coffee break** *Einstein room, ESTEC* 11:00 - 11:30	
	Future GNC technology for ESA interplanetary and small-body missions *Massimo CASASCO*	**Session #4: GNC technologies** *Einstein room, ESTEC* 11:30 - 13:15
12:00	**Round Table** *Celia YABAR* *Einstein room, ESTEC* 12:00 - 13:15	
13:00	**Closure and farewell** *Einstein room, ESTEC* 13:15 - 13:30	

The Rosetta Mission – Challenges in Deep Space

Gunther Lautenschläger, Rosetta Team
Airbus DS GmbH, Friedrichshafen, Germany

Introduction: In March 2004 the European Space Agency started one of the most challenging missions: The Rosetta Mission. It is a journey into the unknown, to comet 67P Churyumov Gerasimenko, where nobody was before and nobody knew the detailed properties of the comet.

Rosetta needed to perform big acceleration manoeuvres to get side by side with the comet. After a decade long voyage spanning more than six billion kilometres, Rosetta is closely orbiting around the comet 67P, upon which its lander Philae initiated 3 historic landings. This was a big challenge for Rosetta and Philae with unpredictable risks. Rosetta performed complex manoeuvres, controlled by ESOC with excellent performance, by which Philae made its first touchdown exactly in the predefined landing area. After two additional jumps “of joy”, Philae was finally safely grounded on the comet and could perform its measurements for 64 hours, as nominally planned. Then Philae went into hibernation waiting for more sun illumination to come. In June 2015 Rosetta could shortly re-establish contact to Philae getting HK data. Due to the strong activities of the comet, Rosetta had to increase the distance and no further contact could be established. Maybe Philae will be impacted by dust, boulders or even eruptions, when the comet gets more and more active, or Philae will “call-back” end of 2015, when the activities of 67P decreased and Rosetta can get closer.

Rosetta is fully alive and in good shape. Rosetta’s primary task is to preserve the 11 scientific instruments from the odds in space. The Spacecraft keeps them warm, supplies them with sufficient energy, provides telecommand and data link, brings them to the comet and shows them the “best” places. The 11 instruments on-board continuously watch the comet and are collect a huge amount of valuable data, while the comet gets closer to the sun and by this more and more active and building its wonderful tail. With excursions across the comet’s coma a detailed profile of the gas and dust density and its consistency could be measured.

The Rosetta mission was an incredible challenge in nearly all disciplines. In 1996 the European Space Agency (ESA) requested Airbus DS GmbH (at this time called Dornier System) to propose a spacecraft design mastering the challenges of this mission. Reaching the orbit of the comet at a distance of Jupiter and then to accelerate to the same speed as the comet 67P, orbit around it and even release a lander on its surface.

Airbus DS designed and built Rosetta as the prime contractor leading a consortium of 96 European companies with contributions from USA. The following major challenges had to be solved to successfully fly the Rosetta mission.

Challenges in Deep Space: In this presentation the following design solutions in the frame of GNC will be presented:

Deep Space Hibernation: Rosetta is a solar powered spacecraft. It had to survive in deep space at a distance of 5.3 AU (distance of Jupiter). At this distance the Sun intensity is only 4% of the intensity on Earth. Therefore Rosetta was equipped with 68 square meter big solar panels; tip to tip is 33 meters. It is the first time a spacecraft relying solely on solar energy has ventured beyond the asteroid belt, a region located at the orbit of Jupiter.

Therefore Rosetta had to survive in deep space with only 440 W of electrical power. The main challenge here was to keep the propellant warm (above zero degree). A new survival strategy had to be invented: The Deep Space Hibernation. This phase of 2.5 years was mastered by converting the 3-axses stabilized spacecraft into a spinning one. As a consequence no HGA dish pointing to Earth was possible and the communication to Earth had to be stopped. All energy had to be concentrated on autonomously controlled heating of the bi-propellant. An unusual but robust mission phase specific survival concept was invented, which inverted the nominal survival strategy during the Deep Space Hibernation phase: “Do not Disturb !”

Optical Navigation: The two asteroid flybys and the comet navigation several 100 Million km away from Earth demanded optical navigation and the related GNC controllers. Keeping the instruments in focus during an asteroid flyby is not possible from ground due to the long TM/TC signal traveling duration. Therefore the Rosetta Navigation Camera was designed to keep always the instruments in focus of the target. All degrees of fredom were used to point the solar array to the Sun, the HGA to the Earth and all instruments follow the moving asteroid.

Dusty Comet Environment: At the comet Rosetta has to cope with more and more dust particles of the comet’s coma and outbursts. Illuminated dust reflects the sunlight like stars. It can ‘blind’ Rosetta’s star tracker and prevent it from getting its bearings for its attitude determination. To prevent this, dedicated cut-ting-edge star tracker software was developed that is capable of recognizing the underlying correct star pat-tern and using it to guide the probe safely through the dust. The Rosetta star tracker can cope with up to 3000 false stars at init acquisition and with up to 10000 false stars in tracking mode.

The big success of the Rosetta Mission demonstrated that the chosen design mastered all challenges of this mission. Rosetta is the first spacecraft:

- Orbiting around a comet and getting detailed images from its surface.
- Mapping and determining the best place for its lander Philae to deliver it safely on the surface.
- Following a comet for a long time and examine from close proximity how a frozen comet is getting active and transformed by the warmth of the sun.

Bepi Colombo
"Mission Impossible" made Possible

T. Strandberg
Airbus DS GmbH, Friedrichshafen, Germany

BepiColombo is the most challenging planetary mission undertaken from ESA so far with solar energy varying in the range from 1.5kW/m2 (near Earth) to around 15 at Mercury with an addition IR/reflection thermal load of 5kW from Mercury itself.

This leads to the introduction of many new technologies for Solar Arrays, antennas, thermal control H/W, sun sensors etc. Also, not many surfaces of the satellite can survive direct sun illumination leading to complex FDIR and control strategies including hot redundant processor for safe and survival mode in case of critical system alarm triggering

In addition, the BepiColombo satellite is composed of different modules leading to an AOCS design and controller tuning capable of coping with 5 fundamentally different configurations with considerable differences in e.g. mechanical properties, axes pointed toward the sun and equipment used as the configuration changes when the various modules are separated en route to Mercury.

The presentation will address some of the key issues of the BepiColombo satellite and the specific design solutions implemented within the AOCS.

Guidance navigation and control for the ESA JUICE mission

P. Regnier, G. Jonniaux, K. Kanani, M. Chapuy
Airbus Defence & Space, Toulouse, France

Chosen by ESA in May 2012 to be the first large mission within the Cosmic Vision 2015-2025 Programme, JUICE (JUpiter ICy moons Explorer) is planned to be launched in 2022 on Ariane 5, to reach Jupiter in 2030. After a Rosetta-like interplanetary cruise including several Earth, Venus and Mars gravity assists, the mission will tour the giant planet system for more than 3 years to explore its atmosphere, magnetosphere and tenuous set of rings and will characterise the icy moons Ganymede, Europa and Callisto through multiple low altitude fly-bys. Detailed investigations of Ganymede will be performed when JUICE enters into orbit around it – the first time any planetary moon will be orbited by a spacecraft. During its lifetime, the mission will give us an unrivalled and in-depth understanding of the Jovian system and its moons. The scientific goals of the mission are enabled by its instrument suite, including cameras, spectrometers, a radar, an altimeter, radio science experiments and sensors used to monitor the plasma environment in the Jovian system. Last July ESA has selected Airbus DS France as the prime industrial contractor for industrial activities for the design, development, integration, test, launch campaign, and in-space commissioning of the JUICE spacecraft.

The JUICE Guidance Navigation and Control (GN&C) will be designed and developed on the same principles than the other GNC systems developed by Airbus DS for past and on-going interplanetary missions : Rosetta, Mars Express, Venus Express, Bepi-Colombo, Solar Orbiter. Furthermore several innovative GNC concepts enhancing the mission scientific return and spacecraft autonomy have been proposed by Airbus DS in the baseline design. To achieve the tight pointing performance requirements of the JUICE payload instruments and fulfil the needs of an interplanetary mission, the JUICE GNC relies on a set of three autonomous Star Tracker Optical Heads and high performance gyros, with high capacity reaction wheels for attitude control. A set of Sun sensors (for safe mode) and bi-propellant thrusters (for attitude acquisition, trajectory manoeuvres and reaction wheels off-loading) complements the GNC equipment. Finally a redounded Navigation Camera provides optical navigation measurements prior to and after jovian moons fly-bys in order to support accurate Orbit Determination on the ground aimed at computing not only targeting and clean-up manoeuvres but also the spacecraft nadir attitude guidance profile during the fly-bys. The main GNC innovation baselined by Airbus DS consists in using the Navigation Camera in an on-board Closed-Loop Attitude Guidance (CLAG) concept in order to improve the spacecraft absolute pointing performance at the fly-by closest approaches. Moon images taken at short distances are processed on-board to extract the limb measurements and estimate the spacecraft relative position vector which is then safely injected in the attitude guidance command. This paper will describe the architecture and capabilities of the JUICE GNC system with a special focus on the CLAG concept design and validation perspectives.

GNC of ExoMars

P. Martella, M. Montagna
Thales Alenia Space, Torino, Italy

Thales Alenia Space Italia is the industrial prime of the Exomars mission. The mission is divided in two flights: the first one planned in 2016 with a launch with Proton scheduled from Baikonur on 14 March 2016 and the second in May 2018 again with a Proton.

The 2016 mission is composed of an Orbiter module named TGO (Trace Gas Orbiter), designed and integrated by TAS-F with the support of OHB for the Mechanical Thermal and Propulsion aspects, that will perform the analysis of the Gasses in the Mars atmosphere and will bring to Mars the EDM (Entry Descent and Landing Demonstrator) designed and assembled in TAS-I Turin. The EDM will land with a small set of meteorological payloads (DREAMS) that will survive few days providing data on Mars climate.

The 2018 mission instead is a joint European- Russian mission composed of a Carrier Module, designed by OHB, a Descent module under Russian responsibility but co-designed by TAS-I that will bring on the Mars surface a Rover Module based on a Rover Vehicle designed and integrated by Airbus DS UK. The rover is designed to survive on the Mars surface for 180 sols while the DM lifetime is expected to be 1 martian year.

This presentation will address the GNC aspects of the EDM and the CM/DM parts as developed in TAS-I Turin.

- The differences between the 2016 and 2018 Mission Phases will be presented such as the driving constraints for the two missions to meet the different requirements at switch-off / touchdown.

- The exchange of the data between the modules “G”, “N” and “C” will be briefly introduced showing the difference between the approach use in in the 2016 and the 2018 mission.

- The DM GNC Verification Methodology will be identical in the 2016 and 2018 mission and it will be presented how the different parts, Analytic verification, Simulation verification and Test bench Simulations are all used to reach the final validation of the design and the SW implementation.

- Also some peculiar aspects of the 2018 mission, for what concern the GNC, will be mentioned to show the performance dependency as function of the mass unbalance of the CM/DM system.

Application of Autonomous Vision Based Navigation in AIM mission

J. Naudet and A. Pellacani
QinetiQ Space, Belgium and GMV, Spain

The Asteroid Impact Mission (AIM) is a small ESA mission of opportunity which objective is to perform scientific observations of a binary asteroid (Didymos) while demonstrating technologies for future missions and addressing planetary defense. The latter will be achieved in cooperation with NASA's DART spacecraft (Double Asteroid Redirection Test) that will impact the secondary asteroid in order to assess the ability to deflect its trajectory. The AIM spacecraft will monitor the impact and observe the geophysical properties and dynamic state of the binary asteroid before, during and after the impact.

One of the main challenges for the AIM mission, is the delivery of the MASCOT-2 lander on the surface of the secondary asteroid. This payload will be released from the AIM spacecraft at a short distance from the surface, requiring advanced on-board autonomy. This can be achieved thanks to vision based navigation that provides high accuracy relative measurements with respect to the asteroid. The presentation addresses the performed work related to this type of navigation, also dealing with the GNC and the FDIR functions needed to have a robust and safe on-board autonomy. The most challenging aspect of the MASCOT-2 release is the lack of a direct range measurement available for the nominal GNC loop due to mass/budget trade-off (and low TRL level of on-board instruments which are considered experiments). This strategy requires an accurate navigation initialization from ground and a reduced autonomous phase not to accumulate a significant navigation error that may jeopardize the MASCOT-2 landing conditions.

GNC for AIM

Tiago Hormigo and Ingo Gerth
Spin.Works, Portugal and OHB, Bremen, Germany

The Asteroid Impact Mission (AIM) is a small mission of opportunity to rendezvous and characterize the near-Earth binary asteroid 65803 Didymos, due to launch in 2020. The mission will carry a small lander, MASCOT-2, to be deployed towards the small moon of the system (nicknamed 'Didymoon'), as well as Cubesats which will operate as a wireless sensor network. Among the several Guidance and Navigation challenges in the scope of the AIM mission, the following four will be discussed in the presentation: the navigation strategy applied to the interplanetary phase, the stepwise rendezvous with the asteroid using vision-based relative navigation, the guidance and navigation aspects of close proximity operations to ensure a safe, precise, detailed observation of Didymos, and the ballistic lander deployment sequence - which entails a very close approach to Didymoon.

GNC for Phobos Sample Return

A. Bidaux-Sokolowski
GMV, Poland

An autonomous GNC system for descent and landing (DL) on Phobos is being developed by GMV Poland based on previous experience of GMV developed under several ESA contracts. The GNC system is based on advanced algorithms and European navigation sensors and actuators. Lessons-learned from ROSETTA have been incorporated in the definition of the ground operations and performance in order to have a realistic mission timeline. In addition, previous results from hardware-in-the-loop (HIL) tests in robotic facilities for asteroid sample return mission has also been considered in the definition of the GNC strategy and descent profile. Two GNC strategies for the descent and landing are assumed: the first strategy considers direct descent from QSO (quasi satellite orbit) with real-time feedback from vision based relative navigation, the second one includes autonomous hovering at predefined altitude with navigation filter reset, using on-board absolute navigation algorithm cross-checked on ground. Four phases for the descent and landing are considered for the strategy with hovering: 2 burn maneuver ground commanded to reach the hovering point above the surface, control hovering, continuous control descent and freefall. For the direct descent strategy two phases are considered: control descent from QSO and free-fall. Autonomous GNC vision-based system lays on two different strategies which are pure Relative Navigation (RN) and Enhanced Relative Navigation (ERN). Both strategies are based on the tracking of unknown features on the surface of the moon. The image processing is identified as one of the most time consuming parts of the system and hence developed as a HW accelerator.

Guidance Navigation and Control for Lunar Landing

U. Soppa and T. Diedrich
Airbus DS GmbH, Bremen, Germany

Despite the fact that there is no moon race anymore, the scientific interest in the Moon is still high. However, the ambitions aim higher today as in the past.

Just landing on the Moon safely is no longer enough. The search for volatile substances drives the interest in accessing permanently shaded areas, to be found only at the poles. Exploring these areas requires being able to land in darkness (or at least close to it), to work in darkness, and to communicate at high bandwidth from low elevation areas.

For mission designers and GNC engineers, this means to be able to land with high precision and to provide infrastructure for landing precision and science return (which can be data or samples).

Looking further ahead, human assisted exploration or the construction of long term surface bases or outposts will require pinpoint landing capability.

The presentation gives an overview about the activities at Airbus DS on the subject of autonomous lunar landing in the past 10 years. The GNC concepts and systems which have been developed in the course of the various studies are compared to the successful lunar landing missions which have already been flown.

The presentation closes with a view ahead onto the current cooperation of ESA with the Russian space agency. Although the European Lunar Lander program was stopped in 2012, this cooperation provides a realistic flight opportunity for the European visual navigation and hazard avoidance technology in the frame of the Luna Glob, Luna Resurs, and Luna Grunt missions.

Flight operations feed-back on GNC systems for interplanetary missions

C. Steiger, V. Companys
ESA-ESOC, Germany

Since June 2003, ESOC has operated several interplanetary missions: Mars Express (MEX), Rosetta (ROS), Smart-1 (S1), Venus Express (VEX). The success of these missions was possible thanks to the excellent work performed by the engineers that created the GNC systems of these satellites.

Now, a number of ESOC-operated interplanetary missions are in preparation – some are to be launched in the near future, others have still a long way to go.

In this context, ESOC wants to take the opportunity offered at the workshop, to give feedback concerning GNC systems of the missions we operate, and to establish a dialogue with the makers of the GNC systems for the future.

Guidance techniques and trajectories of interplanetary and small-body mission Deimos Role and Perspectives

M. Sánchez-Nogales, J.L. Cano, M. Kerr
DEIMOS Space, Spain

Interplanetary and small-body missions represent a challenge, since their trajectories must meet a number of non-conventional mission requirements, environmental and platform-specific features.

Trajectory and guidance profiles around small bodies are designed considering the light gravitational field and the propulsion system capabilities, among other effects. This scenario calls for novel approaches such as QSO (quasi-stable orbits) or PhSO (photo-gravitationally stable orbits), where either the motion deviates from a Keplerian behaviour or the gravitational field is not the key player. This problem will be addressed showing solutions provided by DEIMOS in several cases; PROBA-IP, Marco Polo-R, Phobos and Lunar Polar Sample Return.

Approach to minor bodies requires designing the guidance to tackle specific mission requirements and constraints. Depending on variables like target characteristics and arrival velocity, the guidance profile will be different; i.e. orbiter, impactor, type of propulsion system, etc.

Operations around minor bodies are driven by dedicated guidance techniques like inertial hovering, body-fixed hovering, etc. that allows meeting mission goals (mapping, monitoring, descent, landing). DEIMOS has developed solutions in several activities from which EC NEOShield will be presented, addressing an autonomous GNC solution.

In case of approach to bodies with atmosphere, interesting problems emerge leading to aero-assisted solutions that DEIMOS has worked out in various scenarios (ESA ExoMars, EC AeroFast).

Demanding pointing requirements affect the attitude guidance solution, as in the case of the JUICE mission, that might prevent from using traditional ground-based architectures and call for innovative on-board autonomous approaches. DEIMOS is analysing this problem and will show preliminary conclusions.

Developments of optical instruments for planetary exploration at cosine

M. Esposito
Cosine, Netherlands

Cosine measurement systems specialises in the development of optical instruments for space science, Earth observation and space navigation. cosine operates on a large variety of imaging fields, from participating in big space instruments, to small low cost space instruments to ground industrial pipeline detection, food scanning and aligned 3d ((hyper)spectral) cameras.

We report on past experiences in developing instruments as an aid for navigation. cosine developed the GNC sensors used onboard the Mobile Asteroid Surface Scout (MASCOT), a small lander package build by DLR as part of the JAXA's Hayabusa-2 sample return mission, launched in December 2014. We also report on ongoing activities for the development of multipurpose and miniaturized suite of instruments for navigation, such as multispectral and hyperspectral cameras for relative navigation, and the Small Integrated Navigator for Planetary EXploration (SINPLEX).

GNC for small bodies & interplanetary missions (Thales Alenia Space France vision)

A. Grynagier, B. Dellandrea, M. Montagna
Thales Alenia Space, France and Italy

Thales Alenia Space has worked on multiple projects aiming at developing GNC for interplanetary and small bodies exploration missions. The objective of this presentation is to show a synthesis of the Thales Alenia Space background (missions, mission studies, research and development work, hardware developments, etc.) and discuss the needs raised by the upcoming missions to interplanetary and small body destinations.

This presentation will address R&T activities related to:

- The increase in spacecrafts autonomy, key for high-performance long-range missions,
- Development of new sensors, resulting from user requirements consolidation and missions analysis,
- Test of new algorithms for image-based navigation,
- Development and test of new high performance avionics architecture enable such processing,
- Approach trajectories strategies & capture or landing.

FDIR process and product experience at Airbus

G. Lautenschlaeger
Airbus DS GmbH, Friedrichshafen, Germany

Introduction: The on-board Failure Detection, Isolation and Recovery (FDIR) engineering is part of the core spacecraft elements challenged during all project life cycle. FDIR is spread over system as well as over various subsystems and equipments. FDIR needs early in the project a consistent design concept, but can only be consolidated later with detailed equipment entries. So FDIR is one of the earliest as well as one of the latest system engineering tasks to be performed and by this essential for the success of the project. Feeding late FDIR requirements into SW specification or con-figuration tables may impact the project schedule.

The challenge for the FDIR engineering results in the fact, that the FDIR design spans across nearly all spacecraft disciplines with a highly dynamic and an iterative detailed design feedback. In addition a verification strategies and means for dedicated test functions have to be defined, including test cases, which are not testable on the flight model. All of this shall be per-formed keeping the FDIR solutions simple, cost efficient and in time.

Airbus reviews currently the FDIR engineering process applied to different space projects including GAIA, Sentinel-2 and SolarOrbiter. The final goal is to improve the FDIR engineering process during design, development, validation and operational phases.

The following main themes in the FDIR process were identified as possible stakes:

- Quality and phasing of the engineering effort set in place to substantiate and justify design choices from system requirements, yielding to an un-even Design & Validation to cost mind-set
- Lack of a shared vision between project actors for FDIR engineering, development and V&V lifecycle, yielding to work in silo attitude as a result, and challenge to phase the overall engineering
- Lack of Standardisation & Design policies, from requirement breakdown and traceability into documentation structure to implementation of roles and responsibilities

On the other hand airbus applied and improved best practise in these projects by:

- Improving flexibility in implementation of FDIR solutions
- Introduction of a structured co-engineering be-tween FDIR architect and RAMS engineer related to failure mode effects identification and coverage

Airbus proposed approach to strengthen best practise is to emphasise on:

- Streamlined roles and responsibilities in the RAMS and FDIR development process
- Standardisation of FDIR design and implementation policies
- Identification and control of holistic cost drivers in the development lifecycle
- Use of MBSE techniques to support design definition and justification early in the project
- Phasing of engineering effort in the project lifecycle
- FDIR flexibility in solution implementation

The Key Factors to measure FDIR complexity and cost may be discussed controversially depending on the different Stakeholders within the project and therefore not easy to be identified.

Future GNC technology for ESA interplanetary and small-body missions

M. Casasco
ESA-ESTEC, Netherlands

The Guidance, Navigation and Control Section of ESA will provide an assessment of the state-of-the-art in GNC technologies for interplanetary and small-body missions, based on a review of the past and current ESA missions. The areas of guidance and trajectory optimisation, navigation, control, MVM, FDIR and operations will be covered in this assessment.

Building upon this assessment, a number of lines of development will be presented, which are aimed at overcoming the current limitations of the state-of-the-art to serve the needs of future ESA interplanetary and small-body missions. Particular emphasis will be devoted to on-board adaptation of guidance, global end-to-end trajectory optimisation, optical navigation, stochastic estimation, data fusion, image-processing techniques and architectures, robust control, autonomy and multi-mission integrated GNC solutions.

The planned TRP ITTs in the areas listed above will also be presented.

Finally, this presentation will serve as an opening to the subsequent round-table event, where an open discussion will be held to establish shared priorities in GNC technology developments for future interplanetary and small-body missions.

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