INTEGRATION OF ION PROPULSION TECHNOLOGY
IN A SYNCHRONOUS SATELLITE:
THE ARTEMIS CHALLENGE

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ABSTRACT

The ARTEMIS satellite will use ion propulsion technology for North–South station keeping manoeuvres during up to ten years of in orbit service.

The Artemis Ion Propulsion Package is constituted by four major assemblies:

- PSDA: Propellant Storage and Distribution Assembly;
- RITA: Radiofrequency Ion Thruster Assembly;
- EITA: Electronbombardment Ion Thruster Assembly;
- ITAA: Ion Thrusters Alignment Assembly.

Different European companies are responsible for their design, manufacturing and testing. To cope with this rather complex situation, the Artemis industrial team organization presents one level of responsibility more w.r.t. that normally adopted to manage the conventional propulsion subsystems, that is: Systems/Subsystem/Assembly/Equipment instead of System/Subsystem/Equipment. The paper will discuss the impact on the work to be performed at the System level due to the introduction of ion propulsion technology, in particular concerning:

- the management of the physical interfaces: mechanical, electrical, thermal, between the satellite and the four major assemblies, and between them;
- establishing a proper satellite integration sequence, considering that the integration tasks must be performed by different companies;
- establishing the test sequences, at satellite assembly level, to get confidence on the achieved subsystem functionality and performance.

The results of these continuing activities will be, also, presented in this paper.

1. INTRODUCTION

The ARTEMIS spacecraft will use ion propulsion technology for North–South station keeping in its geostationary orbit for up to 10 years operational life.

The functional performance is generated within the assemblies as described in chapter 2.

The required manoeuvres are performed by firing approximately 3 hours twice per day, in each of the ascending/descending orbital nodes, one of the thrusters (RITA or EITA) which are mounted on the North and South radiator panels of the spacecraft.

The aim of this paper is to describe briefly the constituents of the IPP, the management of their accommodation to the ARTEMIS S/C and the sequence of integration taking into account the importance of the responsibilities on assembly level.

IPP specific tests are briefly described at the end which shall guarantee for a reliable NSSK manoeuvring during the satellite lifetime.

The IPP arrangement on ARTEMIS was selected after careful studies and provides for minimum hardware penalties and minimum power requirement (only 4 redundant thrusters are applied).

Although the added IPP mass is 77 Kg and the thrust efficiency is decreased by a thrust vector declination of 46 degr. mean from the N–S direction, the advantage of the high specific impulse of the IPP results in a GTO mass saving of some 160 to 170 Kg corresponding with a payload gain of about 70 Kg for the ARTEMIS planned mission life of 10 years.

2. IPP ASSEMBLIES

The Ion Propulsion Package (here in after referred to as IPP) is the propulsion medium to be used to perform the orbit control of the Artemis spacecraft during the total mission time of 10 years using Xenon as the propellant.

The IPP consists of the following assemblies:

- 1 Propellant Storage and Distribution Assembly (PSDA);
- 2 Radiofrequency Ion Thruster Assemblies (RITA) using the RIT10 thrusters for thrust generation;
- 2 Electronbombardment Ion Thruster Assemblies (EITA) using the UK 10 thruster for thrust generation;
- 1 Ion Thrusters Alignment Assembly (ITAA) composed of 2 alignment mechanism (ITAM) and one control electronics (ITAE).

The composition of the IPP is shown in schematic form on Fig. 1.

The Propellant Storage and Distribution Assembly will store the Xenon gas at high pressure of 120 bar and reduce the propellant pressure down to a constant pressure level of 2 bar needed for thruster feeding.
The Ion Thruster Assemblies will be able to produce a thrust of 15 mN. The thrusters of the Ion Thruster Assemblies, RIT 10 and UK 10, will be mounted on the spacecraft on the North and South radiation panels near the anti-Earth section.

The Ion Thruster Alignment Assembly (ITAA) allows to adjust the thrust direction through the actual centre of mass of the spacecraft in orbit.

Fig. 1: Composition of the Ion Propulsion Package (IPP).

Fig. 2: Ion Thrusters Geometry in S/C Reference System.
The IPP performs the N/S station keeping by operating 1 thruster in +y direction in 1 node and 1 thruster in –y direction in the opposite node. With the arrangement of 1 RIT 10 and 1 UK 10 next to one another in +y and in –y direction full redundancy with respect to the thruster technology and to the number of thrusters is achieved.

With this arrangement, as depicted in Fig. 2, minimum disturbance torques are generated by a minimum number of 4 Ion thrusters (two operating, two redundant).

The location of the Ion thrusters outside of the ARTEMIS satellite in its launch configuration is shown in Figure 3.

The major parts of IPP equipments however, are mounted inside the spacecraft on the North and South radiator panels and on the main platform.

Each assembly of the IPP consists of several equipment or units in the shape of a box. Within an assembly the units are connected by cables and propellant feed lines supplying the thrusters with power, TM/TC signals and Xenon propellant.

The complexity of the IPP is depicted in Figure 4 describing the subordinate elements of the IPP down to the box level.

Different European Companies are responsible for their design, manufacturing and testing requiring a rather complex industrial team organization too.

The management of the IPP subsystem and the responsibility for its proper function on ARTEMIS lies within ALE-NIA SPAZIO.

Since the propulsion functions have to be provided under responsibility of the assemblies there is one important management level more w.r.t. that normally adopted for managing conventional propulsion subsystems.

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Fig. 3: ARTEMIS S/C Launch Configuration Baseline for PDR 1.
RITA
- RIT10 Thruster Unit (RIT);
- Neutralizer;
- PSCU – Power Supply and Control Unit;
- RFG – Radio Frequency Generator;
- FCU – Flow Control Unit (low pressure);
- MV – Main Valve;
- EGSE1/MGSE1.

ITAA – Gimbaled Platform
- ITAM – Ion Thruster Alignment Mechanism;
- ITAE – Motor Drive Electronics (MDE).

MBB will be responsible for the RITA and has to manage the different unit suppliers (i.e. FIAR for the PSCU, PROEL for the neutralizer, University of Giessen for functional testing and ESTEC for thruster lifetime testing). MSS will be responsible for the EITA and has to manage all their equipment suppliers (e.g. CULHAM laboratory for the thrusters and Philips for the cathode function and lifetime testing).

The S/S contractors will take the responsibility for proper functionality of the PSDA and ITAA and for their integration and testing.

3. IPP ACCOMMODATION AND INTERFACES

3.1 Requirements

For accommodation of the IPP on the ARTEMIS spacecraft requirements generated by both sides, the IPP and the spacecraft, had to be considered in the definition phase B2. Those of major impacts may be summarized in the following:

a) Thrust Level.
In order to meet the NSSK strategy with approx. 3 hrs thrusting time around each orbital node (2 times per day) the thrust levels will be 15 mN (RITA) and 18 mN max. (EITA) at a specific impulse of 3000 sec.

b) DC Power.
The overall IPP power consumption shall not exceed 620 W (570 W for RITA or EITA, the remaining for PSDA, ITAA and Heaters). The IPP will not be operated during eclipse, shadowing of solar array and battery charging at equinox.
c) **Thrust Vector.**
   The accuracy required w.r.t. acceptable disturbance torques is:
   - for cold start: 1 resp. 2 deg at BOL resp. EOL;
   - during warm-up until equilibrium temperature:
     < 1 deg. additional divergence.
   The divergence between 2 consecutive firings of the same thruster shall be < 0.5 deg. half cone.

d) **Alignment Capability.**
   - On ground (without ITAM operation) ±2 degrees;
   - On orbit the ITAM operates in a range of ± 10 deg. with an accuracy of 0.1° (incl. thermal distortion and backlash effects).

e) **Mass of IPP.**
   The specified mass for ARTEMIS accommodation is 70Kg + 40 Kg max. Xe propellant.

f) **Thermal Control.**
   Since all heat radiating surfaces (North-South-panels, thruster cases) can run very cold in the non-operating periods, heater power of 20 W is provided for each of the North and South IPP

3.2 **Accommodation / Interface Management**

As shown in Fig. 4 the redundant Ion thruster assemblies are commonly supplied with Xenon propellant by means of the propellant supply and distribution assembly PSDA. The highly pressurized Xenon stored in one tank is regulated down to a low pressure of about 2 bar by means of an electronic pressure regulator EPRA.

After passing the Oxygen absorber it is distributed to the thruster pairs via their flow control and measurement units (FOU respectively PSME).

The Figure depicts the assemblies and all units which have to be accommodated to the S/C.

Due to the different functions within one assembly the IPP units are mounted on different parts of the structure rear section (anti-Earth section) as described in the following:

- The Xenon tank is one of the four high pressure tanks on the propulsion platform. It is mounted within the rear central cylinder structure in the +x/-y area.
  In the other 3 tanks He-pressure gas is stored for the chemical propulsion.

- The pressure regulator is sensitive to thermal excursions due to its narrow bandwidth and is, therefore, mounted on the main (horizontal) platform lower side together with the other PSDA components. The nearest possible location to the Xe-tank was chosen as depicted Fig. 5 and 6.

No components should be mounted on the central cylinder except the brackets for supply lines and electrical cabling.

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*Fig. 5: IPP Accommodation on Artemis Platform.*
The Xe-line routing begins with the fill and drain valve FVV, to be mounted on the East panel, and connects the Xe storage tank with the PSDA equipment on the main platform.

It further supplies the flow control and measurement units (FCU and PSME) via lines which lead from the North to the South radiator panel around half of the central cylinder.

These units as well as the power supply and control electronics (PSCU's and PCCE's) and the RIT RF-generators are mounted inside the heat radiating North and South panels (see Fig. 7 and 8). The control electronics unit of the two alignment mechanisms is located on the South panel.

Cable connectors and pipe junctions lead through the radiator panels to the outside mounted alignment mechanisms (ITAM's) which carry one thruster pair each.

**4. IPP/SPACECRAFT INTEGRATION SEQUENCE**

**4.1 Overview**

The IPP integration is carried out in three major steps:

- Pre-integration of the assemblies;
- Integration of the PSDA together with the UPS and main structure;
- Final Integration of complete IPP into ARTEMIS Spacecraft.

Each step requires mechanical support, and electrical test equipment suitable for all necessary functional/performance testing to complete the respective integration step.

**4.2 Pre-integration of Assemblies**

After RITA and EITA thruster tests in the vacuum facilities (University of Giessen and Culham Laboratory) the units are pre-integrated into the North and South IPP packages as depicted in Fig. 9 using dummy radiators panels for monitoring and cable routing (compare chapter 3.2).

The North dummy panel carries on the inner side:

- PSCU, FCU, RFG of RITA;
- PCCE, PSME of EITA.

on the outer side:

- ITAM with RIT and EIT thruster pair pre-assembled.

The South dummy panel carrying on the inner side:

- PSCU, FCU, RFG of RITA;
- PCCE, PSME of EITA;
- ITAE for both gimbal mechanisms.

on the outer side:

- ITAM with RIT and EIT thruster pair pre-assembled.
Fig. 7: IPP Units mounted on North Panel.
Fig. 8: IPP Units mounted on South Panel.
After functional testing, the pre-integrated North/South packages are shipped for platform integration and electrical system testing to ALS/Roma together with all necessary ground support equipment. The PSDA equipment (functionally tested at unit level) will be integrated/tested together with the UPS in the integration facility of UPS S/S responsible.

4.3 Subsystem and Spacecraft Integration

The hardware dedicated to UPS S/S responsible for the propulsion subsystem integration consists of:

- Central Structure (Main/horiz Platform, Central Cylinder, Shear webs, Propulsion Platform);
- PSDA equipments (Xe tank, HPT, HFVV, LFVV, EPRE, EPRM, OXA, Filter, piping, manifolds, etc.).

The integration sequence for the IPP in described in the following (compare also with Figure's 5 to 9).

a) IPP Subsystem:

1. Mount Xe-tank on the propulsion platform.
2. Provide pipe junctions/brackets from Xe-tank to central cylinder.
3. Mount all Xe-pipelines to brackets around central cylinder with junctions to:

4. Mount propulsion platform from rear (−z) side into Central Cylinder.
5. Purge Xe-lines, protect line ends and connect HFVV and LFVV on +x (East) side.
6. Perform electrical function check of all PSDA equipments and harness using PSDA unit test equipments.
7. Perform PSDA leak/electrical function test using PSDA unit test equipment.
8. Packing/shipping to ALS S/C integration facility.

b) Platform System Integration:

9. Remove pre-integ. RITA, EITA from dummy panels and transfer all equipment to the flight North and South panels.
10. Connect all Xe-lines of FCU/PSME with lines on central structure. Connect all harness of RITA/EITA equipment with platform harness.
11. Perform IPP leak/electrical function testing for final acceptance (including alignment).
5. IPP SPECIFIC TESTS IN THE ARTEMIS PROGRAM

5.1 Thruster and Assembly Operational Tests

Since Ion thrusters can only be operated in a vacuum of 10 exp. -5 bar all thruster functional, performance, beam diagnostic, and lifecycle tests are performed in dedicated vacuum facilities:

- RIT thruster functional performance, beam diagnostic and acceptance tests are performed at Giessen University.
- RITA Lifetime test with a dedicated development model (flight type thruster, engineering model suppy units) are performed at ESTEC. The required 15,000 hours represent 1.5 times the thruster operating cycles for a 10 years mission.
- UK-10 thruster performance/acceptance test and EITA lifecycle test are all performed at CULHAM Laboratory. Requirements are the same as for RITA.

5.2 PSDA Tests

Functional performance and flight acceptance tests are performed at unit level.

After delivery to integration facilities and relevant activities performed functional, performance and leak tests are carried out at assembly level. Hereby the Xenon tank is loaded, the pressure regulator pressurized and functionally tested and all valves and pipe connections leak tested with the PSDA test equipment. Xe loading and de-loading is performed by means of a special tanking equipment designed especially for this program.

5.3 ITAA Tests

The main development test will be:

- prequalification of ITA Electronics (EOM);
- assembly of an ITAM EOM with mass and thermal dummies for RIT and EIT thruster, but with flight type piping, cables and thermal protection;
- thermal and functional testing of ITAA with the possibility of extension to life cycle testing (if required due to final operational analyses).

The flight assembly will consist of environmental tested components and will be integrated into the S/C as described sequentially in chapter 4.

5.4 IPP Subsystem/System Tests

In the development phase one engineering qual model (EOM) of the IPP will be integrated into the spacecraft EM for functional verification and compatibility testing. The flight IPP will be composed of:

- acceptance tested components (under flight environmental conditions);
- functionally tested assemblies (RITA, EITA, ITAE);
- pre-integrated IPP North and South packages on dummy S/C radiator panels.

After integration/transfer into the flight spacecraft it will be functionally and environmental tested on System level.

6. CONCLUSIONS

The ARTEMIS spacecraft design provides all physical needs for IPP accommodation.

- The NSSK strategy together with the thruster alignment on the S/C allows for a minimum number of redundant hardware (two pairs on North and South panels) resulting in an acceptable dry mass and power penalty for of the S/C of 77 Kg resp. 180 W. The total propellant mass saving is ≥ 160 Kg.

The various mechanical, electrical and thermal functions to the IPP equipment considerably influence the design and lay-out of the spacecraft but can be matched without major problems if considered a priori.

7. REFERENCES

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