# ORBITA: IN-ORBIT DIAGNOSTICS

## Deliverable: Executive Summary Report (ESR)

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## CHANGE RECORD

| Issue | Date | Section affected | Description of change |
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| Issue01 | 14/03/2019 | All | Document release. |
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## REFERENCE DOCUMENTS

| | Document code | Date | Description |
|---|---|---|---|
| RD01 | AVS.EP05.D11.1_Market analysis report_issue02 | 02/08/2018 | ORBITA market analysis report. |
| RD02 | AVS.EP05.D12.1_Requirement specification_issue03 | 24/08/2018 | ORBITA requirement specification. |
| RD03 | ORBITA_SotA review_v1-7_LS_09-05-18 | 09/05/2018 | Critical Review of State-of-the-Art (Excel Spreadsheet). |
| RD04 | AVS.EP05.D11.2_Preliminary trade-off report_issue02 | 02/08/2018 | ORBITA preliminary trade-off report. |
| RD05 | AVS.EP05.D11.3_In-depth trade-off report_issue02 | 10/09/2018 | ORBITA in-depth trade-off report. |
| RD06 | AVS.EP05.D21.1_Preliminary design description_issue02 | 10/09/2018 | ORBITA preliminary design description. |
| RD07 | AVS.EP05.D31.1_Detailed design description_issue01 | 01/11/2018 | ORBITA detailed design description. |
| RD08 | AVS.EP05.D22.1_Preliminary validation plan_issue02 | 10/09/2018 | ORBITA preliminary validation plan. |
| RD09 | ESA-GSTP-TECM-EPL-TP-012337 | 14/01/2019 | ORBITA Diagnostic System Testing at the EPL, Test Plan. |
| RD10 | AVS.EP005.AP001_ORBITA Phase I Assembly Procedure_issue02 | 20/11/2018 | ORBITA phase I assembly procedure. |
| RD11 | AVS.EP005.IP001_ORBITA Phase I Integration Procedure_issue01 | 27/11/2018 | ORBITA phase I integration procedure. |
| RD12 | AVS.EP05.D52.1_Test report_issue01 | 28/02/2019 | ORBITA test report. |

## ACRONYMS

| | |
|---|---|
| COTS | Commercial Off-The-Shelf |
| CPS | Counts Per Second |
| EP | Electric Propulsion |
| EPL | Electric Propulsion Laboratory |
| ESA | European Space Agency |
| FDR | Final Design Review |
| FPI | Fabry-Perot Interferometry |
| GIE | Gridded Ion Engine |
| HET | Hall Effect Thruster |
| ISP | Specific Impulse |
| PDR | Preliminary Design Review |
| PMT | Photomultiplier Tube |
| RR | Requirement Review |
| TRR | Test Readiness Review |
| UV | Ultraviolet wavelength |
| VIS | Visible wavelength |

## SCOPE

The aim of the ORBITA project was to develop a breadboard model of a system that could take EP diagnostic measurements on-ground and potentially in-orbit. This report summarises the findings of the project under ESA contract 4000122786/18/NL/BJ/gp. The deliverables of each major stage of the project are identified and the final outcome discussed. The project ran for a period of 12 months from March 2018 to February 2019.

## 1. PROJECT STAGES AND CONTENT

In this section a review is given for each of the major project stages and the content of each discussed.

### 1.1. Market Analysis & Requirements Definition

The first stage of the project in Q2 2018 consisted of a market analysis, requirements definition, and trade-offs into the choice of diagnostic technique to fulfil the technical objectives and requirements identified. These tasks were reviewed both during and at their completion by way of a Requirement Review (RR).

#### *1.1.1. Market analysis*

The market analysis considered the potential market available to a fully developed ORBITA system. Information was provided with respect to the market opportunity and size, customers, competitors and product differentiation, see *RD01*.

Meetings were held with prospective customers including *QinetiQ* and *Airbus UK* so that input into the system's requirements could be provided. The key inputs were that ion velocity, ISP and thrust were the main thruster performance indicators of interest. However while these performance indicators were of primary interest to the EP manufacturers such as *QinetiQ*, it was conversely spacecraft interaction effects that were of primary interest to spacecraft assembly primes such as *Airbus UK*. No direct competitors were identified, although the Advanced Electric Propulsion Diagnostics (AEPD) system is seen as the most comparable development, albeit mostly reliant on invasive probes to provide plasma diagnostics.

An output of the market analysis concerned the targeting of specific product areas by three proposed versions of the system: *ORBITA I* – spacecraft interaction effects, *ORBITA II* – plume measurement parameters, and *ORBITA X* – combining both applications.

#### *1.1.2. Requirements definition*

Requirements of the ORBITA system were defined and collected in a requirement specification, see *RD02*. The specification was split into several sections in order to provide a thorough background to the eventual system requirements, including the definition and selection of plume parameters to be measured following a state-of-the-art review (see *RD03*) and identification of typical thruster (including GIEs and HETs) and vacuum facility operative conditions.

Ion velocity was eventually selected as the plume measurement parameter of most interest to the ORBITA system since it allows a determination (by measurement of the Doppler shift) of the thruster ISP. This decision was made following the inputs provided by potential customers as had been identified in *RD01*.

A full list of system requirements was generated on which the hardware solution was then based. These requirements included the emission lines of interest (484.5, 504.5, 526.2 nm and 302.4, 326.9, 362.4 nm); thruster ion energy range accounted for (100-1850 eV); and ultimate ISP resolution (50 s).

### *1.1.3. Diagnostic technique trade-offs*

Following the state-of-the-art review and definition of requirements, trade-offs were performed in order to narrow down the choice of diagnostic techniques available to the ORBITA concept. All techniques under consideration were grouped by their diagnostic category: active spectroscopy, passive spectroscopy, optical effects from free electrons, and electrostatic probes.

A preliminary trade-off (see *RD04*) was performed separately for the spectroscopic techniques and the electrostatic techniques with three weighted criteria used to score the techniques in each case. These trade-offs resulted in the full list of a dozen different techniques under consideration to be narrowed down to the three most promising options for the ORBITA system: Fabry-Perot Interferometry (FPI), Optical Emission Spectroscopy (OES), and the Langmuir probe.

A detailed trade-off (see *RD05*) was then performed on these three remaining techniques in order to make final choices of technique for the *ORBITA I* and *ORBITA II* concepts. Four weighted criteria were used to score the techniques in each case. These trade-offs resulted in the Langmuir probe and FPI being selected as the diagnostic techniques of choice for *ORBITA I* and *ORBITA II* respectively.

## 1.2. Preliminary and Detailed Design

Initially running in parallel with the previous project stage were the preliminary and detailed design of the system itself, and validation plans that defined the tests to be performed during the test programme, identified the facilities and laid out the test programme procedures and data acquisition strategy. The preliminary design work package (refer to *RD06*) culminated in the PDR, while a FDR was conducted during the detailed design work package (refer to *RD07*).

### *1.2.1. Diagnostic design*

Development of the ORBITA system consisted of a number of elements including design and selection of optical components including the etalons, bandpass filters, lenses and fibre optics; optical modelling using *ZEMAX* software; selection of electronics and optomechanical components including PMT detectors, motion stages and all other supporting components; thermal and mechanical design and analysis; consideration of budgets (mass, power, data); and interface control.

The collection optics were designed to be located in close proximity to the thruster inside the vacuum chamber. Specific optical components were selected based on a trade-off between optimal photon collection and spatial resolution from sweeping the plume width. In addition, consideration was given to ensuring that all components were vacuum compatible.

The detection optics were designed to be located on a bench in an air-filled environment beside the vacuum chamber. The design consisted of two similar ‘legs’ – one to cover the visible wavelengths that had been selected and another to cover the UV wavelengths. The etalons act as a wavelength selection mechanism, their degree of tilt altering the optical path length and therefore the set of frequencies of light that *do not* destructively interfere and that therefore emerge to reach the PMT detectors.

### *1.2.2. <u>Validation plan</u>*

The tests to be conducted during the test programme were first defined in the preliminary validation plan (see *RD08*) and later finalised in the test plan (see *RD09*). These tests included calibration of the background noise level, thruster beam voltage adjustment, thruster beam current adjustment, vacuum quality adjustment, and collection optics angular adjustment. The exact test sequence was formulated so as to optimise manual and automated operations and therefore minimise the total test duration.

The CORONA vacuum chamber at the EPL, an operational test facility of ESA located at ESTEC in the Netherlands was chosen as the location for the test programme. This particular chamber was chosen for its versatility since it is equipped with an integrated smaller chamber or ‘hatch’ in which the devices being tested can be mounted and isolated from the main chamber if required. The *mini-RIT* was chosen as the thruster to be used during the test programme due to it being a GIE and therefore the ion velocities can be easily modified using the beam voltage.

Finally, this stage described the data acquisition and post processing strategy as had been determined through test sequencing and subprogram flow charts, and development of the bespoke Python script.

## 1.3. Manufacturing & Assembly

Manufacturing and assembly of the system started during the detailed design previously described and continued until the system was finally installed at ESTEC.

### *1.3.1. <u>Procurement & Manufacturing</u>*

Long-lead items including the bandpass filters, etalons and other custom optics, PMT photon counters, custom brackets, and vacuum-compatible components were ordered in advance while all other components were generally available immediately and ordered last. The bandpass filters were ordered from *Laser Components* (supplied from the U.S.), etalons and custom optics from *SLS Optics* (Isle of Man), PMT’s from *Optomechatronix* in Japan, and custom brackets from *EE Engineering* in the UK. Most optomechanical components of the system and non-custom optics were ordered from *Thorlabs* – the basic support structure of the system was designed largely around COTS components from this supplier.

### *1.3.2. <u>Assembly & Integration</u>*

Assembly (see *RD10* for procedure) and Integration (see *RD11*) of the system took place in two stages, initially at AVS Spain and finally at ESTEC. The initial assembly consisted of assembling individual components first into sub-assemblies and then the full collection and detection branches of the ORBITA system. The initial integration procedure consisted of ‘pre-assembly’ verification tasks such as checking the basic functioning of the *Newport* motion stages and *Optomechatronix* PMT’s; and ‘post-assembly’ verification tasks such as verifying that the custom Python code operated correctly, that the optical components of the system were correctly aligned, and that the stepper motor and its electronic control system were operating and correctly calibrated.

Following disassembly and transportation to ESTEC, the final assembly and integration took place in mid December 2018. Final assembly consisted of assembling the sub-assemblies into the full collection and detection branches. The final integration procedure consisted of integration with the CORONA chamber and trolley system; and ORBITA system verification tasks such as PMT photon counter noise measurements, Python code hardware synchronisation checks, optomechanical alignment, and stepper motor calibration. During this stage a number of changes were made to the original design including a change in orientation of the collection branch and a decision not to use the variable optic attenuators that had previously been planned. Neither of these changes had any impact on system operation. Once all tasks had been completed the system was left in a state ready for the test programme.

## 1.4. Test Programme, Results & Development Plan

The 2-week test programme took place in January 2019. Following the procedures given in *RD11* for integration, the system was re-verified and a TRR held prior to the start of tests with the mini-RIT thruster. Following the completion of testing the results were analysed and a test report produced (*RD12*). A development plan has been preliminarily investigated.

### *1.4.1. Test programme*

In total 11 test runs were performed using the thruster and 14 using a reference light source. Most test runs performed with the thruster used set point 1.1 (set points were defined in *RD09*), although several were also performed at set point 7. The reference used was a Mercury-Argon light source with a single spectral line compatible with the UV leg of the ORBITA detection branch.

### *1.4.2. Test results*

As discussed in *RD12*, the system was unable to register either a static or Doppler-shifted representation of characteristic emission lines during the test runs conducted using the thruster. Without such a signal it was impossible to take measurements of the Doppler shift and therefore calculate the ion velocity. Explanations for this negative result were based on three key issues: 1) lack of light reaching the PMT's, 2) absence of a pinhole in the design of the detection branch, 3) imprecise etalon alignment. Despite this, repeated peaks of the characteristic Fabry-Perot Interference pattern generated by etalons were detected in UV data *manually-obtained* with the reference light source and this represented a limited success.

### *1.4.3. Development plan*

Following analysis of the test results a preliminary investigation was made of the actions necessary to rectify the issues that had been identified. As such a series of recommendations have been proposed concerning collection optics positioning, choice of test subject thruster, detection branch hardware redesign and optical performance verification. Finally estimates have been made suggesting an additional 2-4 months and 17% of project cost would be necessary to produce the results that had been expected.

## 2. CONCLUSION

In conclusion, while the results of the test programme did not allow the ORBITA system to prove itself, it is believed that with the modifications to its design as proposed in *RD12* the system should still be capable of providing the measurements first envisaged. The system shares many similarities with other FPI setups (e.g. [1] [2]) that have proven themselves capable of providing ion velocity measurements in similar circumstances. The most careful consideration would need to be taken of the choice of test subject thruster (particularly GIE vs HET) and ways in which the light flux received at the PMT's could be improved. The expected flux would then be modelled accordingly before repeat tests were made. Since the CPS for one of the six selected emission lines (484.5 nm) was already a factor of 10 above the background noise level during this test programme, an improvement in light flux collected would ideally bring some or all of the remaining five lines into contention and therefore improve the validity of any Doppler shift measurements.

# REFERENCES

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[2] Gawron, D. et al., “A Fabry–Perot spectroscopy study on ion flow features in a Hall effect thruster,” *PLASMA SOURCES SCIENCE AND TECHNOLOGY,* vol. 15, pp. 757-764, 2006.