FLEX & SENTINEL 3 : A TANDEM TO MONITOR VEGETATION

E. Jauffraud[1], P. Bassaler[1], P. Coppo[2],A. Taiti[2], E.Battistelli[2], M. Rossi[2]
[1]Thales Alenia Space, France. [2]Selex ES, Italy

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1. INTRODUCTION

The FLuorescence EXplorer (FLEX) mission is selected as the ESA's 8th Earth Explorer opportunity mission.

The FLEX flight segment consists of a single satellite carrying the FLORIS payload and flying in formation with Sentinel 3 mission in a Sun synchronous orbit at a height of about 815 km, making use of data synergy with other visible reflectance (from OLCI) and surface temperature data (from SLSTR).

The satellite is based on a recurrent platform. This ensures that the required levels of performances will be met and allows the satellite development to achieve the industrial cost target while minimizing development risks.

The physical satellite configuration is driven by the accommodation of the payload to be mounted on top of the platform guaranteeing an unobstructed view of the Earth.

FLORIS, a pushbroom hyperspectral imager, will observe the vegetation fluorescence and reflectance within a spectral range between 500 and 780 nm at medium spatial resolution (300 m). Multi-frames acquisitions on matrix detectors during the satellite movement will allow the production of 2D Earth scene images in two different spectral channels, called High Spectral Resolution and Low Spectral Resolution .

The tandem flight are displayed in chapter 2. The satellite configuration is described in subsection 3.1, followed by the FLORIS payload in subsection 3.2 and complemented by the description of the platform in subsection 3.3. The programmatics information are presented in chapter 4.

2. A TANDEM FLIGHT

2.1 Mission

The flying formation with Sentinel 3 is imposed by the temporal co-registration between the FLEX observations and the OLCI and SLSTR (nadir view) observations shall be less than 6 sec (Goal)/15 sec (Target). In addition, the ground swath covered by the FLEX observations shall be entirely contained within the ground swath of the nadir-looking OLCI camera 4. This will impose the satellite inter-distance between FLEX and Sentinel-3

2.2 Formation control

As the slave satellite FLEX shall remain in its formation flying control box during the mission to guarantee the co-registration requirements with OLCI and SLSTR sentinel 3 instruments. The FLEX orbit control manoeuvres will be synchronized with Sentinel 3 control manoeuvres.

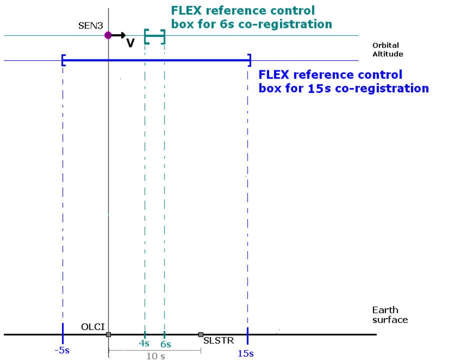

Figure 2-1: Along track control boxes for 6 sec and 15 sec co-registration

2.3 Communication

FLEX might not be able to use its X band transmitter at the same time as Sentinel-3. This restriction concerns communication to the same ground station with overlapping visibility circles, in particular to Svalbard but also to Kiruna which has a large overlap with Svalbard. One solution is to select a ground station in Antartica such as Troll without any RF interference (base line) or to enlarge the satellite inter-distance while keeping the co-registration performance still acceptable.

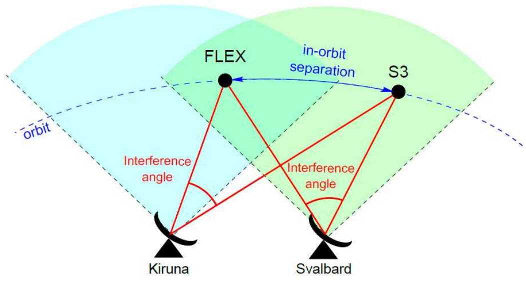

Figure 2-2: Simultaneous communication

3. OVERALL DESIGN

3.1 Satellite Configuration

3.1.1 *Overview*

The satellite is based on the TAS Proteus 150 platform designed for single-instrument LEO observation missions. This platform is part of the TAS platform product line mastered through various past programs.

The satellite in deployed configuration is shown in Figure 3-1. The satellite is flying with a constant roll angle of 60° in order to optimize the illumination of the solar arrays along the orbit. The payload module provides an additional 30° tilt to align the instrument line-of-sight with the nadir direction. This configuration also provides a large access to cold space for the satellite and the instrument.

During observation arcs, the yaw angle is adjusted in order to maintain the slit perpendicular to the ground track. Outside observation arcs, a yaw guidance is applied to optimize the solar array illumination, which further improves the satellite power budget.

In safe mode, the satellite points its solar array toward the sun and performs a slow spin around the Sun axis.

The satellite has a maximum mass of 485 kg. The satellite mass is then compatible with VEGA/VESPA launchers. Maximum Payload mass for VEGA under Vespa configuration is 600 kg, leading to a maximum separated satellite mass of 522 kg (adapter of 78 kg).

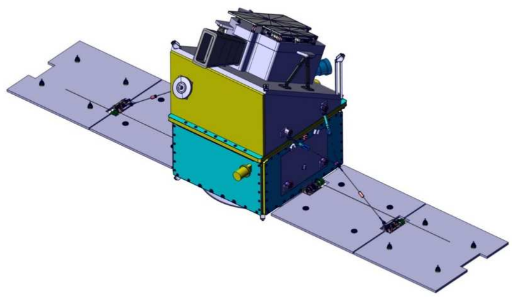

Figure 3-1: FLEX In-flight Configuration

3.1.2 *Instrument accommodation*

Figure 3-2 shows the accommodation of the instrument on the spacecraft.

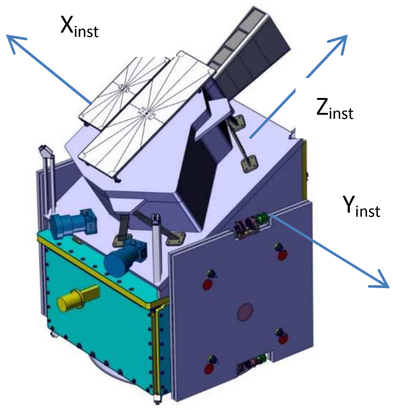

Figure 3-2: FLORIS Instrument on spacecraft (Xinst=cold space, Yinst=speed direction, Zinst= Earth view)

3.1.3 *Launcher compatibility*

The satellite in launch configuration is represented for VEGA/VESPA on Figure 3-3.

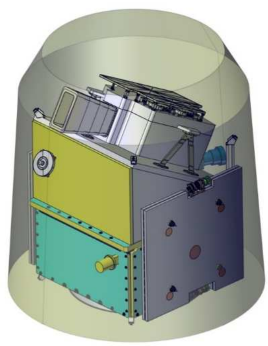

Figure 3-3: FLEX inside VEGA/VESPA Fairing

3.2 FLORIS Instrument

3.2.1 *Optical Concept*

A compact opto-mechanical solution with all spherical and plane optical elements is proposed. A dual Babinet scrambler is placed in front of the telescope in order to reduce the polarization degree of the incoming light and a dioptric fore-optic images the ground scene onto a double slit. Then the radiation is dispersed onto two detectors by means of the high spectral resolution and low spectral resolution grating spectrometers in a modified Offner configuration with unitary magnification (VIRTIS, VIMS heritage). Special attention has been given to the mitigation of spatial and spectral stray-light which could impact on the fluorescence measurement accuracy.

The opto-mechanical design is robust, stable versus temperature, easy to align, showing high optical quality with excellent corrections (by design) of transverse aberration and distortions (keystone and smile).

3.2.1.1 Telescope

Spatial co-registration is enhanced by design using a common fore-optics between the two spectral channels, which has the same ground spatial sampling (300 m) and swath (147 km).

A standard Petzval objective with eight spherical lenses is used as fore optics (Figure 3-4). It has a real entrance pupil located 75 mm in front of the first lens and it is telecentric in the image focal plane.

It is shared by the 2 spectral channels and it works with F#=3.1 in the spectral band 677-780 nm (FOVx=±5.15° FOVy=0) and with F#=6.5 in the spectral band 500-740 nm (FOVx=±5.15° FOVy=0.35°).

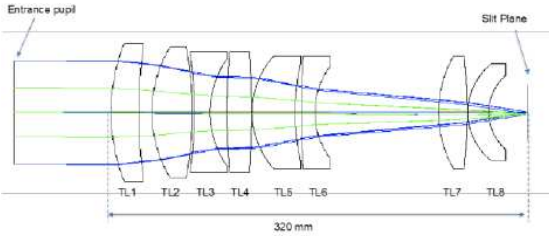

Figure 3-4: Telescope optical lay-out.

3.2.1.2 High Spectral Resolution Spectrometer

The proposed solution is based on the Lobb's theory of concentric designs for grating spectrometer. It works in the spectral range 670–780 nm with a pixel pitch of 28 µm in the spectral direction and 84 µm in the spatial one. The spectral sampling is 0.1 nm/30µm and the F# is 3.1. The magnification is 1. The starting point is the Offnër relay, a unit magnification system composed by a concentric arrangement of a concave spherical mirror (HRM), from which light is reflected twice, and a convex spherical mirror. Performances are improved by the addition of a concentric spherical lens (HRL). The relay is converted in a spectrometer adding the grating structure (HRG) on the surface of the convex spherical mirror. The entrance beam is folded by a flat mirror (HRF) placed after the high spectral resolution entrance slit and passes through the lens (HRL). It is then reflected by the concave mirror (HRM) before to strike the grating (HRG) (Figure 3-5).

The grating-line planes are orthogonal to the plane that is tangent to the grating vertex.

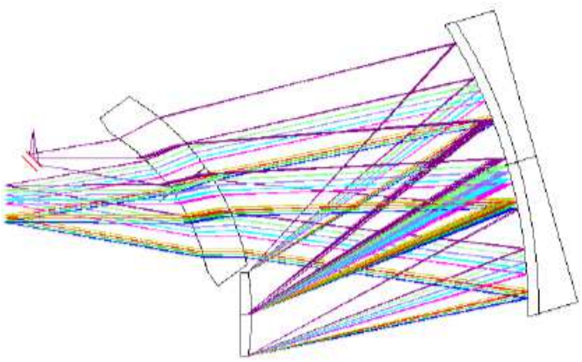

Figure 3-5: High Spectral Resolution Spectrometer optical lay-out.

The grating period is set at 1450 Grooves/mm (0.093 nm/pixel on the focal plane) and the beam incidence angle on the grating is approximately 38.2°. The -1 order of the diffracted beam is back reflected close to the incident beam, with diffraction angles between 21.3° (at 677 nm) and 30.9° (at 780 nm). This beam is then guided towards the focal plane by means of a second reflection of the concave mirror and the second transmission through the meniscus (Figure 3-5).

3.2.1.3 Low Spectral Resolution Spectrometer

The low spectral resolution spectrometer optical design is of the same family of the high spectral resolution one but with a new special design of the corrector lenses. It works in the spectral range 500 – 740 nm with a pixel pitch of 28 µm in the spectral direction and 84 µm in the spatial one. The spectral sampling is 0.6 nm/30µm and the F# is 6.5. The magnification is -1. Starting from a standard 2 mirror Offnër spectrometer, a grating grooves density of 500 lines/mm has been selected in order to minimize the ghosts due to the optical path CCD-grating non operational order-CCD. In order to reduce the astigmatism and to correct smile and keystone, two spherical lenses have been added (Figure 3-6).

The incidence angle on the grating is 17.4°. The beam is diffracted by the first order between 33.2° (at 500 nm) and 41.9° (at 740 nm). The grating has a saw-tooth profile generated byholographic recording. After a second reflection on the primary mirror the beam is folded by LRF2 towards the lens LRL2 before to arrive on the focal plane (Figure 3-6). The design is able to guarantee optical quality at limit of diffraction for each wavelength along the whole field of view and excellent correction for smile and keystone.

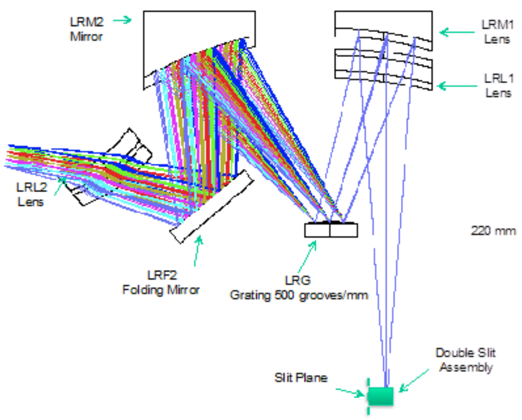

Figure 3-6: Low spectral resolution Spectrometer optical lay-out.

3.2.2 *Detection Chain*

3.2.2.1 Detector & Focal Plane Architecture

Three identical CCDs (Figure 3-7), backside illuminated, split frame transfer, radiation tolerant, 2 double output ports, 1070*460 format with 42 µm*28 µm (spatial*spectral direction) pixel size and x2 spatial on-chip binning have been selected. 1050*430 (rows*column) will allow the acquisition of 147 km swath and 40 nm spectral range for high spectral resolution spectrometer (240 nm for low spectral resolution). Further 10x2 columns and 5x2 rows are used as margin for alignment, while 5x2 columns and 5x2 rows respectively for smearing and dark current signal corrections. 3 MHz readout frequency for port allows download of all pixels at 45 msec pixel reading time. Two ports with similar gains for each transfer serial register are used to select the best direction of the transfer signal to mitigate possible CTE degradation.

A dumping gate has been implemented to skip part of swath during the diagnostic mode: all swath pixels of a homogeneous target are acquired without binning at different times, by using the same CCD timing as the operative mode. The operative detector temperature of 238 K±0.10 K is achieved by using an external radiator & an heater/sensor near the package. Two adjacent detectors along the spectral direction in the high spectral resolution spectrometer are separated of a distance less than 12.06 mm in order to cover the two O_2 absorption bands 677-697 nm and 740-780 nm.

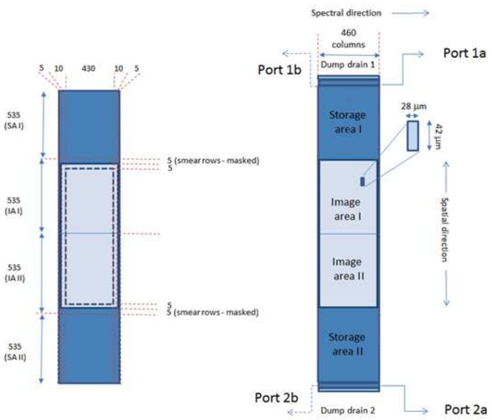

Figure 3-7: Detector configuration.

The Front End Electronic is separated into two parts (Figure 3-8): the Focal Plane Proximity Electronics (FPPE) devoted to pre-amplification and CCD bias conditioning, and the Video Acquisition Unit (VAU) for gain/offset drift compensation, bias and clocks generation/driving, FEE TM/TC and digital processing/serializing. The FPPE is placed at 5 cm from the detector while the VAU is at a distance of about 20-30 cm from FPPE. A 3 MHz VASP ADC working at 16 bit with 1.6 LSB total noise and three space-wire links versus nominal/redundant Main Electronics (ME) are used.

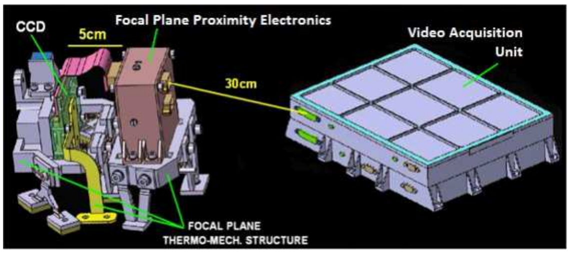

Figure 3-8: FPPE and VAU

3.2.2.2 Main Electronics

Three non redundant FEE (FPPE + VAU) units and one redundant Main Electronics (ME) (Figure 3-9) allows a good reliability of 0.876 for 3.5 years lifetime (0.827 in 5 years). ME is composed by four sections devoted to deliver the payload data processing and TM data flow management, the instrument control and HK TM/TC, the mechanisms and TCS control and the power distribution. Two space wire links versus the Satellite Mass Memory are used.

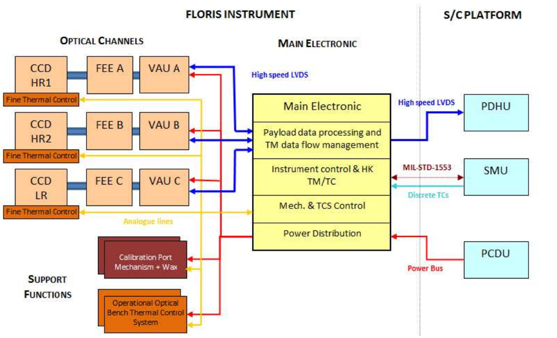

Figure 3-9: Electronics functional block diagram

3.2.3 *Mechanical and Thermal Architecture*

The optical Bench is in Al6061 T6 with optics and supports in Titanium for high thermal insulation & stability (thermal stabilisation ±1K) (Figure 3-10). The baffle is also in aluminium and the calibration unit uses three similar redundant mechanisms (entrance port + diffuser + solar port). Two white painted radiators cooling the detectors and the VAU’s are mounted on the upper side of instrument (Figure 3-11), with a completely view versus the cold space (for optimum S/C accommodation & thermal efficiency). The ME is separated by the instrument and is mounted on the S/C payload module. The isostatic mount concept with three titanium bipods at 120 degrees assures the mechanical stability (Figure 3-10).

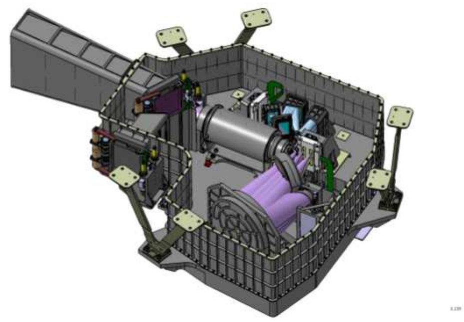

Figure 3-10: Mechanical layout (internal view).

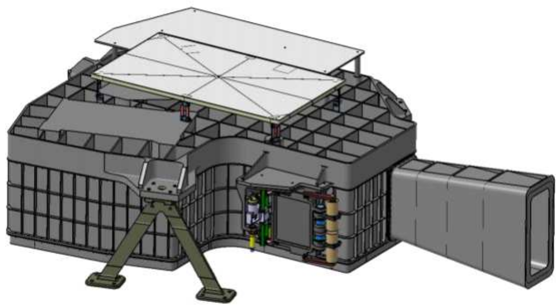

Figure 3-11: Mechanical layout (external view with baffle,radiators and solar port)

3.3 Platform

3.3.1 *Mechanical and thermal architecture*

The thermal concept of the platform is identical to the Proteus 150 product line one.

The Floris instrument possesses its own thermal control which is never dismounted and thus keeps the integrity of the qualification or acceptance tests done at instrument level.

The dissipative thermal hardware of the instruments is exclusively passive. Therefore no complex active thermal hardware such as coolers is foreseen.

The Payload Module has its own thermal control which is simple as only one equipment is inside i.e. the Main Electronic of Floris.

The platform preserves also optimal thermal view factors to the radiators.

3.3.2 *Avionics architecture*

The avionics is scaled down from Sentinel-3 to suit a more compact platform well known by ESA and benefits mostly of an identical ground to space interface and operational concept.

The avionics architecture is centered around the Satellite Management Unit, in charge of:

- Ground interfaces (TM/TC) and S-band communications management,
- Mode management,
- System FDIR,
- AOCS and Thermal Control applications,
- Payload Data Handling Unit management.

Command and control communications is performed through two 1553 buses: one for platform units and one for payload module units.

Telecommands are routed by the on board computer to the instrument Main Electronics using PUS formats.

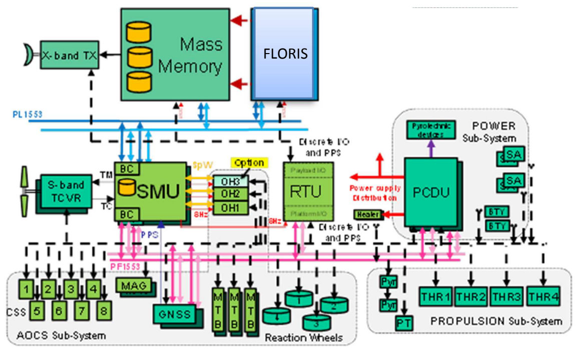

Figure 3-12: Satellite Avionics Architecture

3.3.3 *Propulsion*

The PROTEUS monopropellant propulsion subsystem ensuring in-orbit control and de-orbitation implements 4 x 1 N thrusters. Manoeuvres can be performed using 4 thrusters (large manoeuvres) or a diagonal pair of thrusters (small manoeuvres and contingency case). The tank has a propellant capacity of 28 kg.

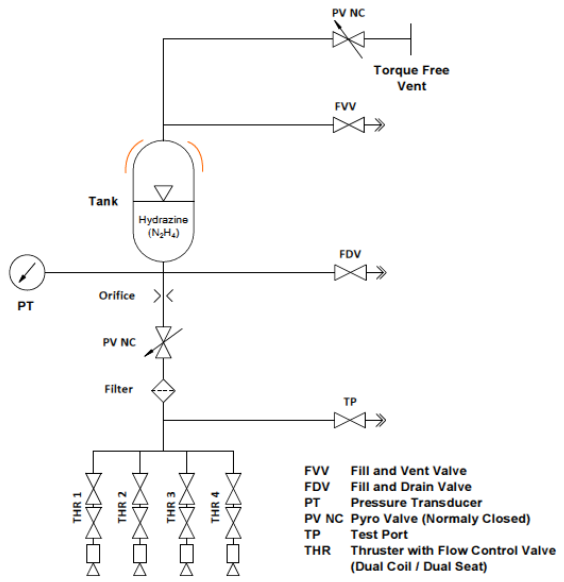

Figure 3-13: FLEX Propulsion Subsystem

4. PROGRAMMATICS

4.1 Overall Design and Development Approach

The FLEX satellite models ensure a robust approach while taking benefit from a strong heritage on this type of platform , the Proteus 150 product line platform with a very high level of recurrence for the FLEX mission with no development risk.

The approach incorporates an early verification of all critical performance and interface requirements, reducing potential for problems later in the program.

The critical elements of the instrument that necessitate some pre-development activities are the detector by itself and the optical module including the telescope, the low and high resolution spectrometers. These pre-development activities are still on-going.

Consequently, the following model philosophy is proposed for FLEX satellite design, development & verification process:

- An Avionic Test bench (ATB) adapted from previous ATB,
- A Proto Flight Model (PFM) to mitigate verification risk. The approach allows for the early testing of critical FLEX performances on ATB model such as functional performance, interfaces issues and secures both schedule and duration of the PFM sequence.

All models benefit from qualification at equipment level and main element level. These lower level models will also provide additional confidence before undertaking the system level tests.

The ATB, and PFM will all be conducted for FLEX satellite, and all models will benefit from equipment level and main element level models preceding the system model. These lower level models will also provide additional confidence before undertaking the system level tests.

For the instrument the following models are proposed:

- An Elegant Breadboard (EBB),
- An Optical Module (OM) by refurbishing the EEB,
- An Electrical Engineering Model of the instrument Main Electronics and of the instrument Front-End Electronics and Detector for functional and interface validation,
- A Structural Thermal Model (STM) for environmental testing,
- The instrument ProtoFlight Model (PFM).

4.2 Schedule

The schedule assumptions are as follows:

- Start of the instrument Phase B2/C/D by mid 2016 (anticipated as the instrument ITT took place prior to the satellite ITT)
- Start of System/satellite Phase B2/C/D by second quarter of 2017.
- Launch by December 2021

5. CONCLUSIONS

The feasibility of the mission with the fulfilment of all the requirements is demonstrated thanks to the TAS satellite and platform product line, and the SES experience on optical instrument development and management . TAS has demonstrated the solidity of the proposed industrial consortium and has all the assets to make the FLEX mission development a success.

Indeed, the proposed mission and satellite design minimise the risks and thanks to the consortium experience to master the development and schedule of both instrument and satellite.

6. ACKNOWLEDGMENTS

The activity has been performed in the framework of an ESA contract, phase A-B1 with Thales Alenia Space (F) as the satellite prime contractor and SES as the instrument supplier. We wish also to thank all industrial partners which have collaborated with TAS-F and Selex ES (I) in order to optimize and consolidate the satellite baseline (DEIMOS, SCISYS, TAS-I) as well as instrument baseline (DIOS, IOF, Zeiss, Sodern, E2v, Selex ES UK, TAS I, TAS E).