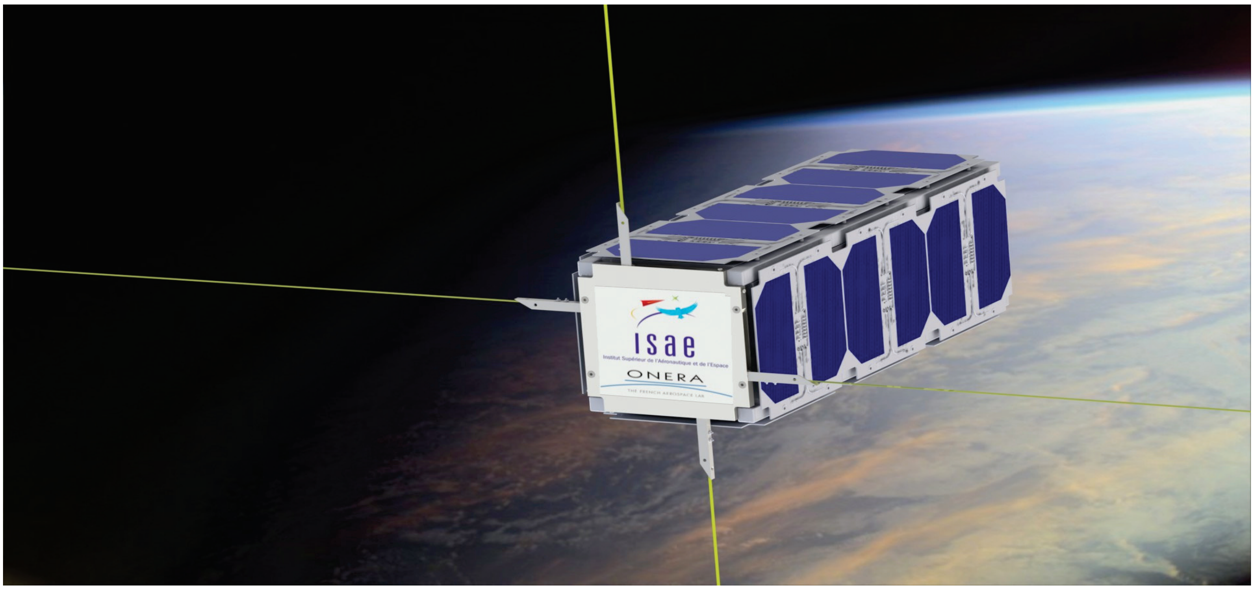
Name of CubeSat: **EntrySat**

Institut Supérieur de l'Aéronautique et de l'Espace



TITLE: Orbital Debris Atmospheric Entry Experiment: EntrySat 3U IOD CubeSat

Proposing Team/Lead Institute: Institut Supérieur de l'Aéronautique et de l'Espace (in collaboration with ONERA)

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CONTENTS

1 QB50 Flight Opportunity

QB50 is a network of 50 Cubesats that is planned to be launched together in the first half of 2015 by a single rocket, a SHTIL-2.1 from Murmansk, Russia into a circular orbit at 320 km, inclination 79 °. This project was created by the Von Karman Institute for Fluid Dynamics in Brussels, Belgium, to fulfill both scientific and educational purposes.

Given the area of expertise of the Von Karman Institute, the scientific objectives are clearly linked with fluid dynamics: obtaining reliable in-situ and globally spread data on the upper-layers of the atmosphere. Given the remaining friction forces at the altitudes considered (90 to 320km) the lifetime of an orbiting object is quite limited. Most national agencies study the upper atmosphere with balloons, sounding rockets, or the occasionally satellite in a highly elliptic orbit. As a consequence, very few global, simultaneous, in-situ measurements have been performed by national agencies with limited data collection amounting to a few minutes. The data does not allow scientists to have an overview of an entire atmospheric layer at one time.

Equally important from the perspective of a French team is that the low orbit altitude leads to a short life-time in orbit, thus respecting the COPUOS recommendations and the regulating of the French Space Law about space debris.

The QB50 project uses satellite designs based upon the standard developed by Stanford University and California Polytechnic Univeristy. This small satellite design enables students and research teams to gain access to space for a much lower price than large national missions. The standard, known as CubeSats, are satellites with very small dimensions (typically 10x10x10cm for a “1U” CubeSat), low power and mass-budgets (1W, 1.33kg). Combined with a coupled desire to utilize COTS components, these satellites typically require less funding. Using less-demanding platforms means that, for the same price, a user can can conceive and build them in small teams of students, professionals, or even amateurs and deploy many copies for a price less than one large typical satellite typically used in exploration or the higher orbits such as geosynchronous communications.

Therein lies the advantage of the CubeSat platform for the QB50 Project:

- The cost per platform is reduced and enables the use of a constellation, therefore producing globally spread data;
- The cost is reduced and can justify a shorter lifetime (typically 3 month when starting on a 320km circular orbit);
- Due to electronics miniaturization, complex instruments can now be used even aboard small platforms;
- The conception and fabrication phases can be performed by students, giving them valuable experience to later work in the aerospace sector.

In conclusion, the QB50 Project will consist of:

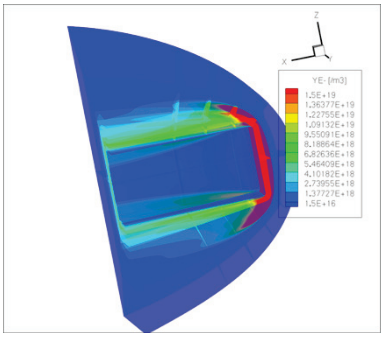
- 40 double unit (10x10x20cm) CubeSats will carry sets of standardized sensors for multi-point, in-situ, long-duration measurements of key parameters and constituents in the largely unexplored lower thermosphere and ionosphere.
- In addition to the 40 atmospheric double Cubesats, 10 double or triple (10x10x30cm) CubeSats for science and technology demonstration will be selected.

The collected data will be communicated to Earth via multiple ground stations and made available to the scientific community. The satellites are expected to acquire data through much of the thermosphere (320 to 90km) before their re-entry and destruction. The instruments and launch aboard a Shtil-2.1 rocket are offered to the teams as part of an FP7 EC Project.

The EntrySat proposed by ISAE is one of the 10 double or triple CubeSats for science and technology demonstration.

2 Executive Summary

In-Orbit collisions and satellite orbital decay have demonstrated that orbital debris represents a potential threat to access to space as well as a threat to ground safety[i]. One promising solution under investigation at CNES – and based on a large OTV – aims to clear low Earth orbit of debris by injecting debris into reentry orbits which ensure a direct controlled atmospheric reentry destruction[ii]. However, equipping a passive target with a suitable spacecraft bus for de-orbit through an orbital rendezvous is a complex operation. Such missions often suffer critical failures, and several missions which had planned for controlled de-orbit saw failures of the de-orbit subsystems that resulted in low-slope, uncontrolled atmospheric reentry[iii]. Meanwhile, existing knowledge on the survivability of a satellite or launch vehicle element during atmospheric reentry remains incomplete. Further, tracking and predictive capability for the trajectory of small objects, either debris or otherwise is lacking, as demonstrated by recent events the International Space Station. Although valuable information has been obtained during complex atmospheric re-entries such as during the ATV program[iv], no dedicated orbital debris in-flight experiment has been performed to date.



Therefore, the EntrySat experiment consists of inserting a nanosatellite in the form of a 3U CubeSat into low-Earth orbit (which is similar in principle to secondary debris typically issued from launch vehicles or satellites). A science module operating during the reentry phase will be able to perform in-situ measurements of the CubeSat environment as well as integrity up to its destruction. Acquired data will be sent in real time through the Iridium constellation back to the ground segment. This In-Orbit Demonstration (IOD) CubeSat is to be injected into a trajectory representative of an uncontrolled atmospheric reentry with both very low slope and high orbital velocity.

Figure 1: Preliminary modeling of reentry flow around EntrySat

Furthermore, no propulsion subsystem or reentry protection subsystems will be utilized during the destructive phase of flight – thus the satellite will respond to the atmosphere in a similar manner as some orbital debris. Figure 3 presents the overall mission profile. The Orbital Debris Atmospheric Entry Experiment "EntrySat" CubeSat will be suitably equipped in order to relate the kinematics and the encountered aero-thermodynamic environment through aerodynamic forces and temperature data. Primary scientific objectives of the experiment are summarized in Table 1. In verifying the aero-thermodynamic models of reentry, the EntrySat will help to increase the accuracy of trajectory predictions for known space debris and other small orbital objects. The system architecture outline is described in Figure 2. EntrySat CubeSat will be controlled by ISAE's ground station, through the local ground station or via the GENSO network. Raw science data shall be sent to the ground station via UHF/VHF (during nominal decay phase) or the Iridium network as necessary through SBD transmission. Mission operations and ground station details are described in section 4.7 and section 4.8.

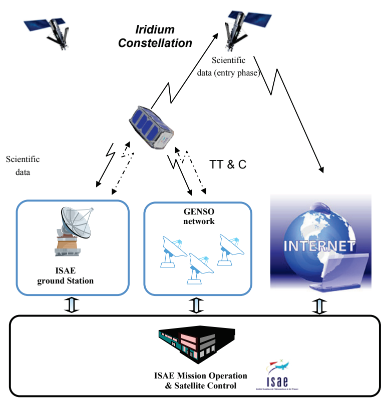


Figure 2: EntrySat System Overall architecture

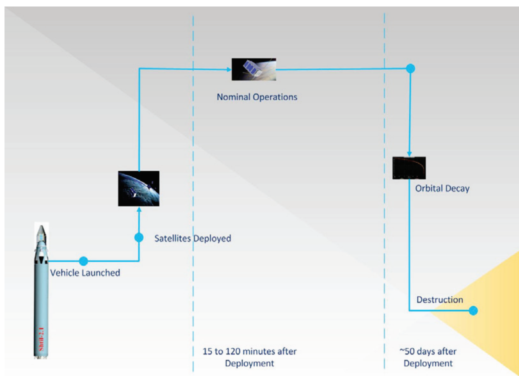


Figure 3: EntrySat Mission Profile

ISAE mission operation and satellite control will be linked to the main QB50 network through the internet. Expected mission duration is between 2 and 3 months, depending on the atmospheric state (see mission analysis section 3.2).

3 Experiment description and required resources

3.1 In Orbit Demonstration Science Case

The proposed in-orbit experiment can be divided between two phases, as can be the natural atmospheric entry of orbital debris.

a) The first part of the experiment deals with accurate prediction of orbital decay, especially with respect to time remaining before entry, typically a few weeks or months. At the atmospheric entry point, the slope angle suddenly increases and the object will reach the ground or be destroyed in a very short time, usually a few minutes or hours. Accuracy of the trajectory simulation during orbit decay depends on the accuracy of several physical models:

- Atmospheric modeling (between 120 and 300 km): the whole QB50 project contributes to increase knowledge of the thermosphere since this is its first goal.
- Aerodynamic coefficients modeling in the rarefied and transitional regime.

To refine these models, aerodynamic forces and associated kinematics (position, attitude motions) should be available; EntrySat will perform these measurements during orbit decay phase.

b) During the second part of the experiment – the destruction phase – EntrySat will melt and break up in a few minutes at a maximum. The expected velocity value is about 7 km/s and the break-up altitude and on-board conditions changes can be only determined if the CubeSat is suitably equipped to send information during re-entry. This kind of information is of primary importance to improve the multi-physics modeling during atmospheric re-entry as well as to improve the prediction of the survivability of satellite or launch vehicle elements.

Scientific Question	*Required In-Flight Measurements*	*Required Minimum Accuracy*		*Proposed Instrumentation*
		Orbiting Phase	Destruction Phase	
What is the kinematics of space debris during reentry?	-Position -Attitude -Velocity	- 1 km, 1 day - 1°, 1 day - 1 Hz	- 10 m, 0.1 s - 1°, 0.1 s - 10 Hz	- GPS - gyroscopes - accelerometer - magnetometer
How do the aerodynamic pressures vary during reentry?	-Drag force	TBA	95%	-Piezoelectric element to measure pressure on panel -Sensors under review
How does the integrity of the satellite vary during reentry?	Temperature of constituent materials	TBA	95%	-Thermocouples

Table 1: EntrySat Mission Science Objectives

While the first part of the experiment (measurements in the rarefied and transitional regime) can be performed with an excellent level of confidence, the data transmission during the second phase, in spite of the blackout expected to occur, will be a true challenge. During the early entry phase, data transmission will be achieved using two Iridium antennas (on both sides of the satellite). However, the exact technological choice for data transmission during the second part of the experiment remains under consideration because they will need further computations and experimental validation in phase A of the project.
The entry profile will be used thanks to the following tools:

- A 6 degree of freedom code will be used by ONERA to simulate the trajectory of the CubeSat. This code is coupled to physical models accounting for the real 3D geometry of the CubeSat, the aerodynamics forces and heat fluxes occurring in the rarefied, transitional and continuous regimes as well as the multi-physics phenomena (ablation and break-up). An integrated Monte-Carlo method allows the quantifying of uncertainties of models (and observations) along the trajectory. That advanced tool, called FAST/SKIP, already used successfully for complex atmospheric re-entry of space vehicles will allow to validate the choice of materials (and their thickness) equipping the CubeSat as well as to accurately define the scientific instrumentation. In particular, the ablation of the CubeSat could be simulated.

- An aero-thermodynamics tool will be built by ONERA and Rtech in order to validate the above-mentioned tool at some flight points using DSMC simulations for the transitional regime and Navier-Stokes computations (chemical disequilibrium) for the last part of the trajectory.
- The scientific instrumentation, especially heat flux sensors, piezoelectric sensors and thermocouples will be tested in a realistic heat loads environment by CNRS.

The present experiment is very complementary to the VKI Re-EntSat experiment. The latter satellite aims to collect data during a controlled atmospheric re-entry of vehicle or debris, while the ISAE experiment focuses on natural uncontrolled reentry of orbital debris and specifically on the prediction of trajectory and understanding of the reentry environment.

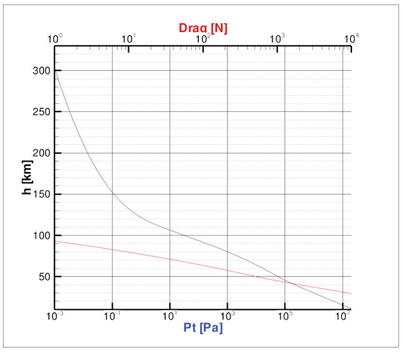


Figure 4 Drag force and maximum pressure during atmospheric re-entry

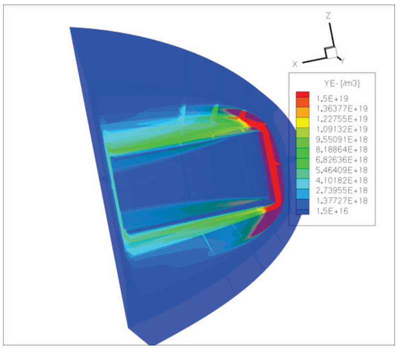


Figure 5 Electronic density around EntrySat during re-entry

3.2 Mission Analysis

Lifetime duration

The scheduled launch coincides with the solar maximum (14 June 2014). This situation provides the possibility for excellent science returns; however, it reduces the satellite lifetime at any initial orbital altitude. Depending on the specific launch date and the corresponding solar activity a maximum orbital lifetime of 12 weeks is foreseen. In order to cope with the uncertainty of orbital parameters during launch, various RAAN have been considered to account for various orbital configurations.

Orbit Parameters	Value
Type of orbit	Circular
Initial altitude	320 km
Inclination	79º
RAAN	0º
	45º
	90º
	135º
	180º
	270º

Table 2 Orbit parameters for mission analysis

Elevation = 10º	Min Access Duration		Max Access Duration		Mean Duration		Total Duration	
	Seconds	Minutes	Seconds	Minutes	Seconds	Minutes	Seconds	Hours
RAAN-0	17,55	0,292	324,13	5,4	253,97	4,23	33015,73	9,17
RAAN-45	72,31	1,205	324,11	5,4	258,32	4,31	32548,48	9,04
RAAN-90	33,23	0,554	324,15	5,4	256,8	4,28	32870,26	9,13
RAAN-135	13,68	0,228	324,14	5,4	255,57	4,26	32969,07	9,16
RAAN-180	74,26	1,238	324,1	5,4	257,85	4,3	32746,89	9,1
RAAN-270	70,29	1,171	324,12	5,4	258,54	4,31	33093,15	9,19

Table 3 Access to Toulouse ground station (10° elevation)

In the worst-case scenario, if the spacecraft maintains a high-drag configuration and solar activity is exceptionally high, the spacecraft orbital lifetime will be lower than 4 weeks. Preliminary mission analysis results, including the study of the contact with the Toulouse station, are depicted in Figure 6 and Figure 7.

Contact with Iridium constellation during reentry

An important part of the mission design relies on the contact between the satellite and the Iridium constellation during reentry. It is necessary that:

1) There is actually an Iridium satellite in visibility during re-reentry to get the data back
2) The Iridium system can compensate for the Doppler shift of the carrier due to the speed difference between EntrySat and the Iridium relay.

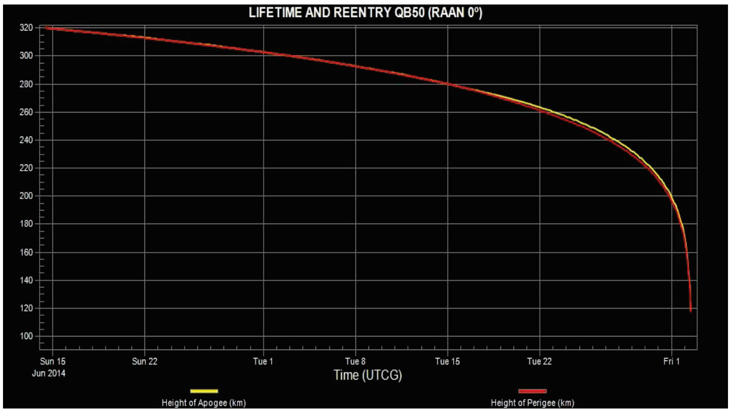


Figure 6: Projected satellite altitude for orbit of RAAN 0° Inclination 79

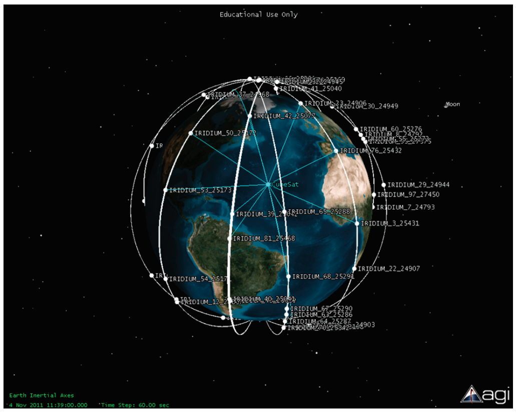


Figure 7: Configuration of the EntrySat – Iridium link

A preliminary study (see e.g Figure 8, Figure 9) has been done to establish the access properties between the Iridium constellation and the EntrySat in the last hours of the EntrySat life. Preliminary results indicate a probability of over 95% to have a link with ad-hoc properties during the reentry phase.

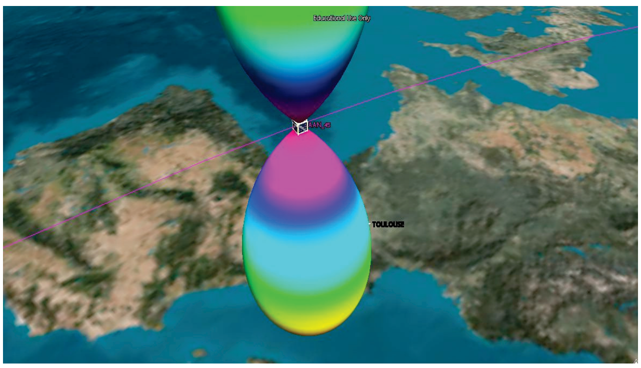


Figure 8: EntrySat Iridium antenna radiative patterns

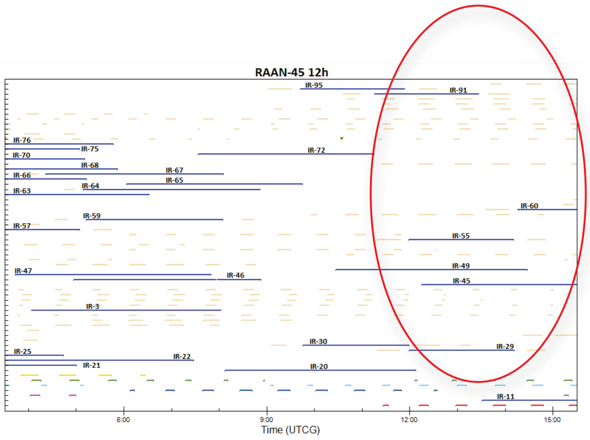


Figure 9: EntrySat – Iridium Access is possible with several satellites during the last 15 hours of predicted orbit

4 Satellite Design

4.1 Satellite Overview

The EntrySatdesign is a still on-going process. Current status is pictured in Figure 10. Starting from payload requirements, we have built a preliminary design mostly based on off-the shelf components bought from ISIS provider. We have initiated the work by producing high-level, subsystem, space systems, and ground systems requirements that can be found in the attached EntrySat requirements document. The process of subsystem hardware selection for the EntrySat is a trade study where components are weighted most heavily by impact on the power budget, mass budget, and whether the component is space-grade or requires (simplified) qualification procedures.

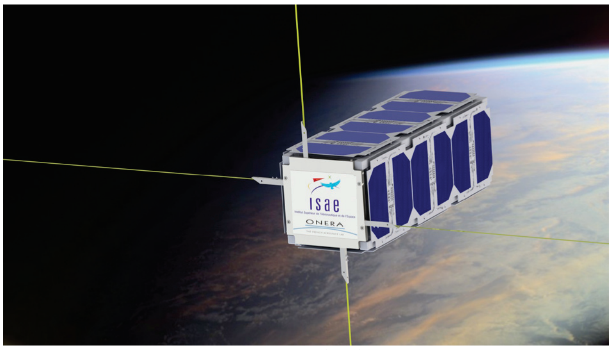


Figure 10: EntrySatCAD model

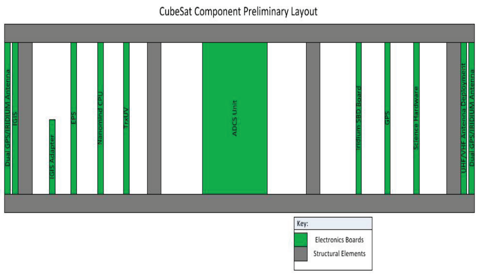


Figure 11: satellite basic schematics

4.2 Bus Description

The EntrySat will have no propulsion unit, and the functional hardware otherwise representative of a spacecraft bus will be fully integrated with the satellite due to size. While CubeSats are modular in nature, the EntrySat mission does not call for a completely separate science module – rather, modularity will be reduced to the level of the printed-circuit boards (PCB) stacked within the CubeSat due to the distributed nature of the EntrySat sensors. Elements of a traditional spacecraft bus included in the EntrySat subsystems include the EPS (batteries, solar panels), ADCS (magnetic actuators, sun sensors, magnetometers, IMU), and GPS. As can be seen in Figure 11, these hardware elements are distributed throughout the length of the CubeSat and modularized by PCB units. ADCS components, under this proposal, will be revisited in trade study, isolated on the component level, and fully modularized into a separate area of the 3U satellite frame. Due to the strong heritage of the ISIS design, no specific thermal control is foreseen. However a preliminary thermal modeling shall determine the need of heaters, although there is no current EPS baseline. The CubeSat structure claims heritage from ISIS CubeSat design.

4.3 Payload Description

The payload for the purpose of accomplishing the EntrySat goals is the Iridium SBD board, the GPS unit, and several sensors including: **IMU with magnetometer**, **washer type-k thermocouples**, and **piezoelectric force sensors**. A GPS sensor will be used to retrieve the EntrySat location. Ground testing will be necessary to validate and characterize the capabilities of two of these items – namely, the Iridium SBD board and the piezoelectric force sensors. Specifically in the case of the force sensors, it is hypothesized that if piezoelectric sensors give adequate information on incident forces, then some atmospheric properties can be deduced based upon the understanding of drag force. This hypothesis, as well as methods of properly affixing the thermocouples and force sensors to obtain the desired data, will be tested and verified during phase B before finalization of sensor selection and construction of the flight model. Figure 12 illustrates the placement of a piezoelectric sensor and thermocouple under each face. Piezoelectric sensors are illustrated in green, thermocouple washers as a small red ring.

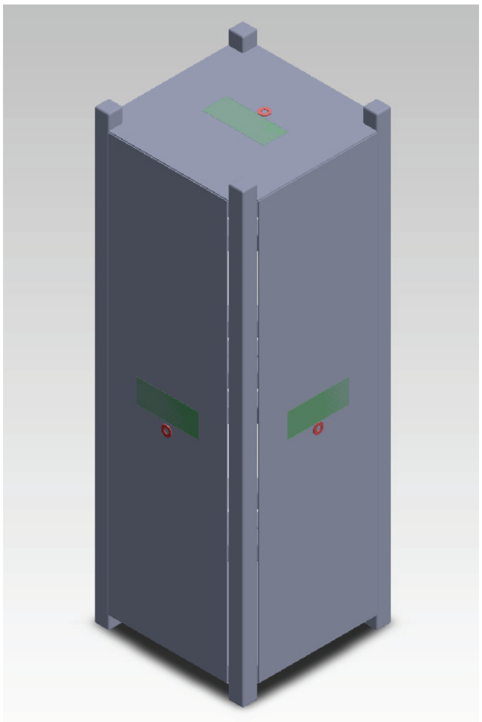


Figure 12: Example sensor locations

4.4 Avionics Architecture

Key to the avionics architecture are the system trade-offs – many of which have already been studied by students at ISAE. A Nanomind A702 CPU has been selected with its capability to communicate with hardware via the I2C protocol. Further trades remain in the selection of specific hardware for the conversion and interface of non-I2C devices with the Nanomind unit. Such conversion hardware, combined with the IMU, is labeled in Figure 11 as the Science Hardware. GPS, Iridium, and Science hardware will be integrated with the PC/104 bus for delivery of data to the CPU. The Nanomind unit, upon receipt of data, will perform necessary computations, send commands, and store necessary data.

4.5 Attitude Determination and Control System

A preliminary analysis requires knowledge of the satellite attitude to an accuracy of 1°, but pointing requirements are looser, especially in the descent phase where the CubeSat must be controlled as little as possible. The satellite can therefore be under-actuated during the nominal orbital phase, and then not controlled during the entry-phase. A 4π steradian visibility during reentry is necessary for communications and will have impact on how little control is used during reentry. The IOD package proposed for EntrySat does not have specific pointing requirements other than what will be necessary for reduction of orbital drag, thermal control, power optimization, and communications. These requirements will be further defined under analysis of the ADCS subsystem. QB50 environmental and interface specifications will be implemented as they are released as they are needed in the IOD context. Table 5 outlines the specific hardware envisioned for each phase of the satellite mission.

Abbreviation	*Full Subsystem Name*	*Description*
CDH	Command and Data Handling	Spacecraft computer, microcontrollers, data loggers, and supporting hardware.
FS	Flight Software	The spacecraft software integrated with the CDH subsystem
EPS	Electrical Power System	The batteries, solar panels, and distribution hardware necessary to provide electricity to satellite systems
STR	Structures	The spacecraft structures
COM	Communications	The radio communication systems of the satellite
ADCS	Attitude Determination and Control System	The systems to determine and control orientation of the satellite and to determine satellite position
SCI	Science	The scientific instruments of the demonstration package
ECS	Environmental Control System	The methods and possible hardware necessary to maintain operable temperatures
LVI	Launch Vehicle Interface	The interfaces necessary to successfully launch the EntrySat

Table 4: Satellite subsystem definitions

ADCS mode	Sensors	Actuator
Orbit Phase	Inertial Measurement Unit Magnetometers Sun sensors Further sensors under analysis	Magnetic actuators
De- Orbit Phase	Inertial Measurement Unit	

Table 5 ADCS sensors and actuators

The Attitude Determination and Control System (ADCS) of the initial design study is distributed throughout the satellite. The Nanomind A702 provides one magnetometer – another magnetometer is located in the IMU. Acceleration and rotation data will be provided from the IMU. Solar panels with sun-sensing elements and embedded magnetic actuators are currently under consideration to complete the necessary hardware suite for ADCS. Additional changes may be made to the ADCS subsystem pending an analysis of the current projected pointing capability in the context of the EntrySat mission.

4.6 Budgets

The results of the preliminary mass budget are shown in Table 6. Margins are based upon annex 4 and are chosen based off of the estimated technology readiness level (TRL) for a subsystem and components. The same margins are also adapted for use in the power budget. These budgets are for the preliminary design and are subject to change as the project advances.

Subsystem	*Weighted Maximum Possible Value (g)*	*Current Margin (%)*
ADCS	549	145%
COM	479	22%
CDH	132	24%
SCI	146	125%
EPS	897	58%
STR	716	12%
ECS	-	-
LVI	80	8%
Total (g) and Average Margin (%)	3000	45%

Table 6: Reference Preliminary Mass Budget. "Weighted Maximum Possible Value" serves as the current requirement of maximum mass per subsystem. See Annex 4: Payload Resource Margin Guide

Subsystem	*Weight Maximum Power (W)*	*Maximum Expected Power Usage (W)*
ADCS	1.015	0.734
COM	0.498	0.387
CDH	0.755	0.493
SCI	0.024	0.013
EPS[1]	0.674	0.498
STR	0	0
ECS	0	0
LVI	-	-
Totals (W)	2.97	2.13

Table 7: Reference Preliminary Power Budget.

[1] EPS numbers include negative contributions from solar panels which cancel battery charging values. Positive values in this table represent power consumed.

Data Rate	Data Quantity (bits)	*Link Time (% orbital period)*
ISAE VHF[3]	315944	5%
ISAE UHF	78986	5%
Iridium Transmit	5893	2%
Iridium Receive	4680	2%

Table 8: Reference Data Rate Budget, GENSO to be analyzed as more information becomes available.

4.7 Ground segment

ISAE will provide ground station facilities capable of UHF/VHF telecommunications. Two ground stations are available at this time, one in Toulouse and one in Cayenne. To maximize communications time, GENSO compatibility will be investigated. GENSO would enable internet communication of commands and data between QB50 ground stations so to optimize usage of visible ground stations. The EntrySatwill also use the Iridium communications network – however the use of this network will not be available to other teams. The utilization of the Iridium network is intended for the final phase of satellite lifetime during reentry to ensure that as much data as possible is returned, regardless of ground station visibility during the reentry phase. ISAE ground stations have proper licensing per French and International amateur radio regulations.

Figure 13: ISAE STELLA ground station in Cayenne.

4.8 Operations

EntrySat operation will be done from ISAE facilities, in close cooperation with the QB50 network. The EntrySat will commence operations upon deploy and will utilize two types of safe-modes to protect the functioning of the experiment – one related to deployment and another related to low power-levels. Antennae will be deployed after a suitable wait time, and the satellite shall begin to attempt data link with a ground station. After successful linking with a ground station, the satellite will fully operational in a nominal sense and shall maintain system health in preparation for the reentry event. Figure 14 describes a preliminary outline of the proposed operation scheme.

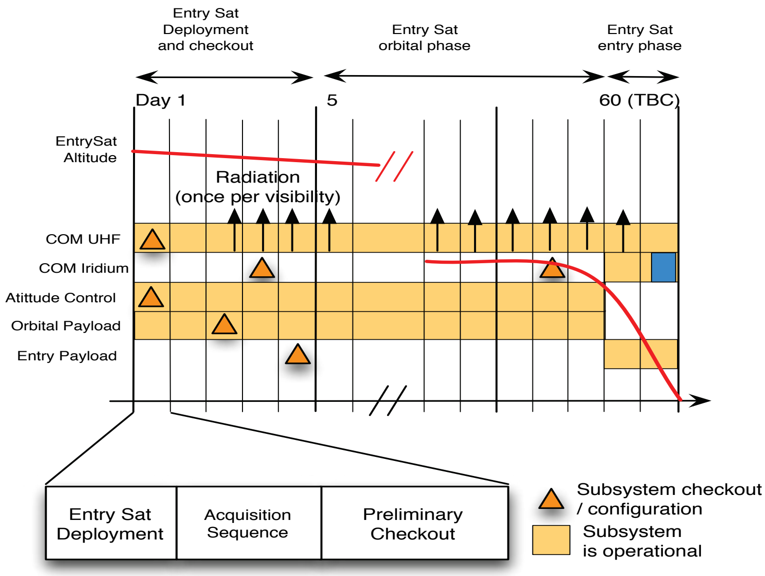


Figure 14: Preliminary operations outline

Three main sequences are considered yet:

- Week 1: EntrySat deployment, first acquisitions and commissioning phase
- Week 2 to 4: Orbital phase, monitoring of orbit decay
- 2 last days: Entry phase, monitoring of satellite environment.

[3] ISAE radio numbers are communications between the ISAE ground station and the EntrySat Satellite. VHF bit rate of 1200 bit/s, UHF bit rate of 300 bit/s.

4.9 Availability of facilities

ISAE has an assembly room available (electronics lab). In case special facilities are required, they may be provided through a partnership with CNES. The mechanical tests will be done first at STM, then at EQM level. These tests will be performed at the Mecano-ID facilities (see http://www.mecano-id.fr/SRC-shocks-testing-services.html)

Figure 15: EntrySat electrical systems under development by ISAE students

Figure 16: Mechanical test facilities at MECANO-ID

4.10 Model philosophy, qualification test plan, AIV plan

The EntrySatwill be produced with a proto-flight design philosophy. Development of the satellite is fast-tracked by the use of off-the-shelf hardware parts in all models, except for circuitry and boards dedicated to the IOD science package. To ensure the creation of acceptable support hardware and equipment, as well as satisfactory design and testing systems, ISAE will construct four (4) satellite models in a timeline as described in Figure 17: Model Development and Workflow. The models will include an Electronics Evaluation Model (EEM) or Breadboard, a structural model (STM) for the verification of intended components, an engineering qualification model (EQM) with flight-grade hardware (test up to qualification level), and a protoflight model (PFM) with flight-grade hardware. EQM will be retrofitted as Spare model, but back-up parts will be available to cope with any eventuality.

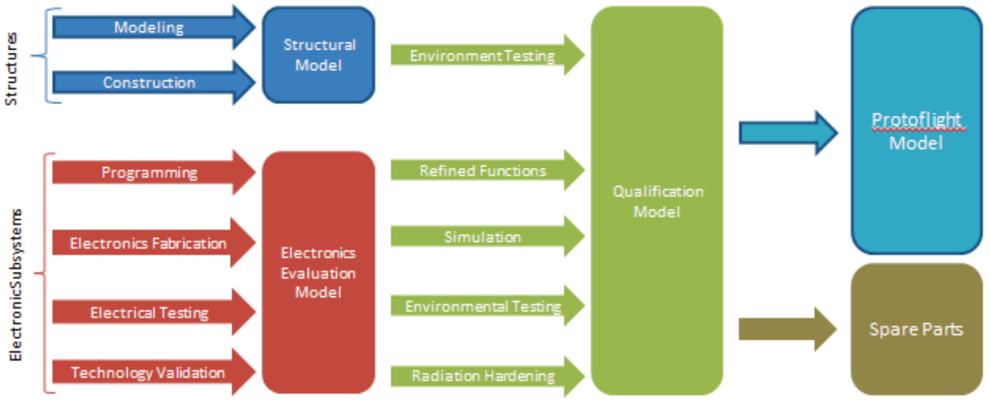


Figure 17: Model Development and Workflow

The EntrySat development track will comply with the proposed milestones as described in the schedule package (see Figure 18). However, the EntrySat progress will be monitored through a series of internal ONERA/ISAE, organized by CNES, in preparation of milestones and to monitor the progress of the EntrySat.

5 Management Plan

5.1 Overall organization, budget and funding route

Please refer to Annex 1 and 2

5.2 Compliance with deliverables and project review requirements

All deliverables as listed in section 17 of the Call for CubeSat Proposals are either compliant or expected to be compliant at this time. Table 9 outlines the current status of each deliverable bullet-point as listed in the Call for CubeSat proposals. Figure 18: QB 50 EntrySat Preliminary schedule provides the current project timeline for the ISAE satellite as well as major reporting milestones.

Deliverables	Compliance
Funding letters of support	Compliant
VKI Contractual Agreement	Compliant
Documentation on-time	Expected
Project Reviews Conducted (PDR, CDR, FRR)	Expected
Operate CubeSat in orbit	Expected
Provide necessary CubeSat data to QB50 archiving center within 6 months of end of operations	Expected
Submit copies of all QB50 papers and conference abstracts to VKI	Expected

Table 9: Deliverables and compliance table

The EntrySatdevelopment track will comply with the proposed milestones as described in the Call for CubeSat Proposals. In addition to this, CNES will organize internal project reviews in preparation of milestones and to direct the progress of the EntrySat.

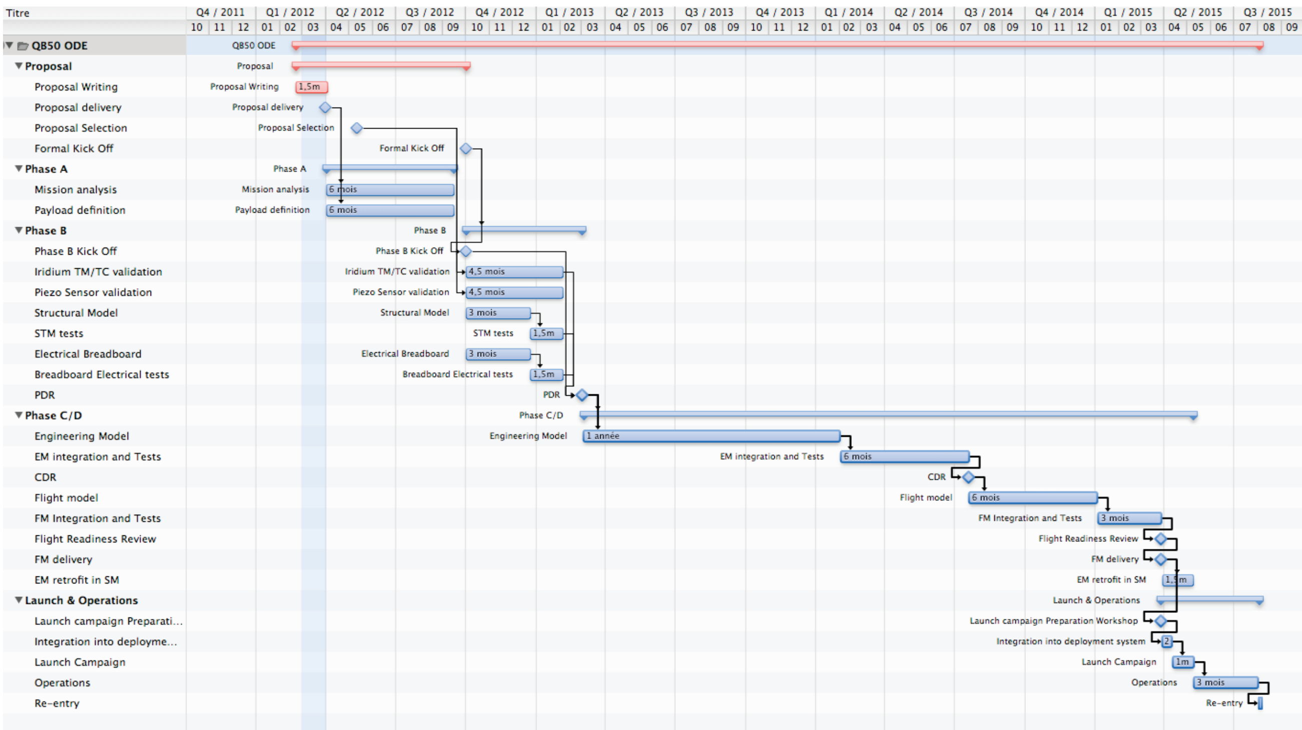


Figure 18: QB 50 EntrySat Preliminary schedule

5.3 Risk Management

The following top 3 risks have been identified at this stage of the project. Mitigation measurements are detailed.

Probability	Risk Level				
5					
4			Risk#3		
3			Risk#1	Risk#2	
2					
1					
Gravity	1	2	3	4	5

>=15	**Non acceptable risk**
5 à 12	**Risk to be thoroughly evaluated**
1 à 4	**Acceptable**

Table 10: Project Risk Table

Risk #1: **Lack of funding**
Risk Description: Source of funding is not secured for remaining costs.
Mitigation: Investigate other collaborations – reduced Science activities funding.

Risk #2 **Management of student project**
Risk Description: The volume of under graduate student activities does not allow a secure planning
Mitigation: Re-inforce graduate student support

Risk #3: **Iridium constellation link.**
Risk Description: Iridium constellation link does not allow enough data retrieval
Mitigation: Investigate other possibilities: we will consider a geosynchronous satellite link.

6 Expertise of the proposing team

6.1 ISAE (University of Toulouse) heritage

The "Institut Supérieur de l'Aéronautique et de l'Espace" (ISAE), member of the University of Toulouse, was created in 2007 from the merger of the two prestigious French "Grandes Ecoles" – SUPAERO (1909) and ENSICA (1945). ISAE is today, a worldwide reference in aerospace higher education and research. The Institute provides high-level Graduate Programs in engineering (SUPAERO and ENSICA), Master's degrees, Postgraduate Specialized Masters, PhD degrees, with a wide range of career opportunities: engineering, research and development, logistics, consulting, finance, etc. It is one of the European leading institutions in Space Education.

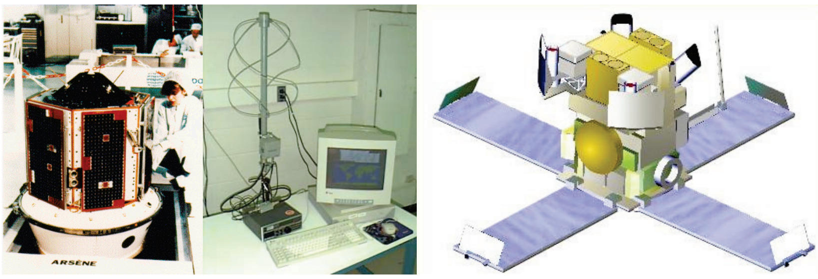


Figure 19: ISAE's Past and Current Projects from left to right: ARSENE satellite, HETE-2 (collaboration MIT)

ISAE has a long-standing cooperation history with the nearby IRAP (Institut de Recherche en Astrophysique et Planétologie) and Observatoire Midi-Pyrénées, also member of the University of Toulouse. The QB50 EntrySat Project will therefore benefit from the IRAP and CNES facilities (Mechanical environment test facilities …) . IRAP (which result from the merger of former CESR, LATT and DTP laboratories) has an extensive record of participation to successful Space missions, in both Astrophysics and Planetology. Among them, one can cite Cluster, Stereo, Cassini, Demeter, Mars and Venus Express, Kaguya, Mars Exploration Rovers, Odyssey, and lastly, a major contribution to JPL's Mars Science Laboratory 2011 Rover, with the CHEMCAM experiment.

6.2 ONERA heritage

ONERA is the French national aerospace research center. It is a public research establishment, with eight major facilities in France and about 2,000 employees, including 1,500 scientists, engineers and technicians. ONERA was originally created by the French government in 1946, and assigned six key missions:

- Direct and conduct aeronautical research
- Support the commercialization of this research by national and European industry
- Construct and operate the associated experimental facilities
- Supply industry with high-level technical analyses and other services.
- Perform technical analyses for the government
- Train researchers and engineers

During the HERMES project, ONERA teams were directly involved in the technical assistance for ESA, playing the role of technical support and expertise concerning the assessment of results in the field of aerothermodynamics re-entry. In this period the high enthalpy F4 wind tunnel was designed and built. Many Departments belonging to the Fluid Mechanics and Energetics scientific branch are involved in the hypersonic studies, particularly through the cold flow research wind tunnels "R2Ch", "R3Ch" and "R5Ch" together with the Computing, Engineering and Testing Facilities branch where the cold flow "S4Ma" and hot flow "F4" wind tunnels are located. ONERA has also been in charge of aerothermodynamics launcher studies since 1980, mainly for the account of CNES. From end of 1999 to 2003, ONERA played a major role for aero-thermodynamic database development in the MARS PREMIER program under the responsibility of CNES, accounted for the Martian orbiter MSRO and the entry capsule NETLANDER [39]. More recently, ONERA has also worked for EADS, CNES and ESA on the Pre-X project and on EXPERT, IXV, EXOMARS, AEROFAST (UE FP7), completed with ESA's TRP. In the domain of NEO and debris atmospheric entry programs, ONERA extended and applied, during the past 4 years, its experience gained on spacecraft reentry to develop physical modeling and numerical tools to address hyper/super/-orbital trajectories issues.

7 Educational and Outreach Value

7.1 Educational value

The EntrySat team is a partnership between ISAE, ONERA and CNES; with contributions of Rtech, Mecano-ID, and CNRS. ISAE (Institut Supérieur de l'Aéronautique et de l'Espace) is the biggest institute in terms of number of graduate students in the field of aeronautics and space in Europe. As such, students from its various graduate programs, as well as students from the graduate program will play a key role in the development of the EntrySatin support of engineering and science goals.

Furthermore, the EntrySatwill be the first CubeSat project of ISAE (after the Arsène spacecraft), generating an infrastructure for future student satellite projects and providing valuable hands-on project experience for ISAE students. The project will involve several layers of student at ISAE:

- Students from the ISAE Supaero program's second year
    - Two groups of 4 Supaero students will be involved each year,
        - one on hardware,
        - one on software and tests
- Students from the ISAE Ensica program's second year,
    - A least on group of 4 Ensica students
        - Focused on mechanical aspects
- Two further doctoral or specialized master students will focalize on the payload and associated science.

In addition, the ISAE's "pole Espace" (http://www.isae-space.com/) will coordinate others students. Such a student organization will also serve to provide contributions in the form of a students' club for ensuring continuity on the QB50 and future ISAE CubeSat projects.

7.2 Outreach Value

An outreach plan is currently being built to advertise widely the project. To produce a coherent outreach strategy, we plan a wide collaboration between all organizations involved in the experiment (ISAE, ONERA and CNES). In order to build an efficient communication strategy, the following outreach activities are planned:

Web-based communication

- Team websites will be regularly updated with current information aimed at various audiences, e.g. interested public, educators, and the media.
- The team will send regular e-mails or bulletins to subscribers showing the construction/ mission progress.
- Social media websites such as Facebook and Twitter will be used to provide updates and to build interest in the experiment.
- The team will plan to set up a webcam at the ISAE facility showing streaming video on the CubeSat progress during construction and testing.

Media awareness

- Media awareness through press releases and press kits
- Science fairs and exhibitions
- Posters and publications
- Milestone announcements

8 Acronyms

ADCS – Attitude Determination and Control System
AEROFAST – Aerocapture for Future Space Transportation
AIV – Assembly-Integration-Verification
ATV – Automated Transfer Vehicle
CDH – Command and Data Handling
CDR – Critical Design Review
CESR – Centre d'Etude Spatiale des Rayonnements
CHEMCAM – Mars Science Laboratory Chemistry and Camera Instrument
CNES – Centre National d'Etudes Spatiales
CNRS – Centre National de la Recherche Scientifique
COM – Communications
COTS – Commercial-Off-The-Shelf
CPU – Central Processing Unit
DSMC – Direct Simulation Monte Carlo
DTP – Dynamique de la Terre et des Planètes
EADS – European Aeronautic Defence and Space Company
ECS – Environmental Control System
EEM – Electronics Evaluation Model
EPS – Electrical Power System
EQM – Engineering Qualification Model
ESA – European Space Agency
EXOMARS – Exobiology on Mars
FAST/SKIP – ONERA Aerothermodynamics software
FRR – Flight Readiness Review
FS – Flight Software
GENSO – Global Educational Network for Satellite Operations
GPS – Global Positioning System
HERMES – CNES/ESA Spaceplane
IGIS – ISIS Generic Interface System
IMU – Inertial Measurement Unit
IOD – In-Orbit Demonstration
IRAP – Institut de Recherche en Astrophysique et Planétologie
ISAE – Institut Supérieur de l'Aéronautique et de l'Espace
ISIS – Innovative Solutions In Space
IXV – Intermediate eXperimental Vehicle
LATT – Laboratoire Astrophysique de Toulouse - Tarbes
LVI – Launch Vehicle Interface
MSRO – Mars Sample Return Orbiter
NEO – Near Earth Orbit
NETLANDER – Proposed network of landers to study the areological and meteorological properties of Mars.
ONERA – Office National d'Etudes et de Recherches Aérospatiales
OTV – Orbital Transfer Vehicle
PCB – Printed Circuit Board

PDR – Preliminary Design Review
PFM – Protoflight Model
RAAN – Right Angle of the Ascending Node
SBD – Short Burst Data
SCI – Science
STELLA - CNES Mission analysis tool
STM – Structural Model
STR – Structures
TBA- to be assessed
TBC – To Be Considered
TBD – To Be Determined
TRL – Technology Readiness Level
TRP – Technology Research Program
UE FP7 – Union Européen "Framework Programme 7"
UHF – Ultra-High Frequency
VHF – Very-High Frequency
VKI – Von-Karman Institute

Annex 1: Cost breakdown and funding sources

The following table provides an outline of the experiment budget. The overall budget of the experiment is about 1.800 kEuros. This includes the procurement of satellite bus external procurement -including scientific studies, missions and manpower.

Ressources financieres (k€ HT, CE 01/2012)	2012	2013	2014	2015	2016	Total
Achats équipement / matériels inventoriables	95	110	155	5	0	340
Achats externes y compris etudes	126.7	261.5	173.8	118	0	680
Petit materiel						
Outillages divers, petites réalisations ISAE	5	5	5	5		20
Petit Matériel ONERA pour tests	15	15				
Etudes ONERA						
DMAE	46.7	119.6	106.3			272.6
DCSD		31.9	24.5			
Entretien, reparations						
Consommables						
Consommables	5	5	5	5		
Contribution lancement				90		
Frais de publications						
			3	3		
Utilisation de moyens informatiques						
Utilisation de moyens d'essais						
Tests environnement méca thermique		15	15	15		45
Tests capteurs piezo		15	15			30
Achats logiciel						
Sous-traitance (étude ou autre)						
RTECH (code mistral)	33	33	0	0	0	66
CNRS (Odeillo)	22	22				44
Missions	0	10.0	10.0	10.0	0.0	29.9
Missions techniques (Belgique) 2 pers 3 j		6.5	6.5	6.5		
Mission CNES Paris 2 pers 1 j		3.5	3.5	3.5		
Vacations / stagiaires	0	0	0	0	0	0
	0	0	0			0
CDD CNES	0	50	50	0	0	100
Coût Direct	0	50	50	0		
Coûts Personnel ISAE	77	200	256	83.488	0	616
Coût Consolidé permanent + environnement CDD	77	200	256	83	0	
Frais de gestion	N/A	N/A	N/A	N/A	N/A	N/A
	2012	**2013**	**2014**	**2015**	**2016**	**Total**
Total Projet hors aléas (k€ HT, CE 01/2012)	298	632	645	216	0	1791

Table 11: Experiment overall budget

The following table presents the Manpower resources and allocations:

#		Ressources humaines (ETP)			2012	2013	2014	2015	2016	Total
1	Scientifiques	PI Projet	D. Mimoun	ISAE	0.10	0.20	0.20	0.10	0.00	0.60
2		Thésard (Payload manager)	Fabien Gachet	ISAE	0.50	1.00	1.00	0.50	0.00	3.00
3		*Ingénieur Recherche*	*F. Sourgen*	*ONERA*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
4		Chef de Projet	DEOS	ISAE	0.20	0.20	0.20	0.25	0.00	0.85
5		Ingénieur Logiciel	DMIA	ISAE	0.00	0.50	0.50	0.00	0.00	1.00
6		Ingénieur Electronicien	DMIA	ISAE	0.00	0.50	0.50	0.00	0.00	1.00
7		Ingénieur Mécanicien	Labo Clément Ader	ISAE	0.00	0.25	0.25	0.00	0.00	0.5
8		Technicien electronique pour AIV, test	IRAP				0.50	0.00	0.00	0.5

Table 12: Experiment Manpower

While some funding will be made available through ISAE, the majority of funding will be provided by CNES through their offices for educational nanosatellite projects. At the time of the proposal submission, ISAE share will be fully funded (616 kE) and CNES will support the experiment through financial commitment (see annex 3 for commitment letters) . Overall, more than 62 % of the project funding is already committed.

Most of the remaining cost to cover is related to the funding of science experimentation manpower. We believe that we can find a solution before the actual project kick-off.

Annex 2: CubeSat management

A2.1 Institutions

The EntrySat consortium includes three types of partners: Hardware-providing institutions, co-I institutions, and outreach partners.

Institution	*Name*	*Funding*
Hardware providing institutions	Institut Supérieur de l'Aéronautique et de l'Espace	Manpower, Hardware, Funding
Co-I Institutions	ONERA CNRS	Manpower
French Space agency	CNES	Direct funding and technical expertise

Table 13: Work distribution amongst EntrySat partners

A2.2 Work Breakdown Structure

Work sharing is depicted in **Erreur ! Source du renvoi introuvable.**. EntrySat Project will benefit from CNES support for additional ressources such as technical experts in satellite design and realization

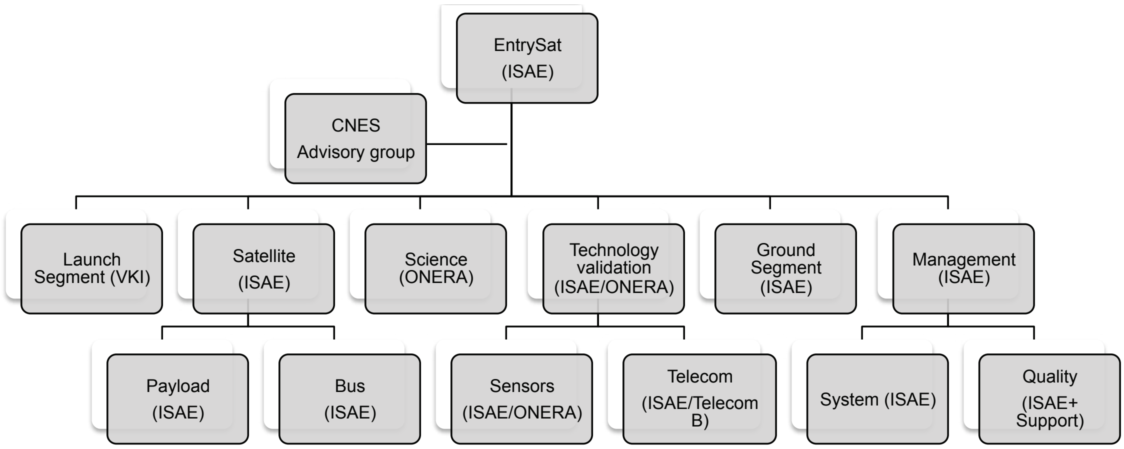


Figure 20: Workshare baseline

A2.3 Project organization

Even if understood as a student project, the EntrySat project will be managed as a classical space project, with a P.I, a project manager and a payload manager. Science support will be provided by ONERA.

Student contributions will include about 8 students each years from SUPAERO engineering degree (4 software and 4 hardware), 2 students from Telecom Masters, and 2 students from ENSICA degree on mechanical aspects.

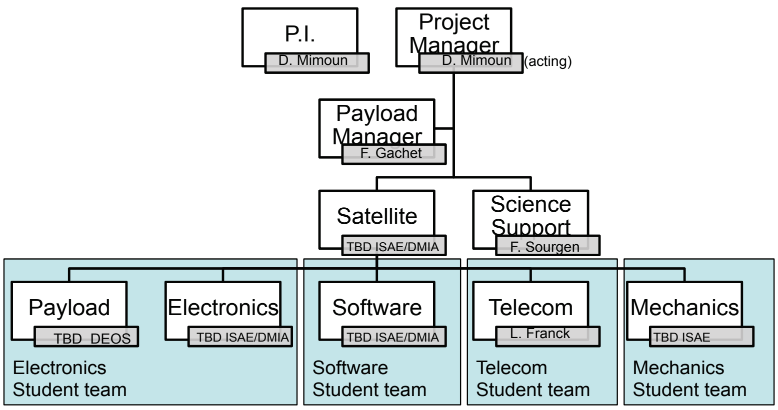


Figure 21: Entry Sat project organization

- 2.5 full time permanent positions will be dedicated to the support and continuity of student activities.

In the early phases of the project, the PI ensures the overall project management. However a dedicated project manager will be designated for the actual kick off of the project (phase B)

A2.4 Key personnel:

Principal Investigator	David Mimoun
Date of birth	7 june 1970
Organization	Institut Supérieur de l'Aéronautique et de l'Espace
Tel./Fax	+335 61 33 8108
E-mail	david.mimoun@isae.fr
Current position	Associate Professor, Space Systems ISAE, Université de Toulouse

Expertise		
2001	2010	• **Co-I / System Engineer** for NASA InSight Discovery proposal SEIS instrument • **Instrument Project Manager of SEIS – ExoMars Instrument.** Coordination of a European consortium of five countries for technical / project concerns. • **Co-Investigator** for the French contribution to International Lunar Network and Selene 2 Missions. • **Contribution** to Ristretto Student satellite definition team. • **Coordination** of the SUPAERO contribution to ESA ESMO and ESEO Student satellite (Star tracker development)
Latest publications		• Mars future geophysical observatories for understanding its internal structure, rotation, and evolution Veronique Dehant, et al (2011) PSS, In press • Farside Explorer: Unique Science from a mission to the Farside of the Moon • David Mimoun. Mark Wieczorek*. et al in « Experimental Astronomy – Astrophysical Instruments and Methods », 2011, (In Press) • LAPLACE A mission to Europa and the Jupiter System for ESA's Cosmic Vision Programme in « Experimental Astronomy – Astrophysical Instruments and Methods », 2009, (M. Blanc et. All)

Co-Investigator	Frédéric Sourgen
Date of birth	1977
Organization	ONERA, Aerodynamics and Energetics Modelling Department
Tel./Fax	+33 5 62 25 28 44 / +33 5 62 25 25 83
E-mail	Frederic.Sourgen@onera.fr
Current position	+ Senior Research Scientist (ONERA Toulouse), Aerothermodynamics and Turbulence team

Expertise		
2001	2010	Research Scientist (French German Research Institute of Saint-Louis ISL) - Development of measurement techniques for supersonic flows : 3D tomography (using the Background Oriented Schlieren technique), ultra-fast pressure sensitive paints. - Computational analysis of supersonic flows - development of gas generative nanothermite based actuators for projectiles and missiles
Latest publications		Sourgen, F., Leopold, F., Klatt, D. "Reconstruction of the density field using the Colored Background Oriented Schlieren Technique (CBOS)", **Optics and Lasers in Engineering**, Volume 50, Issue 1, January 2012, Pages 29-38 Sourgen et al. "Effect of Steps and Gaps on Aerothermodynamics for the IXV Hypersonic Vehicle", accepted for publication in the **International Journal of AeroDynamics** (2012). Sourgen, F., Meuer, R., Gauthier, T., Leopold, F., Sauerwein, B., "Substitution of Hot-Gas Lateral Jets by Cold-Gas Jets in Supersonic Flows, " **Journal of Spacecraft and Rockets**, Vol. 48, No. 1, pp.81-92, January-February 2011

Alain Gaboriaud CNES

Alain Gaboriaud graduated from the "Ecole Nationale Supérieure de l'Aéronautique" (Sup'Aéro, Toulouse, France) in 1978.

He then joined THOMSON-CSF (now THALES) company as a development engineer for on-board aircraft systems, became Project Manager for the development of aircraft head up displays and on-board computers in 1981 and became the manager of the on-board software department in 1984.
In 1986, he joined the CNES as the SPOT (Earth observation satellite) mission center Project Manager. His responsabilities included designing (with the company SPOT IMAGE) and developing the ground segment in charge of programming the payload.
Then, in 1992, he became the HELIOS II (military Earth observation satellite) users ground segment Project Manager. He was responsible for designing, with military headquarters, the programming system for the satellite and the images processing and analyzing system.
In 1997, he became the head of the department in charge of designing and developing scientific data processing system. He worked with French and foreign laboratories involved in CNES micro and mini-satellite missions (DEMETER, PARASOL, CALIPSO, COROT), in European missions (ODIN) and in ESA missions (ROSETTA, SMOS).
Then, in 2004, he became the CNES Project Manager for the French contribution of Mars Science Laboratory, Bepi Colombo and PHOBOS-GRUNT missions. In particular, and in collaboration with laboratories he oversaw the instruments development. He ensured the NASA, ESA and ROSCOSMOS interface for technical and contractual aspects.

From 2011, he is the Project Manager to design and to develop nanosatellites missions with students from French universities and engineer schools.

Annex 3a : ISAE: Letter from a professor

Toulouse, April 30th 2012

Mr. Jean Muylaert
Director, von Karman Institute for Fluid Dynamics (VKI) Chaussée de Waterloo 72
1640 Rhode-Saint-Genèse (Brussels) Belgium

Subject: QB 50 EntrySat proposal
Reference: Call for CubeSat Proposals for QB50

Dear Pr. Muylaert,

I am please to submit in the name of ISAE a proposal to the QB50 call for tender in the frame of the In Orbit Demonstration / 3U satellite option.

The "Institut Supérieur de l'Aéronautique et de l'Espace" (ISAE), member of the University of Toulouse, was created in 2007 from the merger of the two prestigious French "Grandes Ecoles" – SUPAERO (1909) and ENSICA (1945). ISAE is today, a worldwide reference in aerospace higher education and research. The Institute provides high-level Graduate Programs in engineering (SUPAERO and ENSICA), Master's degrees, Postgraduate Specialized Masters, PhD degrees, with a wide range of career opportunities: engineering, research and development, logistics, consulting, finance, etc. It is one of the European leading institutions in Space Education.

Together with ONERA and with the support of CNES, we propose an exciting experiment entitled "EntrySat" (*Orbital Debris Atmospheric Entry Experiment)* whose goal is to improve dramatically our knowledge of the last phases of the reentry of an artificial orbital object. We intend also to make of this project a cornerstone in the frame of our educational policy.

We, our partners and the French Space Agency, have already secured the major part of the experiment funding; therefore we are confident that the experiment will be able to kick-off in the required time frame.

We look forward being part of this exciting experiment,

Sincerely,

David Mimoun.
Professeur Associé ISAE
Responsable de l'Unité de formation "Systèmes spatiaux"

Institut Supérieur de l'Aéronautique et de l'Espace issu du rapprochement SUPAERO et ENSICA
10, avenue Édouard-Belin - BP 54032 - 31055 Toulouse CEDEX 4 - FRANCE
Tél. : 33 (0)5 61 33 80 80 - Télécopie : 33 (0)5 61 33 83 30 - Courriel : isae@isae.fr - Site Internet : www.isae.fr

Annex 3b : CNES Support letter

cnes

Mr Jean Muylaert
Director
Von Karman Institute for Fluid Dynamics (VKI)
Chaussée de Waterloo 72
1640 Rhode-Saint-Genèse
Brussels
Belgium

Paris, 27 MARS 2012
DSP –PB/EA - 2012.0006048

Subject : CNES endorsement of French Cubesats to the network of 50 double and triple Cubesats for the exploration of the lower thermosphere, re-entry research and in-orbit science and technology demonstration.

Dear Mr Jean Muylaert

As part of its educational policy, CNES has encouraged the following French engineering schools to answer the Call for cubesat proposals for QB50 (issued on 15 February 2012) :

- **Ecole Polytechnique** (Palaiseau, France) for the **X-Cubesat** proposal (a standard atmospheric double cubesat)
- **Ecole des Mines Paris Tech** (Paris, France) for the **ThermoCS** proposal (a standard atmospheric double cubesat)
- **Institut Supérieur de l'Aéronautique et de l'Espace** (Toulouse France) for the **EntrySat** proposal (an In Orbit Demonstration Triple cubesat).

If Von Karman Institute (VKI) selects one or all of these proposals, CNES will support the activity of the French engineering schools with appropriate budget funding and technical expertise when required.

We look forward to hearing the results of the selection process,

Yours sincerely

Richard BONNEVILLE
Deputy Director,
Programme & Strategy Directorate

Copy : Vivien Croes (Team leader) — Ecole Polytechnique
Emmanuel Chambon (Team Leader) — Ecole des Mines Paris Tech
David Mimoun (Team Leader) — Institut Supérieur de l'Aéronautique et de l'Espace

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www.cnes.fr
RCS Paris B 775 665 912 – Siret 775 665 912 000 82 – Code APE 731 Z – N° identification TVA FR 49 775 665 912

Annex 3b : ONERA Support letter

ONERA
THE FRENCH AEROSPACE LAB

Letter of support from the Director of ONERA/DMAE

I would like to express with this letter the commitment of the ONERA *Aerodynamics and Energetics Modeling* Department (DMAE) to support the 3U IOD CubeSat project "EntrySat" managed by the French University ISAE (*Institut supérieur de l'Aéronautique et de l'Espace*) in collaboration with us.

For 40 years, ONERA and ISAE have been used to work together and to be regularly involved in major aeronautics and space programs for the benefit of French ministries (Defense, Transportation), agencies (CNES, ESA) and European Union either.

For instance, ONERA/DMAE researchers and ISAE students and professors have recently succeeded in launching an innovative hybrid-propulsion based rocket (PERSEUS project supported by CNES).

This closed relationship is first based on the geographical proximity between the Toulouse Center of ONERA, which is a major actor for aerospace research in France, and the ISAE Institute, which is one of the very first Universities in France and certainly the most renowned for aerospace education. Anyway, a large part of training courses at ISAE are provided by ONERA researchers.

Furthermore, the DMAE department of ONERA is presently involved in several studies concerning the orbital debris re-entry topic. Both ONERA and CNES consider that the "EntrySat" experiment will bring valuable in-flight measurements, a significant added value for improving orbital debris entry modelling and simulation.

I look forward to working with VKI on this exciting scientific endeavour and to make the EntrySat CubeSat in orbit a reality.

Toulouse, April 26, 2012

Dr. Pierre MILLAN
Director of ONERA/DMAE
Office National d'Études et de Recherches Aérospatiales
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www.onera.fr
N° SIREN 775 722 879 - Code APE 7219 Z

Annex 4: Payload Resource Margin Guide[4]

Sub-System Design Maturity	*TRL Range*	*Contingency/Reserve (in percent)*		
		Electrical/Electronics 0-5 kg	Science Instrument	Non-Instrument Mechanisms
Basic principles reported through technology concept and/or application formulated	[0,2]	30	55	25
Analytical/experimental proof of concept through breadboard validation in relevant environment	[3,5]	25	30	15
Sub-system/component prototype demo in an operational environment	6	20	25	10
Sub-system/component engineering unit tested in an operational environment	7	10	10	5
Actual Sub-system completed and flight qualified	8	3	5	3
Actual sub-system flight proven through successful mission operations	9	0	0	0
Maximum Possible Value[5] (MPV) = the physical limit or agreed-to limit				
Maximum Expected Value (MEV) = current best estimate (CBE) + Contingency				
System Margin = maximum possible value - maximum expected value				
% system margin = 100% x system margin/MEV				
% Contingency = 100% x Contingency (units)/CBE				

[4] This document was provided by Professor David Mimoun and originates from application in other projects.
[5] For a particular component that could satisfy the tasks required within a subsystem, mass much greater than allowable are possible. Therefore a weighted MPV is computed based upon the ratio of MPV to total MPV and scaled to a maximum mass of 3 kg.

Annex 5 Some References

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[i] Lyndon B. Johnson Space Center, "Re-entry and Risk Assessment for the NASA Upper Atmosphere Research Satellite (UARS)", NASA Orbital Debris Program Office http://www.nasa.gov/mission_pages/uars/index.html
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[iii] Chinese satellite FSW1: http://www.fas.org/spp/guide/china/military/imint/fsw-1.htm
[iv] S. Löhle, T. Marynowski, A. Knapp, R. Wernitz, T. Lips, "Analysis of the ATV1 Re-entry using Near-UV Spectroscopic Data from the ESA/NASA Multi-instrument Aircraft Campaign", ESA paper 2139747, 7th European Symposium on Aeothermodynamics for Space Vehicles, 09-12 May 2011, Bruges (B)