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AIM (Artery In Microgravity): An ICE Cubes Mission by University Students

Olivia Drayson
ISAE-SUPAERO
Toulouse, France

Nicolò Bernardini
ISAE-SUPAERO
Toulouse, France

Amina Bakkali Abderrahaman
ISAE-SUPAERO
Toulouse, France

Alessandro Cipolletta
ISAE-SUPAERO
Toulouse, France

Luca Cerquetani
ISAE-SUPAERO
Toulouse, France

Blanca Dalfo Ferrer
ISAE-SUPAERO
Toulouse, France

Federico Falcone
ISAE-SUPAERO
Toulouse, France

Stefano Gabetti
Politecnico di Torino
Turin, Italy

Michele Genoni
ISAE-SUPAERO
Toulouse, France

Elena Torta
Politecnico di Torino
Turin, Italy

Federica Vagnone
ISAE-SUPAERO
Toulouse, France

Manuela Aguzzi
Space Applications
Noordwijk, Netherlands

Chloé Audas
Space Applications
Noordwijk, Netherlands

Matthieu Compin
ISAE-SUPAERO
Toulouse, France

Jean-Jacques Favier
ISAE-SUPAERO
Toulouse, France

Stéphanie Lizy-Destrez
ISAE-SUPAERO
Toulouse, France

Umberto Morbiducci
Politecnico di Torino
Turin, Italy

***Abstract*—**The ICE Cubes Facility is a capable experiment platform on board the Columbus Module of the International Space Station that offers flexibility to host many different experiments. The ICE Cubes Facility is suited for any scientific research and technological demonstrator that requires the study of the effects of microgravity and radiation exposure in a pressurised volume. The ICE Cube Service is also open to different schooling levels (primary, secondary, universities) and to different STEAM curricula and offers University students (Master and PhD) the opportunity to design, develop, test and operate a real experiment for the ISS under the supervision of experts from the ICE Cube Service.

The Artery In Microgravity (AIM) project is a 2U ICE Cubes experiment cube and the first experiment to be selected for the Orbit Your Thesis! programme of ESA Academy. The cube is expected to be launched on SpaceX-20 in early 2020. The project is being developed by an international group of students from ISAE-Supaero and Politecnico di Torino.

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The experiment will investigate coronary heart disease, the most common form of cardiovascular disease and the cause of approximately 9 million deaths every year. In view of the very long duration missions to come, such diseases may also affect healthy astronauts in space. The AIM cube is a test-bench for investigating haemodynamics in microgravity and will study the effects of microgravity on blood flow in the coronary artery with and without an implanted coronary stent and the impact of augmented radiation levels on metallic ion release from coronary stents.

The experimental setup consists of a closed hydraulic loop containing two models of a coronary artery in series. An electric pump and reservoir will control the flow of a blood-mimicking fluid through the system. One model of the coronary artery will contain a coronary stent. The pressure of the fluid will be studied along its path using a series of pressure sensors and a camera will visualise the flow. Ground tests will be conducted concurrently in order to perform a comparison between the on-ground behaviour and the behaviour in microgravity.

The paper will showcase the design and development of the AIM experiment cube, the results of testing and the educational applications of the ICE Cubes Facility. The full data and results will be available after the completion of the mission which is expected to be between March and June 2020.

Keywords—ICE Cube Service, STEAM, Education, Haemodynamics, Microgravity

I. INTRODUCTION

The AIM (Artery in Microgravity) project is a 2U experiment cube that can be housed within the ICE Cubes facility on board the Columbus module of the International Space Station.

The cube is being developed by an international and interdisciplinary group of students from ISAE-SUPAERO in Toulouse, France and Politecnico di Torino, Turin, Italy. The project is the first to be selected for the 'Orbit Your Thesis!' Programme of ESA Academy.

The 'Orbit Your Thesis!' programme is the latest student opportunity of ESA Academy that sponsors and supports a group of students to develop an experiment that will be launched to the International Space Station. The other programmes of ESA Education include 'Fly Your Thesis!', 'Spin Your Thesis!' ,'Spin Your Thesis! Human Edition', 'Drop Your Thesis', and 'Fly Your Satellite' in which students develop an experiment for a Novespace parabolic flight, the Large Diameter Centrifuge in ESTEC, Short Arm Human Centrifuge in Cologne, the ZARM Drop Tower in Bremen and launch into space respectively.

The AIM project was selected for the Orbit Your Thesis! programme in October 2018. At the time of selection, the team composed of 7 Master's students of Aerospace Engineering from ISAE-SUPAERO in Toulouse, France. Since the project began, it has expanded to include a PhD student and a master's student of Biomedical Engineering from Politecnico di Torino and 2 more students of Aerospace Engineering from ISAE-SUPAERO who are taking over leadership of the project as of September 2019. The team was split into 3 main sub-groups based on expertise: scientific team, mechanical team and electronics team. Olivia Drayson and Nicolò Bernardini acted as team leaders.

The experiment studies the impact of microgravity on haemodynamics within a stenotic coronary artery and a stented coronary artery and the effect of heightened radiation levels on coronary stents.

II. ICE CUBES SERVICE

A. ICE Cubes

Research in microgravity allows for a wide range of science disciplines and the International Space Station (ISS) is one of the most powerful science laboratories available to the science community to conduct such research. Thanks to a partnership between the European Space Agency (ESA) and Space Applications Services (SAS), it became recently easier to fly experiments on-board the ISS.

The International Commercial Experiment Cubes Service, or ICE Cubes Service, provides a fast and affordable access to the ISS for scientific research, technological demonstrators and for educational purposes that require microgravity conditions and radiation exposure in a pressurised volume. The ICE Cubes Service makes use of the ICE Cubes Facility, a sliding platform permanently installed on-board the ISS that accommodates "plug-and-play" Experiment Cubes and that hosts the functional interfaces to the ISS infrastructure.

Space is becoming an additional room for terrestrial laboratories to increase knowledge and develop businesses thanks to new simplified approaches. Commercial services like ICE Cubes offer the possibility to any organisation or customer to perform their activity in LEO and on the Moon at an accessible cost and at well-predefined conditions. The ICE Cubes Service, by involving students in this inspirational journey, contributes to the next generation of scientists and engineers meant to create terrestrial benefits making use of space assets.

In that respect, the ICE Cubes Service is open to different schooling levels (primary, secondary, universities) and to different STEAM curricula and offers several Educational Packages ranging from concept development up to designing, developing, testing and operating an entire cube. As an example, this paper will present the first student Experiment Cube to be selected for the Orbit Your Thesis! programme of ESA Academy.

III. ORGANISATION OF THE AIM PROJECT

B. Team Structure

After conception of a preliminary experiment design, the priority of the project leaders was to build a team for the project. Originally the project team consisted of only master's students from ISAE-SUPAERO specialising in different majors of Aerospace Engineering. The Mechanical team was chosen to consist of students specialising in Aerospace Structures. The

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Electronics team was chosen to consist of students specialising in Control and Space Systems. The Scientific team was chosen to consist of students specialising in Space Systems. In order to provide medical expertise to the team, two Biomedical Engineering students were recruited to the scientific team from Politecnico di Torino.

Since the project lasted longer than the master's degrees of the technical branch of the team, two incoming students were recruited to take over leadership. They were chosen to be students specialising in Space Systems and were trained in order to lead one of the two branches of the technical team.

C. Project Development Timeline

An ICE Cube Mission typically takes 12 months from contract signature to launch. The current anticipated launch date of the AIM cube is 3rd March 2020 on board the SpaceX Falcon 9 launcher. When planning the timeline of the project development, the phase definition nomenclature used by NASA and other space agencies was adopted [1].

The project was accepted into and thereby commenced the OYT programme in October 2018. At this stage a preliminary concept had been approved and therefore Phase A was complete. Phase B - Preliminary Design and Technology Completion - started upon recruitment of the Biomedical Engineering students and was completed in February 2019 upon approval from ESA of the Experiment Requirements Document and Preliminary Experiment Design. Phase C - Final Design and Fabrication - is almost complete, planned to finish in September 2019. Phase D - System Assembly, Integration and Test, and Launch - was started in July 2019 and is planned to be completed upon launch in March 2020.

IV. Design of the AIM Experiment

D. Scientific Context

Cardiovascular disease (CVD) is the leading cause of death in the world [2]. While cardiovascular disease covers many different pathologies, the one with the highest death rate is coronary artery disease (CAD). CAD occurs due to the presence of atherosclerosis in the arteries that feed the heart. This impedes blood flow and can result in the obstruction of the vessels, stimulating a myocardial infarction (heart attack).

Space exploration increases the risk of CVD through many factors including radiation, confinement and reduced gravitational loading [3]. Therefore, both microgravity and radiation in the space environment are potential triggers for deterioration of the cardiovascular system during manned space exploration.

Atherosclerotic lesions (atheromata) are asymmetric focal thickening of the innermost layer of the artery (the intima) [4]. The localisation of atherosclerosis in the coronary arteries may be governed by local haemodynamic features. Haemodynamic shear stress has been shown to be an important factor in the development of atherosclerosis at several important sites of the arterial system [5].

E. Experimental Concept

An experiment that investigates haemodynamics in coronary arteries was thus developed in order to investigate how the altered haemodynamics in microgravity may exacerbate or diminish atherosclerotic lesions in coronary arteries and thereby determine how the risk to astronauts of myocardial infarction is affected by space travel. In addition, the experiment makes use of the radiation environment on board the ISS to investigate if implantable devices such as coronary stents are at risk of re-stenosis due to the release of metallic ions stimulated by radiation exposure.

The experiment contains two models of a stenotic coronary artery constructed from clear silicone. One artery model contains an implanted coronary stent and a water and glycerol mixture will be pumped through the two models in series. A red dye will be injected afferent to the two models and a camera will visualise the flow whilst in orbit.

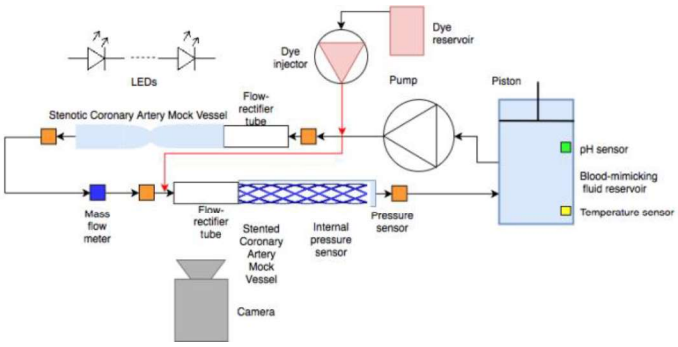


Fig. 1. Test bench for investigating coronary haemodynamics

V. Development of the AIM Cube

F. Hydraulic Loop Construction

The main part of the experiment is the hydraulic loop, consisting of the coronary artery models, the pumps, the dye reservoir, connecting tubing and check valves. This part of the experiment was constructed in Politecnico di Torino and will be combined with the remainder of the cube in ISAE-SUPAERO. A first version of the hydraulic loop has been built and tested by S. Gabetti and E. Torta in Politecnico di Torino capable of performing dye injection without leaks.

Most of the components are commercial off-the-shelf products with the exception of the stent and coronary vessels. The coronary arteries shall be 3D printed in silicone and the coronary stents were provided to the team by AlviMedica who are a sponsor of the project.

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G. Mechanical Construction

The major mechanical components for this project were the external structure of the cube and the reservoir, both of which needed to be built on the university premises (ISAE-SUPAERO) due to lack of commercial options.

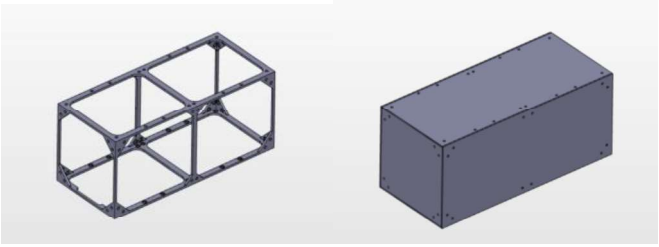


Fig. 2. (a) Internal frame and (b) external panels of ICE Cube external structure

The external structure was designed in order to meet the performance requirements of the ICE Cubes Service regarding launch load factors and random vibration [6]. The amount of material required for the internal frame was then minimised in order to maximise space available for the components within the cube, minimise mass and ease the assembly process. The structure is composed of an internal frame constructed from ABS and with threaded inserts to accommodate screws. Aluminium panels will be screwed onto the frame in order to close the cube. The corners of the cube will then be rounded off to prevent injury to astronauts.

As the ICE Cube is a new type of mission in space it is not possible to find references regarding many aspects of its design, including the structure. For this reason, the structure went through different modifications to finally have the present design. The complexity given by different elements (size restrictions, components dimensions, structural strength) is the main factor that lead to different designs for both internal components and the structure.

The second constructed component was the reservoir. Since the largest risk to the experiment would be a leak of fluid, the reservoir needed to contain a volume of fluid under pressure throughout the mission whilst preventing air from entering the loop. Trapped air bubbles could rupture the system and introduce leaks or affect results. A bubble trapper was considered to reduce the risk of trapped air in the system; however, it was disregarded due to a lack of commercial options that were suited to the flow rate of the experiment. A piston was chosen as the method of pressuring the reservoir without introducing gas.

Once a preliminary hydraulic loop was built, different reservoir sizes were tested with the pumps in order to determine the minimum volume required. It was found that 100ml was sufficient to absorb fluid momentum while leaving a suitable margin. Once the volume had been ascertained the design of the reservoir could be finalised.

Another issue that needed to be addressed when designing the reservoir was the method of sealing connections. In addition to the input and output connections a pH probe will be inserted into the reservoir and the piston itself should be sealed against water and air. The piston will contain two O-rings to separate the air from the fluid. A waterproof connector for the pH probe has been built and tested.

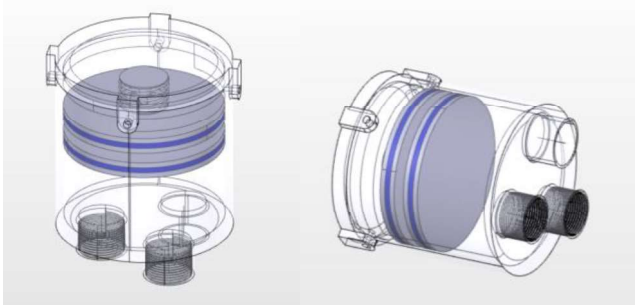


Fig. 3. CAD model of the current reservoir design

H. Electronics Construction

The electronics team has been working on the design of the architecture system to control the experiment so that it works autonomously. The primary requirements that affect the electronics are the power provided[1] and the available data downlink rate[2].

Following all the requirements, the motherboard, as well as all the devices (camera, pressure, temperature and pH sensors, pump and motor drivers) have been selected, in collaboration with the scientific team.

Firstly, the initialisation of the motherboard (Odroid C2) with an OS and all the packages necessaries was prepared, followed by the testing of the camera and every single device to finally define a main script to control the system. It has been decided that the pump will be running continuously during the 4 months, because switching it on and off over the course of the mission increases the risk of fluid leaks. Different flow rates will be imposed; therefore, the pump will be programmed to gradually increase and decrease its intensity using Pulse Width Modulation (PWM). When it does not take the measurements the flow rate will be set at the minimum. Each day measurements will be taken from each sensor; the camera will capture a short video when illuminated by the LEDs. Currently, the design of the code is being implemented and the physical circuit is being developed to find a good configuration that will fit perfectly inside the cube.

[1] A 12V line at 3A and a 5V line at 0.9A is accessible for each DB13W3 connector [6].

[2] up to 4Mbps

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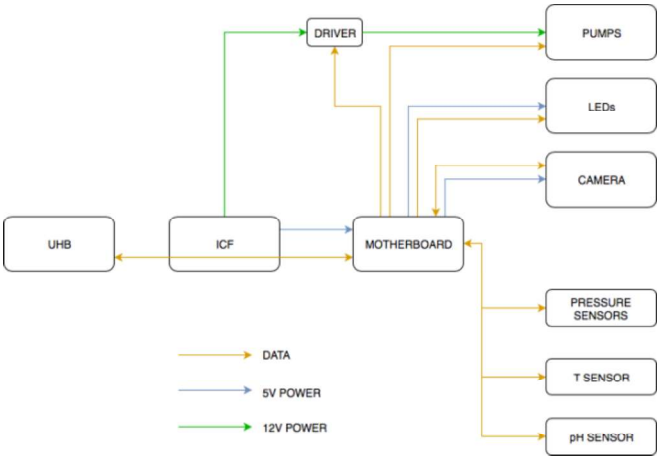


Fig. 4. Electronic block diagram[3]

VI. Test Results

For the external structure, the tests have been performed using FEM (Finite Element Method) on a commercial software. This allowed for computation of the first characteristic frequencies of the structure using the data shown in table 1 and the first 5 frequencies are in table 2. These results are only partial as the analysis has been done taking into consideration only the supporting structure and it does not take into account the effect of the other components. To have a definitive conclusion regarding the vibration study it is necessary to wait for the data from the physical tests.

TABLE I. Mechanical Properties of External Structure

Component	*Density (kg/m^3)*	*Volume (m^3)*	*Mass (kg)*
Internal Structure	1060	4.51 E-05	0.0478
Panels	2700	1.41 E-05	0.0380

TABLE II. Results of FEM Frequency Analysis

Modal Analysis		
Mode	***Frequencies (Hz)***	***Max. Displacement (mm)***
1	93.686	1.393
2	129.61	1.217
3	130.77	1.194
4	144.21	1
5	190.8	1.166

[3]UHB is the User Home Base and ICF is the ICE Cube Facility

VII. Conclusion

Whilst this project is still in progress, the design of the experiment and the choice of its components has been finalised. Construction of the first model is expected to be completed at the end of September 2019 after which a test campaign will be conducted. The test campaign will include random vibration tests, vacuum tests, EMC tests, DC magnetic tests, audible noise tests and an interface test with the ICE Cube Facility.

The primary goal of the AIM Cube is an educational opportunity for the university students involved. On top of the training week conducted with ESA Academy, the process has taught the students about the planning and execution of space missions, management of engineering teams and the application of engineering and scientific principles in a space context. For these reasons, the design and development of an ICE Cube mission is a highly recommended endeavour for any university student team for the educational benefits alone but can also provide access to a unique environment that can benefit university research and student projects alike.

Acknowledgment

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