MARVEL –THE MARTIAN AIRBORNE RESEARCH VEHICLE

Philip Påhlsson[(1)], Liselott Strand[(1)], Sara Powell[(1)], David Steenari[(1)], Mikael Helgesson[(1)], Christian Semne Olsson[(1)], Jonatan Brodin[(1)], Samuel Envall[(1)], Jonas Holmblad[(1)], Ragnar Skoglund[(1)], Thomas Nevalainen[(1)], Christian Sihvo[(1)], Fredrik Forsberg[(1)], Viktor Andersson[(1)], Sergio Martin del Campo[(2)], Bharat Ratanlal Sagar[(2)], Vikas Dalal[(2)], Roberto Sosa Cruz[(2)], Thomas Guisti[(3)]

(1) *Master of Science in Space Engineering Student, Department of Space Science, Luleå University of Technology. Box 812, 981 28 KIRUNA marvel.ltu@gmail.com*

(2) *Erasmus Mundus Space Master Student, Department of Space Science, Luleå University of Technology. Box 812, 981 28 KIRUNA marvel.ltu@gmail.com*

(3) *Génie des Systèmes Mécaniques Student, Department of Space Science, Luleå University of Technology. Box 812, 981 28 KIRUNA marvel.ltu@gmail.com*

ABSTRACT

A UAV dropped into the atmosphere of Mars would have the opportunity to perform high resolution in situ measurements. It would also have the advantage of covering large previously unexplored areas and therefore overcome several limitations associated with the current exploration possibilities, such as land rovers and orbiters.

During the project a prototype will be developed. The flight abilities will be tested by dropping the UAV from a stratospheric balloon at a height of approximately 10 km. The UAV will be controlled by an onboard flight control system utilizing a micro controller, through a telecommunications system from the ground.

The prototype is a conventional design manoeuvred by ailerons, elevators and a rudder, and has been designed to improve the flight ability in a thin atmosphere.

Utilizing UAV's in the exploration of Mars, the understanding of the Martian atmosphere and the knowledge of the Red Planet in whole would be extended.

1. PROJECT OBJECTIVES

MARVEL - The Martian airborne research vehicle is a student project carried out in Kiruna, Sweden, and is currently part of a REXUS/BEXUS programme, namely BEXUS 13 (Rocket-and Balloon-borne Experiments for University Students). The project is supported by the Swedish Division of Space Technology at Luleå University of Technology.

By October 2011 a prototype of a UAV (Unmanned Aerial Vehicle) suitable for thin atmospheres shall be designed, constructed and verified to function according to determined requirements. The UAV shall be dropped from a stratospheric balloon and comply with those requirements and constraints put on experiments enrolled in the REXUS/BEXUS programme. Project Marvel will include:

- An airframe suitable for the proposed flight environment.
- An autopilot to stabilize the UAV during the flight.
- An emergency parachute system in order to comply with safety regulations set by Esrange Space Center.
- A radio link suitable for distances and bitrates required during flight.
- Redundant parachute release mechanisms to ensure that the mission can be aborted at any time, given any system malfunctions.
- An attachment system that will keep the UAV fastened to the gondola until a release command is issued.
- A ground station capable of visualizing and storing required flight data, as well as controlling the UAV via a joystick.
- A backup positioning system to ensure that the UAV position is always known.

For the experiment to be deemed successful, the UAV must be released from the gondola and fly in accordance with the commands from the operations team at the flight management computer.

An additional objective of Project Marvel is to initiate a long-term project within the Space Engineering Programme at Luleå University of Technology and enable the next generation students to further expand Project Marvel as a part of their education. The UAV is designed to carry payloads that may be developed by future students.

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2. EXPERIMENT DESCRIPTION

The overall Marvel experiment consists of three separate segments: the Marvel UAV, the Marvel ground support equipment as well as the attachment and release facilities located on the balloon gondola.

During the balloon launch and the ascent phase of the mission, the UAV will be held in place on the side of the BEXUS gondola by the attachment system. As the balloon reaches a predetermined altitude, a command will be given by Esrange personnel and the UAV is dropped from the gondola by the release mechanism.

Shortly after the release, the UAV should level out and enter controlled and stable flight. At this point the pilot that controls the plane from the ground station will take over and perform various flight tests. A series of manoeuvres will be tried, putting the actual abilities of the UAV in high altitude to the test.

Eventually the aircraft will descend to a level where the flight test ends and preparations for landing commence. The landing will be done by deployment of the onboard parachute after which the airframe should reach terrain, nose first at a low speed. Once landed, the mission will be over and the aircraft will be recovered.

The Marvel UAV houses a number of core subsystems, which are grouped into three larger independent parts:

- The Flight Control System (FCS), which controls the airframe attitude by actuation of flight control surfaces. The system will monitor the airframe attitude and location by utilizing various sensors. It also has a two-way link with the Marvel ground support equipment.
- The Parachute System, which consists of the parachute, the deployment mechanism and necessary electronics.
- The Backup Positioning System (BPS), which ensures the location of the airframe if the communications link with FCS is lost, by relaying data on a redundant RF link.

The ground station segment consists of three different ground station computers and an automatic tracking antenna. During the mission the ground operations team will pilot and control the UAV from the Flight Management Computer (FMC), which has a joystick for manual flight and displays vital information. Any commands sent from the Marvel ground station to the UAV are issued through this computer. The second ground station computer, the Flight Data Computer, displays all the telemetry from the UAV. Finally, the third ground station computer - the ETAG Tracking Computer - is a dedicated receiver for data transmitted from the backup positioning system.

2.1 Mechanical Design

The UAV, which will be made of carbon fibre reinforced polymer, aluminium, Styrofoam and partly polycarbonate, has a conventional design with ailerons, elevators and rudder in order to steer the UAV easily. The fuselage is symmetric, with the main body cylindrical, the rear part a cone and the nosecone with a shape of an ellipsoid, in order to simplify attachment of electronics and future experiments.

Figure 1. The UAV.

The main wing has a trapezoid shape with an aspect ratio of eleven. The wing tips are twisted down which causes the wing tip to stall at a higher angle of attack than the part of the wing which is closer to the fuselage.

For the airframe to withstand a requirement of 10 g, an inner structure has been designed based on a semi-monocoque construction. This means that the loads are divided between the fuselage shell (carbon fibre) and the inner structure (aluminium).

Figure 2. The inner structure of the airframe.

All onboard electronics together with the parachute will be mounted on a polycarbonate plate which goes through the middle of the fuselage. To keep the electronics within an acceptable temperature range, the fuselage will have 25 to 35 mm of insulation around vital parts.

2.2 Electrical Design

The main function of the electronics systems in the UAV is to steer the vehicle in air, which is done by the Flight Control System (FCS). To ensure that the UAV is landed in a safe manner and to give an emergency abort option, a Parachute Deployment System (PADS) is included in the electrical design. A redundant GPS system, Backup Positioning System (BPS), has been added which gives a second option for parachute deployment. The systems have been isolated from each other by optocouplers.

The FCS is microcontroller based; it uses an ATmega 1280 on an ArduPilot Mega board (APM), and holds all sensors necessary to steer the vehicle. Namely a GPS, a static pressure sensor, gyros, accelerometers, an airspeed sensor, a magnetometer, a temperature sensor and battery level sensors. The gyros and accelerometers will be used to determine the attitude of the UAV while the static pressure sensor determines the altitude and the GPS gives the position. A magnetometer has been added in order to compensate for gyro drift in the yaw direction. The airspeed sensor measures the differential pressure and gives knowledge of the velocity of which the UAV is flying. The temperature inside the airframe is of importance and therefore a temperature sensor has been added to the system. The UAV also carries battery sensors so that the power level can be calculated. The sensor values are sent to the APM which also holds an autopilot and the latter demands the servos to be adjusted. A few different autopilot modes may be used during the flight. One of them is to only use the autopilot in order to stabilize the UAV (thus steer the UAV via a telecom link from the ground), another to request the vehicle to circle in a certain radius or for example follow a set of predefined waypoints.

The PADS is able to deploy the parachute by three different inputs, all isolated from one and other for safety reasons. The primary deployment is triggered by the FCS, the signal is sent from the ground station. The secondary deployment triggers if the UAV escapes the flight zone. The backup and third option is to trigger deployment of the parachute with an Automatic Activation Device (AAD). The AAD is activated when the UAV is below a specified height and has a certain speed.

The BPS consists of an ETAG, a GPS with a microcontroller that can be programmed to receive and transmit data via an edge connector. The primary function of the BPS is to transmit an accurate position of the UAV to the ground station as well as deploying the parachute if necessary.

The electronics onboard the UAV will be mounted on a 5 mm thick polycarbonate plate.

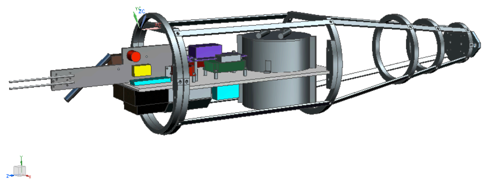

Figure 3. Placement of the electronics and parachute inside the inner structure.

2.3 Thermal Design

The environmental conditions of the flight are very harsh with both low temperatures and low atmospheric pressure. The temperature may very well drop to -60°C during ascent to 10km altitude and even down to -90°C at altitudes around 30km.

If the electronics inside the airframe is to be fully functional at all times prior to, during and after flight, it is important that the temperature does not drop below or above the operational limits. With regard to the different components onboard the airframe an acceptable temperature span is -20 °C to +60 °C. The airframe has to be properly insulated, in order to keep the temperature within the acceptable limits. The primary insulator material is Styrofoam.

The external shell of the airframe is constructed of carbon fibre reinforced polymer. This material has some insulating properties in itself and even though the carbon fibre layer only is 0.2mm thick, it will shield the components on the inside of the airframe slightly.

After thermal calculations and simulations, it was decided that a Styrofoam layer, 25 to 35mm thick, shall be used to insulate the UAV. Due to the telecommunications system, the whole nosecone of the airframe will not be insulated. Instead, there will be insulation covering only the electronics and the transceiver antenna will stick out of the Styrofoam.

2.4 Software Design

The software for the APM will use existing open source software as a basis to build on. Modifications and additions to the software will be done where necessary to ensure that mission specific requirements and safety regulations are fulfilled.

The APM software uses a number of loops that triggers at different intervals to perform its tasks. The fastest loop executes at 50 Hz and handles time critical functions such as controlling flight (reading manual control input, reading IMU and flight sensors and setting servos accordingly.) Autopilot calculations, reading and sending telecom and telemetry messages are also done at 50 Hz.

A second loop that runs at 10 Hz reads GPS data and handles navigation.

A third loop which runs at 3 Hz updates the static air pressure, battery levels and things that do not need real-time updates.

The last loop runs on 1 Hz and transmits the heartbeat message in addition to other low rate telemetry messages and data logging.

2.5 Telecommunications

The telecommunication system consists of two transceivers, one connected to the APM and the other one to the Marvel ground station.

The antennas that are used with the transceiver module were chosen with regard to the long distance between the UAV and the Marvel ground station segment as well as polarization. The ground station antenna setup therefore consists of two high gain antennas with a 90 degree orientation. The orientation minimizes polarization losses to a minimum of 3dB since the displacement of the UAV antenna to the polarization pattern can only be 0.5, which result in 3dB.

The transceiver module combined with the antennas, gives a long-range communications link with a theoretical transceiving distance of 35km. The ground station antennas were chosen due to high gain compared to small size.

2.6 Ground Support Equipment

The Marvel Ground Support Equipment (GSE) consists of the telecommunications equipment, computers with the necessary software and controls for piloting the vehicle and monitoring the flight data. The functions of the four GSE computers are as follows:

- A Flight Management Computer (FMC) to manually fly the aircraft and for controlling software modes for the Flight Control System onboard the UAV. The flight management computer also has manual control of the arming and deployment of the parachute. The main control of the tracking system is also done by the FMC.
- A backup Flight Management Computer (FMC2) which will be on standby if the main flight management computer fails.
- A Flight Data Computer (FMD), which monitor flight and housekeeping sensor data and reduce the load of the flight management computer operator.
- An ETAG Tracking Computer (ETD) to monitor the telemetry data of the backup positioning system and provide a secondary input for the tracking system.

The Marvel GSE also includes an automatic tracking antenna and transceiver to ensure communication with the vehicle from ground. The tracking can be made either by utilizing the GPS data from the FCS over the main RF link, or by using the GPS data from the ETAG over the Esrange ETAG receiver.

The FMC communicates with the FCS onboard the UAV through a two-way RF link.

The backup positioning system onboard the UAV will be monitored on the ETAG Tracking Computer, which will be connected to the Esrange ETAG receiver. The computer will display the UAV GPS position and if any boundary condition of the flight zone has been exceeded.

2.7 Recovery and Emergency Abort System

Safety is of primary concern for the Marvel team and of the supporting organizations. In order to perform a controlled landing the UAV must be equipped with a recovery system. It must also be fitted with an emergency abort system if it were to stray outside the permitted flight area. The main concept is to use a deployable parachute recovery system for routine recovery and also use this as the emergency abort system.

The best design for the parachute recovery system and the emergency abort system is a spring ejected cruciform parachute attached at the rear of the airframe. The parachute will be stored inside the airframe, in a cylindrical housing facing downwards, which also contains the compressed spring and parachute risers. The spring will eject the parachute downwards through the aircrafts belly where it can inflate in the free airstream. The advantage of this configuration is that the housing does not affect the aerodynamic properties of the airframe and that it is placed relatively close to the centre of gravity, therefore not affecting the flight characteristics.

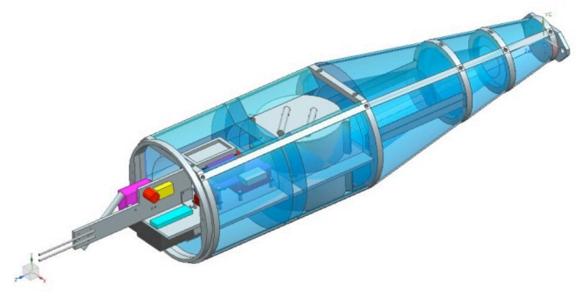

Figure 4. CAD drawing of the fuselage inner structure. The parachute is housed in the cylinder, located in the centre of the body.

The main reason to use the cruciform parachute canopy is due to favourable low opening load characteristics and flight stability. This satisfies the requirement that the system should be operational even at the theoretical maximum flight speed.

3. LAUNCH

The UAV will be mounted on one side of the gondola using a thread and rails on which it will slide down and be guided into a correct direction of flight. Prior to launch the systems will be set to standby, which means that most systems will be disabled in order to save power. Once launch is imminent the UAV will be set to ascent, which has most onboard monitoring systems activated and the FCS offline. Low rate telemetry and logging will be enabled.

Prior release of the gondola, the parachute system shall be armed and all the onboard systems and software functions will be operating.

4. DATA ANALYSIS PLAN

One type of post-flight analysis involves physical investigations of the hardware and aims to evaluate the structural integrity of the parts.

Data recorded during flight will be analysed, preferably by cross-comparisons of values obtained in different ways. Most of the systems onboard the UAV are redundant, which means that two or more systems and devices generate the same kind of value. Expected values will also be compared to the measured ones.

The response of the UAV will be thoroughly evaluated. For example, did the parachute deployment system behave according to expectations? Did its status signal deliver a true picture of the state of affairs? Did the UAV turn as requested? If not, a study must be made of why things went wrong and what really happened.

5.0 ACKNOWLEDGEMENTS

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EuroLaunch, a cooperation between the Esrange Space Center of the Swedish Space Corporation (SSC) and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Experts from ESA, SSC and DLR provide technical support to the student teams throughout the project.