UAV mission design for the exploration of Mars – ESA/EUROAVIA Design Workshop 2006

Lisero Perez Lebbink
MSc student Space Systems Engineering
Delft University of Technology, The Netherlands
L.A.J.PerezLebbink@student.tudelft.nl

Participants:
Team 1: Ivor van Dartel, Jean-François Dufour, Artur Fouto, Nicolas Guiditta, Roberta Guatelli, Nils Harmsen, Daniele Pratali, Tamara Sopek, Roberto Suárez Pérez, Fani Vogiatzi.
Team 2: Carmen Ancuta, Laurent Coutard, Daniel Dodd, Gert Heirman, Sven Lazan, Joao Loureiro, Guiseppe Marrocco, Lisero Perez Lebbink, Giuliano Punzo, Isabel Vera.
Team 3: Athanassios Baltopoulos, Antonio Buonfino, Szymon Cyran, José Domingos Mendes, Ines Fuente Garcia, Karen Geris, Benedicte Gillot, Goran Ivetic, Hessel Meijer, Andrea Simonetto.

Design Workshop 2006 Working Group:
Carmen Ancuta, Antonio Buonfino, Guisseppe Marrocco, Hessel Meiier, Tamara Sopek.

Tutors:
Stephen Ransom (Aerospace Consultant), Rick Ruijsink (Ruijsink Dynamic Engineering).

ESA assistance:
Pierro Messina (Aurora Exploration Programme), Alex Holden

Abstract

This paper describes three different mission concepts for the exploration of Mars by means of a UAV. These concepts have been proposed after a three week workshop held by the European Association of Aerospace Engineers EUROAVIA and the European Space Agency ESA. The UAV designs have been a combined effort of a total of 30 European engineering students. All three design will be addressed in this paper, as well as the design implications of the Martian environment.

1. Introduction

Missions to Mars are characterized by a modest success rate, leaving much physical phenomena still to be clarified. Martian research and exploration is therefore one of the main goals of the European Space Exploration Programme Aurora. This project knows a stepwise approach to the exploration of the solar system, increasing mission complexity from mission to mission. In light of this project, ESA supported 30 students in a workshop organized by the European Association of Aerospace Students EUROAVIA. The workshop was being held at ESA's Research and Technology Centre, ESTEC, during three weeks in the summer of 2006.

Main goal of the Design Workshop was to produce a preliminary design of a UAV (Unmanned Aerial Vehicle) mission for the exploration of Mars. With very limited requirements from the organizing committee the students had to start their design studies. One of the few strict requirements was that the actual design had to be an unmanned aerial vehicle (in the broadest sense of the word) and that the design should be able to house a minimum of 0.5 kg of payload. Also, the UAV should be able to either take-off from Martian soil or be deployed in mid-air, and the UAV should carry out a mission that could not have been carried out by a rover or an orbiter. The students themselves had to transfer these broad requirements into a mission statement, specific requirements and a clear scientific mission goal. The workshop was constructed as such, that three multinational/cultural student teams would compete on the best design.

Never has a UAV mission been conducted on Mars before. A certain mission would become quite complex, for several reasons. The Martian atmosphere for example is a quite harsh and complicating one. When compared to the Earth's atmosphere, the Martian atmosphere has a very low density. This has very large implications on the UAV design, as will be discussed later on. Also in the field of power consumption there are several serious design challenges when a UAV is required to perform extended missions. Required power for example is driven by the UAV's mass, thereby limiting the onboard payload capabilities.

The individual solutions of the three student teams will be extensively addressed in following sections. In order to better understand the design solutions, it is essential to first describe the environment in which the UAV's have to operate and the limiting implications of it.

2. Martian characteristics

Atmosphere

The Martian atmosphere is one of the least engineering friendly atmospheres in the solar system. Especially in terms of aerospace engineering. One of the most challenging characteristics of the Martian atmosphere is its low density. When compared to the Earth's atmosphere, the Martian density is roughly a factor 60 less. This fact is a limiting factor when aerodynamics are considered.

As commonly known in aerospace engineering, for conventional aircraft the required minimum velocity (V_{stall}, assuring stationary steady flight) is related to the atmosphere's density. In particular, the stall velocity is inversely proportional to the square root of the density, as can be seen from following formula:

$$V_{stall} = \sqrt{\frac{W}{S}\frac{2}{\rho}\frac{1}{C_{L_{max}}}}$$

Thus, a lower density of the atmosphere requires a higher minimal velocity to assure steady flight (non descending). A high velocity implies high power requirements, which in turn requires more mass. It is evident that a high minimum velocity requirement makes the design more complicated.

An option to overcome the high velocity requirement is to increase the lift generating capabilities of the UAV. The minimum velocity is proportional to the generated lift of the wings (and possibly the body). As can be seen from gliders in more Earthly applications, a high lift can be obtained by wings with a high aspect ratio. Translated into a design, this means that the wings of the UAV should be made very long and slender. However, designers are limited by the entry capsule where the UAV is placed in. Long wings also require more design effort to assure proper deployment.

A different UAV concept would be to use blimps to explore the Martian surface. Aside from the speed which these vehicles can reach, and their higher vulnerability, the Martian atmosphere is also less suited for such designs. Since the density (and pressure) is at such a low level, it is hard to assign an appropriate gas to the blimp. The gas used in blimps is of a lower density than the surrounding atmosphere, thereby providing lifting power. The lifting capacity of a blimp is directly proportional to the density of the surrounding atmosphere. Therefore, compared to Earth, a blimp would require a gas volume of roughly a factor 60 larger. This results in a higher mass of the blimp and negatively affects the UAV design.

Another negative aspect of the Martian atmosphere is the occurrence of so called "dust devils". These enormous storms occur regularly on the Martian surface and can grow up to a size of 2 km in diameter and 10 km high. With this size, they form a realistic danger to the safe operations of a UAV. It is thus highly advisable to study the area of deployment for possible dust storm occurrence.

It is clear that the atmosphere of Mars results in some interesting challenges for the UAV design.

Position in solar system

Due to Mars' position in the solar system, the mission design is further complicated. The large distance from the Sun affects the power generating capabilities of solar cells. as a comparison, the solar flux at Martian distance is some 43 % of the amount at Earth distance. Thus, power generating capabilities are a factor lower than compared to Earth. When power is to be generated through solar energy, this would mean that the area of the solar cells need to be a factor 2.3 larger. This has further implications on the UAV mass and its overall design.

Since Mars is at a large distance from Earth, communication becomes challenging. Not only is data transfer towards the Earth problematic from this distance, and probably requires an intermediate relay station, also commands towards the UAV will be a challenge. Two way communication from Earth to Mars has a delay of some 9 minutes. Such a delay makes an Earth controlled UAV impossible. The UAV design thus needs to be autonomous, able to perform its mission and to navigate/explore on its own. An autonomous operating UAV requires more sensors and a more complex control system, this will increase the design effort.

Lack of references

Since Mars is a relatively unexplored area, when compared to Earth, there are large issues concerning navigation on the planet. Mission designers on Earth are expected to have several navigational aids to their disposal. One of the most commonly used system is GPS. However, on Mars such a system clearly does not exist and designers are thus assigned to other options. Not only is navigation crucial to follow a pre-programmed mission track, it is also essential for later data processing of the scientific data. Observational data needs to be assigned to the exact areas of the surface of Mars, lack of this information makes the data basically useless.

One of the principles that is commonly used in spacecraft orientation is the use of a magnetic field as a reference. However Mars lacks a magnetic field (apart from its crust), this option can thus not be applied for UAV design.

Other options rely on data acquisition and comparison, reference mapping for example. These techniques require an extensive database of maps however, and also require large computing power onboard the UAV. This has large implications for the onboard data processing subsystem.

3. Initially proposed mission concepts

In an early stage of the workshop, the three teams proposed several mission concepts which were evaluated for their performance. The main mission variable that was evaluated in this trade-off phase, was the configuration of the UAV. Although the three teams carried out the project individually, this phase still showed some similarities in mission concepts. Some UAV configurations that were proposed by nearly all the team are listed below. In this list, also the driving reason of rejection is mentioned.

- Balloon – controllability (dependent on weather)
- Blimp/Airship - vulnerability (weather), speed, stability/controllability, limited payload availability
- Glider – mission flexibility, operational lifetime
- Flying wing – dimensional constraints, complex aerodynamics
- Rotorcraft – complex system (miniaturisation) and complex aerodynamics, high power requirements, high vibrations
- Paraglider – complex control system
- Flapping wings – complex system, vulnerability, high vibrations
- Missile/rocket – operational lifetime, high vibrations

After performing trade offs, the teams did not consider these concepts any further. All team chose to base their design on a conventional aircraft configuration i.e. a tubular body with lift generating wings. However, the individual teams did come up with some interesting and very different configuration details.

4. UAV mission design

The design the three teams have proposed will be presented in a standard format., which allows for a solid comprehension of the design choices of each team. For example, the UAV configuration and the scientific mission goals are directly derived from the mission statement. It is thus essential to present the mission statement in advance of the actual design parameters. The overall design parameters are summarized in a table, after which the design is further elaborated in the subsequent text.

Team 1: ARMaDA

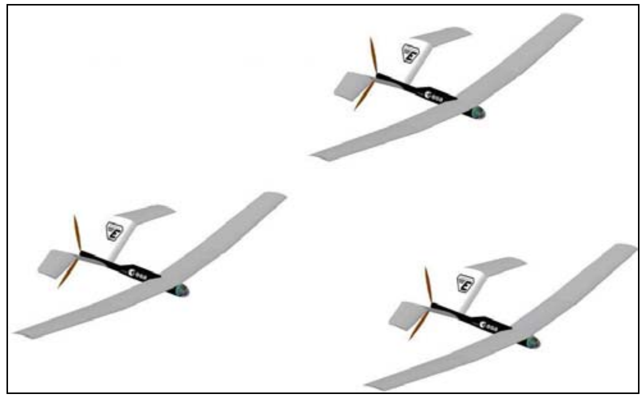

Fig. 1: once deployed, the ARMaDA mission consists of three identical UAV's covering a large area. *Source: [1]*

ARMaDA	
Three identical UAV's, long operational lifetime enabled by radioisotope	
Launcher	Ariane 5
UAV mass	63 kg
Cruising speed	60 m/s
Wingspan	8.0 m (hinged)
Mission duration	Virtually unlimited
Range	Northern hemisphere
Payload	High resolution camera, video imager, spectrometer, laser hygrometer, atmospheric package
Propulsion	3 bladed foldable propeller (d=1.4 m), electrically driven
Power subsystem	Sterling Radioisotope Generator (SRG) based on Curium > 1.2 kW
Guidance, navigation and control	Inertial Navigation System (INS), Terrain Aided Navigation System (TANS), Simultaneous Localisation and Mapping (SLAM) algorithm
Communication	UHF antenna onboard UAV, link with existing orbiter: 0.3 Mbs

Table 1: Mission characteristics and UAV design parameters of the ARMaDA mission.

The Advanced Reconnaissance Martian Deployable Aircraft (ARMaDA) mission concept of team 1 is characterized by the number of UAV's they are including. With three identical UAV's operating in three different areas they have a good coverage of the Martian surface. A radioisotope generator enables a virtually unlimited mission lifetime.

- Mission statement

"...there is a need to design a Martian aerial vehicle capable of doing research, which is
currently not possible by orbiters or rovers, in order to help in the understanding of our
solar system as a part of the preparation to human exploration..."

- Scientific mission goals

Geographical mapping, soil composition analysis, atmospheric characterisation.

- Mission requirements

Primary:
High resolution mapping to find landing sites for future human and robotic missions
Investigate the quality of the soil in situ and determine its composition
Secondary:
Perform a basic analysis of the atmosphere
The mission is intended to be relatively short, but it is desired (not required) that the
mission duration is extended

- Overall description

The ARMaDA mission is specifically designed to provide a large mission duration, in the order of days. However, the power source (radioisotope) enables a mission lifetime up to years, mechanical failure will most probably be the first reason for mission termination.
The ARMaDA includes three UAV's in its mission. All three UAV's are identical to one another and provide a large coverage area, mainly on the northern hemisphere. The UAV's all carry the same payload onboard (in the preliminary design): high resolution camera, video imager, spectrometer, laser hygrometer and an atmospheric package. The payload will map the Martian surface and will perform research on Martian soil and atmosphere characteristics.

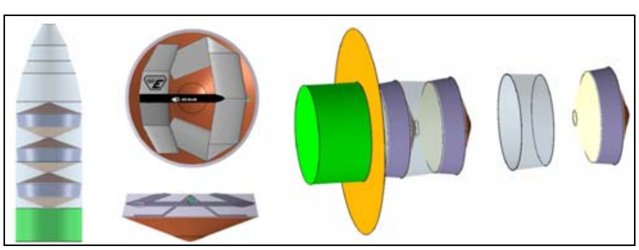

Fig. 2: Different configurations of the UAV during mission phases. The three UAV's are stacked during transfer from Earth to Mars. *Source: [1]*

- Design characteristics
  - key description

Three identical UAV's operating in different areas, radioisotope driven enabling extended lifetime.

  - Payload

3.7 kg: High resolution camera: providing mapping capabilities of Martian surface. Video imager: continuous imaging of surface. Spectrometer: analysis of soil composition. Laser hygrometer: measuring water vapour mixing ratio. Atmospheric package: atmosphere characteristics.

  - Propulsion

Electrically driven 3 bladed propeller (D=2.4m). The propeller is foldable to accommodate the UAV in the entry capsule. The propulsion system enables a cruising velocity of 60 m/s.

  - Power requirements & subsystem

1.2 kW of required power. A Sterling Radioisotope Generator (SRG), based on Curium, will deliver this power.

  - Guidance, navigation and control

Instruments: Inertial Navigation System (INS), Terrain Aided Navigation System (TANS), Simultaneous Localisation and Mapping (SLAM) algorithm.
The landing zone will be mapped by existing orbiters (e.g. MRO) and landmarks and waypoints are indicated. After UAV deployment, payload camera and IR sensors observe landmarks and create maps with a higher resolution. Images of surroundings and INS data are combined in SLAM algorithm to accurately determine position and guide UAV to next waypoint.

  - Communication

UHF antenna onboard the UAV communicates with an existing orbiter (assumed available, e.g. MRO) with a datarate of 0.3 Mbs

  - Wings

Hinged folding system, 2 lifting wings concept. The wings are constructed from carbon reinforced laminates, honeycomb structures and foam to ensure shape retention. Span: 8.0 m, surface area: 8.3 m^2.

  - Mission duration and range

Duration is virtually unlimited due to the implemented power source. The UAV's are designed for a flight level prevailing mainly on the northern hemisphere.

  - Entry capsule

Each UAV is placed in its own entry capsule. The entry capsule has a conventional pyramid shape and will be additionally decelerated by rocket boosters and a parachute.

  - Deployment

The UAV's are deployed from their entry capsule while in mid-air. The UAV is detached from the capsule by a parachute at the end of tail of UAV. This parachute further decelerates the UAV in order to safely deploy the wing and the rotor blades.

Team 2: MAREA

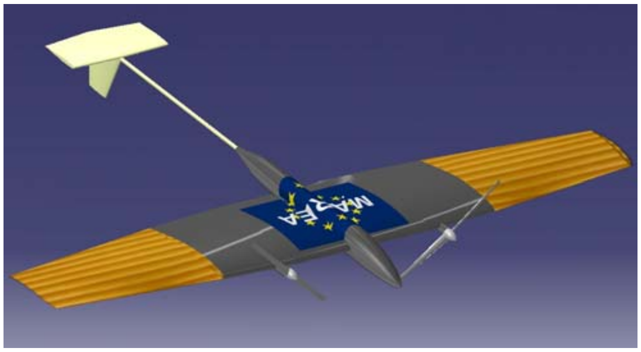

Fig. 3: MAREA UAV in fully deployed configuration. *Source: [2]*

MAREA	
UAV with inflatable wings, transfer vehicle serves as "Martian-stationary" relay station	
Launcher	Ariane 5
UAV mass	50 kg
Cruising speed	40 m/s
Wingspan	8.8 m (inflatable)
Mission duration	40 hrs
Range	5700 km
Payload	Visual camera, IR camera, spectrometer, radiosonde (atmospheric analysis)
Propulsion	2x2 bladed propeller (d=1.3 m), electrically driven
Power subsystem	Solar cells (6.7 m^2) and fuel cell (20.9 kg) > 1.1 kW
Guidance, navigation and control	Internal Measuring Unit (IMU), image referencing, sun sensor, orbiter
Communication	Omni-directional antenna onboard UAV, link with mission specific (transfer vehicle) orbiter: 2.6 Mbs

Table 2: Mission characteristics and UAV design parameters of the MAREA mission.

The Martian Aerial Research EUROAVIA Airplane (MAREA) mission of team 2 has as main characteristic its deployment mechanism. The centre wing structure will be extended by an inflatable structure, pressurized to ensure stiffness. The space transfer vehicle of this mission will remain on orbit at Mars to serve as relay station for the UAV and future missions.

- Mission statement

"To design a fully-autonomous, programmable, Unmanned Aerial Vehicle (UAV) for use in the Martian environment. With coverage capabilities greater than a rover and data accuracy greater than an orbiter. The characteristics for the UAV should be optimized for surface imaging and the study of local atmospheric conditions; this data shall be made available to the end-user".

- Scientific mission goals

Geographical topography, surface thermal characteristics, composition of soil/atmosphere, atmospheric characteristics, magnetic field measurements.

- Requirements
    - Total system must fit within Ariane 5, constraints: mass < 6.5 tonnes, size: within entry capsule dimensions.
    - Range > 1000 km
    - Endurance > 1 day/night cycle (interesting atmospheric characteristics change)
    - Payload ~ 10 kg
    - Re-Programmable systems (enabling reconfiguration of the mission)
- Overall description

The MAREA UAV is designed with an extendable wing structure by means of inflation. This system should be less complex and thus less susceptible to failure than a hinged wing construction, which is highly influenced by aerodynamic conditions.

Once deployed, the UAV will provide research data on Martian soil, atmosphere and magnetic field characteristics. The research period is limited to some 40 hours, one day and night cycle at least, to investigate the changing Martian atmosphere. The mission lifetime is limited by the onboard power subsystem which consists of a pre-charged fuel cell and solar cells.

The MAREA consists of an entry capsule, delivering the UAV into the atmosphere, and a transfer vehicle, delivering the entry capsule to Mars. The entry vehicle is designed as such, that it is able to serve as a relay station when positioned at Mars. This relay station will obtain a "Martian-stationary" position to provide continuous coverage of a large area of the Martian surface.

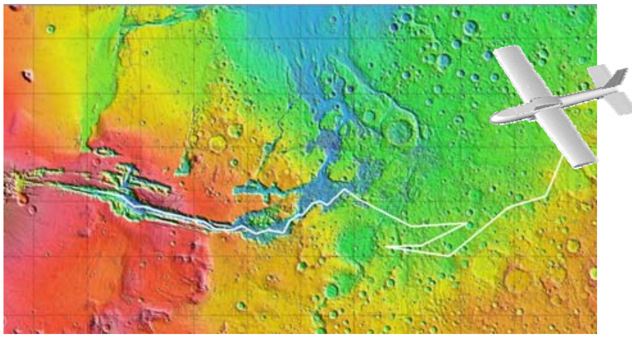

Fig. 4: Proposed mission flight path through the Valles Marineris. This valley and its surroundings has interesting characteristics for research. *Source: [2]*

- Design characteristics
  - Key description

  UAV with inflatable wing design and extensive payload package. The transfer vehicle serves as relay station in Martian orbit.
  - Payload

  3.6 kg: Visual camera: continuous imaging of surface/atmosphere for geographic mapping. IR camera: temperature characterisation of surface. Spectrometer: soil composition analysis. Radiosonde: atmospheric characteristics analysis. Magnetometer: measurement on Martian magnetic field (crustal).
  - Propulsion

  2x2 bladed electrically driven propeller (D=1.3 m). The propulsion system enables a cruising velocity of 40 m/s.
  - Power requirements & subsystem

  1.1 kW of required power. Solar cells (6.7 m^2) and a fuel cell (20.9 kg) hybrid power subsystem will deliver this power.
  - Guidance, navigation and control

  IMU (Internal Measuring Unit) and image referencing, sun sensor, orbital asset (orbiter).

  The IMU obtains the development of position over mission time. At the start of the deployment, taken images are compared with an images database to determine initial position. This cross check will be done by the orbiter to reduce computing power on the UAV. This position cross check will be updated regularly to reduce position determination errors. The sun sensor assists in acquiring the correct orientation of the UAV.
  - Communication

  Omni directional antenna communicates with the "Martian-stationary" orbiter at a rate of 2.6 Mbs. This orbiter is in continuous contact with UAV and covers a range of some 9000 km.
  - Wings

  Inflatable extensions of centre wing body. The wing body is constructed from composites, the inflatable parts are pressurized to ensure stiffness. Span: 8.8 m, surface area: 13.3 m^2.
  - Mission duration and range

  The MAREA is designed for a mission lifetime of 40 hrs. During the mission solar cells are operating during day time together with the fuel cell, at night the fuel cell delivers power to the subsystems. The proposed area of investigation is the Valles Marineris near the equator. The UAV can fly a pattern up to a range of 5700 km
  - Entry capsule

  The MAREA UAV will be brought to the Martian surrounding by means of a spacecraft/entry capsule configuration. Once this vehicle has reach "Martian-stationary" height, the entry capsule, carrying the UAV, will be released to descent towards Mars. This entry capsule has a conventional pyramid shape. The transfer vehicle itself will continue orbiting Mars on an altitude that provides continues coverage of the Martian soil underneath.
  - Deployment

  The UAV will be released from the entry capsule and deployed in the Martian atmosphere. Once released from the entry capsule, the inflatable sections of the wings will be inflated and will increase the lift generating capabilities of the UAV.

Team 3: KLIMars

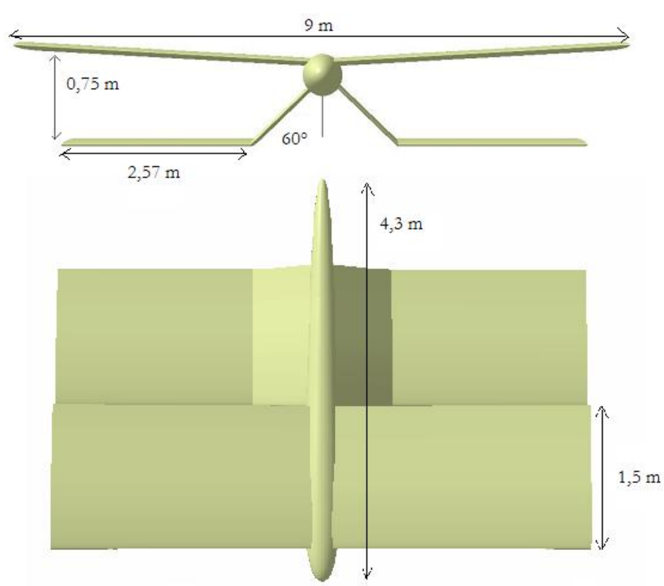

Fig. 5: KLIMars general configuration. Noticeable is the biplane design which enables high lift generation. *Source: [3]*

KLIMars	
Weather stations dropping UAV, serving as relay station when landed on Mars. Data acquisition period up to 5 yrs	
Launcher	Ariane 5
UAV mass	122 kg
Cruising speed	80 m/s
Wingspan	6.0 m (non-foldable)
Mission duration	1 hr flight time, data acquisition of 4-5 years
Range	200 km flight path, 625 km^2 coverage by weather stations
Payload	UAV: video imaging, audio recording, spectrometer Stations: temperature-, pressure-, humidity sensors.
Propulsion	2 bladed propeller (d=3.4 m), electrically driven
Power subsystem	UAV: 3.2 kW required during flight, 37.5 W required when landed. Power delivered by: solar cells (17.0 m^2) and pre-charged battery (2.7 kW) Stations: deployable solar cells
Guidance, navigation and control	Automated Flight Control System (AFCS), gyros, pressure sensors
Communication	Interlinked stations by dipole antennas, link with landed UAV which relays data toward existing orbiter

Table 3: Mission characteristics and UAV design parameters of the KLIMars mission.

The KLIMars mission is characterized by the scientific mission it proposes. The UAV will drop 24 "weather stations" over an extended range on the Martian surface, acquiring data on the atmospheric characteristics and changes thereof.

- Mission statement

"Design a UAV able to perform local meteorological characterization of Mars".

- Scientific mission goals

Obtaining meteorological information of the Martian atmosphere for an extended period.

- Requirements
  - Payload > 13 kg
  - Range ~200 km
  - Flight altitude: a height that ensure precision and safety for the dropped stations
  - Safe landing for UAV to act as relay station
  - Sufficient power both for flight and ground phase
- Overall description

The KLIMars mission consist of a UAV and several deployed data acquisition stations. In total 24 station will be dropped by the UAV over a range of some 625 km^2. The stations will obtain data on the atmospheric characteristics (pressure, temperature, humidity) over a period of 4 to 5 years. After having fulfilled the dropping mission, the UAV will land on the Martian surface to serve as a relay station for the 24 "weather stations".
The UAV will drop the stations faster than a rover (decreased mission time) and with more precision than an orbiter. The UAV has a scientific payload as well. A spectrometer will investigate the atmospheric composition once it has landed on Martian surface. This landing is eased by the design of the UAV's wings. A bi-plane construction is proposed to allow a low stall velocity, enabling a soft landing.
Once deployed, all stations will be powered by it own solar cells. Also the UAV will be powered by solar cells. This results in a data acquisition lifetime of some 4 to 5 years.

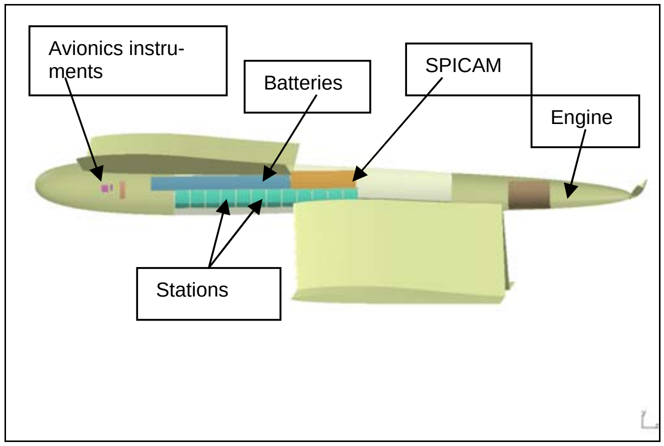

Fig. 6: KLIMars UAV layout. The main body houses the 24 station which are deployed mechanically at a predetermined rate. *Source: [3]*

- Design characteristics
  - Key description

  Weather station dropping UAV, providing large coverage and long data acquisition mission.
  - Mass

  122 kg
  - Payload

  Weather station: mass: 0.3 kg. Temperature sensors, pressure sensors, humidity sensor.
  UAV: Video imaging: providing continuous images. Audio recording: providing "sound of Mars". Spectrometer: composition characterization.
  - Propulsion

  Electrically driven 2 bladed propeller (D=3.4m). Engine: electric, 5 kW, powered by solar cells and pre-charged batteries (84 %). The propulsion system enables a cruise speed of 80 m/s.

- Power requirements & subsystem

3.2 kW required for propulsion, delivered by solar cells and pre-charged battery

37.5W required for UAV payload (flying and on-ground), delivered by flexible silicon solar cells on wings (17 m^2)

Weather stations powered by solar panels.

- Guidance, navigation and control

Automated Flight Control System (AFCS), gyros, pressure sensors.

The KLIMars UAV will rely only inertial navigation and determines control commands out of this data. Image recognition is proposed for landing site determination. To prevent geometry alteration of the wings, piezoelectric actuators are included in the design.

- Communication

The weather stations are inter-connected to ensure data transfer to landed UAV even if direct link is obstructed. Dipole antennas are deployed from station from the stations. The landed UAV communicates with an orbiter (assumed available)

- Wings

Non-foldable "Bi-plane design" (to prevent hinge deployment failure), placed vertically in entry capsule to accommodate large wingspan. Span: 6m, surface area:18m^2. Low stall velocity (assists safe landing) and high lift capabilities. The wings will be constructed from sandwich materials.

- Mission duration and range

The KLIMars UAV will have a flight time of roughly one hour. In this time it will have covered a range of some 200 km. The dropped weather stations will operate for 4 to 5 year, the lifetime is limited by solar cell and battery degradation. The area covered by the 24 stations will be some 625 km^2.

- Entry capsule

The UAV is place in a vertical way to prevent necessity of a hinging wing construction, thereby adding to the mission reliability. The entry capsule has therefore a unconventional design. The capsule is cylindrical shaped and is decelerated by means of retro rockets and parachutes.

- Deployment

Deployment of the UAV occurs by separating the lower part of the cylinder. This will force the UAV out of the cylindrical entry capsule. Once released, the UAV carries out its mission.

The weather stations are deployed from the UAV's fuselage. An electrically powered conveyor belt system will drop the station at a designated rate. The E UAV will fly in a spiral pattern to ensure sufficient spreading of the stations.

5. Conclusion

The three different team attending the workshop have come up with three quite different mission concepts. Where team 1 proposes a mission which incorporates three separate UAV's, fuelled by a radioisotope power generator enabling a very long mission lifetime, team 2 has less unconventional design options. Aside from the inflatable wings, the UAV mission of team 2 is quite straightforward and requires technologies that are currently available and applied. In contrast, team 3 has designed a mission which evolves not around the UAV but mainly around the 24 weather stations it drops on the Martian surface. Although the UAV has a flight time of roughly one hour, the data acquisition mission extends up to 5 years.

References

[1] Design Workshop 2006 Team 1. *The ARMaDA – proceedings DeWo06*. Noordwijk, The Netherlands August 2006

[2] Design Workshop 2006 Team 2. *MAREA, Martian UAV design – proceedings DeWo06*. Noordwijk, The Netherlands August 2006

[3] Design Workshop 2006 Team 3. *KLIMars – proceedings DeWo06*. Noordwijk, The Netherlands August 2006