# AHS Student Design Competition for the Development of Rotary-Wing Technologies for Use in Mars Exploration

## I. Design Competition General Background

As NASA enters a new era of planetary science -- which will ultimately lead to the human exploration of Mars -- there is an increased emphasis on expanding the tools for planetary exploration. Manned and robotic exploration of Mars could be greatly enhanced through the use of robotic aerial vehicles. Since the 1970's a number of Mars (fixed-wing) airplane concepts have been proposed for Mars exploration. Recently, preliminary work has been initiated examining the feasibility of an autonomous rotorcraft for Mars exploration.

Why propose a rotorcraft for Mars exploration? For the same reasons that make helicopters and other rotorcraft such flexible aerial platforms for terrestrial exploration and transportation. Further, a Martian autonomous rotorcraft would have the following specific advantages/capabilities:

- Sidesteps tricky issues of deployment, launch, takeoff and landing of a 'fixed-wing' Mars airplane
- Hovering and low-speed flight capability enables detailed and panoramic survey of remote site(s)
- Rotorcraft configuration enables remote-site sample return to lander platform and precision placement of probes
- Soft landing capability for vehicle reuse (i.e. lander refueling and multiple sorties) and remote-site monitoring
- Hover/soft landing are good fail-safe 'hold' modes for autonomous operation of Mars aerial vehicles
- Greater range and speed than a rover to perform detailed surveys
- Greater resolution of surface details than an orbiter

The Martian atmosphere is 95% CO2 with the remaining 5% comprised of N2 and other trace gases. Further, the atmospheric density of Mars is extremely thin (~ 1/100 of Earth's sea-level atmospheric density). This is roughly equivalent to flying an aerial vehicle at an altitude of 100,000 feet in the Earth's atmosphere. Nonetheless, recent technology trends favor the successful development of Martian autonomous rotorcraft. These include:

- Recent successes in High-Altitude and Long-Endurance (HALE) fixed-wing aircraft (Ultra-light weight structures, low Reynolds number aerodynamics and propulsion systems);
- Demonstration of human-powered flight for fixed-wing and rotorcraft (ultra-light weight structures and Low-Re aerodynamics);
- Recent research efforts in autonomous Micro Air Vehicles (MAV's) (propulsion, microelectronics, and battery powered systems);
- Recent research interest in UAV and robotics technology (electronics and software).

This Student Design Competition topic affords today's University students a unique opportunity to define a radically new class of rotary-wing technologies for the future.

## II. General Description of the Martian Environment

- Mars gravity = 0.373g
- $CO_2$ content 95%; N2 comprises the remainder, except for minor trace gases
- Standard Atmospheric density at surface is $0.0136\rho_{Earth}$
- Standard Atmospheric pressure ~16.6 psf

Note: The impact shall be assessed of applying a knockdown factor of 20% for density and pressure to account for more extreme conditions found at other elevations and to account for large variations in planetary atmospheric mass as a consequence of polar CO2 condensation / sublimation on a seasonal basis.

- Year-round temperature extremes 253 -- 523 deg Rankine; average temp 379 deg Rankine

- Speed of sound 180 -- 268 m/s; mean yearly value = 230 m/s (with 95% $CO_2$)

- Season and location of Mars landing/deployment crucial; ambient wind speeds of 3-7 m/s acceptable for rotorcraft VTOL/flight; higher wind speeds – such as seasonal, global sandstorms -- will pose significant challenges for vehicle storage/protection.

Note: Student design Teams should assume newtonian aerodynamics for their analysis. Rarified aerodynamic analysis is not required for this effort.

## III. Request for Proposals

Three requests for proposals (RFP) are offered for the AHS Student Design Competition including air vehicle design, propulsion subsystem design and flight control subsystem design Each RFP addresses a specific area of technology for development. This will hopefully opening the Student Design Competition to a wide pool of technical disciplines.

Student Teams have the option of responding independently to one of the RFPs or may collaborate with other teams to develop integrated air vehicle – subsystem designs. In the event that teams choose to respond to the propulsion or flight control elements without collaboration with an air vehicle team, they are encouraged to dedicate approximately 15% of their effort in defining an air vehicle concept which best uses their proposed subsystem configuration.

Mission Statement:

Mars Mission landing date 2005. A Martian autonomous rotorcraft will be deployed from a lander on the surface. The mission of this Martian autonomous rotorcraft would be threefold: a proof-of-concept demonstration for rotary-wing flight in the Martian atmosphere, a limited aerial survey (with photographic telemetry) while in flight, successful soft-landing on the Martian surface. Initial proof of concept demonstration will take place as part of an unmanned mission to Mars.

Required Mission Elements include:

Deployment from Mars lander

System Checkout

Start / Warmup

Hover

Cruise / Manuever / Send Telemetry

Return to specified location

Hover

Land

Shutdown

Optional Enhancement:

Restart

Hover

Reposition small distance

Hover

Land

Shutdown

**RFP #1 -- Vehicle Design**

1.1 Scope of Work

Proposals will be developed for the conceptual vehicle design for a Martian autonomous rotorcraft. A rotorcraft shall be defined as a vehicle which utilizes momentum theory to move ambient atmosphere (not on-board mass) to achieve hover and forward flight. It is very important that this conceptual design address the deployment process of the Martian autonomous rotorcraft from the Mars lander. The conceptual design shall be shown to be capable of meeting the Mission statement and vehicle specifications/requirements noted below.

1.2 Vehicle Specifications/Requirements

1.2.1 Vehicle 'Gross Weight' mass not to exceed 50 Kg

As a point of reference teams should use the following derivatives to appreciate the importance of air vehicle weight:

1 kg of air vehicle adds 21.5 kg to the Lander which adds 13 kg to the entry mass which adds 20kg to the launch mass. For reference: the Mars Pathfinder 16kg rover and auxiliary equipment resulted in 16*(1+21.5+13+20) = 890kg of launch mass. Mars Mission costs can be approximated using a fixed launch vehicle cost of $70M and an incremental Mission development/flight cost of $180,000 per kg of launch mass. (Cost numbers based on Mars Pathfinder: $70M plus 890kg*$180,000 per kg = $230M.)

1.2.2 Minimum sustained 'controlled-flight' duration of no less than one half-hour is required. Range is of secondary concern; ideally, range should be greater than 25 km.

1.2.3 Maximum cruise altitude to 100 meters (low-level flight).

1.2.4 Vehicle is capable of hovering / soft-landing on Martian surface after controlled-flight has been demonstrated. It is a desired objective to demonstrate a restart and second takeoff and landing following the required soft landing.

1.2.5 Photographic images taken in flight and post-soft-landing will be transferred via vehicle telemetry to a lander or an orbiter for storage and transfer to Earth Ground Control. Flight profile and vehicle status telemetry should also be transferred from the Martian autonomous rotorcraft to the lander or an orbiter.

1.2.6 Flight/Mission Package 'Avionics' including camera, sensors and telemetry shall be assumed to be no more than 10% of vehicle mass

1.2.7 Martian autonomous rotorcraft will be capable of sustaining continuous full sensor and data relay power consumption (first order power consumption estimate to be made as a part of vehicle design) for four (4) hours after separation from the lander and 3 1/2 hours after demonstration of soft-landing.

1.2.8 The air vehicle must be autonomously deployed from the Mars lander. Complete vehicle autonomy must be demonstrated after release from the lander; only passive telemetry will be received from the Martian autonomous rotorcraft.

1.2.9 Auxiliary (nonflight) systems on the lander can be used to assemble/deploy the Martian autonomous rotorcraft and/or fuel, power, or spin-up the rotor(s).

1.2.10 The vehicle must be capable of sustained hovering flight for no less than one minute duration.

1.2.11 Maximum Mars entry acceleration to be assumed to be 100 m/sec**2

1.3 Specific design description deliverables for the air vehicle RFP in addition to those specified in Section V shall include at a minimum:

Three view drawing

Inboard profile drawing

Description and illustration of rotorcraft stowed in lander

Description and illustration of rotorcraft deployment from lander

Description of major subsystems

Weight empty and mission gross weight derivation

Propulsion System Requirements description ( see RFP 2)

Flight Controls requirements definition ( see RFP 3)

Performance Analysis including:

Payload range curve

Drag prediction

Curve of power required vs airspeed showing power available

Earth based risk reduction program plan ( how can major system characteristics be demonstrated and risk reduced on Earth)

Reliability / Redundancy evaluation analysis

## **RFP #2 -- Propulsion Design**

### 2.1 Scope of Work

Proposals will be developed for conceptually defining a propulsion system compatible with a Martian autonomous rotorcraft. The propulsion system RFP response shall provide a conceptual design that includes the following elements: the engine(s); the transmissions, the drive train (as appropriate), utilities/auxiliary systems, propulsion primary controls, and fuel storage layout (where appropriate). The propulsion system concept selected shall be capable of being sized for a broad range of vehicle 'weight' classes and missions (for example, a vehicle range of 10kg to 150kg of mass). However, to aid in the design process, the propulsion system shall be designed to support the Mission statement noted above.

Among the propulsion concepts that could be proposed are: Akkerman-type hydrazine/monopropellent engines; dual-componentfueled engines; electric and solar-electric engines. Solar-electric propulsion concepts will require definition of a solar cell installation/arrangement in a notional aerial vehicle design as part of the Propulsion RFP response. Akkerman-type hydrazine engines will require more detailed design and analysis for a comparable score to other propulsion concepts given the relative maturity of the various propulsion concepts.

2.2 Propulsion Design Specifications/Requirements

Small package size and ultra-light-weight components are critical to successful application of proposed propulsion systems to a Martian autonomous rotorcraft and evaluation of the RFP response. Teams are to develop propulsion system requirements from their own air vehicle conceptual designs or may coordinate with an air vehicle design team responding to RFP1 to define propulsion subsystem requirements. At a minimum the following requirements apply:

2.2.1 Service life of propulsion system is 20 hours of operation.

2.2.2 The propulsion system must have a probability of successful start of not less than 99.9%

2.3 Additional propulsion system requirements shall be derived from air vehicle requirements and shall include at a minimum:

System weight

System space allocation / dimensions

System reliability in excess of 99.9% requirement

Start up and shutdown requirements

Control and telementry

2.4 Specific design description deliverables for the propulsion RFP in addition to those specified in Section V shall include at a minimum:

System weight estimate and methodology

System reliability

Layouts of system packaging

**RFP #3 -- Flight/Mission Computer Architecture Design**

3.1 Scope of Work

Proposals will be developed for conceptually defining a flight / mission control architecture compatible with a Martian autonomous rotorcraft. A highly integrated flight and mission architecture design is anticipated to be proposed. The flight/mission architecture shall be comprised of the following elements: the flight/mission computer/processor and digital bus; Guidance, Navigation, and Control (GNC) electronics and sensors; the flight/mission power bus, battery and power management electronics; science/mission package (including sensors); flight/mission telemetry; general software approach. To aid in the design process, the flight/mission architecture shall be designed to support the Mission statement as noted above. Teams are to develop control system requirements from their own air vehicle conceptual designs or may coordinate with an air vehicle design team responding to RFP1 to define subsystem requirements. At a minimum the following requirements apply:

3.2 Flight/Mission Architecture Specifications/Requirements

3.2.1 Battery power (at full power drain) for a minimum of four continuous hours of operation subsequent to separation from the lander.

3.2.2 Burst (versus continuous) telemetry can be used for power conservation.

3.2.3 Ability to handle 4-6 control outputs (and corresponding actuator position input) for vehicle flight controls.

3.2.4 A minimum of 20 channels of sensor input for both flight control and mission science requirements is required.

3.3 Additional control system requirements shall be derived from air vehicle requirements and shall include at a minimum:

System weight estimate and methodology

System space allocation / dimensions

System reliability

System power consumption

Start up and shutdown requirements

Control Response rates

3.4 Specific design description deliverables for the control system RFP in addition to those specified in Section V shall include at a minimum:

System architecture diagrams

System weight estimate and methodology

System power consumption analysis

System reliability analysis

Layouts of system packaging

## IV. General Work Description for all Three PFPs

1. Mission refinement (filling in the details).
2. Generation of Concepts and Down-Select.
3. Conceptual Design Development
4. Engineering trade-off and sizing analysis of key performance parameters of design and associated refinement of the design based upon analysis.
5. Feasibility Assessment of Design (as to meeting Mission requirements).
6. Technology roadmap for development of critical technologies and key components in the proposed conceptual design.

## V. Proposal Deliverables

1. Conceptual Design Report. ( Note: Reports shall be limited to 100 pages)

    1.1 Statement of Mission requirements

1.2 Define comprehensive list of design alternatives 'brainstormed.'

1.3 Concept down-select. Qualitative and quantitative selection criteria identified.

1.4 Engineering trade study and/or sizing analysis of the key design parameters of the selected design concept.

1.5 Design drawings and associated information for clearly defining the critical attributes of the conceptual design as defined at a minimum in each RFP description. Show drawings/information for assembly and deployment of the Martian autonomous rotorcraft from the lander on the Martian surface.)

1.6 Feasibility assessment of the design concept meeting the Mission Requirements

2. Project Plan. Plan details of the technology roadmap for design and development effort -- and associated critical technologies -- to enable the construction of a flight article in a reasonable time period (for a development program less than five years).

2.1 Critical Technologies and Risk Assessment

2.2 Technology Roadmap (including proposed risk-reduction testing)

2.2.4 Preliminary Resource (Funding and Personnel) Estimates for executing Technology Roadmap and Vehicle Development

3. Executive Summary Presentation. A videotape of a 30 minute executive level summary presentation shall be provided with each proposal. The videotape shall be accompanied by hard-copies of all presented slides. The presentation shall provide a concise summary of the attributes of your proposal.

## VI. General Proposal Requirements and Design Competition Rules

- <u>The vehicle design concept must be clearly seen as being a rotary-wing vehicle</u>. This would include, but not be limited to: helicopters, coaxial helicopters, tipjet driven helicopters, tiltrotors, autogyros, tiltwings, tailsitters. Hybrid vehicles (for example, lighter-than-air structures, or rocket-assisted propulsion during take-off/landing, may be proposed but rotary-wing propulsion must contribute the majority of vehicle lift in hover )

- Proposal will be evaluated per the following relative scoring criteria: 40% for design innovation, 40% for the detail and rigorousness of the engineering analysis, and 20% for the detail and comprehensiveness of the technology roadmap and resource estimates.

- Extra weighting will be given to engineering analyses used in the design that minimizes use of future/advanced technology 'extrapolations.'

- Extra weighting will be given to propulsion systems that employ renewable or in-situ energy sources versus fuel components that have to be wholly transported from Earth.

- Extra weighting will be given to concepts that provide maximum Mission flexibility for Mars exploration.

- Extra weighting will be given to teams which show strong collaboration with other RFP teams or innovative collaboration tools.

## VII. Suggested Reading and Technical References

This is not a comprehensive nor definitive list of technical references but, hopefully, will prove useful for additional background information for the design problem.


- Ezell, E.C. and Ezell, L.N. "On Mars: Exploration of the Red Planet, 1958-1978" NASA-SP-4212, January 1984

- Clarke, V.C., Jr. "The Ad Hoc Mars Airplane Science Working Group" NASA CR-158000, November 1978

- Totah, J.J. and Kinney, D.J. "Simulating Conceptual and Developmental Aircraft" AIAA-98-4161
- Akkerman, J.W. "Hydrazine Monopropellent Reciprocating Engine Development" NASA Conference Publication 2081, 13'th Aerospace Mechanisms Conference, Proceedings of a Symposium held at Johnson Space Center, Houston, TX, April 26-27, 1979
- Savu, G., et al. "An Autonomous Flying Robot for Mars Exploration" IAF Paper 93-445, International Astronautical Congress, 44'th, Graz, Austria, October 16-22, 1993
- Sridhar, B. et al. "Passive Range Estimation for Rotorcraft Low-Altitude Flight" NASA-TM-103897, October 1991


Web-sites URL addresses of interest:

http://www.atmos.washington.edu/mars.html

http://mpfwww.jpl.nasa.gov/MPF/science/atmospheric.html

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## VIII. Points of Contact:

Questions can be asked in writing to the authors of this RFP. All questions and responses shall be provided to all teams. The authors will work with teams to help make connections with other participating teams or will provide limited guidance to RFP 2 and RFP 3 teams on potential overall air vehicle requirements if these teams do not choose to coordinate with an air vehicle team.

**Contact:**

Larry Young NASA Ames at 650-604-4022

Chris Van Buiten Sikorsky Aircraft at 203-386-7049

Kim Smith, American Helicopter Society, 703-684 6777

## IX. RFP Timeline

September 1999: RFP Release

October 15, 1999: Letter of Intent to compete due. Describe school, team, RFP which will be addressed , interest in collaboration with other schools, and one page summary of RFP response approach.

November 15, 1999 Air Vehicle teams must publish Propulsion and Controls requirements documents including allocations of space, weight and power and critical required characteristics. Deliverable shall include description of primary design concept.

June 1, 1999: RFP reponses due at AHS headquarters Alexandria VA

## X. **Awards:**

Awards will be given for both undergraduate and graduate teams for each of the three RFPs as follows:

First place $TBD

Second Place $TBD

Third Place $TBD

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