Planetary Flight Vehicles (PFV): Technology Development Plans for New Robotic Explorers

Ray D. Rhew[1], Mark D. Guynn[2],
Jeffrey A. Yetter[3], and Joel S. Levine[4]
NASA Langley Research Center, Hampton, VA, 23681

and

Larry A. Young[5]
NASA Ames Research Center, Moffett Field, CA, 94035

The Vehicle Systems Program (VSP) of NASA's Aeronautics Research Mission Directorate (ARMD) has been investigating the technologies necessary to enable new planetary science and exploration missions using Planetary Flight Vehicles (PFVs). PFVs bridge the gap between orbiters (global scale and limited resolution) and rovers (local scale and high resolution). PFVs enable data gathering of phenomena at a regional scale that is not attainable with current surface based robotic system concepts. An example of such is localized magnetic fields that may provide radiation protection for human explorers. This paper outlines the goals, objectives, perceived technical challenges, and technology development approaches as they relate to enabling planetary exploration technologies. The process used for prioritizing technology investments based on science and exploration requirements with state-of-the-art assessments is discussed. Highlights of recent accomplishments in the Vehicle Systems Program's PFV technology development activities are also presented.

I. Background

Planetary Flight Vehicles (PFVs) are being considered as science and exploration platforms on other planetary bodies due to their unique capabilities. While there are numerous planetary bodies of interest to the scientific community that have atmospheres capable of supporting a flight vehicle (e.g., Mars, Titan, Venus), the main focus of this paper is Mars. The focus on Mars is due to NASA's near term Mars Exploration Program goals and it's Vision for Space Exploration. Many of the technology areas discussed are applicable to other planetary bodies while the specific technical goals, objectives and approaches are Mars focused.

Scientific and exploration needs are, and should be, the impetus for developing PFV platforms. Studies conducted by the Space Science community have resulted in numerous measurement requirements for all types of platforms - orbiters, flyers (PFVs) and landers/rovers. Measurements that are needed and uniquely suited for a PFV platform are described below (Refs. 1 and 2) and establish the basis for the technology development.

1. Measurements at an altitude of 1 to 2 km over regional-scale distances fill the missing spatial measurement gap between global scale, limited spatial resolution measurements obtained from orbit, and very high spatial resolution over very limited surface area obtained by landers and rovers.
2. Measurements of geological features and terrain that are inaccessible to landers and rovers, i.e., volcanic craters, impact craters, mountains, valleys, canyons, polar caps, etc.
3. Simultaneous in-situ and remote measurements of planetary surface and atmosphere. Orbiters use remote measurement techniques with relatively limited spatial resolution from orbit.
4. Unique scientific measurements obtainable using PFVs include:

---

[1] Project Manager, Planetary Flight Vehicles, Vehicle Systems Program, AIAA Member
[2] Systems Analyst, HALE Sector, Vehicle Systems Program, AIAA Senior Member
[3] Associate Manager - Airframe, HALE Sector, Vehicle Systems Program, AIAA Member
[4] Senior Research Scientist, Science Directorate
[5] Associate Manager - Planetary, HALE Sector, Vehicle Systems Program, AIAA Senior Member

a. "Follow the water" over regional scale distances ("Follow the water" is the overarching theme of the Mars Exploration Program).
b. Search for gases of biogenic and volcanic origin using conventional in-situ techniques (e.g., mass spectrometry).
c. High spatial resolution measurements of crustal magnetism (e.g., magnetometry).
d. High spatial measurements of the chemical composition and mineralogy of the crust (e.g., point spectrometry).
e. High spatial images of surface and terrain features (e.g., cameras).

5. Measurements from a Mars PFV to support human exploration include:
   a. High spatial resolution measurements of potential human landing sites to map out the geology and terrain (e.g., imaging systems).
   b. High spatial resolution measurements of sub-surface water needed for human in-situ resource utilization (ISRU) (e.g., Neutron spectrometer, ground penetrating radar).
   c. Measurements of the ionizing radiation environment of the surface of Mars in the vicinity of potential human landing sites (e.g., Dosimeter).
   d. Measurements of atmospheric density and the three-dimensional structure of winds and their variability in the planetary boundary layer over regional-scale distances (e.g., mass spectrometer, air data systems).

This is an extensive, although not a complete, list of measurements that can be satisfied by PFVs. Many of the measurements can be performed simultaneously using the same PFV platform. Figure 1 depicts one mission concept for gathering scientific/exploration measurements. This concept has accommodations for multiple measurement systems and hence will allow multiple measurements. This and other mission concepts will determine the target areas on Mars that will impact the PFV concepts, through considerations such as local atmospheric conditions and terrain.

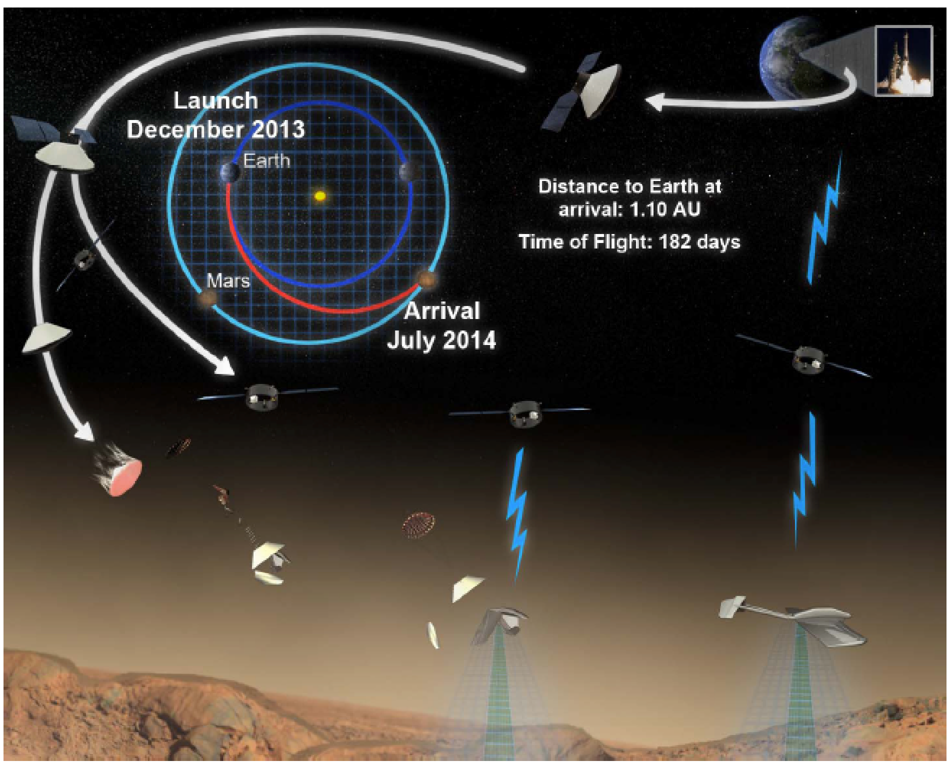

Figure 1. Mars Aerial Regional Survey Mission Concept (Ref. 2)

Another critical element required in defining the PFV platform capabilities is the payload or measurement system requirements. Table 1 lists instruments that will potentially be utilized for the science objectives listed above and provides payload, size and power requirements. Additional requirements on platform stability, duration, altitude and flight path are derived based on the instrument performance specifications.

Table 1. Mars Mission Concept Instruments

Instrument	Mass (Kg)	Power (W)	Volume (cm)	Data Rate (kbps)	Reference	Comments
Nepholometer	0.5	1.3	10 x 10 x 10 (estimated)	TBD	Pioneer Venus probe	Technology would have to be adapted to aerial platform
Solar Radiometer	5	3	10 x 20 x 20 (estimated)	TBD		Needs technology development to be adapted on aerial vehicle
Mass Spectrometer	4.7	6.4	Instrument 27 x 25 x 23 Electronics 15 x 15 x 10	1.5	ARES Scout concept, Viking	Mass Spectrometers have flown on many space missions.
Neutron Spectrometer	1	2	9 x 14 x 3	1.5	Los Alamos concept	Lunar Prospector, Mars Odyssey
Dosimeter	0.2	1	8 x 4 x 2		MSL concept	Technology is mature and will be used on MSL.
Imaging systems - Context	0.5	5	7 x 9 x 12	23.1	Malin	Technology was space qualified for Mars Climate orbiter
Imaging systems - Video	0.2	2	7 x 9 x 8	122.9 kb/frame	Malin	Technology mature
Ground Penetrating Radar	1.2	5	2600 cm3	1 KB/sec	JPL Mars Technology Program	Ground test performed, concept verified. Needs to be adapted to aerial vehicle.

The combination of the science needs and measurement system requirements leads to the development of a notional set of PFV capabilities for Mars. These capabilities are depicted on the timeline in figure 2. Note that the timeline is not based on technology development expectations, but is an estimate of the timing of the Exploration vision needs. Table 2 lists Regional, Global and Mars Scout mission opportunities for Human Exploration precursors that PFVs can support. As with many technology development plans, accelerating the technology development can be accomplished by additional support where practical.

II. Capabilities, Goals, Objectives, Technical Challenges, and Approaches

Considering the great potential for PFVs to provide vital measurements for planetary science and exploration, the NASA Vehicle Systems Program (VSP) has established a research and development plan to advance PFV technologies and enable future capabilities. PFV capabilities to support science and exploration needs as depicted in figure 2 provided the basis for this plan. The first target capability is a regional-scale survey using the class of vehicle proposed for the Aerial Regional-scale Environmental Survey (ARES) Mars Scout mission (Ref. 3). This initial capability would demonstrate the ability to gather important scientific data from Mars using an aerial vehicle. While able to provide valuable scientific information that cannot be obtained by any other means, the initial capability would be limited in flight endurance and payload mass. The next PFV capability set would seek to improve upon the flight endurance and payload mass, offering greater mission flexibility and an overall increase in data collected. Such a vehicle would be able to traverse large regions of the planet's surface, while providing unprecedented spatial resolution relative to satellite assets. In the third target capability, the ability to repeatedly land and takeoff is desired. This capability provides benefits in two areas. First, additional types of data can be collected with the vehicle and instruments close to or in contact with the surface; e.g., incorporating the functionality of an aerial vehicle with a lander. Second, landing introduces the potential to recharge or refuel for subsequent flights. Having this capability would greatly extend the total mission time. Also, the time between flights would give scientists on Earth the ability to plan future sorties based on the data that has been collected. Surface interaction of an aerial vehicle in an uncertain environment on a distant planet is very challenging. However, the benefits derived are tremendous and justify pursuit of such a capability.

PFV technology investment areas have been established using a top-down approach referred to as the Goals, Objectives, Technical Challenges, and Approach (GOTChA) process. This process has been used extensively by the Department of Defense to plan technology development programs. It has been adapted and utilized by the VSP to clearly tie technology investment to specific technology goals, which ultimately lead to achieving desired capabilities.

Table 2. **Human Precursor Exploration Campaigns (Ref. 2)**

	Reference Campaign		Alternate Campaign	
Launch Year	Exploration Missions	Other Missions	Exploration Missions	Other Missions
2011	Global	Mars Scout	Global	Mars Scout
2013	Regional	MSR		MSR
2016	Local	Mars Scout	Regional	Mars Scout Aerocapture/EDL #1
2018	Aerocapture/EDL #1	AFL		AFL
2020	ISRU #1	Mars Scout	Local	Mars Scout Aerocapture/EDL #2
2022	Aerocapture/EDL #2		ISRU #1	
2024	ISRU #2		Aerocapture/EDL #3	
2026	Aerocapture/EDL #3		ISRU #2	
2029	Send Infrastructure		Send Infrastructure	
2031	Humans to Mars		Humans to Mars	

***Red Circles indicate PFV opportunities**
Reference Campaign: Based on minimum set of missions and using existing exploration timeline.
Alternate Campaign: Based on moving selected Aerocapture/EDL missions forward and combining with Scout missions.
Missions:
Global = Orbiter mission
Local = Lander mission
MSR = Mars Sample Return
EDL = Entry, Descent and Landing (to study/characterize EDL for future manned missions)
ISRU = In-situ Resource Utilization
AFL = Astrobiological Field Laboratory

Although PFVs will fly in a broad range of planetary environments, the fundamental principles of terrestrial aeronautics still apply. Therefore, performance enhancements for a PFV require advances in the traditional aircraft technology areas of: aerodynamic efficiency, airframe weight, propulsion weight, and propulsion efficiency. The unique aspects of the PFV mission introduce additional technology areas. Autonomy is a critical technology area because the vehicle cannot be piloted or remotely operated. Since the vehicle must be launched from Earth and carried to another planet prior to executing the flight activities, packaging and deployment of the vehicle greatly influence the vehicle design and flight capabilities. Finally, the desire for landing and takeoff capability in an uncertain environment (e.g., without prepared runway surfaces) means vertical takeoff and landing (VTOL) performance will eventually be needed. Goals, objectives, technical challenges and approaches in these areas are discussed in the following sections. Metrics have been identified for all of the goals and objectives, but target values have not been assigned in all cases. These values will be determined through an analysis of what is needed to achieve the desired capabilities.

A. Aerodynamic Efficiency

The goal in the aerodynamic efficiency technology area is to increase lift-to-drag ratio (L/D). L/D values for Mars aerial vehicles tend to be lower than terrestrial vehicles due to the flight environment and mission constraints. Improvements in L/D for PFV designs can be pursued through addressing drag reduction objectives in the areas of parasite drag and drag-due-to-lift. The low density, low temperature, CO_2 atmosphere on Mars leads to the aerodynamic challenge of low Reynolds number, high Mach number flight. Not only does low Reynolds number

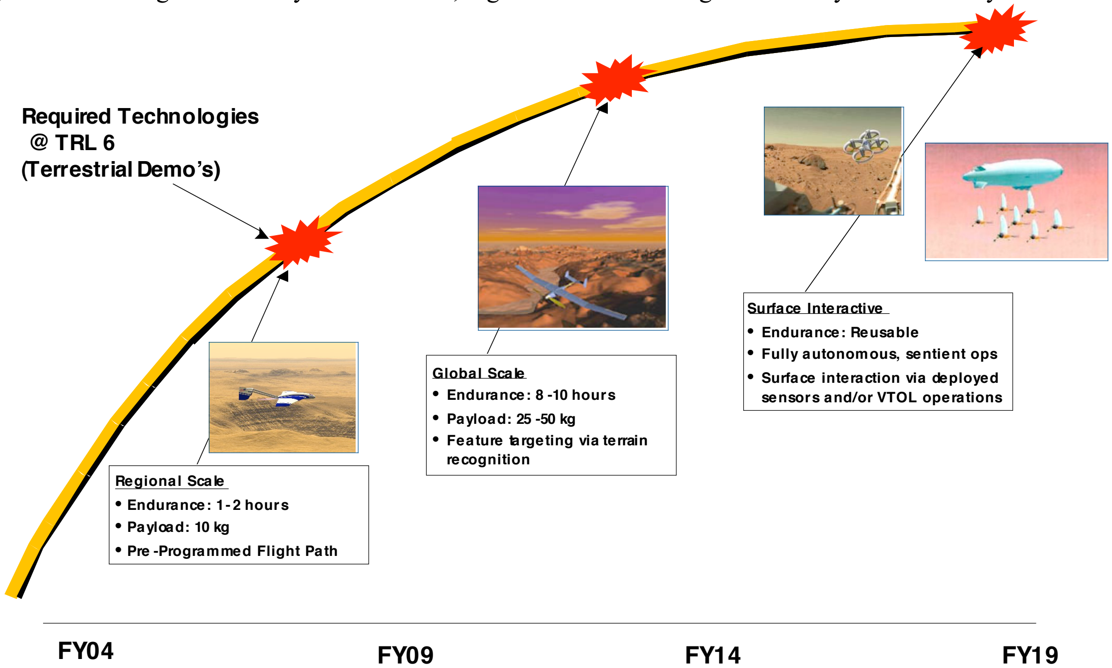

Figure 2. Planetary Flight Vehicle capabilities timeline

result in higher skin friction drag, but also the increased tendency for flow separation, which increases drag further. High Mach number, transonic effects can magnify any flow separation tendencies. Understanding and controlling the airfoil boundary layer flow, whether through active or passive measures, can be used to minimize PFV parasite drag. From an aerodynamic standpoint, the simplest approach to reducing drag-due-to-lift is increasing wing span. However, packaging of the vehicle in an aeroshell for transport and entry at Mars places constraints on the wing span. Packaging constraints, therefore, become the primary technical challenge to large reductions in drag-due-to-lift. Reducing drag-due-to-lift requires development of new and innovative means for efficiently packaging wings (typically rectangular shape) into an aeroshell (typically cylindrical shape). Possible technologies include folding of rigid structures, telescoping structures, inflatable structures, and a truss structure with flexible skin (umbrella-like approach).

B. Maximum Lift

The maximum amount of lift the vehicle can produce is related to the size of the wing (S_{wing}), the maximum lift coefficient (C_{Lmax}), and the dynamic pressure. Due to the thin Martian atmosphere, a large wing area is required to generate substantial lift. Typically, however, the size of a planetary aircraft wing is limited by the size of the entry aeroshell, which in turn is limited by the size of the launch vehicle payload fairing. For a given launch vehicle and aeroshell size, the more lift capability realized, the more fuel/batteries or payload that can be carried and the greater the mission effectiveness. Because lift capability has such a direct impact on PFV capabilities, a technology goal has been established to achieve a lift of 700 N per square meter of aeroshell cross-section area. The size of the wing is limited by the size of the aeroshell and for a given packaging scheme the wing area is roughly proportional to the aeroshell size. The objective for wing packaging efficiency is to increase $S_{wing}/S_{aeroshell}$ to 2.0 (where $S_{aeroshell}$ is aeroshell cross-sectional area). The value of $S_{wing}/S_{aeroshell}$ depends on the wing packaging approach (e.g., number of folds, rigid vs. flexible wing, etc.). For a given size wing, lift capability is related to C_{Lmax}. A C_{Lmax} greater than 1.8 is needed to reach the lift capability goal of 700 N/m^2. Although 1.8 is not an especially high value, the low Reynolds number, high Mach number flight regime on Mars makes achieving a high C_{Lmax} difficult. For conventional airplanes, high-lift systems can be used to greatly increase C_{Lmax}. However, these systems can be complex and are not as effective at low Reynolds number. Simple, very lightweight, reliable systems that are effective at low Reynolds number are needed for Mars flight.

C. Airframe Weight

The weight of a vehicle flying on Mars is only about 37% of what it would be flying on Earth due to the lower gravity. However, this reduction in weight does not compensate for the extreme difficulty generating lift with a ~99% reduction in atmospheric density. With maximum total weight limited by lift capability, any reduction in airframe weight can be used to increase payload weight or fuel weight (increasing range/endurance capability). The airframe weight technology goal is to reduce the airframe empty weight fraction. (Note that in the current context empty weight fraction does not include the propulsion system, which is addressed in separate goals. Only the airframe structure and subsystem weights are included.) The empty weight fraction goal can be decomposed into two objectives; reduce structural weight and reduce subsystem weight. Structural designs for PFVs have to consider more than just the normal aircraft load cases. In addition to flight loads while at Mars, the vehicle will experience significant loads during launch from Earth, entry at Mars, and during any type of deployment from a stowed configuration. In fact, the load condition that ultimately dictates the size and mass of structural components may not be associated with the actual flight. The PFV airframe will be subjected to the harsh environment of space for several months to a year while in transit to Mars. Lightweight materials used in construction of the vehicle have to be acceptable for this type of space exposure. As the weight of the airframe structure is reduced, the weight of subsystems becomes a larger fraction of the total airframe weight. Subsystem weight can be especially significant in the case of a PFV due to the need to space and radiation harden the systems. Continued miniaturization of electronics will lead to some reduction in subsystem weight. However, the weight associated with integrating those systems needs to be addressed through innovative integration approaches such as multi-functional structures.

D. Propulsion Weight & Efficiency

The primary issues for Mars propulsion are the lack of atmospheric oxygen (O_2) to serve as an oxidizer for fuels and the very thin atmosphere. Since rocket motors do not depend on an ambient atmosphere for operation, the ARES concept uses that approach to overcome these propulsion issues. However, rocket propulsion is inefficient, resulting in large fuel (reactant) weight requirements. Achieving long endurance, long range PFV capability requires a different, more efficient propulsion approach.

In most cases the propulsion system can be logically divided into elements that are sized by the power output and those that are sized by the amount of energy carried. For both areas the goal is to minimize weight/mass, as reflected by the specific power (W per kg) and the specific energy (W-hr per kg) of the system. By measuring the power and energy in terms of the overall output, the efficiency of system components can be accounted for in these metrics. Key underlying objectives address the conversion of stored energy to mechanical power, the conversion of mechanical power to thrust, and the mass of the energy storage system. The energy storage system could be batteries for an electric based system or reactants and reactant tanks for a consumable fuel system. Note that the weight of fuel and oxidizer, if applicable, is captured in the energy storage specific energy metric. The thin atmosphere on Mars presents an especially difficult challenge in the energy conversion area. Releasing stored energy, whether electrochemically or through combustion, usually generates a significant amount of waste heat and heat rejection is problematic in the low-density Mars atmosphere. Also, the thin atmosphere means that large propellers (diameter and solidity) are needed to effectively and efficiently convert mechanical power to thrust. Compounding this difficulty is the packaging constraints associated with fitting the vehicle inside an aeroshell. The lack of atmospheric O_2 for use as an oxidizer greatly impacts the specific energy of the propulsion system. For example, in a H_2-O_2 based system the mass of O_2 required is 8 times the mass of H_2. Development of lightweight, efficient, non-airbreathing powerplants is a critical enabling technology for long endurance PFV missions.

For some propulsion system concepts the above decomposition into specific power and specific energy is not possible. In particular, if energy is collected from an off-board source (e.g., solar) the specific energy metric no longer has meaning. While the amount of solar energy available at Mars is much less than at Earth, other options for off-board energy exist, such as using microwave or laser beams to transfer energy to the vehicle from another asset (e.g., satellite or ground station). Technology goals for these types of systems include not only reducing total system mass, but also minimizing the collector area required since collector area could negatively impact the vehicle design or be the factor that limits available power.

E. Autonomy

Vehicle autonomy is a key technology for PFV by the very nature of the mission. Communication latency between Earth and Mars (on the order of 17 minutes) is too large to make real-time control of the vehicle possible. Furthermore, except in the case of the far term “surface interactive” vehicle, the length of the mission is too short to permit re-tasking from Earth as new knowledge is gained from the data collected. To fully exploit the value of an aerial vehicle on Mars, it is necessary for the on-board systems to provide a high degree of intelligence, replacing human management of the mission. The PFV technology goal is to achieve the capability of autonomous collaborative operations. For autonomous collaborative operations, a group of systems (which can include aerial vehicles, rovers, satellites, etc.) are able to work together to accomplish a high level objective without human involvement. Once the system is provided a high level objective, it is translated into a set of individual tasks for all the elements of the system without further intervention from a human operator. With such a large investment in time and resources to get a vehicle to Mars, it is imperative that the systems perform as intended and the high level mission objective be accomplished.

There are several technical challenges to achieving this level of mission success using autonomous systems. Autonomous operation at Mars requires the ability to automatically respond to dynamic and uncertain environments. There is no way to abort the mission, make repairs, and fly again. System reliability needs to be increased, but with minimal hardware redundancy to avoid penalties in weight and power consumption. Navigation and mission management has to be performed without the aid of human direction or navigation aids such as GPS. And finally, efficient interfaces between autonomous systems need to be developed to enable effective collaborative mission execution. These challenges can be addressed through a suite of technology approaches to several aspects of intelligent systems, including: robust, fault tolerant system architectures; automated contingency management; intelligent mission management systems with payload directed tasking and multi-asset coordination; and vehicle management systems that can sense faults and adapt systems accordingly.

F. Deployment Reliability

Deployment reliability is an important issue for PFVs because they must unfold or deploy from a stowed configuration to become airborne. Achieving high deployment reliability is especially challenging in the case of long-term storage, such as in a mission to Mars where the vehicle will be in a stowed configuration for over a year. Because deployment is absolutely essential to mission success, a technology goal of 3σ deployment reliability has been established for PFV systems. This goal is consistent with the requirements imposed on deployment systems in other space missions. High reliability is needed for both systems that mid-air deploy (such as the approach used in the ARES mission, Ref. 3) and systems that deploy and launch from the ground. Mid-air deployment is a mission critical event with likely no "second chance." Deployment must occur on-time and in proper sequence to transition from falling to flying. A failure in mid-air deployment generally results in mission failure. Deployment and launch from a ground station does not have the same time critical aspects as mid-air deployment. There may be time for trouble-shooting if a problem is encountered in unfolding, for example. However, failure of the launch system during launch would probably lead to mission failure. With a ground system the possibility exist for multiple launches and recovery of the aerial vehicle. The ability to recover and redeploy adds complexity to the system that cannot be permitted to decrease the reliability. Developing materials, which retain their full functionality after long-term exposure to harsh environments, is an important technology approach to increase deployment reliability. Rigorous testing of deployment components and systems also contributes to increased reliability. Since it is impossible to completely replicate Mars conditions on Earth, multi-body deployment simulation tools can be used to evaluate system performance over a wide range of possible conditions and identify problems areas that would decrease reliability.

G. VTOL Efficiency

As noted previously, the ultimate vision for PFVs is the ability to land and takeoff multiple times. Unless there are precursor missions that establish appropriate infrastructure (smooth, obstacle free surfaces), a VTOL capability will be needed. The technology goals in this area are a hover figure of merit (FOM, ideal power/actual power) ≥ 0.6 (at relevant conditions of tip Reynolds number 40,000 to 100,000 and tip Mach number 0.5 to 0.7) and a L/D ≥ 3 (at an advance ratio ≥ 0.2). Reynolds number and Mach number ranges are those of interest for modest-sized Mars VTOL explorers with takeoff mass < 100kg. Advance ratio is also based on a Mars VTOL mission focus. There are three underlying objectives associated with achieving these goals. The first is to reduce profile drag of low Reynolds number, compressible flow rotor blade airfoils by 50%. Reducing profile drag has the most profound effect on PFV VTOL hover performance. The technical approach is to develop a new family of low Re, compressible-flow blade airfoils with low pitching moments, at moderate sectional lift coefficients (i.e., $C_l \approx 0.4$ to 0.7). Also, new blade construction approaches must be devised to optimize planform geometry, blade properties, and rotor/propeller dynamics. For example, flat-plate cambered-arc airfoils with graphite epoxy and Mylar® film construction yield the minimum blade weight solution, but airfoil profile drag is too high. Also, blade tuning for center of gravity and rotating frequency placement invariably yields heavier blades than those with relaxed blade dynamic targets. The second objective is to reduce rotor induced drag by 30%. The technical approach to meeting this objective is to develop lightweight, high stiffness and strength, aerodynamic efficient propulsors with efficient packaging (in aeroshell) and reliable deployment. As with wings, packaging and deployment of large rotors needed for performance is an important challenge. The third objective is to reduce VTOL vehicle parasite drag by 50%. Reduction of parasite drag while keeping fuselage weight to a minimum is crucial. Mars VTOL landing gear are a larger contributor to vehicle total weight and drag than for conventional VTOL because of the larger propulsors required. Achieving low drag at high forward speed is difficult when forced to employ skeletal-like airframe construction (for weight considerations). Reducing parasite drag requires development of large (relative to rotor diameter), low drag vehicle landing gear foot tread designs while ensuring lightweight and high stiffness and strength characteristics.

III. Technology Development and Status

The focus of the current technology development efforts is the first capability set shown in figure 2 (Regional Scale). Table 3 relates this capability set down to the GOTChA and to specific technologies being matured in the NASA Langley Research Center (LaRC) Planetary Airplane Risk Reduction (PARR) project. A description of PARR, the technologies under development and current status are discussed below.

The PARR project is the near term multi-disciplinary technology development project in the VSP. Figure 3 depicts the PFV technologies that are being matured for the Regional Scale capability set.

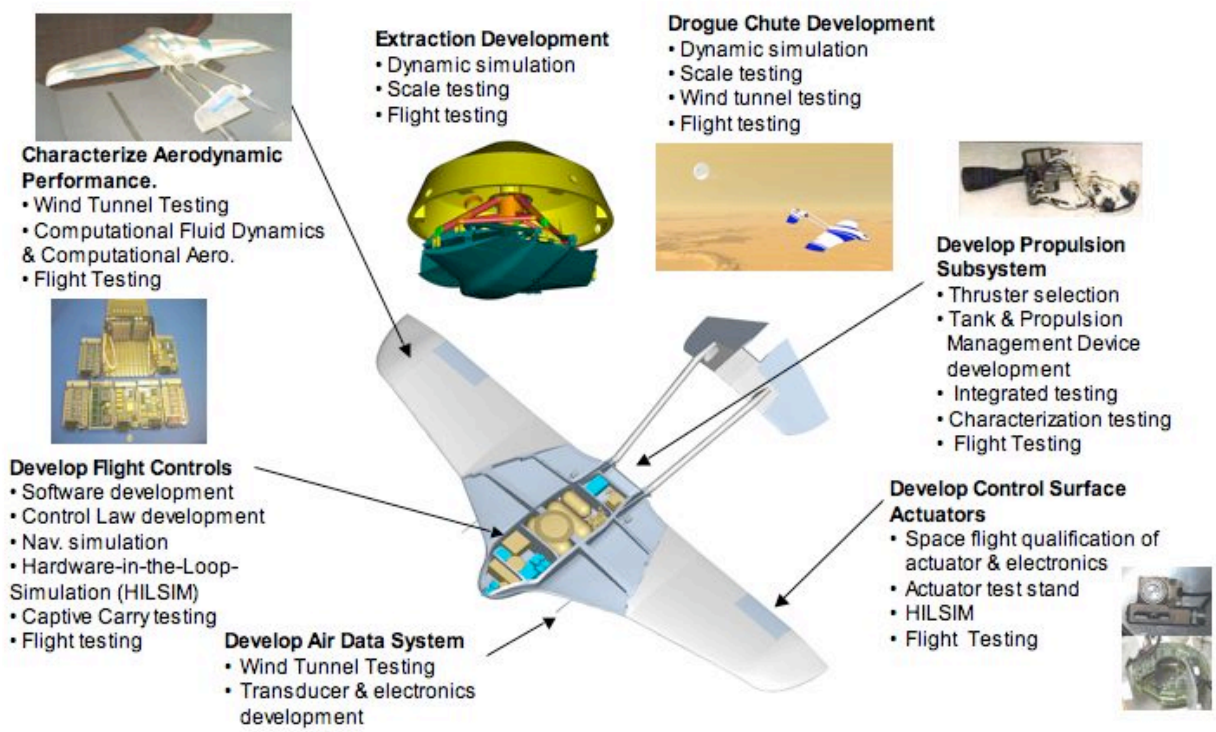

Figure 3. PARR Technology Development Areas

The objective of the PARR project is to mature technologies by performing appropriate demonstrations focused on the most critical enabling technologies. A primary emphasis for PARR is demonstration of the deployment from a stowed payload to a stable, autonomously controlled flight vehicle. In addition, PARR will mature other system technologies, such as propulsion, to higher levels of technology readiness just short of flight demonstration. State-of-the-art (SOA) for PFV technology, used as a basis for measuring many of the future PFV technology development against, will be the capabilities demonstrated in the PARR project. These SOA values will be listed in subsequent areas.

Table 3. Tracing PFV Technologies from Capabilities to Application

Capability	Technology Goals	PARR Technology Area
Endurance and Payload	Aerodynamic Efficiency	Aerodynamic Performance
	Maximum Lift	
	Airframe Weight	
	Propulsion Weight and Efficiency	Propulsion Subsystem
	Deployment Reliability	Extraction System Drogue Chute
Flight Path	Autonomy	Flight Controls
		Air Data System
		Control Surface Actuation

Aerodynamic performance characterization was accomplished through a combination of computational and experimental activities. Significant wind tunnel data were collected to update the computational models and continue maturing the aerodynamic database for the proposed first flight concept (figure 4). A full representative (3-D) 25% scale model was tested in the NASA LaRC Transonic Dynamics Tunnel (TDT) and the NASA LaRC 12-Foot Low Speed Tunnel (12-Ft LST) where data were collected and used to validate the first phase of unfolding aerodynamics, stability and control characteristics, and pullout and cruise performance at the high M (up to M=0.7) and low Re (<300,000) numbers expected on Mars. Additionally, 2-D airfoil testing was completed in the NASA LaRC 20-inch Supersonic Wind Tunnel (SWT) to determine the location and type of flow transition system that provides the best performance. Figure 5 is a collage of wind tunnel pictures from these wind tunnel experiments.

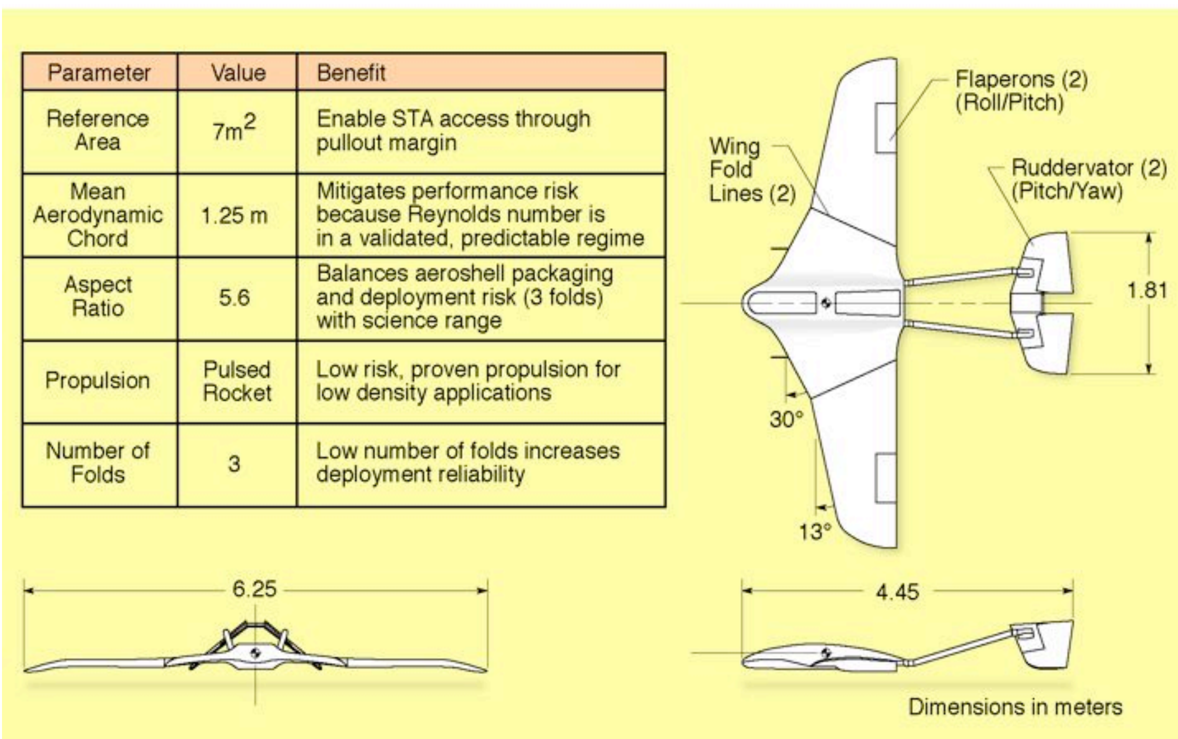

Figure 4. NASA Mars Airplane Concept (ARES-2)

Figure 5. Photographs of PARR wind tunnel test configurations (from top left, clockwise: TDT, 12-Ft LST (two photos), and 20" SWT)

A large portion of the PARR activity is devoted to preparation for the High Altitude Drop Demonstration (HADD-2) flight test (first drop described in Ref 4.) Technologies to be demonstrated in this flight test include the airplane extraction and pullout (which includes the drogue chute), updated airplane control laws, control surface actuators and airplane aerodynamics. Figure 6 shows the first backshell and airplane extraction system that was delivered for HADD-2. Progress in airplane integration (with subsystems avionics, landing gear, etc.) as depicted in the 3-D model, in figure 7, is continuing.

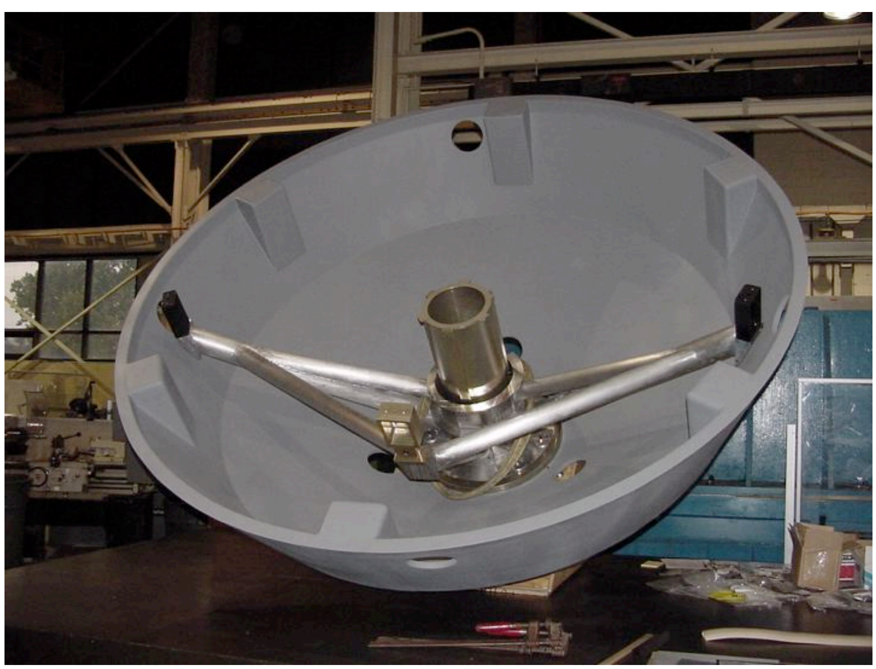

Figure 6. HADD-2 Backshell and Airplane Extraction System

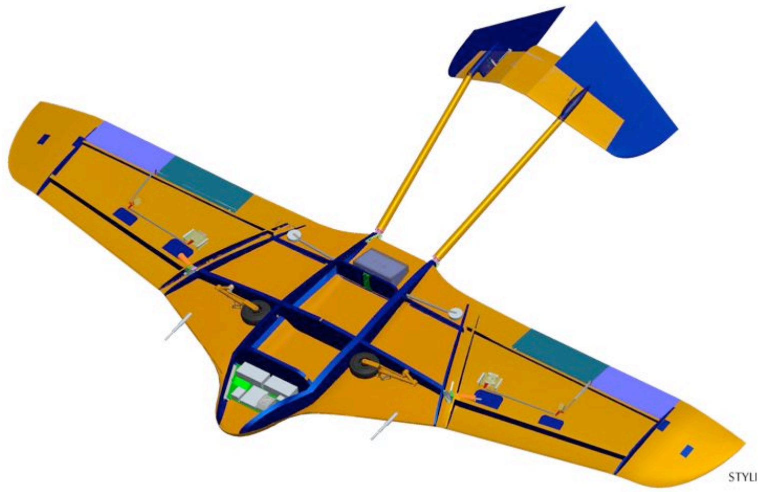

Figure 7. 3-D Model of HADD-2 Airplane Configuration

Maturation of a rocket propulsion system has progressed in the PARR project with the completion of a Lockheed Martin study to validate the original conceptual design. This task included the tanks, propulsion management device, thrusters, and engineering details of the integration into the airframe. Figure 8 shows a schematic of the propulsion system design that was validated by the study.

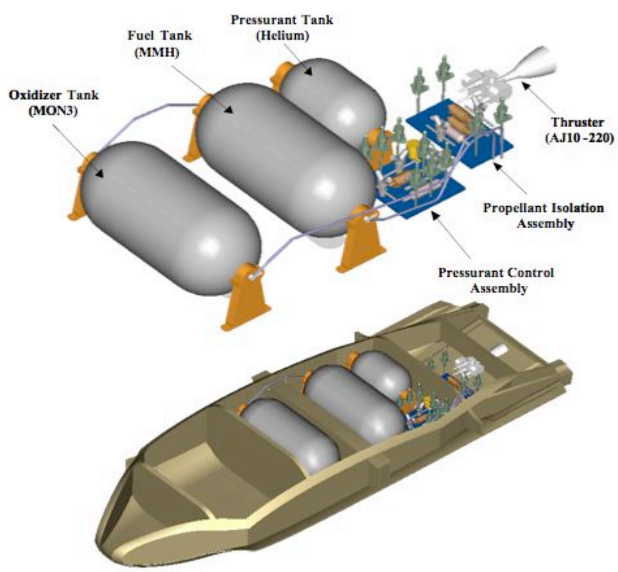

Figure 6. Validated Rocket Propulsion System Concept – Study Configuration

Another large effort being conducted as part of PARR is the development of flight control system technology for flying the first concept on Mars. Selection and purchase of the flight control computer (FCC) engineering development unit (EDU) based on the science data, flight data and autonomy requirements was completed. The first set of control laws for the airplane were determined and delivered for simulation activities, a very important part of airplane development especially for a Mars application. Initial sensor system concepts have been identified for navigation and will be further evaluated. Navigating on Mars poses a special challenge since traditional Earth based systems such as GPS and a global magnetic field are not available. Figure 9 shows the FCC being used for engineering development.

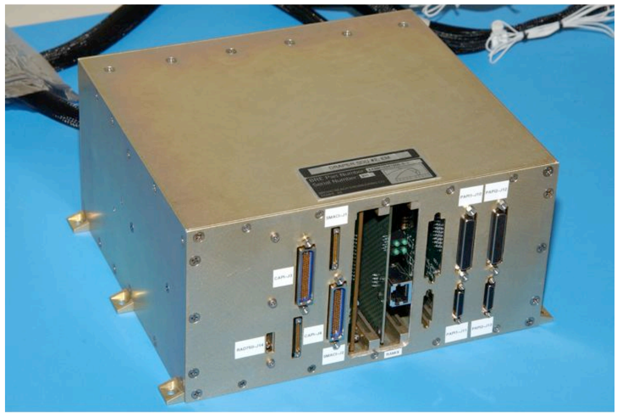

Figure 7. Flight Control Computer Engineering Development Unit

IV. Concluding Remarks

The Vision for Space Exploration, outlined by President George W. Bush in January 2004, currently provides an overarching goal to NASA. One of the vision objectives is to eventually extend human exploration of the solar system to Mars. Numerous precursor missions will be required to conduct the measurements necessary to adequately characterize the Martian environment and prepare the way for human explorers. Aerial vehicles provide a unique capability for conducting science and exploration on Mars. Just as on Earth, aerial vehicles bridge the gap between orbital and surface assets by providing higher resolution than possible with satellites and greater coverage than possible with surface systems. Technology research and development is necessary, however, to realize the full potential of Planetary Flight Vehicles as a tool for science and exploration. A series of desired PFV capabilities have been developed based on science requirements. Technology needs and approaches associated with these capabilities have been identified using the top-down "GOTChA" process. Focus areas for PFV technology development resulting from that process include aerodynamic efficiency, airframe weight, propulsion efficiency, propulsion weight, autonomy, deployment reliability, and VTOL efficiency. Initial progress in some of these technology areas has been made in the PARR project funded by NASA's Vehicle Systems Program. In particular, the PARR project has focused on maturing and demonstrating the areas most critical to realizing a near term PFV capability, such as deployment reliability, autonomous flight control, aerodynamic performance, and propulsion design. The activities in the PARR project have advanced the level of understanding in these areas and significantly matured the technologies needed to achieve the initial PFV target capability set.

Acknowledgements

The major portion of the work presented herein was performed under the sponsorship of the NASA Aeronautics Vehicle Systems Program (VSP). The authors would especially like to acknowledge the leadership of Mr. Lawrence Camacho, manager of the High Altitude Long Endurance (HALE) Sector, VSP. We would like to acknowledge the contributions of Mr. Steve Smith, NASA Ames Research Center, and Mr. Tony Colozza, NASA Glenn Research Center for their persistence in helping the HALE Sector team develop their GOTCHA. Finally, we would like to acknowledge the invaluable contributions of Mr. Henry Wright and Mr. Mark Croom of NASA Langley Research Center Planetary Aircraft Risk Reduction (PARR) project.

References

1. Levine, Joel S.; et. al, "Science from a Mars Airplane: "The Aerial Regional-Scale Environmental Survey (ARES) of Mars," AIAA-2003-6576.
2. Troutman, Pat; Levine, Joel S.; Edwards, Chris; Rudisill, Marianne; "Preparing for the Human Exploration of Mars: Developing the Measurement Database to Ensure the Safety of Humans Exploring and Living on Mars," A RASC Study
3. Wright, Henry S.; et. al., "ARES Mission Overview – Capabilities and Requirements of the Robotic Aerial Platform," AIAA-2003-6577.
4. Lede, Jean-Charles; Parks, Robert W.; Croom, Mark A., "High Altitude Drop Testing in Mars Relevant Conditions for the ARES Mars Scout Mission," AIAA-2003-6609.