Parametric Study for Increasing On-Station Duration via Unconventional Aircraft Launch Approach

Christopher A. Kuhl, Exploration Engineering Branch
Robert W. Moses, Exploration Engineering Branch
Mark A. Croom, Vehicle Dynamics Branch
Stephen P. Sandford, Earth & Space Science Program Office

NASA Langley Research Center
Hampton, Virginia

ABSTRACT

The need for better atmospheric predictions is causing the atmospheric science community to look for new ways to obtain longer, higher-resolution measurements over several diurnal cycles. The high resolution, *in-situ* measurements required to study many atmospheric phenomena can be achieved by an Autonomous Aerial Observation System (AAOS); however, meeting the long on-station time requirements with an aerial platform poses many challenges. Inspired by the half-scale drop test of the deployable Aerial Regional-scale Environmental Survey (ARES) Mars airplane, a study was conducted at the NASA Langley Research Center to examine the possibility of increasing on-station time by launching an airplane directly at the desired altitude. The ARES Mars airplane concept was used as a baseline for Earth atmospheric flight, and parametric analyses of fundamental configuration elements were performed to study their impact on achieving desired on-station time with this class of airplane. The concept involved lifting the aircraft from the ground to the target altitude by means of an air balloon, thereby unburdening the airplane of ascent requirements. The parameters varied in the study were aircraft wingspan, payload, fuel quantity, and propulsion system. The results show promising trends for further research into aircraft-payload design using this unconventional balloon-based launch approach.

1. INTRODUCTION

Recent technology advances offer an opportunity to take a fresh look at the strategy for conducting scientific Earth observations and measurements. Inspired by the recent successes of the Mars ARES airplane[1], these advances may make possible continuous, multi-day, regional-scale measurements of geophysical parameters that are currently unaffordable by the Earth Science community. Visions of the Earth Observation System (EOS) of the future involve real-time communication and data processing among multiple platforms designed to work collaboratively and autonomously[2].

The key to this vision resides in the ability of aerial platforms to provide affordable, real-time, *in-situ* measurements over two diurnal cycles, measurements that can be correlated with those made with traditional ground-based and Earth orbiting platforms. By increasing the resolution of atmospheric measurements along the horizontal scale, analysis[3] indicates that weather forecasts could be extended confidently to more than 14 days, well beyond the current 5 day predictions. This requires powered aerial platforms capable of not only horizontal range but also able to stay with a weather system as it develops. One vision of that aerial platform is an autonomous airplane. This AAOS would include other elements in addition to the aerial platform itself[4]. For instance the aerial platform must communicate with other assets to ensure safe launch and recovery of the reusable vehicle, to reduce cost and coordinate mission parameters during autonomous flight, and to make the desired measurements. It may take years to develop and implement the proper infrastructure. However, without a capable aerial platform, the need for this infrastructure is not apparent. Hence, there is a continued push to bring aeronautics and atmospheric science together in the context of aerial platforms.

2. CONCEPT OF OPERATIONS

Compared to satellites or ground-based platforms that remain in position or on station for months, the aerial platform must be launched from the ground and then landed safely a few days later, as shown in the operational profile in Figure 1. The mission may require many aerial platforms be employed on a continuous and phased rotation.

The primary driver for the AAOS is reduced life cycle costs compared to other aerial platforms currently used by the Earth Science community. Two elements of life cycle cost have been have been identified as key to meeting this goal[5]: the unit cost to produce each AAOS must be less than $1M, and the deployment cost must be less than $2000 per hour of operation. One possible way to reduce deployment cost has been suggested by the successful proof-of-concept flight demonstration of the Mars ARES airplane[6]. In that test, the airplane was lifted by a non-powered balloon to an altitude of over 100,000 feet and dropped to demonstrate the wing deployment, pull-out, and maneuvering. The balloon launch is operationally simple. It relieves the aircraft from expending valuable fuel for takeoff and ascent and permits the aircraft to be optimized for flying at the operational altitude. Another study[7] showed that increased un-powered flight durations can be achieved using this launch approach. The aim of this study is to examine the durations possible through minor changes to the ARES powered aircraft designed for Mars atmospheric flight.
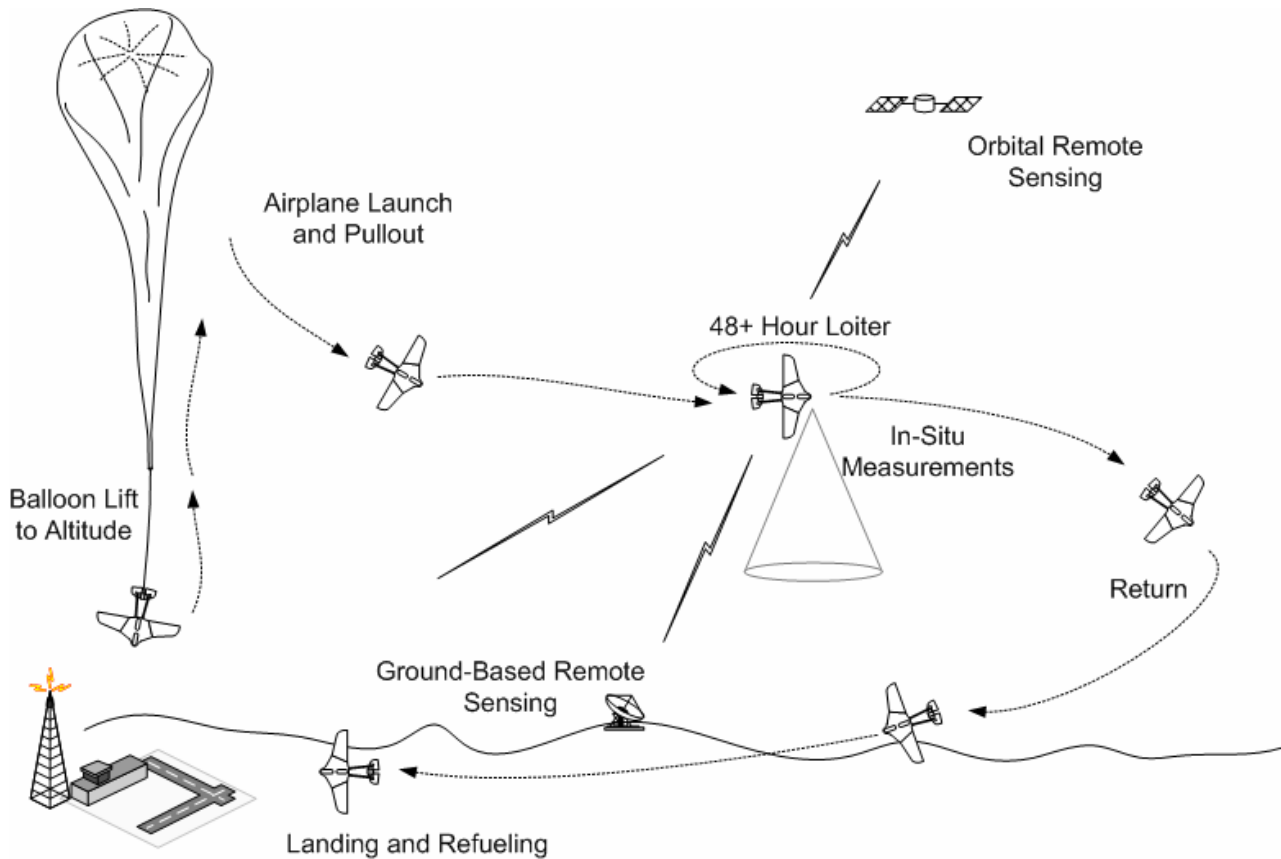

Figure 1. Concept of Operations for a Balloon Launched AAOS.

3.   AAOS SIZING TRADE STUDY

The purpose of the study reported herein was to determine the feasibility of a powered ARES-like airplane to meet the diurnal loiter requirements after reaching altitude by this unconventional balloon-based launch approach. This study determined the fuel load and wing span requirements for meeting a variety of loitering times on station up to 60,000 feet.

The current ARES airplane conceptual design was used as a baseline for assessing and quantifying the performance of this class of airplane for long-duration, high altitude terrestrial science. ARES was designed to fly in the thin atmosphere of Mars at about 1000 meters above the surface, which has an equivalent density to that of about 100,000 ft on Earth. ARES is designed to deploy from an aeroshell, and fly by means of a bi-propellant rocket propulsion system[8]. This propulsion system is simpler and less risky than a propeller driven airplane but the volumetric and weight limitations restrict aerial flight on Mars to a few hours. For Earth atmospheric flight up to approximately 60,000 ft, an air breathing, liquid fueled rotary engine and propeller was considered to capitalize on the available atmospheric oxygen and the more desirable specific fuel consumption. For this feasibility study, the propulsion system selected was a common UAV engine, the Rotax 912ULS outfitted with a multi-stage turbocharger for high-altitude operation. The 4-stroke engine has a mass of about 64 kg, a max power rating of 100 horsepower and consumes about 7 gal/hr of AVGAS fuel at full power.

A trade study was conducted to determine the feasibility of flying a 25 kg science payload on a propeller-powered airplane for a minimum duration of 48 hours. To maximize flight endurance, the airplane would be lifted to altitude by an air balloon and released to begin flying under its own power. The baseline airplane for this trade study has similar wing, airfoil, and performance characteristics as the ARES conceptual design (See Figure 2). Flight endurance was determined using a time step approach considering level flight with velocity optimized for maximum loiter time. For each time step, the required thrust, power, and fuel consumption rates were calculated. As fuel is consumed and the airplane mass decreases, the optimized loiter velocity decreases because less power is needed to maintain flight, which allows the engine to be continuously throttled back to reduce fuel consumption.

The following list details the baseline assumptions from the analysis:

Minimum Flight Duration	48 hours
Maximum Altitude	18.3 km (60,000 ft)
Flight Velocity	~100 m/s (loiter)
Nominal Engine Power	51.4 kW (68.4 hp)
Maximum Engine Power	74.6 kW (100 hp)
Nominal Fuel Consumption	20 liter/hour (14.4 kg/hr)

The characteristics of the baseline airplane are shown below in Figure 2:

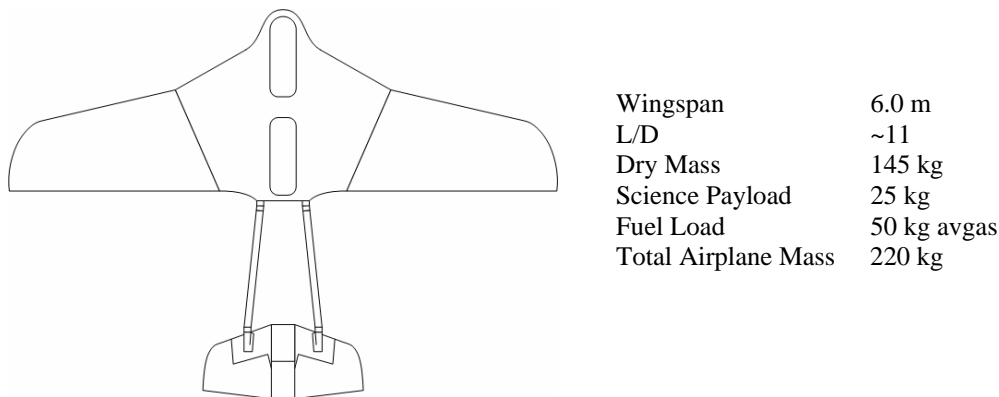|	
Wingspan	6.0 m
L/D	~11
Dry Mass	145 kg
Science Payload	25 kg
Fuel Load	50 kg avgas
Total Airplane Mass	220 kg

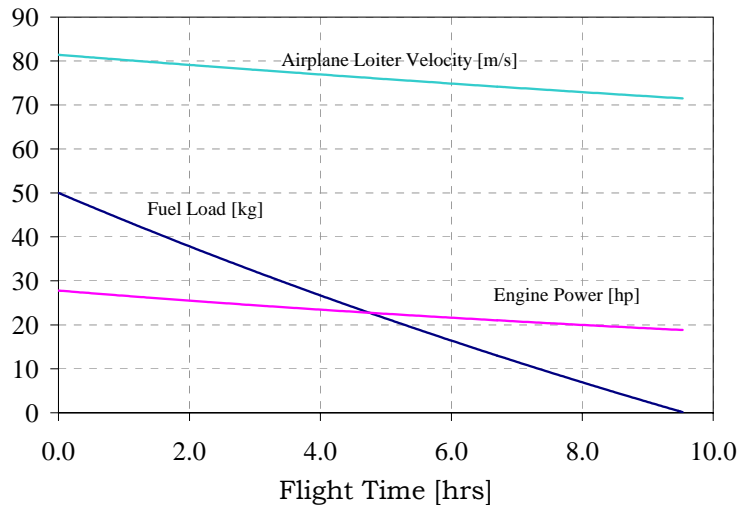Figure 2. Baseline Trade-Study Airplane. *Spawned from ARES conceptual Mars airplane.*

Figure 3. Operational Characteristics of Baseline 6 m Wingspan Airplane with 50 kg Fuel Load.

With the selected propulsion system, the baseline airplane has an estimated total flight duration of less than 10 hours, well below the desired 48 hours. The fuel load, power, and airplane velocity throughout the flight are shown in Figure 3.

To find an option capable of the desired endurance, a parametric study on the influence of wingspan and fuel loading was performed. To accommodate the increased demands on the structure, the structural portion of the overall dry-mass (which includes science payload mass, airframe structure, and all non-fuel masses) increased as the overall vehicle size and mass increased. However, for this first-order study, the chord length and engine type remained fixed for all cases considered. Other attributes such as preserving tail volume for stability and control concerns, were not considered in the current study. The results, presented in Figure 4, show that an endurance of 48 hours can be achieved by an aircraft with a 9.4 m wingspan carrying 365 kg of fuel operating at nominal power of 68 hp (shaded circle). By operating the engine up to the 100 hp limit (the open circle on Figure 4) over 100 kg of additional fuel can be accommodated, which would provide an additional 4 hours of flight time. By increasing the wingspan to 10 m, the required fuel load drops to only 288 kg and by increasing the wingspan to 12 m, the airplane requires less than 180 kg of fuel to achieve 48 hours of flight. The characteristics of the 9.4 m airplane are shown in Figure 5 and details of the operational profile are shown in Figure 6.

The persistent need for larger science payloads adversely affects airplane flight endurance. The larger airplane dry-mass requires more power from the engine, thus reducing flight time by consuming fuel at a faster rate. To determine the
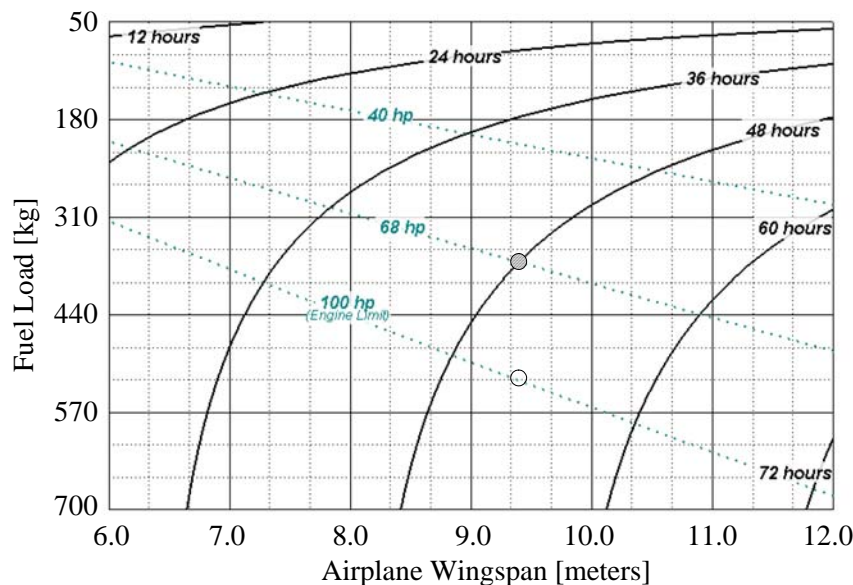

Figure 4. Trade Study Results for Airplane with 25 kg Science Payload. *Solid lines show contours of flight time and dotted lines show required power for a given wingspan and fuel load.*

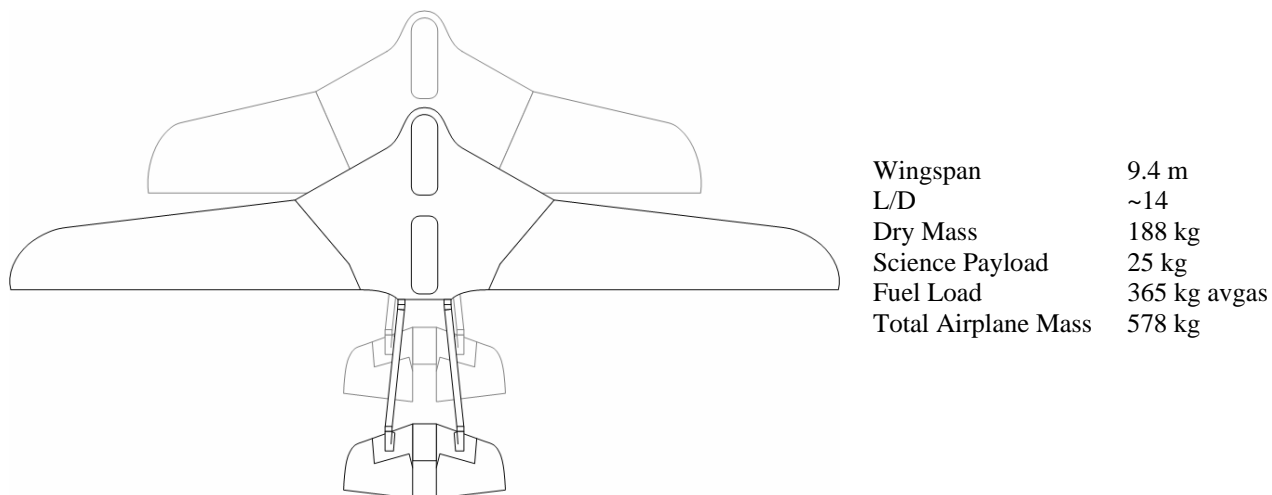| Wingspan | 9.4 m |
L/D	~14
Dry Mass	188 kg
Science Payload	25 kg
Fuel Load	365 kg avgas
Total Airplane Mass	578 kg

Figure 5. AAOS Candidate Aircraft. *Characteristics of this airplane satisfy the science requirement of 48 hours of flight endurance.*

sensitivity of the science payload mass on flight duration, the airplane dry-mass was increased by 75 kg to represent a science payload mass increase from 25 kg to 100 kg. Figure 7 shows the results for the case of a 100 kg science payload. The minimum 48 hour flight duration requires an airplane with an 11 m wingspan operating a near the maximum power (shaded circle shown in Figure 7).

For both science payload capacities examined, this analysis indicates that increasing time on station to 48 hours seems feasible using a balloon launch approach. For a 25-kg payload, a 50% increase in the wing span of the current ARES configuration is required to meet the mission goals. The flight time requirement of 48 hours for a payload dry mass of 100 kg requires nearly doubling the wing span. In both cases, additional increases in flight time can be achieved through combinations of increases in wing span and fuel load. Since only minor changes to the aircraft were required to show feasibility in this study, this unconventional balloon-based approach offers tremendous promise.
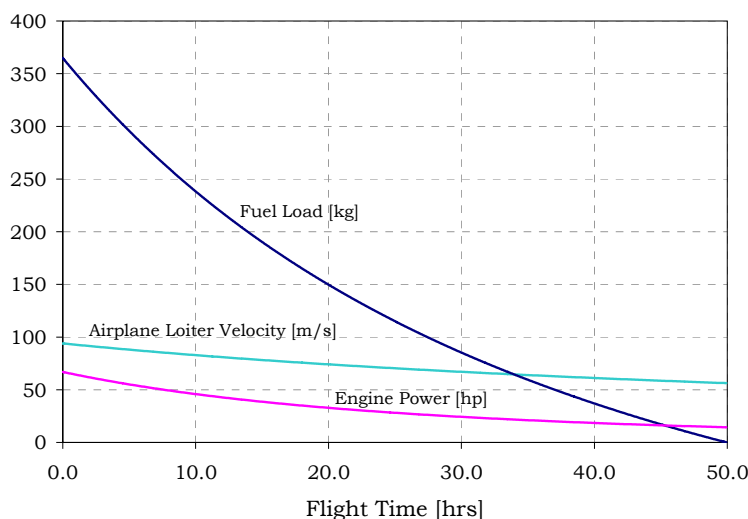

Figure 6. Operational Characteristics of the 9.4 m Wingspan Airplane with a 365 kg Fuel Load.
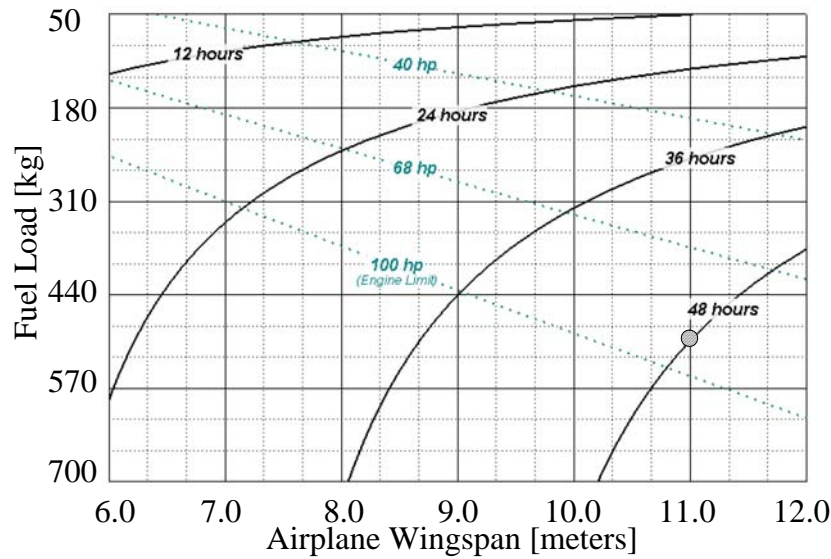
Figure 7. Trade Study Results for Airplane with 100 kg Science Payload *Solid lines show contours of flight time and dotted lines show required power for a given wingspan and fuel load.*

4. CONCLUSION

The recent advances in planetary aerial flight have provided opportunities for this technology to be used as an Earth observing platform. This study has shown that by using current airplane and engine technology, on-station time can be extended well beyond two diurnal cycles by launching the aircraft directly at the desired altitude. Working in concert with ground based sensing and orbital remote sensing platforms, higher-resolution in-situ measurements can be achieved, which could ultimately lead to a better understanding of atmospheric dynamics, life-cycles of tropical and severe storms, and better weather forecasting in general.

5. REFERENCES

1. Wright, H.S. Croom, M.A., Braun, R.D., Qualls, G.D., and Levine, J.S., "ARES Mission Overview- Capabilities and Requirements of the Robotic Aerial Platform," AIAA-2003-6577, 2nd AIAA "Unmanned Unlimited" Systems, Technologies, and Operations – Aerospace Conference, 15-18 September 2003, San Diego, California.

2. Sandford, S.P., Croom, M.A., Moses, R.W., Kuhl, C.A., Guynn, M.D., Braun, R.D., Levine, J.S., and Langford, J.S., "ARES and Beyond: Autonomous Aerial Platforms Provide a Unique Measurement Capability for Earth and Planetary Science," AIAA-2003-6610, 2nd AIAA "Unmanned Unlimited" Systems, Technologies, and Operations – Aerospace Conference, 15-18 September 2003, San Diego, California.

3. Steiner, M., Seablom, M., Neeck, S., McConaughy, G., Clausen, M., Kalb, M., and Muller, R., "Future Architectures for Operational Forecasting: Two-Way Interacting Sensorweb and Model/Assimilation System," JP 1.24, Third AMS Conference on Artificial Intelligence Applications to the Environmental Sciences, 9-13 February, Long Beach, CA.

4. Liberatore, V., Newman, W.S., and Bhasin, K., "IP Communication and Distributed Agents for Unmanned Autonomous Vehicles," AIAA-2003-6594, 2nd AIAA "Unmanned Unlimited" Systems, Technologies, and Operations – Aerospace Conference, 15-18 September 2003, San Diego, California.

5. Harrison, F.W., Sandford, S.P., and Moses, R.W., "Autonomous Aerial Observation Systems Workshop", National Institute of Aerospace, NASA Langley Research Center, 9-10 October 2003, Hampton, Virginia.

6. Lede, J.C., Parks, R., and Croom, M.A., "High Altitude Drop Testing in Mars Relevant Conditions for the ARES Mars Scout Mission," AIAA-2003-6609, 2nd AIAA "Unmanned Unlimited" Systems, Technologies, and Operations – Aerospace Conference, 15-18 September 2003, San Diego, California.

7. Lachenmeier, T., and Lede, J.C., "High Altitude UAV Performance Improvements Using Non-Powered Balloons," AIAA-2003-6837, AIAA 3rd Annual Aviation Technology, Integration, and Operations (ATIO) Conference, 17-19 November 2003, Denver, Colorado.

8. Kuhl, C. A., Wright, H.S., Guernsey, C, Colozza, A., Hunter, C., "Liquid Rocket Propulsion for Atmospheric Flight in the ARES Proposed Mars Scout Mission," AIAA-2004-3696, 40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Fort Lauderdale, Florida. July 11-14, 2004.