# The Return of the Balloon as an Aerospace Test Platform

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Abstract

Stratospheric balloons have served the scientific community for over fifty years. The primary use of these balloons has been to carry cosmic ray and astronomical observation equipment to altitudes above 99% of the Earth's atmosphere. Balloons played an equally important role as aerospace test platforms in the 1950's and 1960's. As techniques and technologies matured, stratospheric balloons emerged as reliable platforms for scientific studies in the 1970's and 1980's with very little activity in the area of aerospace testing. The late 1980's showed a return to using the economical balloon as a tow vehicle to carry test vehicles into the stratosphere to test models of manned space planes for NASDA (Japan) and ESA.

The successful test of the ARD (Atmospheric Recovery Demonstrator) recovery system using a balloon to carry the system to 23 km. was an excellent example of the utility of balloons in recent times for testing purposes. Recently, balloons have been used to test planetary entry systems to study the possibility of deploying a balloon in the atmosphere of Mars. A rocket powered reentry vehicle model was launched in the Gulf of Mexico by Raven Industries in the Fall of 1998. The launch was conducted from a ship using a static launch technique. The success of this launch technique has encouraged plans for heavier payloads and the possibility of launching small payloads to low Earth orbit using balloon carried rockets.

## 1.0 Background

Stratospheric balloons have a long history of service to scientists and engineers in the area of aerospace testing.

When compared to conducting tests from aircraft, balloons have several distinct advantages. These advantages include the ability to attain altitudes near the edge of space, flight durations up to several days, and the ability to carry out flight operations very economically. As will be shown later in this paper, balloons routinely carry their payloads above 99.5% of the Earth's atmosphere. From this height, experiments with low Q, high Mach number vehicles can be carried out that are not possible with low altitude aircraft. These altitudes can be maintained over many days if necessary, thus simulating an orbital flight with all environmental considerations except the experiment is at 1 G throughout the flight. This duration capability is many times that of aircraft and many more times the durations of sounding rockets on ballistic trajectories. In addition to the obvious benefits of long durations at high altitudes, stratospheric balloons are also very economical. An entire flight operation could cost less than a few hours in the air for an aircraft. These advantages have long been factors in the selection of balloons for high altitude testing.

In the 1950's, a variety of experiments were carried out to study the effects of high altitude ejection on instrumented dummies. Spacecraft nose cone recovery systems were tested in simulations that equaled the near-space environment of the latter stages of atmospheric entry. Some of the most notable uses of balloons in the 1950's were the manned flights into the Stratosphere that tested the reactions of the pilots to near-space conditions. These flights provided valuable information that paved the way for manned flights into space on rockets.

The early 1960's saw the end of manned stratospheric ballooning with two spectacular flights. In 1960, U.S. Airforce test pilot Joe Kittinger culminated years of high altitude ejection tests with a jump from 31.4 km. This is a world record parachute jump that still stands today. In 1961, U.S. Navy doctor/aeronauts Malcolm Ross and Victor Prather ascended to a record altitude of 34.7 km in an open gondola wearing only Mercury Astronaut space suits for protection from the vacuum of space. This flight, occurring on the eve of Alan Shepard's historic flight, set an official altitude record that stands today.

In the late 1960's and early 1970's, balloons were used to carry full-scale models of the Mars Viking aeroshell to certify it for the Viking missions. This series of tests involved carrying the model to increasingly higher altitudes for static drop tests. The series concluded with tests in which the vehicle was released at an altitude of 36.6 km and boosted to an altitude of 44.5 km by a rocket motor. These tests proved the aeroshell and the parachute landing system for the Viking vehicle.

## 2.0 Recent Uses of Balloons for Testing

After the Viking tests, there were very few tests of aerospace systems on balloons. Descent and landing tests of the U.S. Space Shuttle used full-scale models too heavy to be carried aloft by balloons. Consequently, the first time the Shuttle was flown in a high altitude supersonic condition was during the first manned space flight in 1981.

As new spacecraft were developed in the 1980's for various agencies around the World, balloons have once again come into use for evaluating the descent and landing phases of these systems. A model of ESA's Hermes shuttle was tested from a balloon. Japan's Hope space shuttle was tested from a balloon with a rocket assist in 1989.

### 2.1 Atmospheric Re-entry Demonstrator

The recovery system for the highly successful ARD recovery system was tested first from a balloon. A Raven 0.103 million cubic meter (mcm) balloon, shown in Figure 1, was used to carry the 3950 kg ARD model and recovery system to an altitude of 23 km. The flight began at the Italian Space Agency's launch facility in Trapani, Sicily.

**Figure 1 - ARD Recovery System Test Balloon Prior to Launch**

(ASI Photo)

The ARD test vehicle ascended under the balloon to an altitude of 23 km and moved to a point over the Mediterranean Sea off the West Coast of Sicily. From that point the system, as shown in Figure 2, was released and a successful test of the landing and recovery system was conducted.

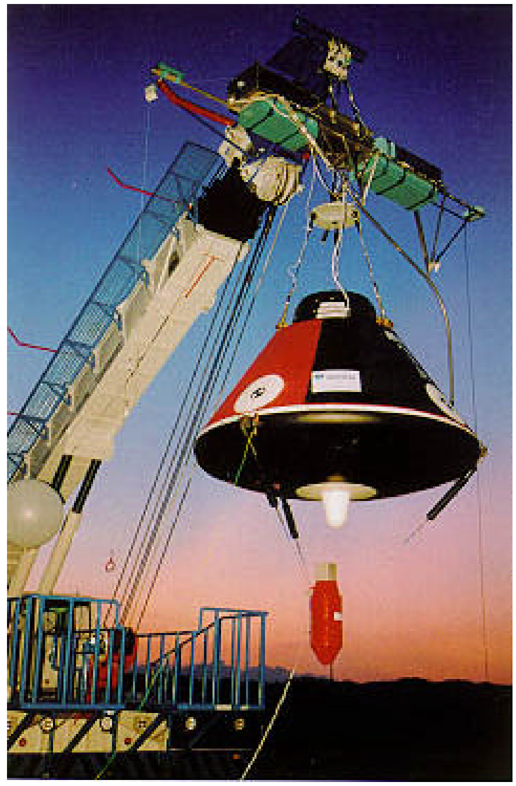

**Figure 2 - ARD Test Vehicle**

**(ASI Photo)**

## 3.0 Challenges to Balloon-Borne Testing

While highly economical, using balloons for testing does present challenges when compared to testing from aircraft. Surface weather conditions are much more critical for launch, payload capability is smaller than that for aircraft, range coordination is more complex, and established ballooning centers are not necessarily willing to support non-scientific flights.

Typically, large stratospheric balloons must be launched in surface winds that are less than 3 meters per second. This is necessary to allow for a safe inflation and release of the delicate balloon. This constraint sometimes limits the location and time of year for flights. It can also lead to significant delays in launch operations.

The 3950 kg system weight of the ARD test flight was near the limit of payload for dynamic launches of polyethylene balloons. In a dynamic launch, the upper portion of the balloon is inflated and held down to the ground. For launch, the inflated portion is released quickly and the balloon lifts itself off of the ground quickly. A crane holds the payload until the entire system is vertical. The lightweight, delicate nature of these balloons is the limiting factor in the amount of dynamic loading the balloons can withstand.

When balloons are used for drop tests, range planning and coordination are much more complex than aircraft based tests. The balloon, carried by the winds, can drift over a large area and exact prediction of the drop point is not possible. The launch point must also be positioned such that the wind profile will not carry the balloon off of the range.

Another challenge to using balloons for aerospace testing is the fact that most established ballooning centers are oriented toward support of scientific payloads. Scientific flights generally only involve ascending to a constant altitude for a specified amount of time and then descending. The payload is recovered on a large parachute, which is deployed throughout the flight. Deviations from this typical mission are sometimes not supported.

In an effort to demonstrate a mission that would overcome all of the above mentioned challenges, High Altitude Research Corporation and Raven Industries conducted the launch of the BLRV (Balloon Launched Recovery Vehicle) in October of 1998. The test of the BLRV is summarized in the following section.

## 4.0 The BLRV Experiment

The BLRV Experiment was conducted by HARC to design, develop, and flight test a prototype of a reusable low cost balloon launched rocket powered vehicle and return it to a preselected location. This program is intended to lead to a low cost launcher to place small payloads into space. This innovation centers on an experimental flight-verified prototype of a rocket powered aerodynamic lifting-body (aerospace plane). The lifting-body is lofted by a balloon to over 23 km for a rocket-propelled ballistic launch into space. The vehicle then glides back with payloads to a designated site. This prototype was used to design both reusable sounding rockets and vehicles to launch microsatellites into orbit. The BLRV incorporates the use of a powerful low cost hybrid rocket motor that is integrated into a vehicle with low cost, yet sophisticated, flight control systems. Potential cost reductions for balloon launch are demonstrated by using a utility boat and "free-standing" balloon inflation techniques instead of the standard balloon launch equipment. The boat traveled in a vector which made the winds across the deck essentially zero. The relative wind on the balloon is kept to zero enabling use of static launch techniques as shown in Figure 3.

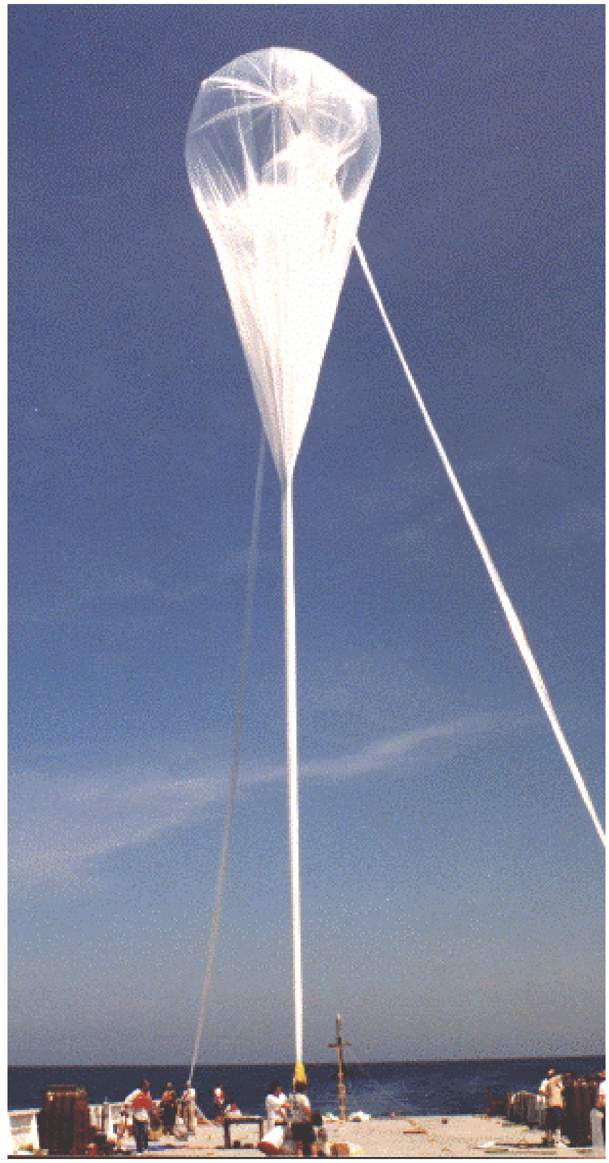

**Figure 3 - Ship-board Static Launch**

### 4.1 Test Objectives

The objectives of the BLRV experiment are summarized below:

1. Validate the vehicle performance model and controllability by launching the BLRV from a balloon at 23 km for a rocket assisted

hypersonic glide down from the edge of space.

2. Validate the concept of using a sea launched balloon to enable operations from lower cost ranges in which missile flight and drop experiments are routine. Establish system costs and operational crew requirements.

3. Validate the technique of a "free-standing" balloon inflation (static launch) to enable operations from a boat matching velocity with the wind to minimize the use of balloon launch equipment.

4. Conduct tests of components and methodologies to demonstrate the technical feasibility of the BLRV.

4.2 Vehicle Description

The overall shape is of a long thin flat body with two fins on 45 degree angles to vertical. The BLRV was about 190 cm long and 94 cm wide, not including fins (161 cm with fins).

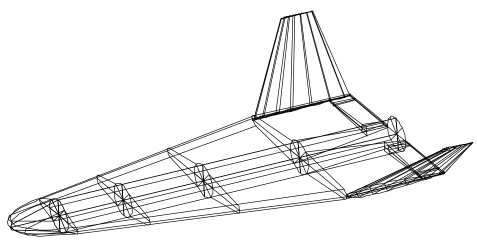

**Figure 4 BLRV Vehicle Concept**

4.3 Configuration

As shown in Figure 5, the BLRV structure consists of a phenolic central body tube in which the motor, avionics, and payload are mounted. The body shape is developed from ribs spaced along the length of the body tube. A low density foam is sandwiched between the ribs. The aft section of the vehicle contains spruce spars that provide load bearing structures for the vehicle fins and control surfaces. The aerodynamic loads are spread across the structure by a thin fiberglass skin.

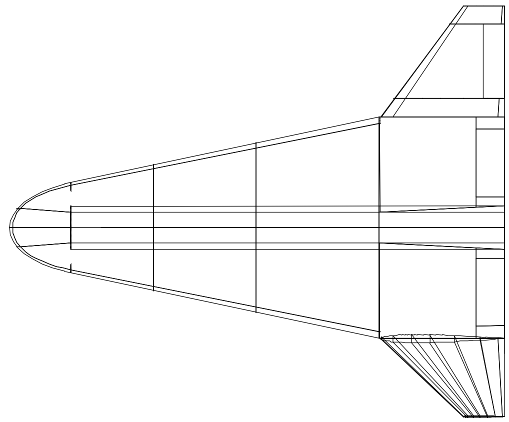

**Figure 5 BLRV Vehicle Structure**

4.4 Telemetry System

4.4.1 Vehicle Uplink Command / Downlink Telemetry Avionics

The BLRV avionics package onboard the flight vehicle provided a live television camera and telemetry downlink. In addition, an onboard control receiver was to allow the ground crew to radio control the flight surfaces.

The TV downlink consisted of a high resolution color camera, microwave transmitter and an omnidirectional antenna imbedded in the vehicle. The camera was forward facing allowing the ground station operator the means of a remote cockpit view. The TV transmitter also has a sound subcarrier feature which transmited telemetry information.

A separate telemetry transmitter on a FM UHF transmitter relayed the same information as the TV audio subcarrier for system redundancy.

Flight vehicle telemetry information consisted of the following:

- Fluxgate Magnetometer (3 axis information)
- Accelerometer (3 axis)
- GPS position, velocity and heading information

Other avionics onboard included three piezo gyros, batteries and 4 servos.

4.4.2 Launcher Platform Avionics

The Launcher Platform electronics, which facilitate pointing of the BLRV in azimuth for launch, have been built and successfully subjected to bench and flight-testing. It consists of a 2-axis magnetometer, Basic Stamp II and relay driver circuitry for actuating valves which control the gas to the orientation nozzles. The design of the motor firing control circuitry and associated software is available for future programs. A VHF uplink command receiver furnishes firing commands.

4.4.3 Ground Station

The operator sits in front of a TV screen that displays the live video from the flight vehicle. He can control all flight surfaces via a joystick connected to a radio control unit. The telemetry received from the flight vehicle during it's mission was overlaid on the live video to allow the operator information necessary to pilot the vehicle. The ground station for the BLRV flight is shown in Figure 6.

4.4.4 BLRV Flight Control Avionics

Ground to air control of flight servos has been demonstrated in the laboratory and in the field using flight and flight-like equipment. The control box generates pulse width control pulses that take a path to the servos. The actual control receiver, demodulator, decoder and a servo used in the BLRV Proof-of-Concept flight was used in rocket powered field-testing of a two-thirds scale model. The rest of the system includes the VHF ground transmitter, flight gyros, control microprocessor and control software.

The hardware and software to display BLRV azimuth and attitude during flight includes a 3-axis flux-gate magnetometer/ accelerometer sensor and a 9600 baud modem transceiver. Operating together, this system transmits azimuth heading and attitude to the ground


Figure 6 - BLRV Ground Station

The ground station consists of uplink command transmitters for BLRV ignition, safety termination, and launch platform control. In addition there is a flight control transmitter to relay the radio control information to the flight vehicle. Television reception is accomplished via a microwave downconverter and a high gain steerable antenna system.

Computer stations were in place for telemetry downlink and data storage as well as weather and flight path prediction.

station for display on a PC monitor.

A camera, located in the nose of the BLRV, was to provide an aid for piloting the BLRV during descent to the landing site. The BLRV video transmitter consists of a 10 milliwatt exciter and a 2 watt amplifier which operates at 2.418 GHz. The transmitter antenna was of a cloverleaf design and was located in the BLRV wing.

Pressure transducers were used in an arrangement that, in conjunction with a microprocessor, provide air speed and rate of descent data for transmission to the ground station. A Video Overlay Board and appropriate software formatted and imposed this data and

**Figure 7 - BLRV Ready for Launch**

GPS data on the transmitted video signal. The information contained therein was displayed on the video monitor at the ground station that displays the scene from nose camera.

### 4.5 Flight Controls

The BLRV vehicle was controlled by four independent control surfaces. Two control surfaces are mounted on the trailing edge of the vehicle and acted as body flaps, and the control surfaces in the fins acted as elevons as well as rudders. A flight control computer is used to "mix" pitch, yaw and roll commands as well as piezo gyro inputs into surface deflections. This mixer, developed from a Basic Stamp II microprocessor, was initially tested on a two-thirds scale model of the flight BLRV. The piezo gyros were used for an open loop autopilot to give stability to the vehicle during the flight. The control surfaces were also programmed for use as an airbrake to add stability during the launch phase of flight.

### 4.6 Launch Operation

Launch operations were conducted in the Eglin Air Force Base restricted air space in the Gulf of Mexico south of Pensacola, Florida. The launch boat was a basic utility boat used for servicing oil platforms in the area. It had an open deck 15 m wide and 27 m long. Conducting the standing inflation from the deck of the boat was remarkably easy. The balloon lifted out of its shipping box as inflation progressed. Once the balloon was completely lifted out of the box, system lift was monitored on a load cell attached to the deck. After inflation was complete, the flight system, shown in Figure 7, was lifted from its staging platform and the system was hand launched.

Ascent progressed nominally and all on-board functions of the BLRV performed nominally as the balloon reached its ceiling altitude of 23 km. The system is shown in Figure 8 just after launch.

**Figure 8 – BLRV on Ascent**

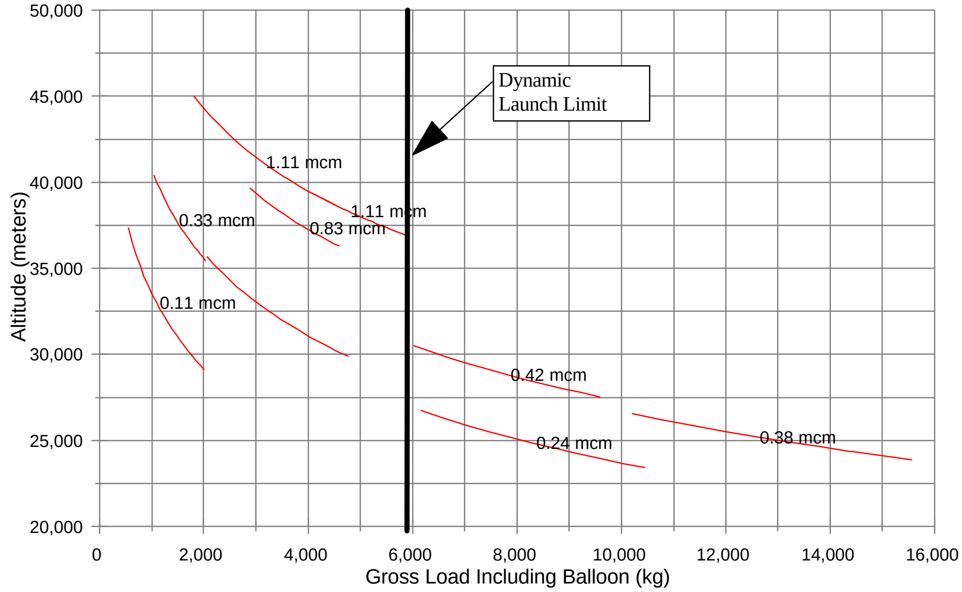


**Figure 9 - Balloon Performance Summary**

4.7 Flight Results

The goals of validating the concept of static, ship-board launch was achieved with much success. By sailing with the wind, the balloon was inflated in completely calm air throughout its length. Unfortunately, the BLRV vehicle's engine failed to ignite. The problem was later traced to a pyrotechnic device that would not ignite at the ambient pressure at 23 km. The device was replaced with an improved design and the motor was successfully test fired in an altitude chamber.

## 5.0 Balloon Capabilities

The static launch method was chosen for the BLRV to demonstrate the concept and to test the launch procedure on a small system before larger launches are attempted. The launch of the BLRV could easily have been conducted from the ground with a dynamic launch. The future of aerospace testing from balloons exists in the ability to carry much larger payloads than are possible using dynamic launches. If a static launch method is used, very large payloads can be launched and carried into the stratosphere.

The graph in Figure 9 shows the performance for Raven's standard large scientific balloons. The current maximum payload for these balloons is 3600 kg. As stated previously in this report, the payload for the ARD test flight was 3950 kg. It is estimated that the payload limit for dynamic launches is approximately 4500 kg. This limit is based on two conditions, the dynamic loads placed on the balloon during the launch and the load limit of easily available cranes to carry the payload during launch.

Since the limits are based on launch conditions, the balloon itself could be designed to carry much heavier payloads if a static launch is used. The curves on the right side of the graph show performances of designs that could be used to carry very heavy payloads into the stratosphere using a static launch.

## 6.0 Future Applications

Balloons are scheduled for use in the test and evaluation of aerospace vehicles on a variety of applications. The most immediate use of balloons will be to tow prototype systems into the stratosphere for deployment tests of Mars exploration vehicles. Balloons are being used by the Jet Propulsion Laboratory to tow a simulated system to 35 km for release over the Pacific Ocean. The system contains a mockup aeroshell, a packed balloon, a helium supply and a parachute. Upon release at 35 km, the system deploys and inflates the on-board balloon from a high-pressure helium tank. After inflation, the tank, aeroshell, and parachute are released and the balloon is able to continue on its mission. This system is being tested for future missions to carry balloons to explore the atmosphere of Mars.

Balloons will be used to validate the deployment system of an aircraft that will be taken to explore the atmosphere of Mars. In this experiment, the balloon will be used to carry the folded aircraft to an altitude of 36.6 km for release, deployment and landing tests.

One of the most ambitious planned uses of balloons involves the balloon as part of a space mission. During the next year, HARC plans to carry a 136 kg rocket to an altitude of 23 km on a balloon. At that altitude, the rocket will be ignited and will climb to a predicted altitude of 200 km on a suborbital flight. The results of this flight will be used to carry progressively heavier payloads with the ultimate goal of launching a small payload to Low Earth Orbit. The design for the balloon is possible, as shown in previous sections of this paper. For this concept to be viable, it will be necessary to have a fully developed static launch capability from a ship at sea.

## 7.0 Summary/Conclusions

The utility of balloons as economical, reliable test platforms for aerospace testing has been demonstrated in numerous tests both historically and in recent experience. To enhance the usefulness of balloons for heavy payloads, the static launch method is being developed. This method offers the following advantages.

- Increased launch opportunities because of the ability to negate the effect of winds on the launch process
- Simplified range coordination because of the wide areas of ocean-based test ranges
- The ability to launch payloads of up to ten tons to 23 km

As new spacecraft are developed for Earth re-entry, and for planetary atmosphere entry, balloons are uniquely qualified to provide test opportunities to engineers for high fidelity tests of full-scale systems.