AIAA 81-1917R

Air Bag Impact Attenuation System for the AQM-34V Remote Piloted Vehicle

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This paper describes the air bag impact attenuation system for the AQM-34V remote piloted vehicle. The developed hardware, consisting of the main bag, tail bag, and inflation systems, is described. Operation of the system from electrical initiation through cover deployment, main and tail bag inflation, and ground impact is discussed. Development ground drop tests, environmental tests, structural tests, and the contractor flight tests are summarized. Test results substantiated system performance.

Introduction

A DEVELOPMENT and qualification test program was conducted for the air bag impact attenuation system (ABIAS) for the AQM-34V remote piloted vehicle (RPV). The work was an outgrowth of a feasibility demonstration program jointly funded by Teledyne Ryan Aeronautical (TRA) and Goodyear Aerospace Corporation (GAC) using a MQM-34D RPV.[1]

Much of the impact bag technology used in the program was based on the work conducted by GAC for the B-1 escape capsule impact attenuator system.

The prime contractor of the program was TRA, which conducted the work for the Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. TRA's responsibility included all developmental tests, ground and flight qualification tests, modification of the AQM-34V, and supply of the inflation system for the ABIAS.

Under subcontract to TRA, GAC analyzed, designed, and fabricated the impact bags for the ABIAS, and also developed the packing procedure for the main and tail bags.

Background

The AQM-34V impact attenuation system was an outgrowth of the MQM-34D feasibility demonstration program (see Fig. 1), with much of the technology being drawn from the B-1 Escape Capsule Impact Attenuator Program (see Fig. 2). Technology used from the B-1 program included 1) a 6DOF mathematical model (three translational and three rotational) of the impact attenuator system to help initially define the configuration based on the predicted performance; 2) fabric identical to that used on the B-1 impact bags (consisting of a square woven nylon cloth coated with a Goodyear-developed synthetic rubber compound called Natsyn,‡ specially formulated to meet the requirements for cold temperature deployment without cracking); 3) use of the rectangular-shaped bags without internal structure for obtaining improved energy stroke characteristics; 4) use of proved blowout disks to release the stored energy in the impact bags during the ground stroke; and 5) use of various fabrication techniques, cements, building forms, and procedures that could be adjusted to the requirements of the AQM-34V program.

Thus, as a starting point, the majority of effort could be concentrated in developing an impact bag configuration to handle the unique landing configuration associated with the AQM-34V RPV.

Description of Developed Hardware

The AQM-34V ABIAS is a ground impact attenuation subsystem consisting of two inflatable Natsyn-nylon impact bags, gaseous nitrogen storage bottles, bag inflation lines, associated hardware, and electrical control provisions. Figure 3 shows the inflated system during parachute descent. The ABIAS subsystem is divided into a control system, a main bag and its inflation system, and an auxiliary tail bag and its inflation system. Figure 4 shows the relative arrangements of the bag system. It is specifically designed for the ALE-2 or ALE-38 chaff pod version of the AQM-34V. Total weight increase to the AQM-34V RPV with the ABIAS system installed was 147.7 lb plus 8 lb of GN_2.

Main Bag and Inflation Segment

The main bag segment consists of inflation hardware, an aspirator, a main bag container/cover assembly, and GN_2 storage bottles, fabricated or assembled by Teledyne Ryan Aeronautical, and the main impact bag assembly, fabricated by Goodyear Aerospace Corporation.

The main bag inflation hardware consists of two identical 327-in.^{3}, 3000-psig (operating pressure), welded steel pressure vessels with common charge/discharge lines that tee into the bag inflation line.

The pressure vessel charge/discharge lines are manifolded to a common charging valve, pressure gage, and manual dump valve. These components are accessible through an added cutout in the right-hand side of the RPV engine nacelle. (See Fig. 5 for a schematic diagram of the inflation system.)

Pressure vessel thermal overpressure relief is provided by a single relief valve mounted on the right-hand pressure vessel. This valve is set to relieve pressure at 3500 psig and reset at 3200 psig.

A single two-position, one-way solenoid-operated valve with a built-in leakage pressure vent is employed to control nitrogen flow into the main bag inflation line. An air filter is

Received Oct. 14, 1981; presented as Paper 81-1917 at the AIAA 7th Aerodynamic Decelerator and Balloon Technology Conference, San Diego, Calif., Oct. 21-23, 1981; revision received Feb. 18, 1982.

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provided upstream of the solenoid-operated valve to protect it and other inflation components from moisture and contamination.

A pressure regulator downstream of the solenoid-operated valve reduces nitrogen flow pressure to approximately 100 psig prior to entry into the aspirator. The aspirator is essentially a venturi and uses the high velocity nitrogen flow to pull ambient air into the bag inflation line, thus augmenting the basic inflation gas supply.

The main bag is approximately 80 ft^3 in volume and is the primary ground impact force attenuator. It consists of two sections, stacked vertically and joined externally by side and end curtains. (See Fig. 6.) At the contact surface between the two bag sections, two valves are provided to control differential pressure between the upper, high pressure bag (5 psig) and the lower, low pressure bag (1 psig).

Two 1-psig valves in the lower bag, and one 5-psig valve in the upper bag provide bag inflation overpressure relief.

Controlled deflation of the main impact bag is provided by three impact pressure blowout disks. Two are located in the upper stage bag and one in the lower stage bag.

The main impact bag assembly is hand-packed into a sheet aluminum and fiberglass "slipper" container and is held in the container by captive studs and noncaptive screws. The fiberglass and aluminum cover attached to the container by shear rivets encloses the impact bag in the container assembly after packing. The entire packed container/cover assembly is fastened to the RPV lower nacelle by the same captive studs used to attach the bag to the container. The entire container/cover assembly, with impact bag installed, has major dimensions of approximately $40\times18\times6$ in. and weighs approximately 50 lb (35 lb for the bag and 15 lb for the container/cover assembly). (See Fig. 7.)

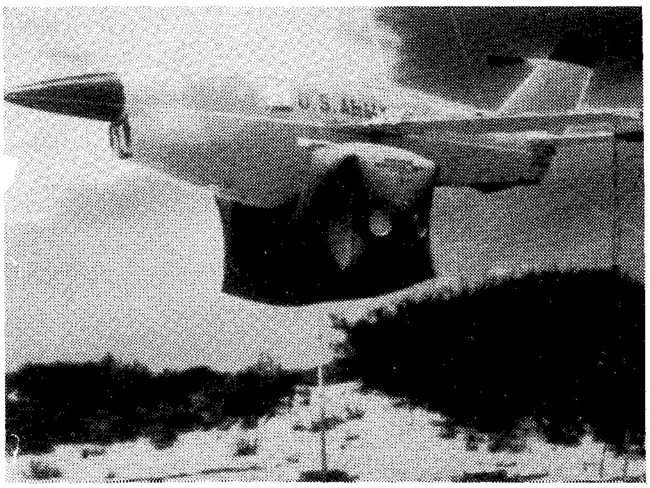

Fig. 1 MQM-34D feasibility demonstration program.

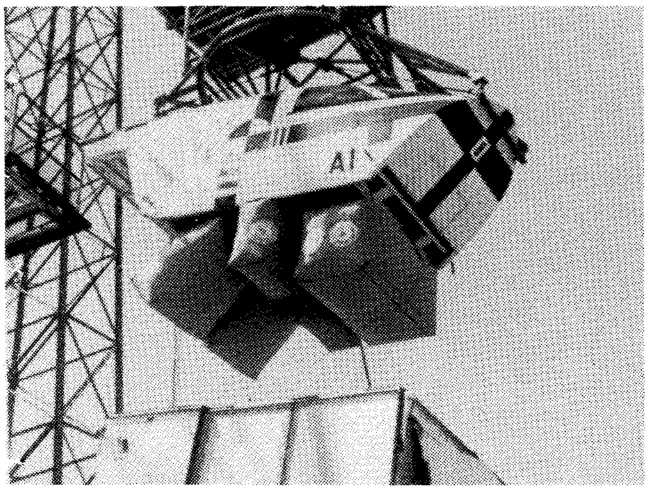

Fig. 2 B-1 escape capsule impact attenuation system.

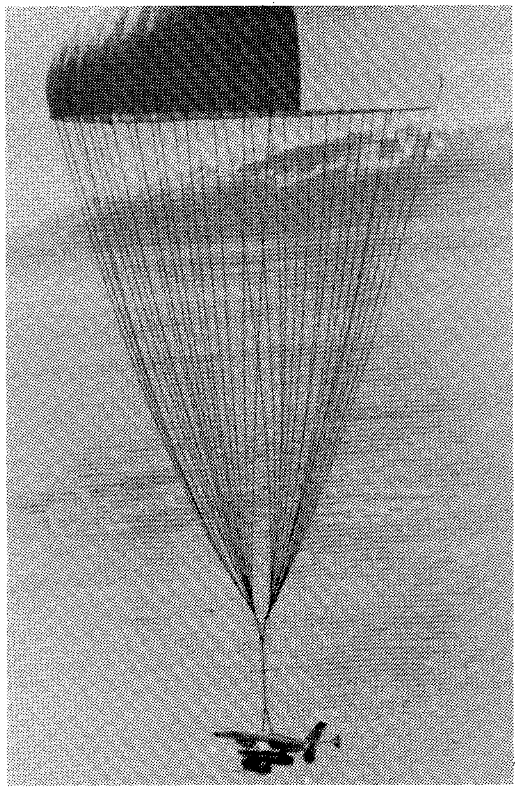

Fig. 3 AQM-34V during parachute descent with ABIAS deployed.

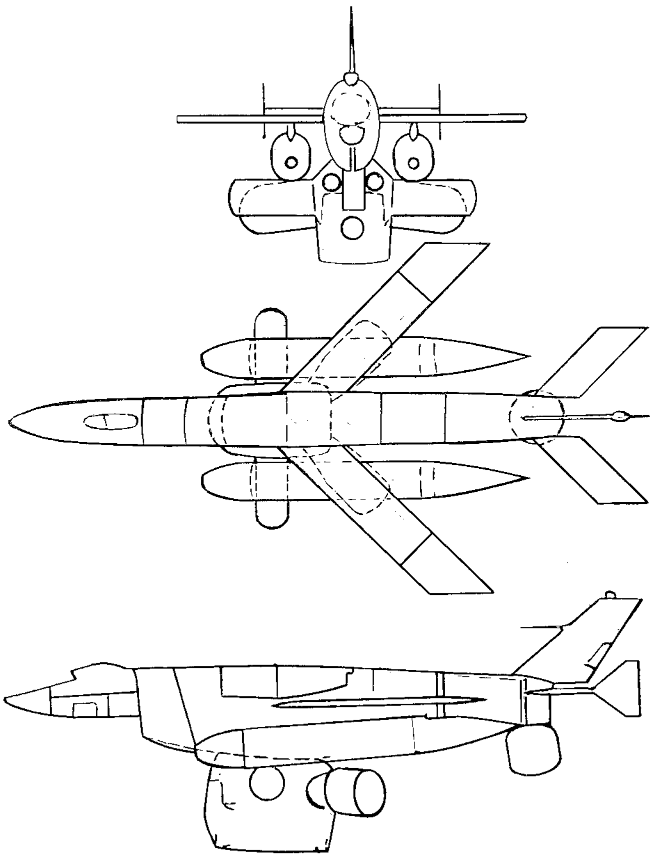

Fig. 4 AQM-34V with ABIAS bags deployed.

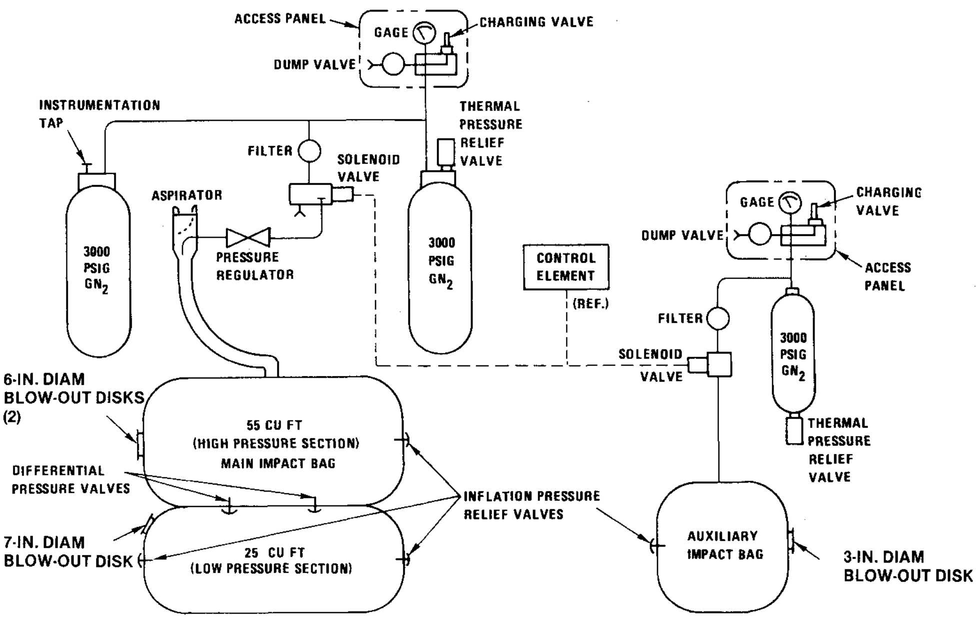

Fig. 5 ABIAS inflation system schematic.

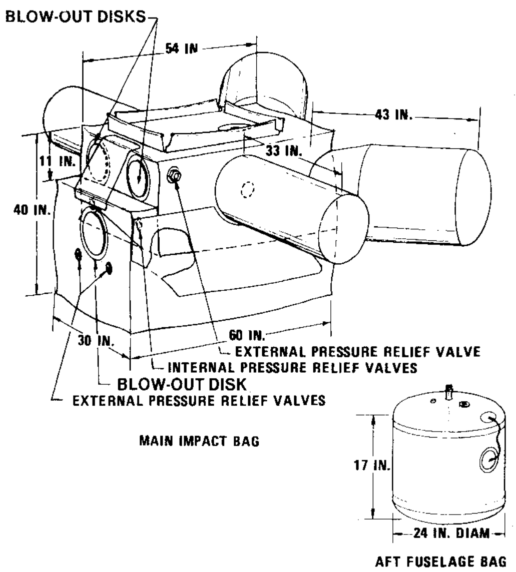

Fig. 6 Fabricated shape of main and tail bags.

Two aluminum stamp-formed and aluminum framed fairings are attached to the RPV nacelle, one forward and one aft of the main bag container/cover assembly, to provide aerodynamic drag reduction.

Auxiliary Tail Bag and Inflation Segment

The auxiliary tail bag segment consists of inflation hardware, an auxiliary tail bag container/cover assembly, fabricated by Teledyne Ryan Aeronautical, and the auxiliary tail impact bag, fabricated by Goodyear Aerospace Corporation.

The auxiliary bag inflation hardware consists of a single 3000-psig (nominal operating) welded steel pressure vessel (61 in.^{3}) manifolded to a charging valve, pressure gage, and a manual dump valve, and teed into an auxiliary bag inflation line.

The charging valve, pressure gage, manual dump valve, and manifold are identical to the main bag inflation hardware. Access to these components is via an added cutout on the left-hand side of the RPV aft fuselage.

Pressure vessel thermal overpressure relief is provided by a relief valve identical to the one used for the main bag.

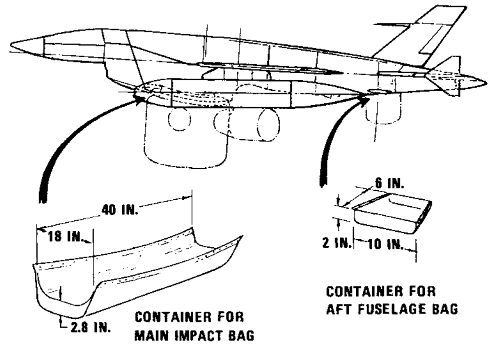

Fig. 7 Containers for main impact and tail bags.

A single two-position, one-way solenoid-operated valve controls nitrogen flow into the auxiliary bag inflation line. An upstream air filter is provided for protection from contamination, as in the main bag system.

The auxiliary tail bag is located on the underside of the RPV fuselage below the empennage. The bag is barrel-shaped, with a major dimension of approximately 2 ft. It is provided primarily to protect the aft fuselage and empennage from impact damage during main bag deflation and aft vehicle pitch.

The auxiliary bag is maintained at 1.5-2.0-psig inflation pressure by a single pressure relief valve. Controlled deflation is provided by a single impact pressure blowout disk.

The auxiliary impact bag is packed into a trapezoidal-shaped metal container/cover assembly measuring approximately $6 \times 10 \times 2$ in., and weighing approximately 5 lb complete with packed auxiliary bag. (See Fig. 7.)

The assembly is attached to the RPV aft fuselage adjacent to the ground launch hold-down fitting. Two fairings are added to the aft fuselage just forward of the container assembly for aerodynamic drag reduction.

Electrical System Operation

Activation of the ABIAS power control relay coil provided closure of two sets of normally open relay contacts, which allows 28-vdc voltage from the vehicle 28-vdc main bus to flow to the main and aft bag inflation system solenoid valves. These valves release and allow the stored gaseous nitrogen to flow from the pressure bottle to the inflation lines for the main and aft bags. Flow of the nitrogen into the packed bags in their respective containers causes a pressure buildup that shears rivets on the covers, causing the covers to fall free and the bags to inflate.

Cover Deployment Operation

The main cover is designed to fail its 26 (per side) attaching rivets either in rivet shear or shear bearing of the fiberglass container at an applied pressure range of 12-16 psig. Upon being pressurized, the main bag exerts force on the cover causing rivet failure on either the right- or left-side line of attachments. The cover then rotates around the remaining attachments and the expanding bag exerts force that completes the failure of all rivets and allows the cover to fall away as an expended item. The aft cover is designed to fail two rivets, located at the centerline, at 16-21 psig.

Main Bag Inflation Operation

The main bag inflation system consists of two 327-in.^{3} bottles pressurized to a minimum pressure of 3000 psig. A thermal relief valve located on one of the bottles provides a means of relieving the two bottles of excessive gas pressure in the event the pressure builds up to 3500 psig or more. Both bottles are relieved through the common manifolding. A filter protects the solenoid from dirt contamination.

The gaseous nitrogen flows through the solenoid-controlled valve to a 100-psig pressure regulator to reduce the pressure flow into the aspirator. The high pressure gas flows through the aspirator venturi and causes outside air to be pulled past the spring-loaded back-flow check valve on the aspirator, thereby augmenting the flow of nitrogen gas into the bags. The outside air continues to augment the nitrogen gas until a back pressure is built up to greater than 2 psig, at which time the aspirator back-flow check valve closes. Remaining nitrogen gas from the bottles continues to flow until it is equalized by the bag pressure or the solenoid closes at ground impact when power is shut off.

The inflation gas (a mixture of nitrogen and outside air) builds up to 3.75 psig in the upper stage of the main bag. When pressure exceeds 3.75 psig, two pressure valves located between the upper and lower main bag sections open, allowing the mixed gas to enter the lower main bag section. Pressure continues to build up in the lower bag until it reaches 1.0 psig. Two inflation pressure relief valves, one located in the lower bag section and one in the upper bag section, begin relieving when the pressure exceeds 1.0 and 5.0 psig, respectively, in the two main bag sections.

Aft Bag Inflation Operation

The aft bag has its separate inflation system consisting of a 61-in.^{3} nitrogen bottle, filter, solenoid valve, and thermal pressure relief valve (an identical unit to that used on the main system). When electrical power is applied to the solenoid valve (as described in the Electrical System Operation section above), the 3000-psig minimum pressure flows directly into the aft bag inflation fitting and into the bag. Pressure buildup in the bag causes two shear rivets in the cover to separate, allowing the bag to deploy and inflate. The aft bag has a single pressure relief valve that opens when bag pressure exceeds 2.0 psig and releases excess nitrogen gas overboard. The aft bag inflation system does not need external air augmentation.

Ground Impact Sequence of Events

Both the main and aft bags continue to fill and relieve excess gas until the bottle gas supplies are expended or the vehicle ground impacts. Upon ground impact, the two series-connected g-switches activate and shut off battery power, which in turn shuts off both the main and aft bag inflation solenoids and causes the parachute to disconnect.

Main bag pressure builds up in the lower stage of the main bag as the vehicle depresses against it upon hitting the ground. A pressure control deflation blowout disk located on the forward face of the main bag is held in place by four 0.064-in.-diam aluminum shear wires. As the lower bag pressure builds up to approximately 5 psig, the blowout disk is released, thereby relieving the gas pressure buildup and exhausting the gases at a rate controlled by the physical size of the orifice. This deflation determines the bag pressure-time curve, which defines the energy absorbed by the lower stage main bag.

During the pressure buildup in the lower pressure section of the main bag, the upper bag, with its pod protrusions, also starts seeing a pressure buildup because of the loads transmitted to it from the lower stage. When this pressure increases to approximately 7.5 psig, the three 0.094-in.-diam aluminum shear rivets in each of the two blowout disks, located on the forward face of the upper bag, fail in shear, releasing the blowout disks. The gases begin to exhaust at a rate controlled by the diameter of the blowout orifices. Gas flow restriction is further provided by internal flow restrictors located between each protrusion and the main bag upper section. This delay prolongs the pressure decay under each pod, further enhancing their value in keeping the vehicle in an upright position during wing leading drift conditions. The upper and lower section bag pressure decay then combines into a single time-pressure curve defining the total energy absorbed by the entire main bag.

A single blowout disk of smaller diameter is installed in the aft bag, similar to the installation on the lower main bag. Two 0.051-in.-diam aluminum shear wires secure it in place. When the aft bag sees a pressure rise of approximately 5 psig (the maximum pressure varies with the drift direction and velocity), the blowout disk releases the aft bag pressure at a controlled rate. The aft bag is used primarily as a vehicle stabilizing device, but also provides and adds to impact attenuation as a secondary function.

Both the main and aft bags become completely deflated as the vehicle comes to a final resting position on the pods and rear fuselage. The weight variation of the vehicle at recovery impact (pods empty—2600 lb—to pods full—3350 lb) requires a compromise in blowout disk number and sizing, quantity of shear pins, and shear pin and rivet sizing. The "tuning" of the deflation system was accomplished during the ground drop test program for a nominal weight condition and configuration. Significant variations from the nominal can cause a possible "no deflation" condition of any one of the blowout disks or bags. This condition in conjunction with variation in descent velocities and drift directions may require manual deflation of the bags at the recovery site prior to the bag systems being removed from the vehicle. This was accomplished during the flight test program by removal of one of the pressure relief valves.

Surface Impact (non-MARS Recovery)

The desired mode of operation is to deploy bags in the event no mid-air recovery (MAR) occurs, and to inhibit bag deployment if a MAR occurs.

With the vehicle in the recovery mode and without a mid-air recovery, bag deployment will occur when 1) the vehicle descends to the preset altitude above the intended recovery terrain altitude, and 2) more than 30 s have elapsed after main chute deployment. The foregoing altitude and timing functions are provided by the existing adjustable (2000-15,000-ft MSL) barometric switch and 30-s timer.

A barometric switch setting of 2500 ft above the intended recovery terrain altitude provides adequate time for full bag inflation.

During descent with the bags deployed, the fuel dump valve is open, and any remaining fuel is expelled.

Upon impact of the vehicle on land, the g-switches actuate, causing the main chute to be released, the fuel dump valve to close, and battery power to be cut off in 5 s. (Adequacy of the g-switches to actuate for a ground impact has been assessed during flight tests by measuring the impact acceleration signature.) Also at impact, the normally closed bag inflation solenoids close, preventing entry of dirt, etc., into the GN_2 system upstream of the solenoid valves.

Mid-Air Recovery (MAR)

If a helicopter mid-air retrieval (MAR) and the attendant stability chute deployment occur above the setting of the adjustable barometric switch, impact bag deployment is inhibited.

Tests Conducted

Development ground drop tests, environmental tests, structural tests and flight tests were conducted on the ABIAS system. Each is discussed below.

Development Ground Drop Tests

The ABIAS ground drop test program consisted of three series of tests.

The first series of tests, consisting of 12 tests, was an engineering evaluation between two competing attenuator bag designs. Vertical drop, 5-knot wing leading, 5-knot nose leading, and 5-knot tail leading tests were conducted to evaluate the two designs with the result that the Goodyear design was selected.

The purpose of the second series of tests, consisting of 21 tests, was to "fine tune" the GAC impact bag system. Vertical drop tests, 5-, 10-, and 15-knot nose leading, tail leading, and wing leading tests were conducted with vehicle weights between 2601 and 3351 lb.

The last series of tests, consisting of 11 tests, was devoted to qualification testing. Vertical drop, 15-knot nose leading, 10-knot tail leading, and 5-knot wing leading tests were conducted. (These values were established as the no-damage threshold in the development tests previously run.) Vehicle weights varied between 2601 and 3351 lb.

Environmental Tests

One main bag and two aft bags were used for the environmental tests to verify that the impact bags would function after being subjected to the following environments: vibration, impact shock, acceleration, altitude, high-temperature deployment, and low-temperature deployment.

No problems occurred except in the tail bag during the low-temperature deployment. The pressure relief valve was found to be located too close to the inflation fitting, thereby allowing the inflation gas to escape before the pressure in the bag could build up and blow off the cover. Other changes were also made and the tail bag was successfully deployed at $-33°F$.

Structural Tests

These tests were conducted to demonstrate that the ABIAS impact bags manufactured by GAC would provide a safe margin of strength over the predicted and test loads. For these tests the main and the tail bag were confined in the vertical direction, simulating the compression encountered during the landing impact.

The bags passed the test without failing when pressurized to 1.5 times the normal maximum pressure experienced in the actual ground impact.

Contractor Flight Test Program

Three successful flights and recoveries with ABIAS-configured AQM-34V RPV's with ALE-2 and ALE-38 chaff pods were accomplished during this phase of the program. Along with these tests, 25 hangar deployment tests were run to validate the packing procedure and verify that the government had sufficient informal operations and maintenance training to accomplish the government flight test program.

Results of the flight tests showed that no significant or noticeable increase in drag had occurred as a result of the incorporation of ABIAS. The effect of the additional weight added by ABIAS appeared to be no more significant than any other weight increase on the vehicle.

The design goal for impact attenuation was to absorb 75% of the kinetic energy of the vehicle at touchdown on level ground. The range of the vehicle weights, from 2756 to 3306 lb, provided the following range of kinetic energy test points.
Flight No. 1 approximate impact kinetic energy: 9600 ft-lb.
Flight No. 2 approximate impact kinetic energy: 16,500 ft-lb.
Flight No. 3 approximate impact kinetic energy: 24,800 ft-lb.

A rough integration of the main bag upper and lower stage load-stroke curves, which were crudely developed from bag pressures and footprint area, shows that the bag system absorbed practically 100% of all vertical kinetic energy for each of the three recoveries.

The ground impact damage after the ABIAS recoveries was minimal. Particular attention was given to inspecting for damage to RPV structure, pylons, pods, bags, and structural alignment. Damage assessments for each of the flights are given below.

Flight No. 1 Damage Assessment

The vehicle impacted with a slight nose forward drift and slid approximately 9 in. forward. The vehicle and pods had no apparent damage. The low pressure section of the main bag expelled the orifice disk, but the high pressure section disks remained in place owing to bag pressures not exceeding design blowout values. The RPV came to rest with the high pressure bag supporting it under the chaff pods. The aft bag blowout disk was expelled. A small hole due to an error during packing was found in the upper front of the main bag.

Three minor pin holes were found in the bottom of the aft bag. The tail end plates were undamaged although ground contact was made. Figure 8 shows the RPV at rest after

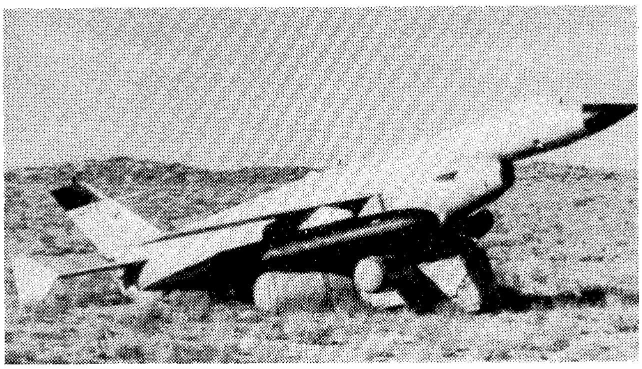

Fig. 8 RPV after ABIAS recovery, Flight No. 1.

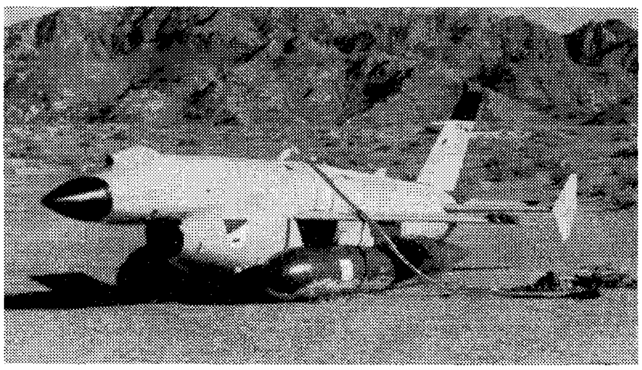

Fig. 9 RPV after ABIAS recovery, Flight No. 2.

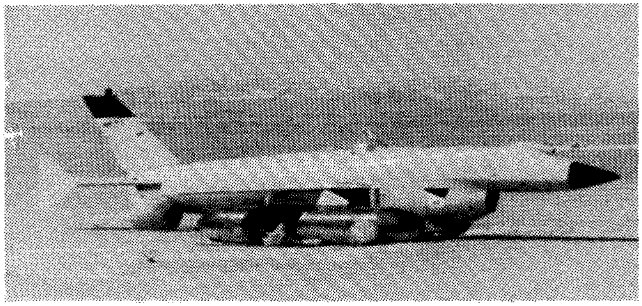

Fig. 10 RPV after ABIAS recovery, Flight No. 3.

recovery and shows the type of terrain at the recovery site. The alignment data changes did not cause any measured parameter to exceed allowable limits.

Flight No. 2 Damage Assessment

The vehicle impacted with a left and slightly forward drift at an estimated 4-5-knots horizontal velocity into flat, soft loam. Damage occurred in the wing tip and pod areas owing to side drift effects. None of the repair or replacement work was extensive, as can be seen in Fig. 9.

The aft bag suffered a 14-in. tear in the top due to failure of the cover to detach. Apparently, at impact, the relatively sharp upper edge of the cover cut into the bag. The cover had hung up at its forward shear rivet.

Flight No. 3 Damage Assessment

The RPV impacted with a slight quartering left forward drift (315 deg) at an estimated 3-knots horizontal velocity. Terrain was a flat, moist loam and sand combination. Figure 10 shows no apparent damage to the basic airframe. Soil marks indicated that the main bag slid about 3 ft in a left quartering forward direction. The aft bag hit lightly and bounced 18 in. to the left and remained inflated. The aft blowout disk remained in place. The left vertical stabilizer end plate touched down lightly, leaving a 1/2-in. marking in mud from the bottom along the entire length of the end plate. There was no indication that the right vertical end plate or the wing tips touched the surface.

The RPV had no visible damage, although alignment data indicated that the right-hand horizontal stabilizer incidence was slightly out of tolerance.

Conclusions

Test results showed that the ABIAS system as installed on the AQM-34V RPV, configured with ALE-2 and ALE-38 pods, is a highly reliable and efficient system for impact attenuation.[2-4] All program objectives and design goals were met.

The system was adequately tested to provide impact attenuation capability and proper mechanical function of the ABIAS deployment. It was not tested to environmental extremes of hot day or cold day temperatures or for all possible varying velocities, directions of drift, and types of terrain at impact. Experience in those nominal conditions, as well as experience with aging and wear, would be accumulated with operational usage.

No noticeable difference in RPV aerodynamic performance was caused by the ABIAS installation. The effects of added weight and small increases in drag did not appear to change adversely aircraft controllability, stability, or flight performance.

The system proved to be easy to service and maintain. Reliability was high, and no unexpected safety hazards were experienced.

Servicing, packing, and operational procedures developed during the test program proved to be quite adequate.

The bag system performed per design, was easy to pack and repair, and sustained minimal wear and impact damage, exceeding design goals for reuse by a large factor.

The prototype AQM-34V ABIAS system has been tested successfully and has been sufficiently developed to the point that it is ready for incorporation in production units and for use on "clean wing" RPV's.

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