# Development of a Recovery System for the AN/USD-501 Surveillance Drone

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**The development of a two-stage aerodynamic decelerator system for a surveillance drone is described. Results of flight tests of the original design and the subsequent corrective action taken to eliminate early problems are presented. Because of volume limitations, a pressure packed density of 50 lb/ft³ is used for packing the main chute into a rectangular metal cannister, which in turn is used for deployment. As a consequence unusual main parachute fill times and shock loads were encountered, and were overcome by reducing main parachute deployment speed and increasing line strength. Problems involved in using the parachute compartment cover to aerodynamically deploy the drogue parachute, the reliability problems associated with the use of pyrotechnic cutters for interstage separation, and the methods used to overcome them are also discussed.**

## I. Introduction

CANADAIR Limited, Montreal, completed the development of the Recovery System for the AN/USD-501 drone in 1966. The drone is now being manufactured by Canadair for the armies of Canada, the United Kingdom, and the Federal Republic of Germany. Canadair developed the complete system, including system installation, sequencing and subsystem ejection.

The first stage drogue and main canopies were designed and manufactured by Irvin Air Chute Ltd., and the airbags for shock absorption by Air Cruisers Division of the Garret Corporation.

The requirements of the system have extended beyond the state of the art in areas such as allowable weight, volume, installation, accurate deployment of canopies, drag control, and interstage timing. This has been due to the following system requirements: 1) low opening forces due to low longitudinal deceleration limits, 2) a very tight landing dispersion requirement to meet the tactical needs of armies operating out of clearing in the battlefield environment, 3) low weight and volume (9.8 lb and 370 in.³), 4) reliability of operation of 97.5 per flight, and 5) angular oscillation at landing ±5°.

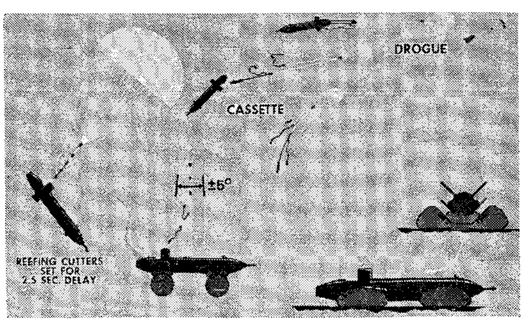


**Fig. 1 AN/USD-501 drone recovery system.**

These requirements, particularly low weight, volume, and oscillation, coupled with a high subsonic initial opening speed, defined the type of parachute system used. The design and development of the parachute system and a brief description of the landing bag subsystem is the subject of this paper.

## II. System Description

The system consists of two main components, a retardation device (the drogue) to slow down the vehicle to a speed at which the main recovery device (main chute) can be deployed. There is virtually no alternative to a parachute for the main recovery phase. It is simpler, lighter, and less expensive than retrorockets. It can be refurbished and will meet a 10× reusability requirement.

Figures 1 and 2 show the basic system deployment and sequence logic. On the initial design a variable delay pyrotechnic cutter was used; this was subsequently superseded by a pneumatic release system. The detailed sequence of deployment is as follows:

1) The parachute compartment cover is released, deploying the drogue chute. The cover and deployment bag detach and descend separately.

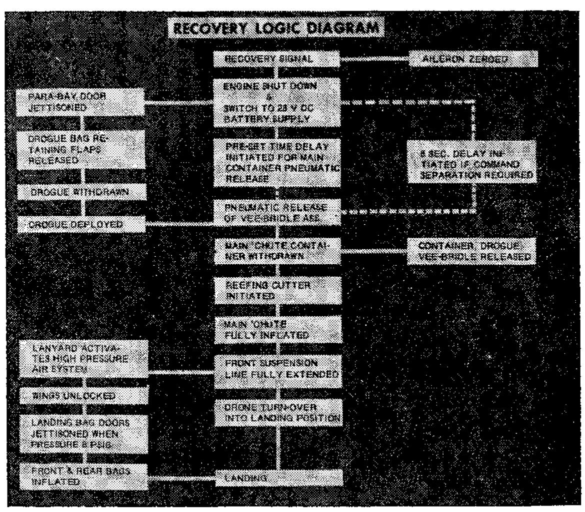


**Fig. 2 Recovery system logic diagram.**

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2) The drogue inflates and slows the vehicle to a speed suitable for deploying the main chute. This is achieved in $5\frac{1}{2}$–6 sec.

3) After 6–24 sec, dependent on deployment altitude, the drogue separates, the cassette is released, and the drogue extracts the main chute cassette.

4) The main chute then fills and slows the vehicle down to 50 fps. The main riser, which is reefed by a $2\frac{1}{2}$-sec cutter, is dereefed and the main chute pulls on the drone forward riser.

5) The landing bags take 10 sec to inflate, and the drone descends at a nominal descent rate of 32 fps.

## III. Development Tests and System Design

The system tested at Canadian Forces Base, Cold Lake, Canada, and the U.S. Army Proving Ground, Yuma, Ariz., had a 3.2-ft-diam drogue, 19.7-ft main chute, and a pyrotechnic cutter separation system. Extraction and deployment of the drogue was made via the door; these two units were interconnected by a 4-point suspension from the door to the drogue bag.

The main chute, pressure packed into a metal cassette, was retained during drogue operation. The retention device used a pair of holddown straps that were cut mechanically by a force exerted by the drogue chute separation.

### Test Summary

The test results obtained from the Cold Lake and Yuma Trials will be discussed. The main areas analyzed were rate of descent, force and velocity, opening process, structural integrity, and system performance.

The average rate of descent on the main chute, analyzed over 5 drops, was 31.4 fps. This is associated with an average drop weight of 220 lb, and the average drag coefficient value ($C_{D_0}$) of 0.51.

The velocity data are classified and will not be discussed. Average loads on the drogue were 2000 lb and in the order of 1300 lb on the main chute.

Time to maximum opening forces of the drogue was found to be consistent. Maximum load is achieved at $T + 0.150$ sec; this includes door off and line stretch of the system.

Time to maximum opening forces on the main chute was found to be inconsistent. Discussions with specialists indicated that the opening could be affected by 1) variation of total porosity, 2) drogue terminal velocity, 3) pressure packing into a metal cassette, and 4) temperature, altitude, and humidity.

Analysis also showed that the main chute suspension lines were critical, as tests had shown that variations in 200-lb cord and joint efficiencies of the main chute could cause catastrophic failure.

Because of poor reliability demonstrated by the recovery system in the early stages, flight trials were terminated for a short period. A description of flight failures follows:

1) Main parachute container deployed before drogue disconnect due to use of 100-lb cord in place of 300-lb cord.

2) Hangup occurred on drogue when vee bridle failed to slip through connection. This was due to stitching of vee bridle to slip through loop.

3) Vee bridle failed at the cutter connection joint, resulting in premature separation of the drogue.

4) Vee bridle became wedged between cutters causing drogue hangup and no main deployment.

5) Lazy leg from drogue to main chute retention cutter entangled in flaying ends of vee bridle, thus preventing deployment of the main chute.

After completing initial flight trials, a complete failure analysis was made of the recovery system. The subsystems analyzed were main chute failures, separation system failures associated with pyrotechnic cutters, and door-drogue extraction—bridle failures. The latter two items will be discussed later under Separation Systems, and Drogue Deployment.

Main chute failures were attributed to increased terminal velocity on the drogue due to the drone weight increase, fast inflation times, and high shock loads caused by pressure packing, and poor material strength; the latter created by tolerance and environmental variations.

A review of the main and drogue chute parameters indicated that a change to the drogue chute diameter was possible, but altering the main chute size or type would not contribute very much; furthermore a larger drogue would decrease terminal velocity, and thus possibly reduce shock loads due to pressure packing.

Investigations made on component performance showed that most components in the drone would survive a 25-$g$ deceleration. Consequently, the structural load limit in the longitudinal axis was amended, and the maximum opening shock on the drogue increased. It was decided to keep the terminal velocity on the drogue chute down to 190-fps maximum; so based on this and a drone weight of 225 lb, a drogue diameter of 3.7 ft was selected with an assumed $C_{D_0}$ of 0.5.

The new opening force on the drogue at the maximum recovery $q$ became 3860 lb, and the new drogue had a safety factor of 1.3 on a maximum allowable load of 23$g$ or 5200 lb. In actual hardware design, all parts of the drogue system are capable of handling a load limit of 6000 lb with all inefficiencies included. Details of the test results will be discussed under Development Test.

During this phase of the redesign, other canopies for the main chute were reviewed. These included a modified ribless guide surface chute.

A solid canopy in general has higher opening forces than a ribbon canopy, and with lower deployment speed of the main canopy, this chute could become acceptable. The same comments given previously also apply to the personnel guide surface chute; however, the stability of this chute is not acceptable, i.e., $\pm 7°$.

Because of the experience gained in pressure packing and the amount of testing already carried out, it was decided to stay with the ribbon canopy.

## IV. Main Parachute Pressure Packing Development

In the early stages of the system design, it became apparent that the available volume allocated in the drone for the recovery system was inadequate in terms of a normal handpacked parachute system.

Various packing methods (canvas bags and vacuum packing into a cylinder) were tried but it was found that as soon as the packed bag was removed from its jig to be placed in the drone compartment the bag grew. To restrain the system a metal cassette was developed, consisting of a rectangular can, of 0.040-in.-thick heat-treated 6061 aluminum alloy, with an inner cloth liner incorporating retention flaps attached to the can.

The main parachute, complete with cutters and risers, was packed into this can (the can being supported in a wooden jig) to a packed density of 45–50 lb/ft$^3$. When removed from the jig after packing, the metal cassette showed no significant distortion, and it has been found under controlled tests that all growth takes place in the first hour after being removed from the jig.

In the earlier systems, pressure packing density reached 50 lb/ft$^3$ with a specific packing pressure of 380 ($\pm$20) psig (see Fig. 3). With these high values, concern was felt for possible damage to the parachute material, therefore, tests were carried out to check for material searing and strength degradation. All tests showed that the parachute had not

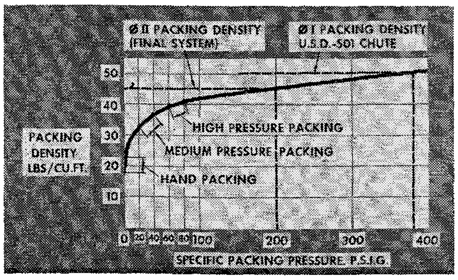


**Fig. 3 Pressure packing/density curve.**

been affected. However, at this pressure packing time was 48 hr and not acceptable.

It was obvious that this was not satisfactory for tactical use, therefore, two main changes were made to remove this problem. The drone compartment length was increased by 0.5 in., which allowed the cassette to be lengthened accordingly, and a continuous ribbon parachute, which gave considerable saving in parachute weight and volume, was developed.

With these modifications, the cassette volume was increased to 187 in.$^3$ and the parachute weight reduced to 4.8 lb. The subsequent packing density was reduced to 44.5 lb/ft$^3$, reducing the packing time to 12 hr and the soaking period to 4 hr.

## V. Separation Systems

In order to detach the drogue chute from the drone and extract the main chute, a variable delay system is required. The minimum time is dictated by time taken for the drogue to reach terminal velocity. The second criterion is the maximum altitude at which the drogue is deployed. On the AN/USD-501, the time delay requirements range of 6–24 sec. This section reviews a pyrotechnic separation and the finalized pneumatic system.

### Pyrotechnic Cutters

On the initial design a pyrotechnic cutter with four different time delay cartridges was recommended and used. It became obvious that this system has a number of drawbacks. They are 1) too expensive, 2) the attachment and method of cutting was not sound and reliable, 3) logistically the sytem would not work, 4) the time delay tolerances on the cutter, i.e., ±20%, created numerous problems, and 5) installation in a drone when mounted on the launcher is difficult.

The logistics problem associated with a tactical system is the greatest disadvantage with a pyrotechnic system. Figure 4 shows the operating bands of the 4 cartridges recommended. At −65°F, a system did not exist, as it would require 8–10 cartridges. Furthermore, they would have to be installed fairly late in the mission plan. It is next to impossible to install the cartridges when one mentions a packing density of

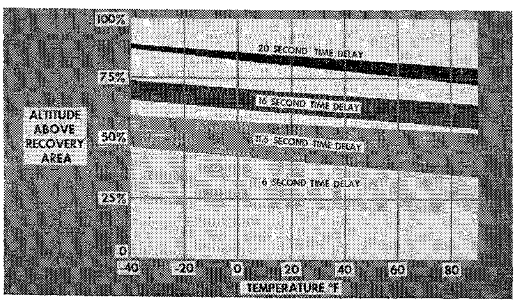


**Fig. 4 Time delay variation/temperature.**

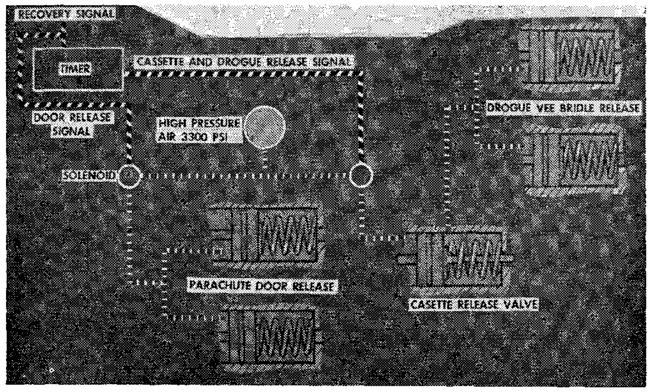


**Fig. 5 Recovery system pneumatic sequence diagram.**

50 lb/ft$^3$ and the volume available in the AN/USD-501 for the chute assembly.

With these problems and consistent flight failures of the separation system, a new and more reliable system was considered. This led to the design and development of an electrically timed pneumatic system, which will be discussed next.

### Electrically Timed Separation Systems

An investigation carried out on the availability of electronic timers showed that an electronic network was feasible for use in controlling the time delay of the separation system.

Further schemes showed that it was possible to attach the drogue vee bridles to a hard point within the drone, and it was noted that the pneumatic actuator/solenoid system used for releasing the parachute compartment door had performed remarkably well. A design review on this system confirmed the following advantages achieved with a pneumatic system: 1) highly reliable, 2) it is reusable, 3) it can be ground tested completely prior to flight, 4) there are no safety precautions required, and 5) the scheme is cost-saving, since the cutter system is one shot and each cutter costs 25 dollars. Two are required per drone.

The block diagram in Fig. 5, shows the finalized arrangement. It includes a cassette retention valve which was introduced as a more positive means of retaining the cassette during deployment.

This value acts as a sequencing value and insures the release of the cassette prior to the release of the drogue vee bridles. The bridles when released pull on the cassette via the ejection straps.

Before resumption of flight trials, a complete ground test program was carried out. The major changes made to the system, showing the old vee bridle cutter system and the new release device, are shown in Fig. 6.

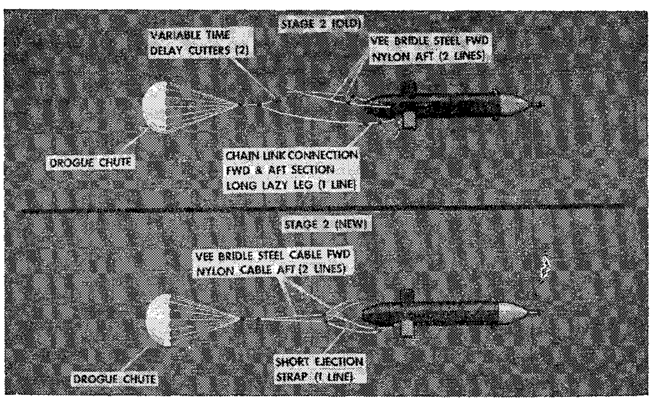


**Fig. 6 Old and new vee bridle separation.**

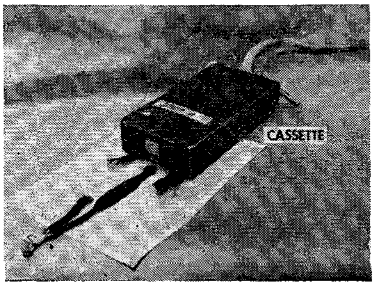


**Fig. 7 Ejection strap failure.**

### Development Tests

The ground tests were broken up into three main series starting with component test, followed by drogue assembly deployment and separation, and finally by complete system operation.

### Component Tests

The object of this test was to cycle the valve and cable assembly to obtain strength and endurance substantiation, a typical test cycle being: 1) 25 cycles with a preload of 2500 lb, 2) 25 cycles with a preload of 3000 lb, 3) 25 cycles with a preload of 3500 lb, 4) actuation of the valve at 1000 psi (actual pressure available 3000 psi), and 5) establishment of failure loads. The results obtained from the cable and valve tests proved satisfactory.

### Drogue Deployment Tests

The object of this test was to carry out eight deployments of the revised separation system. The door was ejected, using a force of 700 lb, giving the door a relative velocity of 170 fps. Problems were encountered initially as it was found that there was a large delay between the operation of the release values.

This was corrected by porting, sizing and adjusting pipe lengths. The final analysis showed that a difference of 50–70 msec existed between the release of the two values. This was considered an acceptable response time.

### Parachute Deployments with Integrated Pack

Ten deployments were made using the new integrated pack and cassette release valve. The system performed satisfactorily, and indicated an acceptable delay between cassette ejection and the vee bridle release valves. On one test, the failure of the bridle shackle to release was attributed to instrumentation which caused the air supplying solenoid to close after operation of the first bridle valve.

## VI. Parachute Deployment Problems

The method employed for ejecting the drogue chute and main chain are subjected to snatch forces. With the drogue system, the door (a flat plate) is used; the system depends on the inertia of the door at high velocities to extract the drogue. The problems encountered and the method used for absorbing snatch loads will be discussed. In the case of the main chute deployment, a similar condition exists. The cassette when ejected by the drogue chute is given a high whip force via the ejection straps; analysis and development of this part of the system is discussed below.

### Main Chute Cassette Ejection

At separation, because of its high-drag and low-mass characteristic, the drogue chute decelerates rapidly and is accelerated back to drone speed within a few milliseconds.

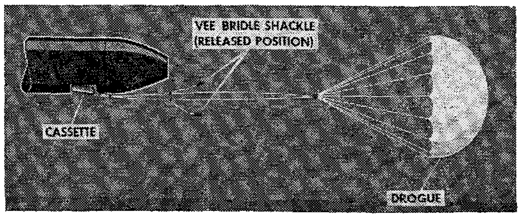


**Fig. 8 Cassette ejection.**

The force created by this acceleration is transmitted through the ejection straps and appears as a snatch load. Equating energies, it can be shown for one line that

$$P^2 = 2P_0E/L_0E_0$$

where $P$ = snatch load, $Lo$ = unstretched length, $E$ = energy to be absorbed, $Eo$ = extension at break expressed as a function of $Lo$, and $Po$ = breaking load.

Using the preceding equation, and the following data it can be shown that $Po$, the breaking load, occurs at 1325 lb. $\Delta V$ = 200 fps, $dt$ = 5 msec, weight of system = 1.5 lb.

Actual tests made on a simulated system showed failing loads in the weakest part of the system to be 1200 lb. This is the ejection strap to the cassette, which originally was four 1000-lb straps. Initially it was thought that four straps would handle the load; dynamic tests confirmed that this was not so because of the instantaneous time value. Subsequent drops incorporated 2500-lb ejection straps. No failures have since been recorded. Figures 7 and 8 show actual strap failures and system mechanism.

### Drogue Deployment

The second case of snatch forces in the system occurs when the door extracts and deploys the drogue chute. Initially the connection between the drogue deployment bag and the door consisted of 36 in. of 750-lb line attached to cords which made a four point attachment to the door (see Fig. 9).

During flight tests it was found that the lines were failing, and it was not known, whether the cords were cut or broken. It was finally attributed to a combination of cutting and high loads since the door tumbles when let out into the air stream. Analysis made on the door bridle attachment, using the method of Ref. 1 calculated the snatch force to be 1290 lb.

This is the maximum snatch force, as it assumes that the drogue bag has infinite mass. An actual step-by-step calculation shows that the actual snatch force is approximately 60% of this maximum force.

The total snatch force is a combination of the mass snatch plus the door drag force and is given by actual $Fc$ = 774 lb (60%), door drag $F$ = 250 lb, total snatch force = 1024 lb.

To achieve the correct load carrying capability, the cord strength was increased. An analysis of the new strength cord indicated a point of no return, because as the cord strength is increased, the snatch force goes up. This is due to increased weights, and reduced cord extensions required to absorb the load. Typical results show that when using one 3-ft line of 1000 lb and four suspension lines of 550-lb strength each, the snatch force becomes 1530-lb maximum.

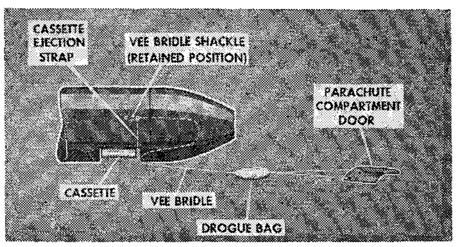


**Fig. 9 Drogue and bag extraction.**

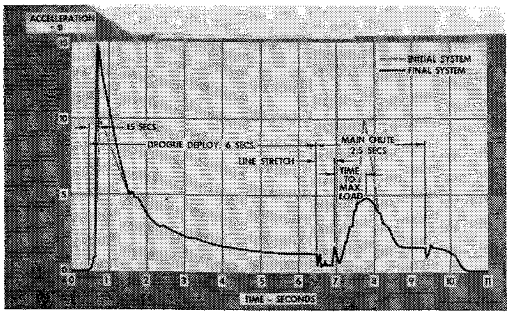


**Fig. 10 Acceleration/time trace for main and drag chute.**

After reviewing the situation, it was decided that a two-point suspension would be less prone to tangling and cutting than the four-point attachment, and a new attachment was designed consisting of one 3-ft line with 1500-lb strength plus two 22-in. 1500-lb lines attached to the rear corners of the door. A check was made of the snatch force and actual $Fc = 980$ lb, $F$ drag $= 30$–$500$ lb, $Fs = 1480$ with a mean of 1230 lb.

With this two-point attachment, the door streams end-on relative to the air stream, and concern was shown as to whether the drag force would be sufficient to deploy the drogue. Calculations showed that after snatch, the door and drogue bag both have a high velocity with a velocity relative to the drone of 96 fps. Therefore, with this relative velocity, if the drogue bag did not extract, there would be a further snatch force available. This force works out to be 480 lb and is sufficient to extract the bag and deploy the drogue.

To improve matters the final device installed consisted of a load link, which was designed to fail at increments of 300 lb and 500 lb, respectively. Material used was 1000-lb tape, lapped and sewn at 6-in. intervals with the final extended length of 36 in. A device of this length and with incremental failing loads gave sufficient shock attenuating properties and has been successfully flown as a two-door attachment for the Service Trials.

### Main Chute Inflation Problem

Using a metal cassette as the housing for the main chute appears to have caused a problem. It became evident during flight trials that the filling characteristics of the main chute were unpredictable, since the chute deploys in a very ragged manner. Discussions with specialists indicated the problem could be associated with the main chute porosity being too low, high terminal velocity of the drogue, and deployment of a canopy from the cassette.

#### *Main chute porosity*

A series of tests were conducted using main chutes with different porosities, these included chutes with 19% and 23% constant porosity and 19% variable porosity (VP).

The canopy designed for the drone has a 19% constant porosity and it was this one that was compared with the other two. Parameters compared included opening time, terminal velocity, and opening shock loads.

The results showed that the 23% constant porosity chute had the longest filling time, and hence the lowest opening shock. The 19% variable and 23% constant porosity (CP) chutes had a terminal velocity approximately 5% greater than the 19% CP chute. The opening shock was greatest on the 19% VP. This was established by placing a break tie of approximately 1400 lb in the main riser; and in most of the 19% VP chute drops this tie was broken.

A point brought out by the tests was the fact that the opening patterns of all the chutes did not appear to be different, so it was decided to stay with the existing constant porosity value of 19%.

#### *Drogue terminal velocity*

Because of drone weight changes, drogue terminal had increased and it became obvious that a larger drogue chute was required. The development of the new chute and activity in that area has been described previously.

#### *Deployment of a canopy from a cassette*

It appears from film data that when the cassette flaps are released, the chute pours out, and it immediately takes up a size and shape greater than the drogue chute and this slows down the process of separating the cassette from the remaining cloth of the main chute. The casette is finally extracted by the drogue, but by then the main canopy is uncontrollable and ragged. Two approaches to solving the problem were made; first, the canopy weight and density of pressure packing was reduced by producing the semicontinuous main chute, and second, the main chute suspension line strength was increased to absorb the high loads created by the ragged inflation.

These changes have reduced the problem but have not completely removed it. It is felt that there is still a possibility of getting a peculiarly loaded main chute because of the filling problem; however, the flight results indicate that the changes carried out have handled the high loads encountered.

## VII. Redesigned System Test Trials

The test trials were carried out in two stages. Both stages were implemented as a follow-through to the ground testing and were intended to demonstrate, flightwise, the reliability and integrity of the recovery system. The two stages were defined as dart trials and drone system flight tests; dart trials being mainly boost and recovery phase such that the complete regime of $g$'s and drone weight were covered. The flight trials will not be discussed since they contributed mainly in showing the reliability of the system.

### Recovery Test Vehicles (Dart Trials)

Ten flights were scheduled, the first few being to demonstrate the new separation system. The drogue and main chute used for flights 1 and 2 was the same as those used in previous flight trials.

Deployment was at low speeds and the drogue chute deployment appeared normal. However, analysis showed that the $C_{D_0}$ value for this drogue was on the low side, $g$ loads were low, and the terminal velocity was high.

Analysis of a main chute failure on the second flight showed an asymmetric filling condition that caused sequential failing of the suspension lines. Other points noted were that suspension line strengths were low compared with design requirements and that the filling characteristics of the chute when deployed from the cassette were very ragged. A study into the problem decided the following actions had to be taken: 1) decrease the terminal velocity on the drogue chute for future flights, 2) increase the strength of the main chute suspension lines, and make sure that a minimum figure of 250 lb/line is obtained (this minimum load includes degradation due to ultraviolet, abrasion effects, and joint inefficiences), and 3) investigate main chute filling characteristics, particular attention being paid to total porosity (this has been described under Main Chute Inflation problems).

For flights 3 and 4, a new system was flown, consisting of a 3.7-ft-diam drogue with continuous suspension lines sewn into the shroud, over the radials; also the main chute construction was semicontinuous with 300-lb nominal suspension lines.

Chute operation was good; both drogue and main performing normally. However, the drogue $C_{D_0}$ value appeared low as the terminal speed on the drogue was 202 fps, as this was a medium speed flight, with a drone weight of 225 lb.

Following investigations on the drogue performance, the drogue chute for the next flight was 3.7-ft diam using standard construction; continuous suspension lines were deleted. This change achieved an increase in drag and the drogue load recorded was 2250 lb. The deployment speed was low; terminal on the drogue, with a 225-lb drone weight reduced to 165 fps. Fill time on the main chute was very encouraging as it moved up to 1.1 sec. The main chute loads were also the lowest recorded (1080 lb). The five remaining flights used the new 3.7-ft-diam drogue, finalized main, the new pneumatic release system which included the cassette release valve.

The flights varied from medium high to high speed, all the flights were successful. Maximum load recorded on the drogue chute was 3400 lb, $C_{D_0}$ on the drogue varied from 0.46 to 0.52, and fill time on the main ranged from 0.8 to 1.2 sec. A typical trace and recovery stage sequence is illustrated in Fig. 10.

## VII. Shock Absorption at Landing Using Pneumatic Bags

The final recovery stage makes use of pneumatic bags. The energy to be absorbed is a function of the terminal velocity of the main, and at 42 fps, which is the high-altitude high-temperature requirement, it is difficult to absorb such a large energy. This becomes more difficult with the packing volume and weight allowance specified for the landing bags.

A complete test program has been carried out along with a computer study to establish the bag system parameters and a typical result is shown in Fig. 11. At 32 fps main chute terminal velocity, main parameters are: maximum stroke = 19 in., maximum shock $g$'s = 24 (2400 lb), time to max $g$'s = 45 msec, max pressure at diaphragm blowout = 4.25 psig, initial charging pressure = 1 psig, bag volume = 10 ft$^3$.

A description of the working mechanism is as follows: two bags each having a volume of 10 ft$^3$ are placed at the correct moment arm in the drone. They are charged from a one-shot system supply initially at 3300 psi; final inflation pressure is regulated not to exceed 1 psig.

At a specific stroke pressure combination, coincident with the energy to be absorbed, fixed area orifices are blown off. The peak pressure finally achieved generally overrides the blow-off point, so the size of orifice was determined by continual testing at various descent rates.

A significant problem encountered during ground and flight testing was the inability of this type of device to be stable in cross-wind conditions. Roll-over can occur; however, it was noted from test results that the major part of the energy in the moving body has been removed prior to roll-over, and landing shocks do not exceed the allowable $40g$.

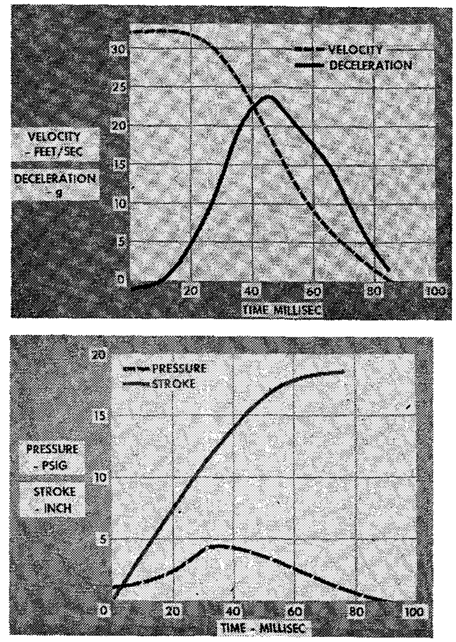


**Fig. 11 Landing bag performance.**

In many cases, especially at high descent rates, bounce was noted. This has been taken out by the addition of pressurized bolsters, which added to the footprint area and thus improved the efficiency of the system.

The finalized system has proved itself during flight trials, and one drone completed 14 flights with minor repair, indicating that this unsophisticated, cheap absorption device works satisfactorily.

## IX. Conclusions

The recovery system finally designed and tested for the AN/USD-501 has operated successfully. It has achieved the reliability required and in 86 flights only 2 flights have been lost, both attributed to a human error in rigging.

Although this approach to system proving has not been scientific, due mainly to cost, the analyze-and-fly technique adopted has proved successful. There are possibly a few more gray areas which may show up in the production article due to environment; nevertheless the system is over-strength and will be capable of handling problems as they arise.

## Reference

[1] Delurgio, P. R., "Retardation and Recovery Systems," Irvin Air Chute Co., Calif.