# Application of Aerodynamic Deceleration Systems to Target Drones

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**The Ryan Firebee Target System is a jet-powered, swept-winged, recoverable drone. It is a complex aircraft with numerous control and telemetry systems, and is remotely controlled through all flight maneuvers. To reduce recovery impact damage to both the airframe and its contents, a new recovery system has been developed called Mid-Air Retrieval System (MARS). In addition to the main 100-ft parachute, it includes an engagement parachute with its load line and associated hardware. A pole hook and winch arrangement aboard the helicopter permits mid-air hook up of the engagement parachute, release of the main chute reeling in the target drone, and returning the Firebee Target to home base with no damage. Improvements in this system now being developed are discussed. The second part of this paper presents several design studies relating to the reduction of impact damage from parachute recovery, including retro-rockets, impact bags, shock struts, and landing pads. Typical requirements for drone recovery are summarized and compared. A new concept for gliding drone engagement and towing by helicopter is described.**

## I. Mid-Air Recovery System

Our purpose is to present some of the deceleration and recovery problems faced within the Firebee Target System, how these problems have been solved to date, and current efforts to improve the recovery phase of the system. Further, we present some of our thinking on possible future means for continued improvement of target recoveries.

A brief description of the Firebee drone is necessary, to obtain a sufficient understanding of the recovery problems. Ryan's jet-powered, swept-wing Firebee target drone is a pilotless, recoverable aircraft of advanced design and is remotely controlled through all flight maneuvers. As a target, the Firebee is in operational service with the three military services. (See Fig. 1.) The Firebee is larger than the usual concept of a drone, with a length of approximately 23 ft and a basic gross weight of 2150 lb. (See Fig. 2.) In addition to its size, it is a complex aircraft with various control and telemetry systems incorporated. (See Fig. 3.) It is obvious that such a system, from both monetary and logistical aspects, must be recovered with the least amount of damage to both the airframe and its contents. The Firebee can be either ground- or air-launched. (See Figs. 4 and 5.) The Firebee recovers on a main parachute and is retrieved either from the water or from land. (See Fig. 6.)

Even with the rate of descent of approximately 16 fps afforded by the main canopy, there have been numerous recoveries where slight to severe damage of the drone has occurred. To avoid this damage, the Mid-Air Recovery System was developed. The normal methods of recovery of the target drone appeared readily adaptable to airborne retrieval, and the advantages of such a system were obvious. In addition to elimination of impact and salt water immersion damage, the loss of the target if it should impact in an inaccessible area could be prevented. A more timely return of the target to a prepared maintenance area and a saving in man-hours and subsequent turn-around time because of the elimination of repair prior to the next flight could be realized.

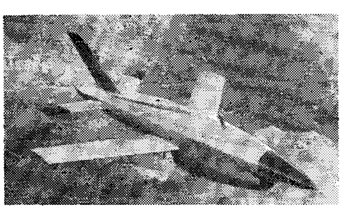

**Fig. 1 BQM-34A in flight.**

The Mid-Air Recovery System, or MARS, retained most of the previous recovery system with the addition of certain components to permit the airborne retrieval. It was decided that helicopters would be used for the recovery vehicle, because fixed-wing aircraft provided no means of docking the drone after recovery. The drone does not lend itself to a practical means of being taken aboard the recovery vehicle, such as is accomplished in rocket payload recoveries. The various elements of the system were tested separately before being combined into the MARS.

The pole, hook, and winch system installed in the helicopter was manufactured by the All-American Engineering Company, which provided technical assistance for support of the development program. The main recovery parachute, made by the Pioneer Parachute Company, was retained, and the engagement parachute load-line system was developed by Recovery Systems Research. The release mechanism was designed by Ryan. These are the major components of the system, but a detailed description is necessary to understand its operation fully and to point out some of the problems encountered and solved during the development program. (See Fig. 7.)

Item 1 is the engagement parachute, which is retrieved by the hooks-and-line portion of the helicopter recovery system. Numerous design changes were required for this parachute before one was developed which would fly high enough over the main canopy with enough stability that it could be hooked by the helicopter pilots. Item 2 is the load line connecting

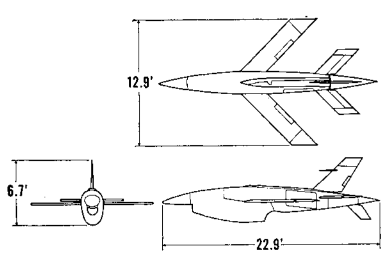


**Fig. 2 BQM-34A general arrangement. Gross weight (basic), 2150 lb; max. gross weight, 2500 lb; power plant, J-69-T-29 Continental; rated thrust, 1700 lb sea level standard thrust.**

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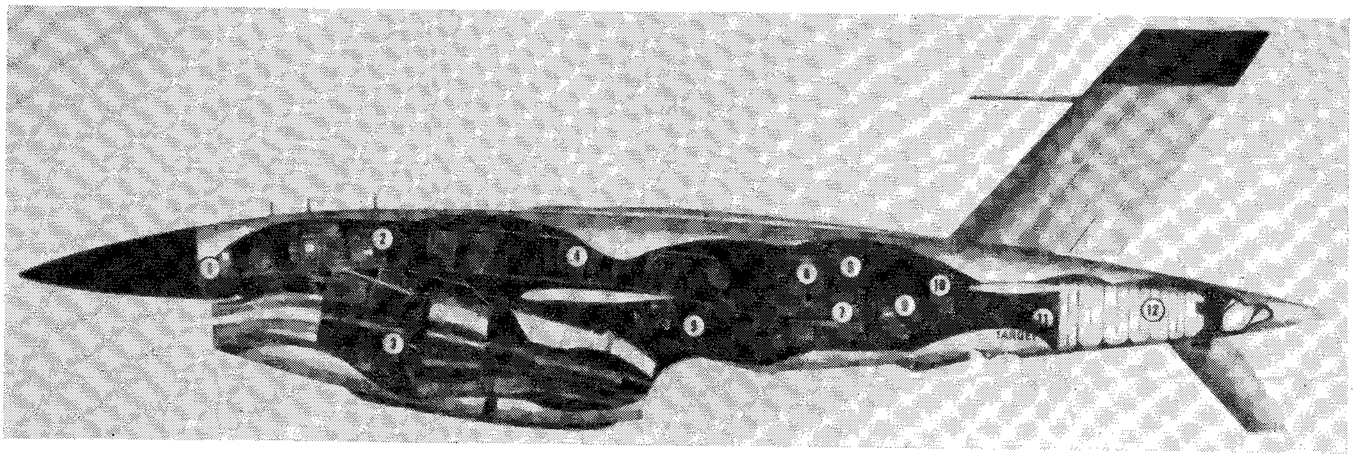

1) Scoring systems
2) Glide battery
3) J-69-T-29 engine
4) Fuel tank
5) Aileron servo
6) Flight control box
7) Radar augmentation equipment
8) Telemetry system
9) Radio control receiver
10) S-band beacon
11) Elevator servo
12) Parachute compartments

**Fig. 3 BQM-34A inboard profile.**

the engagement parachute to the Firebee. This line, after jettison of the main canopy, is reeled into the winch in the helicopter until the drone is stowed about 15 ft below the helicopter for return to base and docking. To avoid breaking this 10,000-lb test line and to avoid recovery damage to the drone, a 1.6-$g$ load setting is placed in the winch braking system, which absorbs that initial recovery load. At the apex of the main parachute, item 3, are installed two pyrotechnic cable cutters provided by Technical Ordnance Inc. These cutters have a 20-sec powder train that initiates a cutting blade separating a 6000-lb retaining line. The purpose of this retaining line is to absorb the deployment loads so that the load line will remain attached to the apex of the main parachute. This attachment was found to be necessary for the engagement parachute to maintain a position at a sufficient distance above the main parachute to permit a proper approach by the helicopter. After the retaining line is cut, the load line is maintained in position by a 550-lb breakline that is separated upon recovery by a helicopter.

Item 4 is a black flag attached to the load line to assist the helicopter pilots in locating this line before attempting an engagement. Experience showed that if the engagement was made in such a manner that the nylon load line was dragged through the main canopy, the action of nylon upon nylon could easily fail the load line. With the load line located, the helicopter approach could be made in such a manner that the load line would be pulled away from the main canopy. Item 5 is the release mechanism and ground impact separation device. Research into results of similar past recovery attempts showed that it was not feasible to recover the system with the main canopy remaining attached because the large canopy would not tow properly and could pose dangerous conditions during the docking operation. Therefore, a release mechanism was developed which would release the main canopy by the breaking of a shear pin when the weight of the drone was transferred from the main parachute to the load line upon engagement. At first this mechanism con-

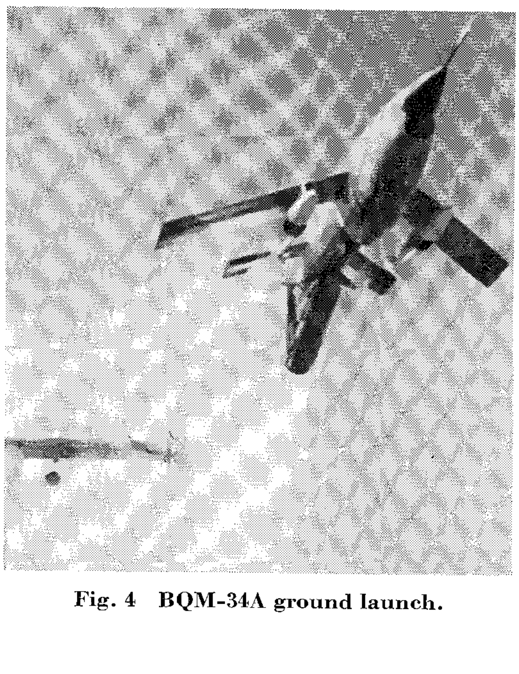

**Fig. 4 BQM-34A ground launch.**

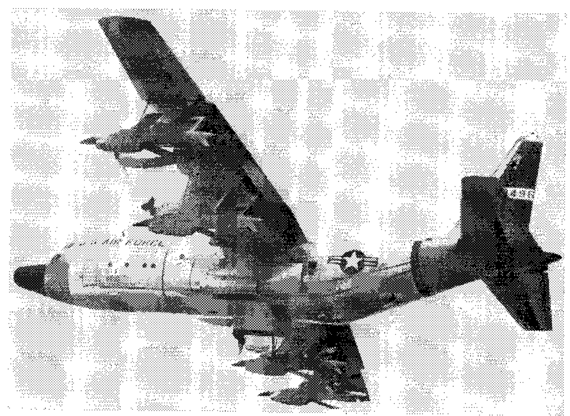

**Fig. 5 BQM-34A air launch.**

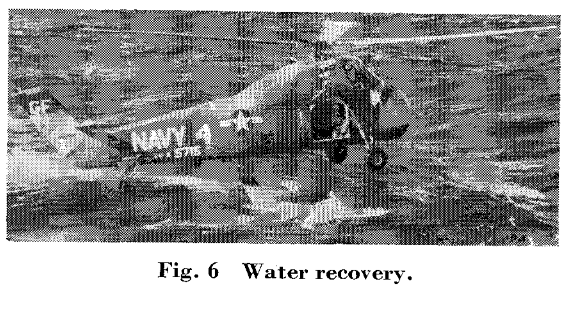

**Fig. 6 Water recovery.**

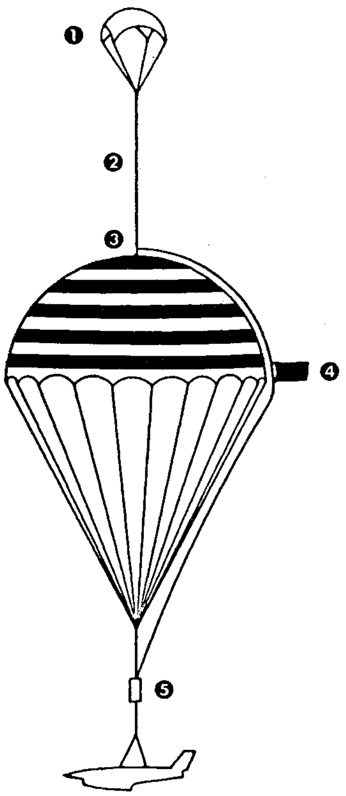


Fig. 7 MARS.

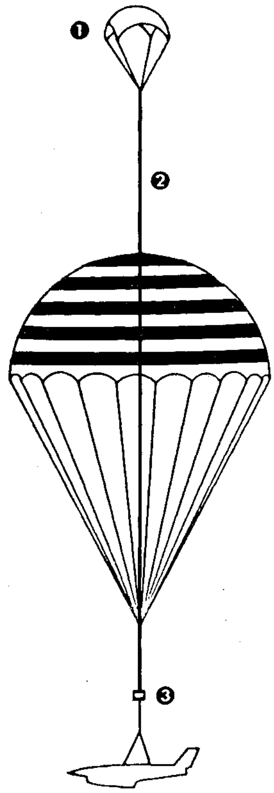


Fig. 9 MARS product improvement program (PIP).

tained a similar pyrotechnic to that of the cable cutters, so the pin would not be sheared during deployment. This was found later to be unnecessary and was removed. The impact release is an electrically energized explosive bolt that releases the drone from the load line upon contact with the ground.

The various sequences of the recovery are as follows. (See Fig. 8.) Upon completion of the target mission, while the Firebee is still at altitude, a drag chute that is housed in the tail cone of the target is deployed on command. The target then descends to an altitude of 15,000 ft, where a barometric switch fires squibs that release the MARS container. The drag chute and this container fall away from the system. Both the engagement and main parachutes have 4-sec reefing cutters installed for the initial deployment sequence. The system then assumes the configuration previously discussed. Once the system is fully deployed, with the engagement parachute in position, the helicopter approaches, locates the load line by means of the black flag, and sets up its approach for engagement. The pilot flies the helicopter directly over the engagement parachute and hooks it with one or more of the three hooks attached to the pole and hook line. Upon engagement, the main canopy is jettisoned and the drone is reeled into towing position and ultimately docked. A successful mission will return the drone to the desired location literally unscratched.

Fig. 8 MARS retrieval.

The MARS just discussed is proving to be worth all the effort devoted to its development. During its development much information was accumulated which could improve system reliability, and a product improvement program is now being pursued. Item 1 involves further development of the engagement parachute so it will present a better and more stable target for the helicopter pilots. This development is considering increasing parachute size and length of load line above the main canopy in an effort to reach more stable air, away from the effects of the main canopy. Experience further led to the conclusion that the main canopy might, in fact, be retained during the engagement, towing, and docking operations. This would require the development of special rigging to prevent paraplanning of the parachute during tow and billowing while docking. (See Fig. 9.) By maintaining the canopy on the load line, the two 6000-lb retaining line cable cutters and the 550-lb breakaway line can be discarded. Further, because the load line will no longer be pulled through the main canopy, the black flag can also be discarded. The release mechanism, item 3, is no longer required. All that remains is the ground-impact separation device.

In addition to simplification and reduction in cost of the MARS, there will be an obvious increase in reliability because of the elimination of possible failure features, such as pyrotechnics and shear pins. This final system will also have the advantage of redepolyment of the main parachute and possible recovery of the drone in the event the system must be jettisoned because of an emergency condition arising aboard the helicopter.

By means of an improved recovery system, the life and efficiency of our product has been improved. However, this is an area that must always be scrutinized for further development. With drone growth in complexity, size, and weight, it may be necessary to look to other means of recovery.

## II. Recovery Systems Design Studies

This portion of our presentation is concerned with the design areas of potential development for drone recovery systems that keep pace with the increased value of the units to be recovered. Current systems can be improved to reduce impact $g$'s, accept lateral drift energy, and resist damage from irregular surface terrain.

As mid-air retrieval reliability approaches 100%, the need for impact provisions vanishes. However, being practical, one recognizes the likelihood of occasional drone inadvertent impacts, allowing for weather and human factors. The following discussion is primarily concerned with recovery in the event of missed mid-air retrieval or where mid-air retrieval is not employed, as for instance within a live anti-aircraft firing range.

The current parachute recovery system began with small, radio-controlled models used for target practice during World War II. The parachute is excellent up to the point where the target impact damage usually sustained is minor. However, for heavier and more complex drones, the impact damage increases to the point where it is profitable to augment the parachute with a terminal energy absorber system. The designs discussed include several options for this type of combined parachute plus impact shock attenuation system.

Attention to the recovery system is justified by the relative cost of impact damage sustained vs recovery system amortized cost. In general, recovery system cost is a function of weight and is spread over 10 flights or more, whereas impact damage cost is magnified by systems complexity and is recurrent with each flight.

Statistical analysis of the Ryan Aeronautical Company target drone recovery system, prior to the MARS technique, shows that 90% of the Firebee target drones going into the recovery sequence are actually recovered, 3.3% are abandoned or lost during recovery, and 6.7% are expended by recovery system failures or undetermined causes. These figures combine to bound the area of design interest. The goal can be summarized as reduction of losses by minimizing impact damage, while improving the over-all reliability of the recovery system.

Figure 10 shows a typical drone configuration and identifies the main components of a combined parachute, retro-rocket, and landing-pad approach. The parachute is rigged so that the drone is approximately level at the time of impact. The main risers are attached near the vehicle c.g. and stowed in a trough along the fuselage during flight. The drogue chute decelerates the drone to roughly 180 knots prior to extracting the main canopy. Recovery is often initiated at high altitude, with the drone guided toward the recovery zone during the steep descent with the drogue deployed. Typical descent trajectory roll control permits the recovery zone diameter to be just over 1 mile.

A barometric switch would deploy the retro-rocket height sensor, arm the rocket circuitry, and extend the landing pads. The circuit would have a command override for the typical case of mid-air retrieval success. It would also be desirable to extend the landing pads independently of the rocket system, for winch-down of the drone after helicopter retrieval and return.

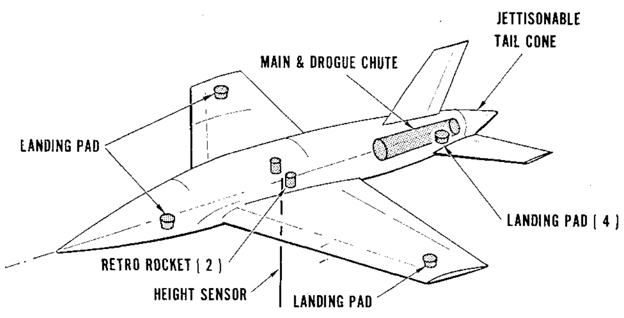


**Fig. 10 Retro-rocket and landing pad general arrangement.**

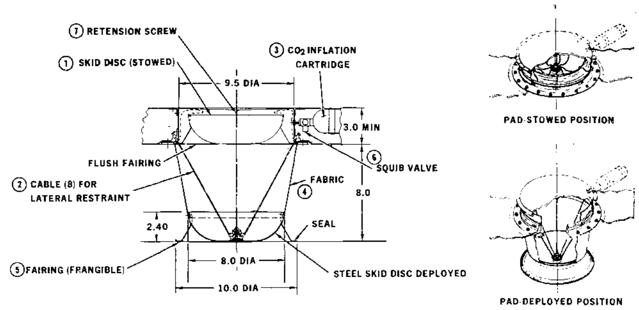


**Fig. 11 Landing pad detail, stowed and deployed.**

### Landing Pads

The need for deployable landing pads has evolved from the general requirement of negligible impact damage to the drones when coupled with the typical horizontal component of impact velocity from parachute descent. Including both the velocity due to the parachute oscillations and the horizontal velocity from wind, the total can be over 30 fps in any direction. This velocity can be reduced efficiently by sliding friction over a reasonably smooth surface. For sliding, the vehicle needs skids that are supported against drag load, spaced for resistance to vehicle turnover, and with enough ground clearance to prevent scraping of the airframe bottom. The skids should also be capable of absorbing secondary vertical energy equivalent to the off-nominal error anticipated from the main energy absorbers.

The design evolved to meet these requirements is illustrated in Fig. 11. It is a system of widely spaced landing pads, each consisting of a stainless-steel disk 8 in. in diameter, with a flat center and a $2\frac{1}{2}$-in. edge radius. The bowl thus formed can be stowed in a 3-in. depth, yet will resist digging in when sliding over the ground. The pad was sized for 20-psi footprint bearing pressure, using four pads to support the drone. This is equivalent to "soft lawn"-type soil. The design shown includes internal tension cables tied to the center of the skid disk to react the drag loads on the disk from any direction generated by sliding friction. The pads are deployed by $CO_2$ pressure bottles from their flush stowed positions in the nose, outer wing panels, and tail. The pressure from the $CO_2$ cartridge acts against the skid plate and retention screw. The screw snaps at a necked-down area, releasing the skid for deployment. The bags are of laminated and reinforced, biased, high-strength fabric capable of 50-psia peak pressure. The bags are not vented but act as springs with rebound. The extent of deflection permitted is a function of the tolerable $g$ levels of the structure when loaded at the pad points. Pressures can be modified between bags to equalize deflections or can be adjusted for various off-nominal impact velocities. The pads would be reusable by replacement of the fairing skin, the cartridge of $CO_2$, the charge in the squib valve, and the retention screw. Pads of this type have advantages for landing the drone by helicopter winch-down procedure as well as for general ground-handling supports. Their weight is estimated at 7 lb each plus 2 lb each for the inflation system.

### Retro-Rockets

Studies of retro-rocket arrangements have led to an internal mounting design for two motors. Location of the motors for this case is on the c.g. mounted on the wing rear beam within the fuselage. Flush mounting is achieved by use of cylindrical motors with a mounting flange consistent with the contour

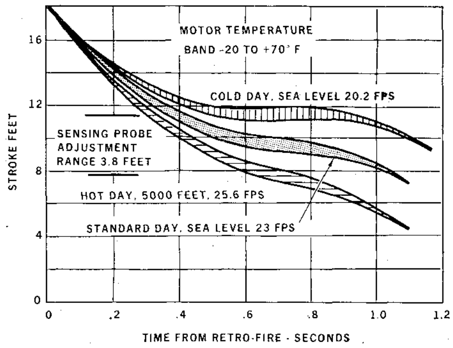


**Fig. 12 Retro-rocket performance.**

of the lower surface. The design permits installation from the outside in a manner that is foolproof and safe. A prearming pin and flag are removed prior to flight to clear the igniter circuit for subsequent inflight arming. The motors are inserted into matching cans built into the structure just aft of the firewall.

Typical retro-rocket characteristics are specified in Table 1. The retro-rockets are sized to provide a nominal velocity change of 23 fps at 70°F and sea level. The emphasis is on reliable motors designed for volume production and low unit cost. Motors are sealed prior to firing and mounted flush with the surface contour. Dual bridgewire igniters are employed to permit redundant firing circuits. Throughout the recovery system, initiators qualified for aerospace applications have been selected to upgrade the over-all system reliability.

The retro-rockets are mounted vertically in the body to avoid thrust losses from nozzle canting. The predictable chute oscillation of ±8° produces at most a 2% loss of vertical thrust. By specification of a 0.70-sec burn time, an 8-ft nominal stroke or deceleration distance is assured. This limits the net load on the airframe to two $g$'s from combined rocket and parachute, for the nominal case. The retro-rocket performance variations from manufacturing tolerances and mounting misalignments have been found to be insignificant. For this application, rocket thrust varies with motor temperature roughly 3 lb per degree Fahrenheit. This effect can be minimized, by determining the rocket compartment temperature from flight test and providing insulation as needed. Once flight test envelopes are established, the motor sizing can be adjusted for production units.

The major variable between flights which affects the rocket thrust initiation point is the parachute descent rate changes induced by climatic conditions. It appears that the motor ignition height must be varied to compensate for the variations in pressure altitude and temperature of the recovery

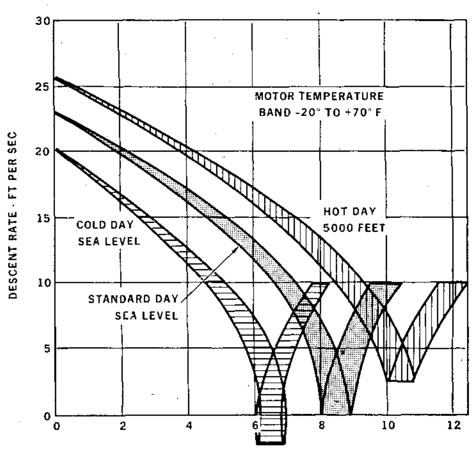


**Fig. 13 Retro-rocket impact velocity variations.**

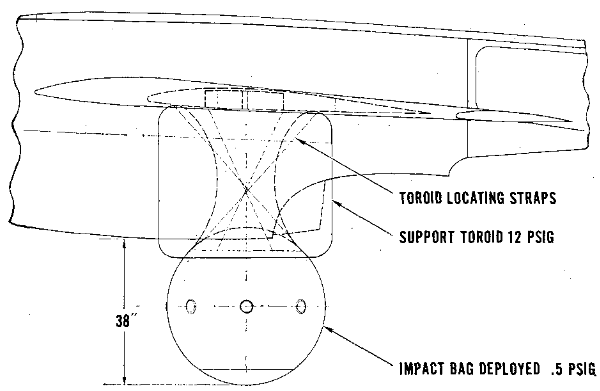


**Fig. 14 Impact bag wing installation.**

zone. The curves of Fig. 12 show the difference in the point of thrust initiation for various velocities of parachute descent. Three cases are plotted, covering initial descent rates from 20.2 to 25.6 fps. These descent rates correspond to a standard cold day at sea level and a hot day at 5000 ft. The adjustment of initiation height can be accomplished by the use of a velocity sensor or simply by extending or shortening the sensing probe in advance of the flight. The range of adjustment is shown to be 3.8 ft to compensate for the selected range of initial conditions.

If for each pressure altitude and air temperature combination the best single initiation height is chosen, and the rockets are correctly sized for standard sea level conditions, the corresponding initiation heights and impact velocities are as shown in Fig. 13. Using the landing pads for off-nominal velocities, it appears that one size of retro-rocket will satisfy the requirements assumed.

### Impact Bags

Investigation of impact bag performance with burst diaphragms and variable orifices has been adequately treated, and tested by industry and NASA.[1,2] One problem area arising from these tests, however, is the restraining of the deployed bag from shifting with side forces resulting from impact with drift. Figure 14 defines a design, applied to a mid-wing drone, which offers a solution to the lateral stability of the bags under combined impact and has reasonable stowage provisions. It also provides a means of extending the bag position below the supporting surface. The general specifications of this system are listed in Table 2. The principle of a spherical impact bag nested in a toroid is utilized. The toroid is deployed simultaneously with the impact bag, but to a higher pressure. It does not deflate at impact but supports the impact bag during deflation. The crossed cables react the side loads imposed on the toroid from the impact bag sliding friction. The cables are preloaded by toroidal pressure, so that the toroid base is reasonably rigid up to the

**Table 1 Retro-rocket requirements**

Number per aircraft—2
Shape—cylindrical
Diameter—5 in.
Length—max. 14 in. (8 in. plus igniter and cans)
Total impulse—1570 lb-sec
Nominal thrust—2200 lb
Burning time—0.70 sec
Time to 90% thrust—0.020 sec (max.)
Specific impulse ($I_{sp}$)—200 sec minimum
Weight—motor assembly: 12 lb max.; ($W_p$ = 8 lb) each
Thrust—time curve—rectangular
Mounting provisions—sliding fit within tube, before and after firing
Reuse not required
Shelf life required—10 yr

**Table 2 Impact bag requirements for drone aircraft recovery**

- Example data
  - Suspended weight—2800 lb
  - Vertical velocity sea level standard 20 fps
  - Impact $g$ (vertical)—4.0 nominal, 6.4 limit, 8.0 ultimate
  - Horizontal $g$ limit (horizontal)—4 ultimate lateral, 8 ultimate fore and aft
- Bag system
  - Shape—spherical (diameter 41 in.) (2)
  - Toroids—D section: 45-in. o.d., 15-in. i.d., 40 in. high
  - Features—burst diaphragms around horizontal equator
    - —strap ties to wing for horizontal loads
    - —abrasive resistant for ground handling use
- Inflation system
  - Central bottle—inflates spheres and toroids
  - Squib valve—single actuator
  - Blowoff panels—nonstructural, spring loaded, expendable
  - Check valves at bags, 1 each
  - Height sensor—or microwave command guidance system (MCGS) command signals inflation
- Deflation system
  - Burst diaphragms, 16 each
  - Variable orifices—elastic sleeves
  - Sealed orifices after deflation—to prevent water collection after water impact
- Bumper system
  - Toroidal bags surrounding main bags retain air and support impact bags during stroke

compressive limit. The cables are tied to the main spar caps at rib intersections. The reaction of the toroid on the wing surface surrounds the cutout required for stowage of the inflatable system. The toroid further serves as a bumper for wing leveling after impact and as flotation volume for water landings.

Since the location of the recovery c.g. of the vehicle is known in advance, only two bags are shown for this approach, one on each wing at the station of the recovery c.g. A similar arrangement could be devised for a fuselage installation. In this case the toroid would vary in thickness to accommodate fuselage contour on top and provide a flat lower surface for bag support on the bottom.

### Shock Struts

As the study of the retro-rocket application for drone recovery progressed, the need for additional shock attenuation became clear if airframe impact damage is to be eliminated. The impact case, however, is expected to be the exception rather than the rule, now that the MARS has been developed. Since the shock system would seldom be used,

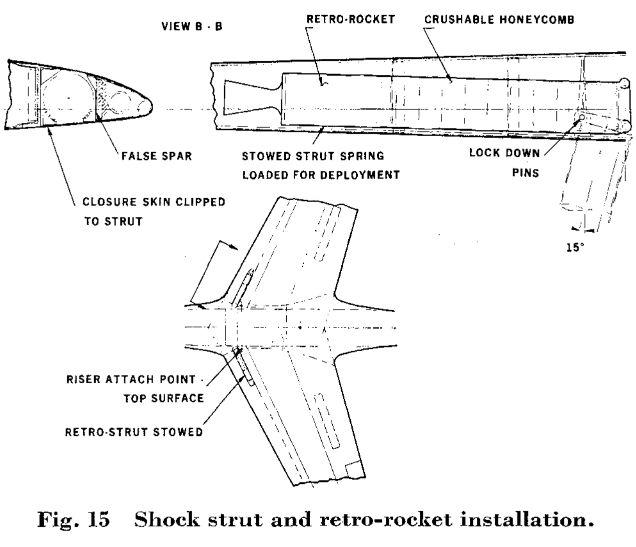


**Fig. 15 Shock strut and retro-rocket installation.**

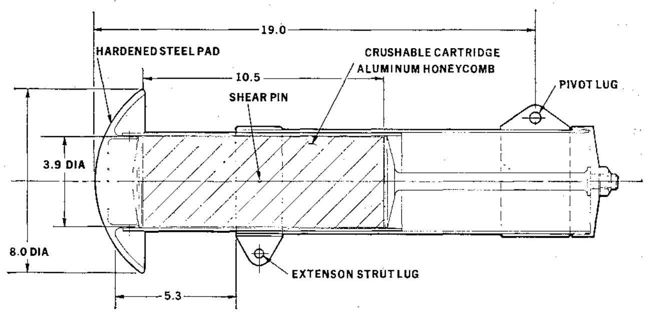


**Fig. 16 Shock strut detail.**

it follows that a replaceable cartridge type of shock strut using deformation energy to reduce weight would be appropriate. Many types could be selected, but the aluminum honeycomb crushable cartridge has both ease of replacement and high efficiency. Typical 8-lb/ft$^3$ aluminum honeycomb core will absorb over 7500 ft-lb/lb of honeycomb.

The problem resolves into one of gaining adequate stroke to limit the $g$ loads while still reacting the substantial side loads in an extendable lightweight cylinder. One concept is shown on Fig. 15. The system consists of two forward shock struts plus a crushable ventral fin. The drone is rigged for tail low impact followed by rotation about the aft fin. The fin acts as the sensing probe to fire the retrorockets. In this example, the function of the retro-rocket case is to act as the compression piston against the honeycomb. Since the stroke exceeds the length of the exposed case, the main tube is deformed by swaging or peeling as the case moves up the tube. Simultaneously, a side load from any direction can occur from ambient winds.

The high lateral landing forces require the design of the struts to incorporate high-tensile steel telescoping cylinders and equivalent forgings in the wing root for strut mounting. Figure 16 shows the detail of a similar strut designed to withstand the 4-$g$ lateral case. It weighs over 25 lb. For this design, the retro-rocket has been placed in the body, permitting a universal skid to be fitted at the strut base. The size of this spherical disk is limited by the available storage dimensions in the wing. Although the shock struts provide high ground clearance, they are ineffective for water landings.

A summary comparison matrix of energy absorbers is included as Table 3. No specific "best system" can be identified without taking into account the vehicle configuration, performance goals, and operating conditions. However, the retro-rocket and landing pad combination offers the lowest weight approach and best handles the horizontal velocity components of the parachute descent.

Returning to the subject of mid-air retrieval systems, a brief description of a proposed approach to in-flight pickup is shown in Fig. 17. As wing loadings of drones decrease and

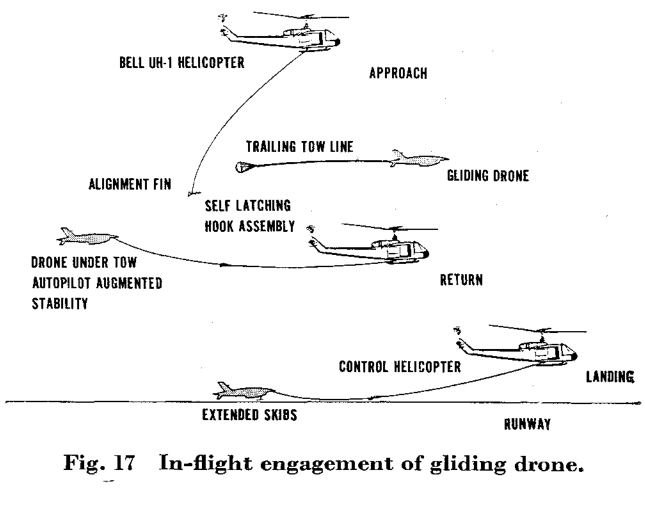


**Fig. 17 In-flight engagement of gliding drone.**

**Table 3 Comparison matrix—impact energy absorbers**

| | Impact bags | Retro-rocket and landing pads | Retro-rockets and shock struts |
|---|---|---|---|
| Basic feature | Controlled air escape cancels vertical and lateral velocity | Reaction stops descent, pads slide | Reaction plus shocks stop descent, pads slide |
| Primary advantage | Independent | Efficient | High ground clearance |
| Primary disadvantage | Subject to rupture | Sensitive to descent rate | Retraction system |
| Weight | Low | Lowest | Heavy |
| Limit of stroke | Size and stability of bag | Sensing precision | Bending load on struts |
| Typical impact $g$'s | 4 | 2 | 2 |
| Structural compromise | Bag stowage cutouts in wing and body | Small pad cutouts | Wing slots for struts |
| Overload potential | Negligible | Good | Good |
| Timing sensitivity | Noncritical | Close tolerance | Close tolerance |
| Hazard and source | High-pressure bottles | Pyrotechnics | Pyrotechnics |
| Reuseability | Good | Good on pads, replace rockets | Good on struts, replace rockets and crushed material |
| Surface limitations | No sharp rocks, reasonably level | Reasonably level | Reasonably sloped and rocky |
| Development status | Many prior efforts | Rockets developed, pads new | Rockets developed, shocks—lunar excursion module |
| Secondary uses | Water flotation | Ground cushion | Ground handling |
| Maintainability | Overhaul bags, pack, and recharge | Stow pads, replace rockets, and cartridges | Reload struts, replace rockets |

helicopter performance improves, the ability of the drone to glide at helicopter cruise speed is reached. Once the drone stabilizes in gliding flight, the mid-air recovery engagement may be revised and simplified. Instead of using a large parachute for descent, the gliding drone could tow a drag chute. The retrieval helicopter could overtake the drone from above and behind at a small angle to the flight path of the drone, as shown on the slide. A hook-ended line hung below the helicopter would intersect the trailed line of the drone. As the hook was pulled up to the drone line, the open jaws would engage and lock the two lines together. The remaining slack would be taken by the helicopter maneuvering above and ahead of the drone and adjusting to a towing speed and position.

The empty drone would glide at less than 100 knots and sink less than 10 fps. Once in the recovery area, it could be programmed to glide in large circles, giving the helicopter opportunity for repeated passes if needed. The low sink rate would double the time available for intercept, as compared with the parachute method. It would, in effect, be a cooperative target.

Helicopter pilots prefer not to approach a hover at altitude because of the high power required and the possibility of power settling. Unlike the parachute retrieval system, this type of engagement would be in the helicopter's cruise speed range. The relative speed between the drone and the helicopter would be less than 10 knots, and the impact forces would be reduced to towing surges. Since the towing force required to keep the drone trailing the helicopter would be approximately 150 lb for a 2000-lb empty drone, the ratio of helicopter-to-drone size is obviously grossly changed. A helicopter could retrieve a drone of empty weight greater than the gross weight of the helicopter using the towing technique. Once the engagement between the gliding drone and the overtaking helicopter is made, the helicopter pilot would be responsible for both vehicles. He would position his machine to accept the towing load at an efficient cruise speed and head for the touchdown area. Long-range towing would be facilitated by this retrieval means.

To provide a trailing line tie-in to the drone and also a forward towing attachment, a swinging Y link is proposed. The attachments to the drone would be at the wing spar root fittings, where two steel straps would be hinged. The straps would be stowed externally along the fuselage contour, apex aft to form the attachment point for the trailing towline and take the small chute drag force. The straps would swing forward during the air snatch to form the nose fitting for reaction of towing forces well ahead of the drone c.g. The strap stiffness would present fouling of the lines on the tail of the drone and would guide the tow cable over the top of the drone to the towing position. Proper position of the forward attachment of the tow cable could match the cruise speed of the helicopter with the towed position of the drone.

To commit the drone to a power-off landing, the helicopter pilot would simulate an airplane type of approach to the runway. The pilot would gradually reduce helicopter speed and altitude over the runway, causing the drone to sink. As it touched down, the helicopter pilot would maintain the drone's heading, by keeping the tow line taut. A gradual transition to hover and helicopter landing would complete the mission.

Only two operations are required on board the drone for this system to function. These are the trimmed gliding flight using the autopilot on board, and the deployment of the trailing line, a barometric actuator function. Since one end of the system is manned, the interaction of the dynamic forces between the vehicles, such as towing surges, downwash effects, etc., can be recognized and counteraction taken by the helicopter pilot.

## References

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