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# REVIEW OF THE SPACE VEHICLE LANDING AND RECOVERY RESEARCH AT AMES

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## Introduction

A very limited effort has been directed at manned space vehicle recovery and landing systems at the Ames Research Center. In general, up to this time, most of the wind-tunnel test results have been directed at specific projects of the Manned Spacecraft Center such as the steerable parachute for the Apollo mission and the paraglider development for the Gemini mission. Some work has been done at small-scale of the variation of lifting reentry body shapes to give significant range in the earth's atmosphere and enable horizontal landing capability. In this regard, large-scale wind-tunnel studies are planned of a lifting reentry configuration with an inflatable afterbody and control system for glide and landing. The fourth system which Ames has done some work and plans to do more is in the use of lifting rotors, both rigid and flexible, for deceleration, glide and landing of manned space vehicles.

## Discussion

Parachutes. - The tests in the development of the Apollo steerable parachute were conducted in the Ames 40- by 80-foot Wind Tunnel and were primarily directed at determining the extendable flap arrangements for the best lift-to-drag ratio and static stability. A short motion picture film shows how the studies were conducted with a single parachute having an extendable flap for glide path control. The motion picture film is a supplement of TN D-1334. In these studies the extendable flap span was varied from 7 gores to 13 gores and the flap chord was varied from 10 percent to 33 percent of the parachute diameter which resulted in maximum L/D varying from 0.4 to about 0.55. The static longitudinal and directional stability was also measured for a range of conditions of the extendable flaps. The control response characteristics of letting out and pulling in the flap were measured which indicated that the control response would be instantaneous and the L/D ratios at dynamic conditions could be approximately 40 percent higher than at static conditions. The maximum value L/D ratio was controlled by the stall of the second skirt at the leading edge of the parachute, however, in this condition, the parachute remained very stable.

Wind-tunnel studies of multiple parachutes were also made which are shown in figures 1, 2 and 3. For the case of two side-by-side parachutes with extendable flaps the lift-to-drag ratio obtained was approximately the same as the single parachute of the order of 0.5, however, the dynamic stability was considerably poorer. For the triple parachute with a single pusher as shown in the next slide, the maximum L/D ratio was very low of the order of 0.1 to 0.3 depending on the number of parachutes utilizing extendable flaps for control. The low value of 0.1 was obtained with only the single pusher utilizing the controllable flap. For the case of the double pusher with a triple parachute system the L/D ratio obtained was the same as with the single parachute and the stability of the system appeared fairly good although some small oscillation did occur probably due to the inability to control the yaw.

Future studies are planned with multiple parachutes in the presence of bodies to determine the effect of a large wake on the stability and performance of a cluster system of parachutes.

Paragliders. - Wind-tunnel studies have recently been completed of a half-scale model of the Gemini paraglider landing system. Studies were made for the glide regime, pre-flare, and flare-to-landing as shown in figure 4. Line loads and the normal six component aerodynamic measurements were made for various conditions of pitch attitude, sideslip angle and control variations. Studies were also made in the U-shape first phase of deployment. Motion pictures were shown to indicate the method used to obtain these results and also show tests where the lines were let out quite rapidly during the last stages of deployment just preceding paraglider gliding flight.

Lift-to-drag ratios of the order of 2.7 to 2.9 were obtained dependent on the configuration. Three-bolt rope settings of 4.1 percent, 8.2 percent and 12.3 percent were studied with the 8.2 percent giving slightly better values of lift-drag ratio than the others. The stability and control of the vehicle appears adequate for glide and landing with possible touchdown speeds of about 45 knots for the full-scale vehicle.

Deployment of the paraglider to the U-shape was attempted, but due to the inadequate tie-down and bolt-rope attachments on the paraglider, the deployment and the inflation of the keel and booms during this phase of the deployment could not be accomplished. The deployment studies are planned to be continued in the near future with improved design and inflation techniques. Several problem areas appear to exist during deployment such as, the length of inflation time and the effects of the body flow on the oscillations of the partially deployed paraglider.

Inflatable afterbody. - A number of wind-tunnel studies have been made of small-scale models at Ames of lifting-body reentry shapes. Some of the tests have been directed at numerous afterbody shapes with control surfaces on the M-1 vehicle for glide and landing as shown for one case in figure 5. At present plans are to conduct large-scale tests of an M-1L configuration with an inflatable afterbody and control surfaces that would be deployed at high subsonic speeds. From the small-scale tests, it appears the maximum lift-to-drag ratios of the order of 4.0 can be obtained and landings with horizontal velocities of the order of 120 knots on runways would be required with a lifting-body type of configuration. Dependent on the success obtained, the deployment of inflatable afterbodies and control surfaces and their ability to carry the loads and give the required lift-drag ratios and stability and control, further studies would be pursued with inflatable systems applied to obtain low aspect-ratio wing shapes on the lifting body reentry configuration. Deployment of the afterbody at a supersonic Mach number of the order of 2.5 is being considered as well to provide glide ranges of the order of 150 miles.

Lifting rotor. - It is planned at present to conduct wind-tunnel tests of large-scale lifting rotor system for deceleration, glide and landing of a manned space vehicle. Two stages, the deceleration and glide phases are illustrated in figure 6. The intention at present is to conduct studies at deployment and deceleration phases at subsonic speeds where the dynamic pressures at high altitudes are of the same order as can be obtained in the Wind tunnel. During the deceleration, the rotor blades will be operating in the stalled blade state to give high-drag at subsonic tip speeds. The drag forces for deceleration should be controllable thus eliminating high deployment loads and enabling control of the rotor loads and oscillating stresses. Wind-tunnel studies will also be made in the autorative glide state with cyclic control to enable trim at higher lift-to-drag ratios than possible by simply tilting the rotor axis. It is anticipated that lift-to-drag ratios of the order 5 to 6 can be obtained with rotor systems.

During landing, figure 7, the horizontal and vertical velocity components can be made to be essentially zero by conducting a cyclic and collective flare as done by helicopters in autorotative landings. The other method is to conduct a collective flare from a vertical descent configuration. The effect of higher disc loading of this type of rotor system can be offset by tip weights so that flares can be accomplished with little or no vertical velocity at touchdown.

A number of problem areas can exist which should be studies, among these are deployment, operation in the stalled blade state, high rotor tip speeds, flare and landing with high disc loading rotors. Consideration is being given to conducting studies at supersonic speed to determine the effectiveness of a highly coned rotor as a deceleration device to enable autorotative glide to be started at high altitudes and thus enable extensive increases in the useable range.

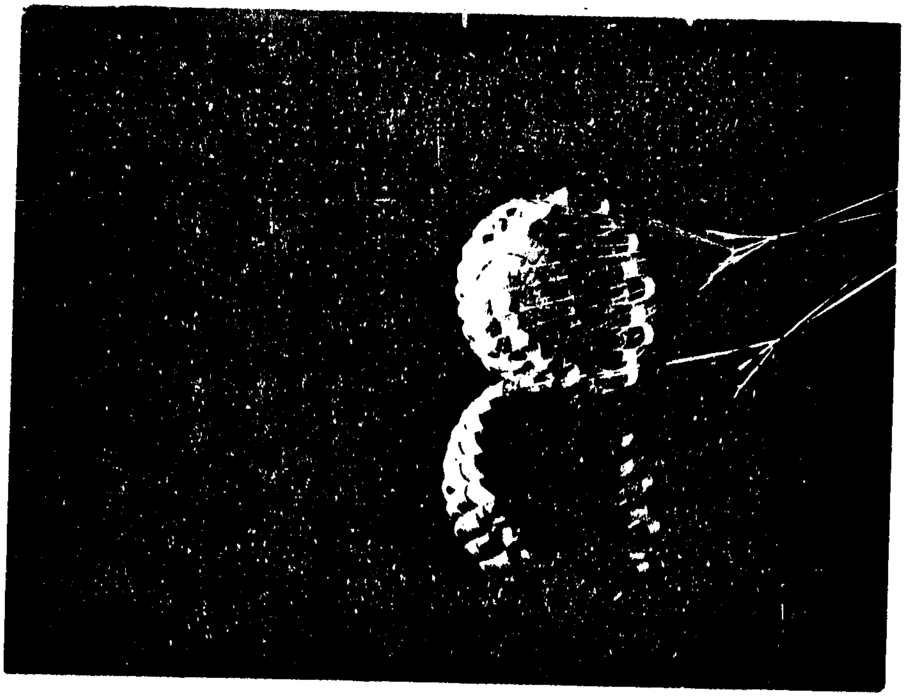

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FIGURE 1.- SIDE BY SIDE

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FIGURE 2.- SINGLE PUSHER

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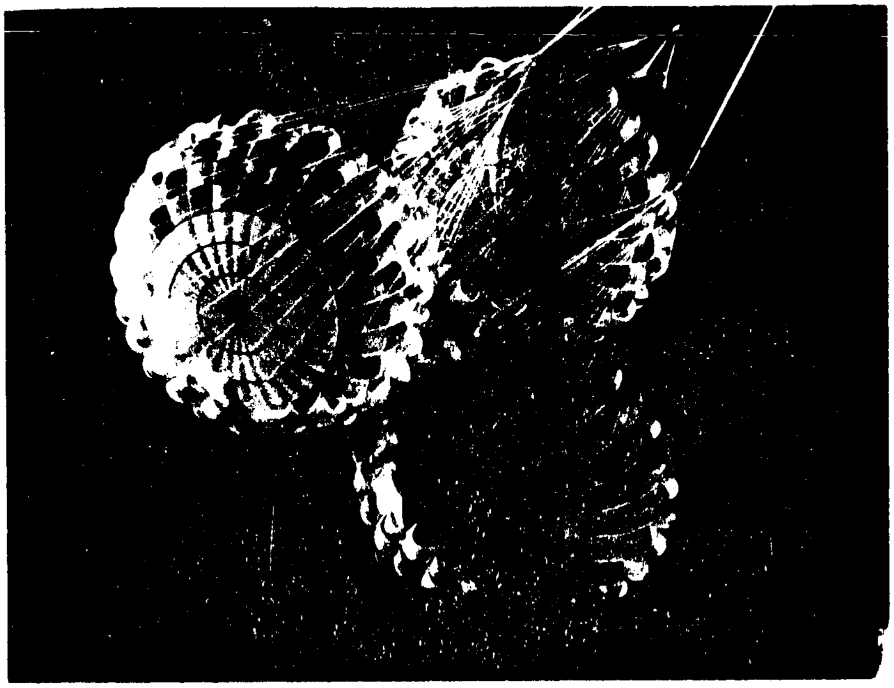

FIGURE 3.- DOUBLE PUSHER

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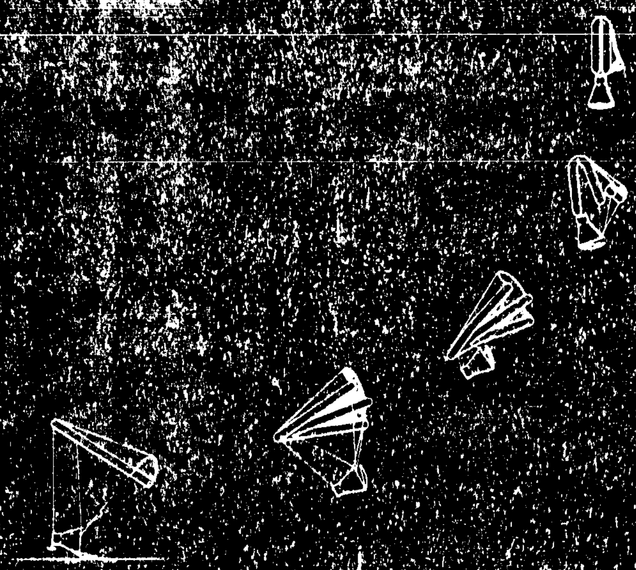
## DEPLOYMENT AND GLIDE

### PARAGLIDER



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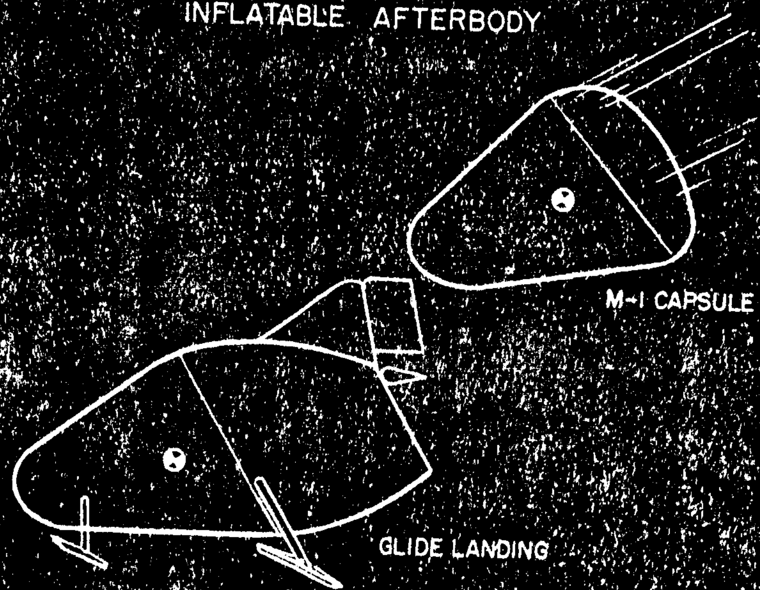
SLIDE FIG

## INFLATABLE AFTERBODY

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## ROTOR LANDING SYSTEM

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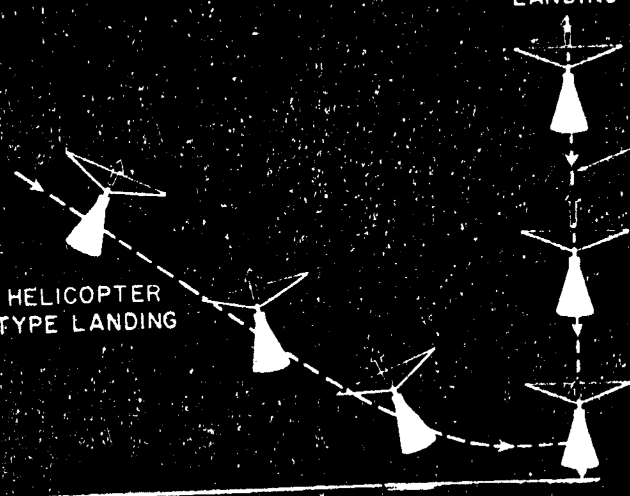
## LANDING MANEUVERS

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SLIDE FIG
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