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NASA - Langley

HEADQUARTERS MEETING July 10-11, 1962

THE PROBLEMS OF THE ENERGY DISSIPATION SYSTEMS IN SPACECRAFT RECOVERY

By Lloyd J. Fisher

Several aspects of earth landing requirements for manned space vehicles are being investigated by Langley Research Center. The character of research undertaken consists of experimental and analytical studies of the fundamental energy dissipation capabilities of materials and methods and of the landing characteristics of space vehicles having various landing systems. The requirements generally placed on the energy dissipation system are that the landing accelerations and landing motions resulting from contact with the landing surface, be kept within tolerable limits both for occupants of the vehicle and for the vehicle structure. For man in space flight the non-emergency limit has been placed somewhere near 20g's maximum acceleration and 250g's/sec. onset rate of acceleration. The spacecraft has been permitted to sustain some small damage. Mercury vehicles were not intended for reuse but some of the other vehicles such as Gemini, will be reused. In any case, both from the standpoint of safety for the astronaut and for maintaining the integrity of the spacecraft, violent behavior on landing should be avoided.

We are currently investigating landing impact energy dissipation systems for the Apollo earth landing module simulating a parachute type landing. We are wearing the completion of a brief model investigation of the landing loads and stability characteristics of a Saturn booster recovered on a hard surface runway -- simulating a paraglider type landing. Investigation will be started soon on the ditching characteristics of the Gemini vehicle, which will also simulate a paraglider landing. A limited program is underway on the use of certain materials as energy dissipators. Our current emphasis in the materials program is on materials for the frangible metal tube dissipator, and we are planning some work on foamed metals as energy dissipators. Since the fragmenting tube process is probably not familiar to everyone, the first slide illustrates the essential components of this system. An example of a frangible-tube installation could be a hard aluminum-alloy tube such as this attached to a vehicle, and a die such as this attached to a landing skid or foot. The tube presses over the die during impact and fails in fragments as shown here. This is a system for working metal to its ultimate strength and through a large percent of its length.

The next slide 2 shows the energy dissipation capabilities of several materials that have been used or considered for use in landing systems. Some of the less efficient but readily adaptable dissipators, such as the fabric air bag and aluminum honeycomb, which absorb about 4000 and 6000 ft-lbs of energy per pound of material, have received considerable attention to date. This is to be expected because of the ease of application and availability of these materials. Honeycomb has been one of the most often suggested energy dissipators taking many forms, shapes, and sizes and has been proposed in one application or another for most spacecraft. Its main disadvantages are bulk and the fact that it can take relatively little side load. The air bag has also been proposed in many forms as a solution for spacecraft landing problems. The fabric air bag lends itself extremely well to storage, as on a capsule type spacecraft where volume is at a premium, and it is being used on Mercury. Susceptibility to puncture and to side-load failure are its major disadvantages. The strain strap, which absorbs about the same energy per pound of material as does aluminum honeycomb, has also found ready application; one case in point being the strut-type landing gear of Dyna-Soar. The pressurized metal cylinder and balsa wood have fairly high efficiencies, absorbing about 14000 and 24000 ft-lb per pound of material. These systems are bulky to store, although no more so than honeycomb. Balsa, however, has an undesirable rebound characteristic. The frangible metal tube has high efficiency absorbing about 31,000 ft-lb per pound of 2024-T3 aluminum alloy but loads must be applied along the axis of the tube, and the tube must be kept snug against its working die. As mentioned earlier work is continuing at Langley on the fragmenting tube process. Alignment is a problem with all of the systems and when appreciable velocity components are involved, either horizontal or vertical or both, some positive means of positioning the energy dissipation element is required.

The following slide shows a sketch of a practical installation of a strain strap in combination with landing skids. The strain strap is a replaceable element which fails by plastic yielding and the skid moves aft and up while alignment is maintained by the strut. Such a gear when used on Dyna-Soar would be retracted and stored through doors in the lower surface of the wing which serves as the heat shield. However, on the Gemini configuration a somewhat similar gear has been kept separate from the heat shield. Slide 4, please. The Gemini vehicle has been rotated over on its side for landing and the tri-skid landing gear is positioned accordingly. Here the heat shield is undisturbed by the landing gear. Currently, hydraulic shocks are being considered for Gemini although at least one "McDonnell" man says they will be heavier than strain-strap dissipators.

The strut arrangements shown are very suitable for systems having positively controlled forward landing directions. Energy due to vertical velocity is dissipated principally by the strain strap or hydraulic shock absorber and most of that due to horizontal velocity is dissipated by friction during the landing runout. Fairly good runways, or at least selected sites, are required for stability in such landings.

Methods of integrating the energy dissipation system with configurations that land on the heat shield are shown in the next slides. This slide illustrates a passive system that has received strong consideration for Apollo earth landing. Aluminum honeycomb or some such material would be used between the heat shield, which is expected to "oil-can" during impact, and the astronauts' pressure compartment. There is a very short stroke available in this system resulting in accelerations of about 40 to 50g's on the capsule structure, so couch support systems must further attenuate the landing impact loads. The passive system is of interest primarily because no malfunction in operation can occur prior to usage since no extension or deployment of parts is required. The following slide shows another approach taken with Apollo toward integrating the landing gear with the components of the spacecraft. The heat shield is extended in this case and shock absorbers are installed between the heat shield and the upper capsule. One set of absorbers shown here in an approximately upright position is used to dissipate vertical loads and another set of absorbers shown here at an appreciable angle us used to dissipate horizontal loads. Both of the Apollo versions shown are expected to land on the ground on the heat shield at a nose down attitude and skid and rock on the heat shield during runout. Slide off.

In general, there are several ways of dealing with vertical energy dissipation. Some systems are more efficient than others, some package better than others, but a variety of promising systems are available. Horizontal energy dissipation is, in a way, simpler to deal with than vertical energy dissipation since translational friction is all that is involved; however, runout becomes a factor. The right or wrong combination of landing surface and landing speed is critical during runout and vehicle configuration also enters the picture. The results of inadequately dealing with these parameters are high accelerations, instability, and turnover. Parachute let-down systems have more trouble with horizontal velocity than do most of the other Systems because they aren't designed for horizontal velocity. This is just as true of cargo drops as it is of spacecraft landings and it is easy to appreciate the problem. The parachute landings of manned vehicles, for example, have been planned at velocities of about 30 feet per second vertical with expectations of from 0 to about 50 or 60 feet per second horizontal. The horizontal velocity is due to the wind and so is unpredictable making design difficult since a wide speed range must be accounted for by the energy dissipation system. Also, direction of landing with the parachute is unknown, consequently, it is desirable that the energy dissipation system be omnidirectional in behavior and this too is hard to achieve. Let down systems that have a more or less fixed horizontal velocity such as the paraglider also have positively controlled forward landing directions and even braking rockets, since they do not drift as easily with the wind (as do parachutes) have more exactly defined design loads, speeds, directions, etc.

The following movies show some conditions at which models of various spacecraft tend to turn over or have undesirable behavior.

The first movie shows a model of the Mercury vehicle landing on water at simulated velocities of 30 feet per second vertical and 60 feet per second horizontal. This is a repeat run. The turn-over is primarily the result of too high a velocity.

The next movie shows an Apollo type model landing at velocities simulating 30 feet per second vertical and 30 feet per second horizontal. First a landing on sand, then a landing on a hard surface runway. The turn-over is caused by the "oil canning" of the model heat shield.

Now a model having a four strut landing gear landing at relatively low speeds, 10 feet per second vertical and 10 feet per second horizontal. Here is a landing on a hard surface, then a landing on a soft powdered material. Penetration and pile-up of the surface material caused tip-up.

The next sequence of movies show turn-overs that are not caused by horizontal velocity or landing surface, but by vehicle shape and landing attitude. Here is a skid-rocker landing of a vehicle with a c.g. height to base diameter ratio of 0.3 Now a vehicle with a ratio of 0.2. The landing attitude and speed were the same in both bases. Vehicle shape or proportions caused turn-over.

The next movie sequence shows model landings of a Saturn booster-simulating paraglider let-down on a smooth, hard-surface runway. The landing gear is a four strut tail-skid gear. The landing speeds are relatively low considering the size of the vehicle, simulating 80 knots horizontal and 10 feet per second vertical. The following movie shows a tricycle landing gear employing a wheeled nose gear and skids on the main gear. There is little to choose from in behavior between these gears although we did find some wheel problems due to model design that could cause ground loops as shown here. Movie off.

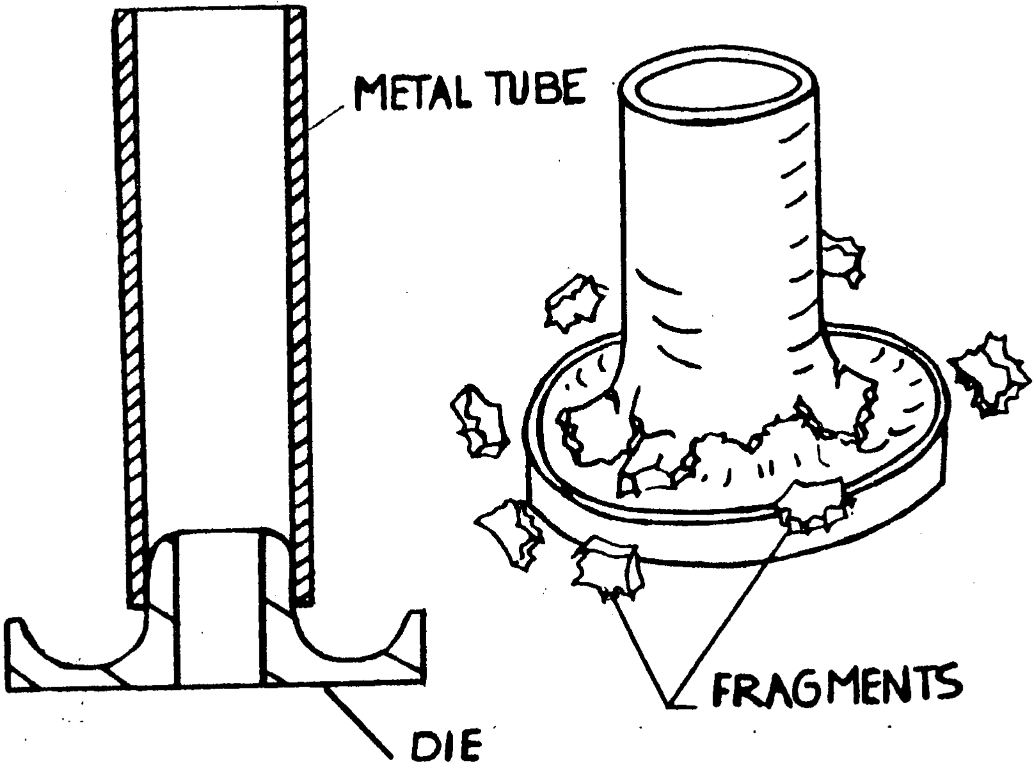
The next slide (7) shows maximum normal and longitudinal accelerations for the passive system Apollo configuration during landings on sand at a vertical velocity of 30 feet per second and horizontal velocities of 0 to 50 feet per second. Horizontal velocity had little effect on the maximum acceleration, either normal or longitudinal as shown by the scatter of the velocity points. Landing attitude had little effect on normal acceleration due to the degree of penetration into the sand. The solid points indicate test model turn-over during impact.

The last slide (8) gives computed limits of stability for a skid-rocker landing gear. Computed limits for a friction coefficient of 0.4 and a c.g. height to base diameter ratio of 0.24 are shown. The stable region is below the curves.

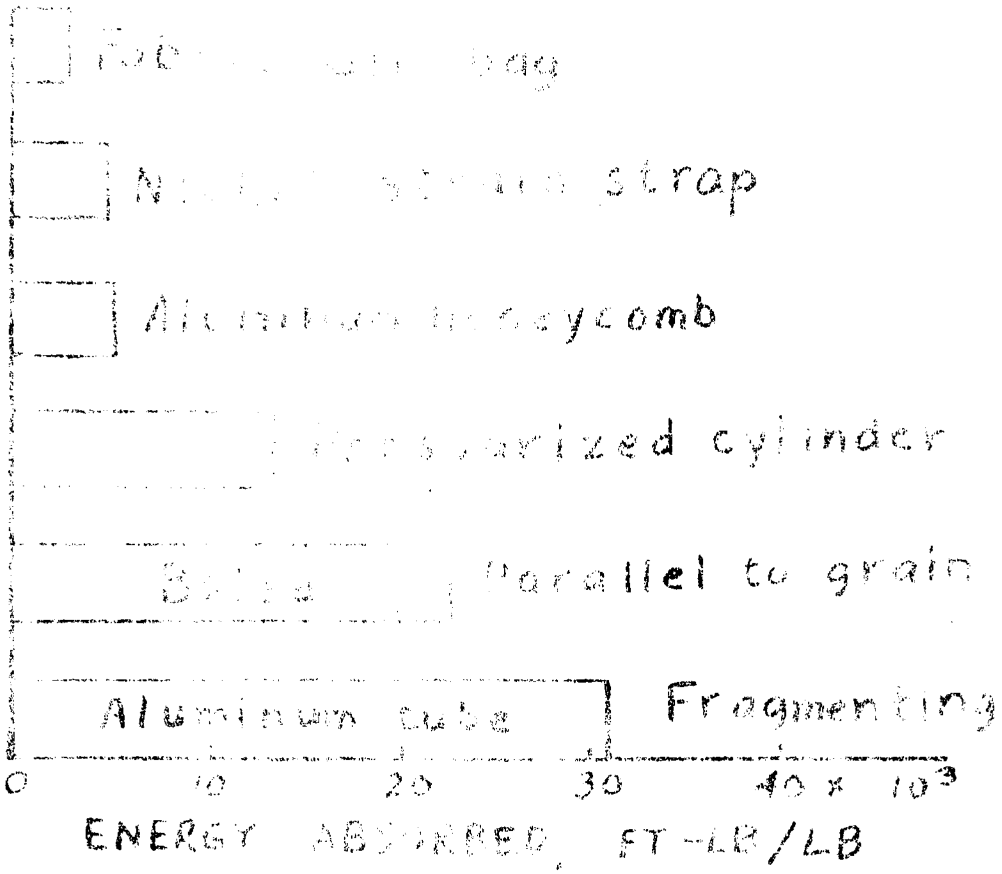
Turn-over would be expected at conditions above the curves. The equations of motion show that turn-over for a skid-rocker configuration is independent of change in horizontal velocity and this has been substantiated by model tests for a range of touchdown speeds. This plot shows the effect of vertical velocity. The range is well outside that of the model investigation which simulated paraglider landings at vertical velocities of about 10 feet per second and less. The skid-rocker landing method is most suited to horizontal type landing and these data show this. For example, at 10 feet per second there is a stable range of some 45° in landing attitude. In a vertical type landing at say 30 feet per second this stable range is reduced to only 12°. The curves approach asymptotically the friction angle. (The friction angle is about -12° for this configuration, and is the angle that the resultant of the friction force and the normal force makes with the normal axis of the vehicle. It is also the angle at which the vehicle would slide during landing without oscillation in trim.) Slide off.

There are several problem areas in the landing energy dissipation systems being used for spacecraft recovery. There are also regions, or areas, for most systems presently being considered that result in satisfactory landing impact and runout. This is a natural situation because every vehicle whether it be helicopter, airplane, or spacecraft can be expected to be limited somewhat in landing attitude and speed.

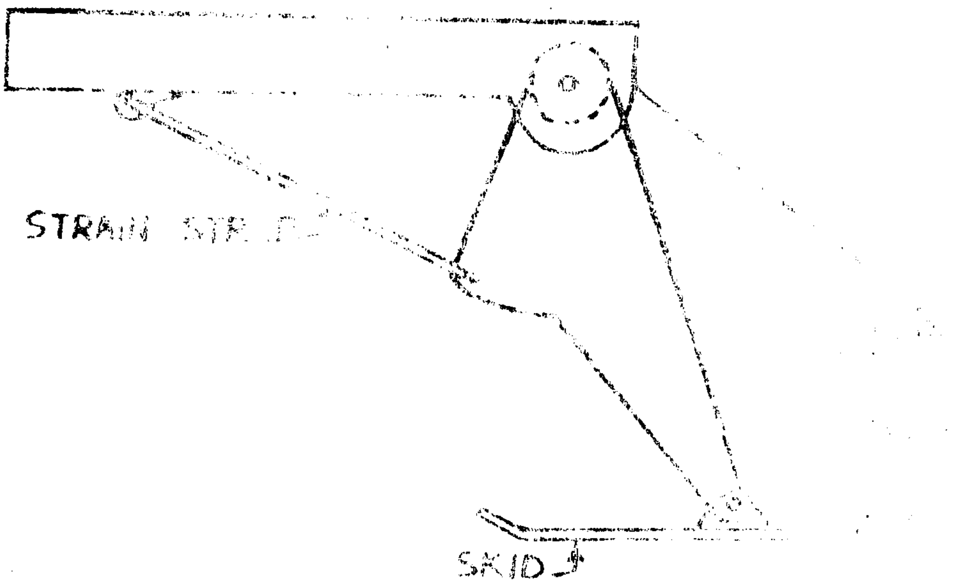
FRAGMENTING TUBE SYSTEM



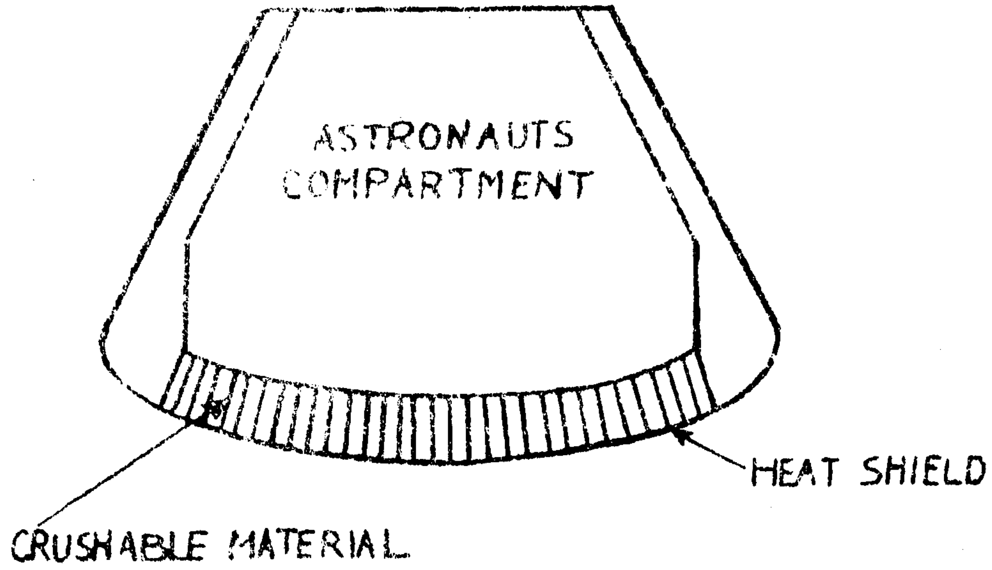
ENERGY ABSORPTION CAPABILITIES



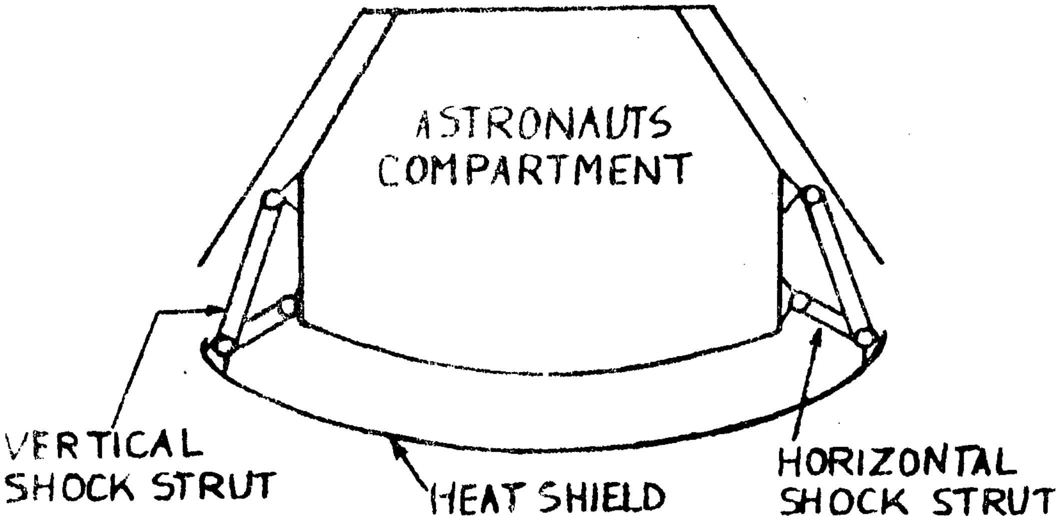
LANDING GEAR COMPONENTS



PASSIVE LANDING SYSTEM



MULTI-ABSORBER SYSTEM



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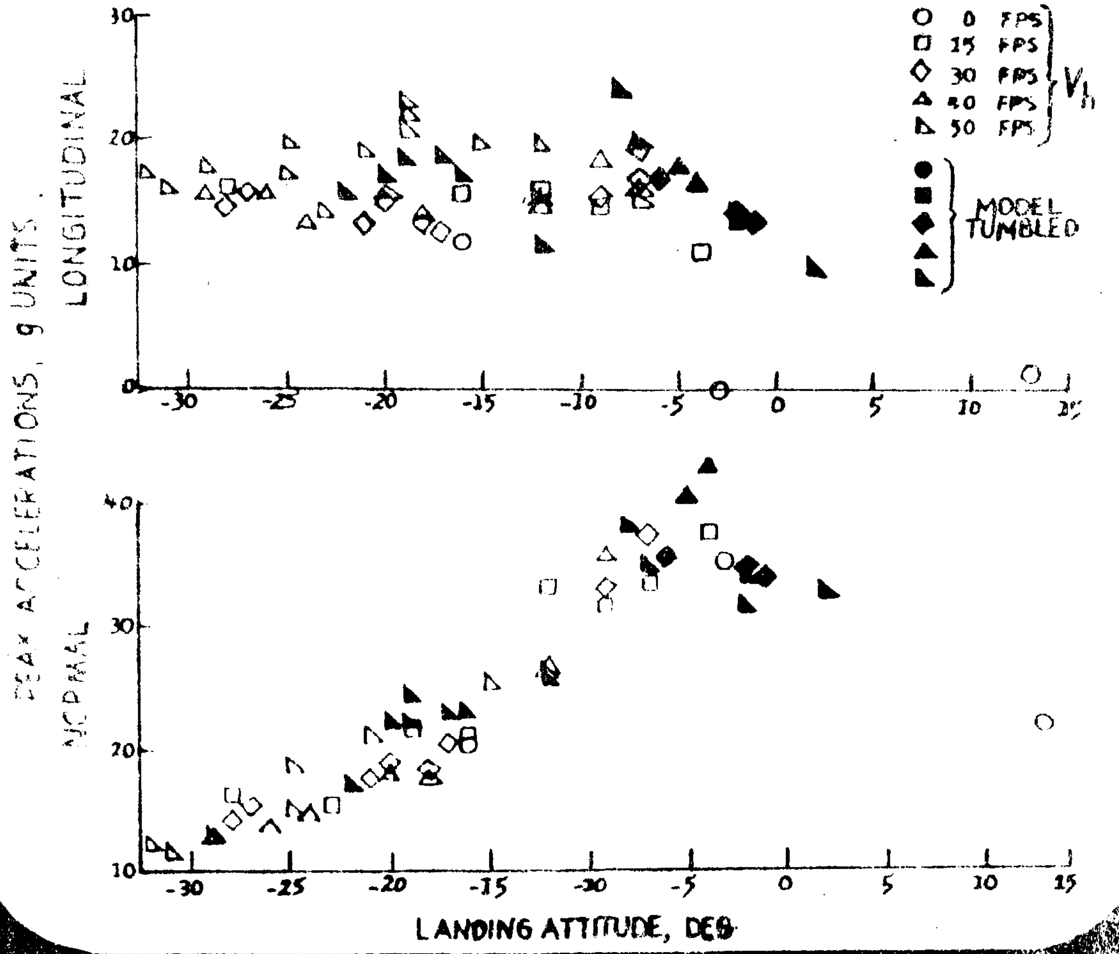
LANDING ACCELERATIONS



AGENDA

MEETING ON SPACE VEHICLE LANDING AND RECOVERY RESEARCH AND TECHNOLOGY

NASA Headquarters
July 10-11, 1962
9:00 A.M. EDT

I. July 10, 1962 - Opening Remarks - J. E. Greene- Headquarters

II. Presentation of Program Summaries from the Centers

Parachute Recovery Systems Design and Development Efforts Expended on MERCURY-REDSTONE Booster and SATURN S-1 Stage - Barraza, R. M. - MSFC

Application of Paragliders to S-1 Booster Recovery for C-1 and C-2 Class Vehicles - Mc Nair, L. L. - MSFC

Recovery of Orbital Stages - Fellenz, D. W. - MSFC

A Review of Launch Vehicle Recovery Studies - Spears, L. T.- MSFC

A Review of the Space Vehicle Landing and Recovery Research at Ames - Cook, W. L. - ARC

Survey of FRC Recovery Research - Drake, H. M. - FRC

Manned Paraglider Flight Tests - Horton, V. W. - FRC

Gemini Landing and Recovery Systems - Rose, R. - MSC

Apollo and Future Spacecraft Requirements and Landing Systems Concepts - Kiker, J. W. - MSC

III. July 11, 1962 - Continuation of Program Summaries

JPL Requirements for Spacecraft Landing and Recovery - Pounder, T., Framan, E., and Brayshaw, J. - JPL

Langley Research Efforts on Recovery Systems - Neihouse, A. I. - LRC

Summary of Static Aerodynamic Characteristics of Parawings - Sleeman, W. C., Croom, D. R., and Naeseth, R. L. - LRC

Dynamic Stability and Control Characteristics of Parawings - Johnson, J. L., and Hassell, Jr., J. L. - LRC

Deployment Techniques of a Parawing Used as a Recovery Device for Manned Reentry Vehicles and Large Boosters - Burk, S. M. - LRC

An Analytical Investigation of Landing Flare Maneuvers of a Parawing-Capsule Configuration - Anglin, E. L. - LRC

Paraglider Loads, Aeroelasticity and Materials - Taylor, R.T. and Mc Nulty, J. F. - LRC

Rotary-Type Recovery Systems - Libbey, C. E. - LRC

Parachute Performance at Supersonic Speeds - Charczenko, N.- LRC

Aerodynamic Drag and Stability Characteristics of Solid and Inflatable Decelerator Devices at Supersonic Speeds - Mc Shera, J. T. - LRC

The Problems of the Energy Dissipation Systems in Spacecraft Recovery - Fisher, L. J. - LRC