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APOLLO EXPERIENCE REPORT - COMMAND MODULE CREW-COUCH/RESTRAINT AND LOAD-ATTENUATION SYSTEMS

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16. Abstract

The Apollo command module crew-couch/restraint and load-attenuation system was required to support and restrain the crewman during mission phases and to limit the load imposed on the crewman during landing. Component designs evolved when requirements changed and tests were conducted. Advancement in the state of the art for energy-absorbing devices and changes in restraint philosophies for impact protection resulted from the efforts and experiences presented.

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SUMMARY

The development of the crew-couch/restraint system and the crew load-attenuation system for the Apollo command module resulted in a significant advancement in the state of the art. During the Apollo Program, changes in program requirements caused a change in system requirements. These changes, together with research and testing, resulted in the design and flight of various couch, restraint, and attenuation systems.

The pre-Apollo impact-loading restraint philosophy dictated a requirement for complete restraint and support of the body that resulted in cumbersome straps and massive, individually contoured couches. The development effort for the Apollo Program resulted in a couch that accommodates all size crewmen, is self-adjusting to the contour of the crewman, and can be disassembled, folded, and reassembled in flight by a suited crewman without the use of tools. The restraint system that was developed for the Apollo Program is a six-point suspension system incorporating an easily actuated single-point release. This couch/restraint system allows the crewman the necessary mobility for spacecraft operations and affords him adequate restraint during landing impact.

The load attenuators available during the early stages of the Apollo Program met the specified spacecraft requirements, but could not meet the controlled-load and reversible-stroke requirements of the final Apollo Program definitions. The couch load-attenuation system developed for the spacecraft to protect the crewman primarily during land landing uses two methods of energy absorption: friction and two forms of cyclic deformation of material. The spacecraft couch load-attenuation system is compact, will absorb energy in both compression and tension stroking, and can be cycled with an accumulative life of approximately 100 inches of stroking without load degradation. The long stroking life and repeatability of the load levels made possible a pre-acceptance load/stroke test that allowed the determination of the actual stroking load value before installation in the spacecraft.

INTRODUCTION

The Apollo crew-couch/restraint system was designed to support and restrain three crewmen during all phases of the mission from launch to landing. The load-attenuation system was designed to control the impact loads imposed on the crew during landing, and to remain nonfunctional during any other phase of the mission.

The functional and physical design requirements, the evolution of the design, and the command module (CM) interfaces of the crew-couch/restraint and load-attenuation systems are discussed in this report. A brief description of the systems and some of the problems encountered during development and flight are also included.

The development of the crew-couch/restraint and load-attenuation system was a 5-year effort. During this time, philosophies and program requirements changed which resulted in different generations of equipment and in the use of more than one design in the program.

DESIGN REQUIREMENTS

The following are the final design requirements for the Apollo crew-couch/restraint and load-attenuation system. Since all the requirements were not imposed initially or recognized in the early stages of the Apollo Program, the evolution of the design and requirements is described in the text. The abort mission requirement of land landing the CM had the greatest influence on finalizing the crew-couch/restraint and load-attenuation system requirements.

Couch

Final design requirements for the Apollo crew-couch/restraint system are as follows.

1. Support: The couch shall support the crewman during all mission phases.

2. Restraint: The crewman shall be restrained, when necessary, during the mission.

3. Mobility: The crewman shall be allowed adequate freedom, while restrained, to perform spacecraft operations.

4. Accommodation: The couch shall accommodate any size crewman between the 10th- and 90th-percentile dimensions as defined in reference 1. No tools or special equipment shall be required for positioning the couch during flight.

5. Operation: Operation of the couch shall be compatible with a crewman in a pressurized space suit.

6. Disassembly: The couch shall be foldable and stowable in flight to increase the interior working volume of the CM for mission operations.

7. Strength: Structurally, the couch shall be adequate to support a crewman under loads imposed by the attenuator system.

Attenuators

Final design requirements for the Apollo load-attenuation system are as follows.

1. Stroking level: The stroking level of the attenuators shall limit the loads imposed on the crewman during landing. The attenuators shall not allow the couch to move during any mission phase other than landing.

2. Stroking distance: The attenuators shall absorb the landing energy transmitted to the couch within the stroking distance allowed in the CM.

3. Reversibility: The attenuators shall absorb energy in both tension and compression stroking.

DESIGN CONSIDERATIONS

Although support and restraint of the crewmen during all mission phases was a primary couch requirement for Project Mercury and for the Gemini and Apollo Programs, some program differences that influenced the design and development of the couch and load-attenuation systems did exist. The differences in the program requirements are listed in the following paragraphs.

1. Mobility: Mobility within the spacecraft was not a requirement in Project Mercury and the Gemini Program. In the Apollo Program, an intravehicular mobility requirement made it necessary to design a folding couch.

2. Launch abort: In both Project Mercury and the Apollo Program, an escape tower was provided for separation of the spacecraft from the booster in the event of a launch abort, during which the crewmen would remain in the spacecraft. In the Gemini Program, individual ejection seats were provided for pad and low-altitude aborts.

3. Landing: Although all three programs had a primary water-landing capability, design of the Mercury and Apollo spacecraft required incorporation of a secondary land-landing capability in case of a pad or very-low-altitude abort. Landing-load attenuation was provided externally on the Mercury capsule, but it was provided internally on the Apollo CM. The requirement for a land-landing capability with internal attenuation was a primary factor in the design of the Apollo couch load-attenuation system.

The orientation of the couch, restraint, and attenuation systems within the CM is shown in figure 1.

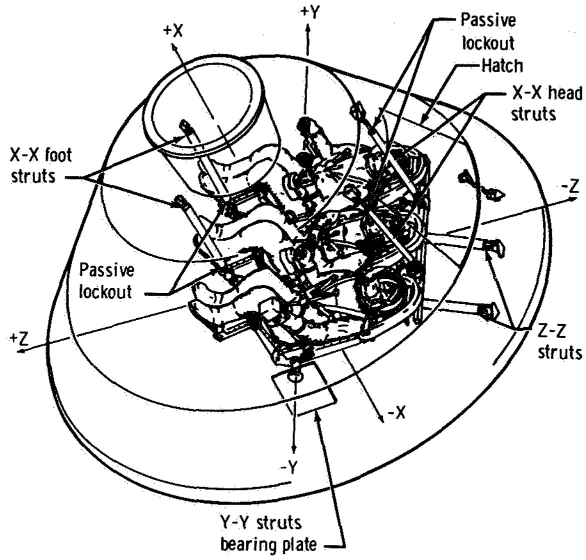


Figure 1.- Orientation of the CM crew-couch/restraint system.

During the Apollo Program, two mission designations were made, which resulted in a Block I and a Block II CM. The Block I vehicle was used for an earth-orbital mission only, and the Block II vehicle was used for the lunar-landing mission. The CM requirements were redefined for the Block II mission, which resulted in a change in spacecraft equipment. The redefinition requirements resulted in changes to the crew-couch/restraint and load-attenuation systems design considerations that are identified later in this report.

Couch

The Apollo Block I crew-couch assembly was required to provide comfortable support in the proper operating position and, during all mission phases, to provide adequate restraint for crewmen in both the ventilated- and pressurized-space-suit conditions. The crew-couch assembly was required to allow inflight position adjustment for all specified mission operating requirements and to provide mounting space for rotational and translational flight controls.

The original couch design was influenced strongly by the human factors (that is, size, reach, mobility), by the biodynamic requirements for impact protection, and by a lack of knowledge about the landing characteristics of the spacecraft. A requirement that the crewman must be restrained completely to survive the landing impact was dictated by these factors. A need for further investigation of crew impact, with consideration given to spacecraft operational-requirement trade-offs, became evident from the couch design shown in figure 2. This design resulted from a study conducted by an independent contractor very early in the Apollo Program. The criterion used for the study was the existing human-impact-protection philosophy. The crew support and restraint system that resulted from this study was entirely too cumbersome, complex, and massive.

The first prototype of the Apollo couch assembly, built by the prime contractor to meet the early program requirements, is shown in figure 3. After a review of this couch, impairment of the inflight mobility of the crewman, both by the massiveness of the couch and by the complexity of the restraint harness, was apparent.

As a result of the review, research and human-impact testing were conducted to maximize inflight crewman mobility and to maintain adequate impact protection. The results of human-impact testing reduced the requirement for complete restraint of the crewman within the deceleration loads specified for the Apollo CM crew couch.

The advancement of the support and restraint philosophy resulted in changing the couch design from the individualized, contoured-seat concept that was used in the

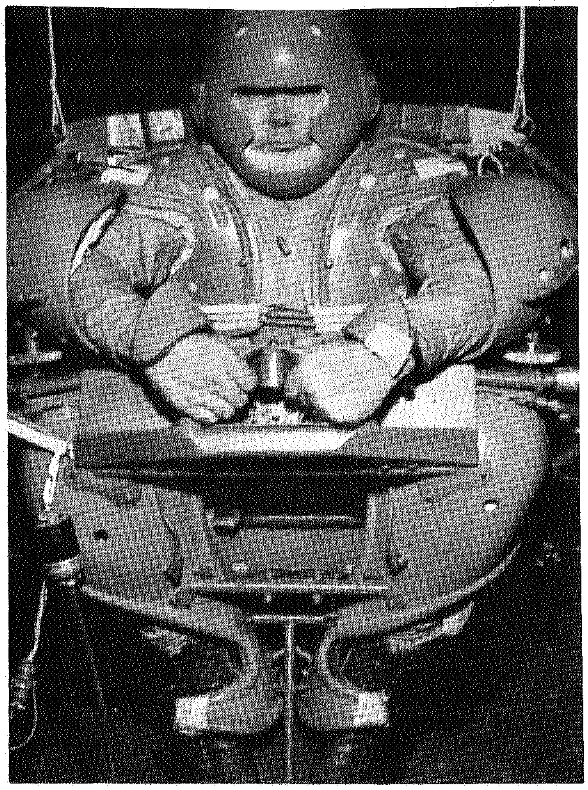


Figure 2. - Universal integrated couch/ restraint system.

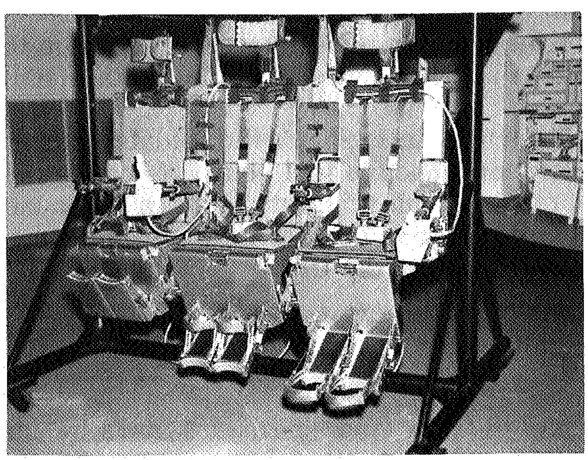


Figure 4. - Apollo unitized-couch flight design.

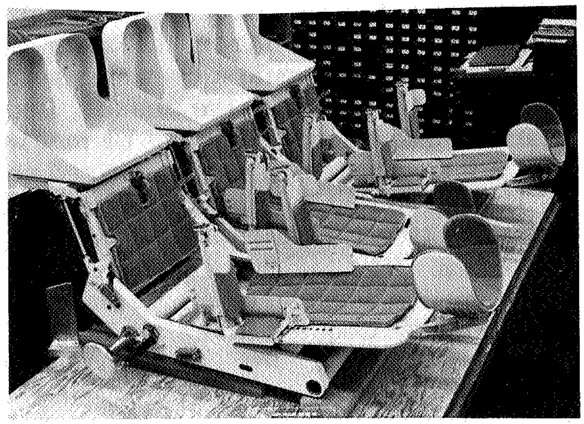


Figure 3. - Prototype Apollo unitized couch.

Mercury and Gemini Programs to a universal couch that would fit all crewmen between the 10th-and 90th-percentile sizes. With the new restraint requirements, the crew-couch/restraint system was redesigned to the configuration shown in figures 4 and 5 (unitized couch) and was flown on the Apollo 7 mission.

The Block II redefinition of the Apollo Program emphasized the requirement for more work volume in the CM to allow intravehicular mobility and the requirement to open a center aisle for side-hatch extravehicular activity (EVA) by a suited crewman wearing a portable life support system.

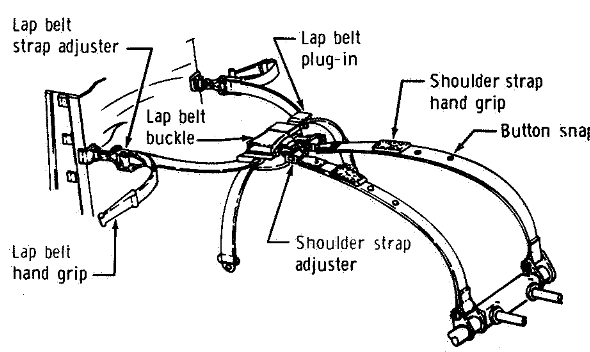


Figure 5. - Restraint-harness components of the Apollo unitized couch.

The side-hatch EVA requirement allows for a contingency return from the lunar module (LM) to the CM should a crewman not be able to return through the tunnel. Because these requirements could not be met without a major redesign of the unitized couch, a new couch that had minimum mechanical complexity but maximum flexibility was designed. The foldable couch (fig. 6) was developed and was used on all manned missions subsequent to the Apollo 7 mission.

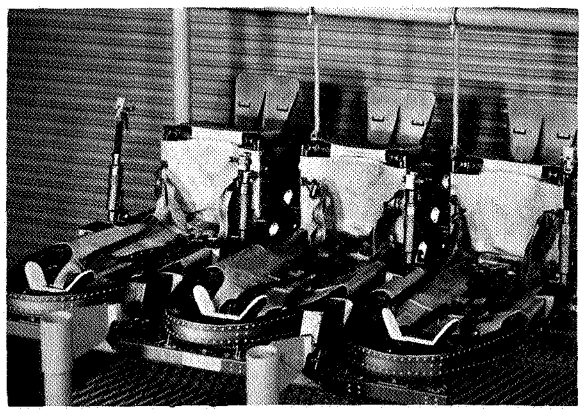


Figure 6.- Apollo foldable-couch flight design.

A further review of the crew-couch requirements determined that the early requirement for the couch to translate the left- and right-hand crewmen from the launch positions to the docking window was not necessary. This requirement was deleted in favor of the crewman moving himself up to the docking window without the couch and then using the couch-restraint system to secure himself. Also, as a result of the review, the crewman-operated foot-restraint system was deleted and replaced with a passive heel restraint (fig. 7).

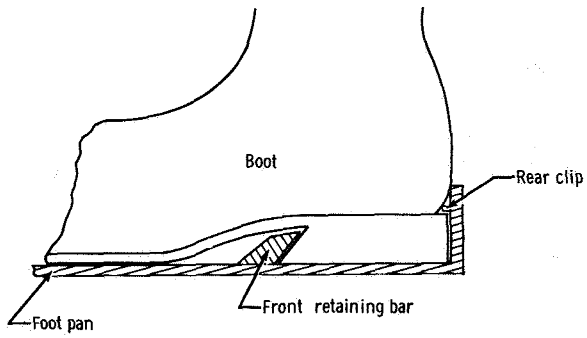


Figure 7.- Passive heel restraint.

The elimination of the functions just described reduced the complexity of the crew-couch system. The passive heel restraint design on the foldable couch eliminated inaccessible mechanisms in the restraint system and resulted in increased crew safety. The passive heel restraint was incorporated on the unitized couch just before the launch of the Apollo 7 spacecraft. Translation of the man, instead of the couch, to the docking position was verified on the Apollo 7 mission because the Apollo 7 couch design allowed investigation of both methods.

Installation tools were not needed for prelaunch installation of the foldable couch and, consequently, installation time was reduced from 4 hours to 1 hour. Because the couch was easy to remove and install, removal of the couch was permitted in the launch-readiness countdown to maximize the CM accessible interior and to minimize the time required for activities (such as stowage and repairs) inside the CM.

Attenuators

In the Apollo Program, the crew was protected from landing-impact loads by controlling only the loads imposed on the crewmen and the crew-couch/restraint system, not the loads imposed on the whole vehicle as in conventional craft. In other words, the landing gear was inside the vehicle.

The requirements imposed on the attenuators were rather simple and direct. Because the CM did not have any facilities for limiting the landing impact, the attenuators were required to provide support to the crew couch during all mission phases and to limit the energy transmitted to the crewman during landing impact. Also, the attenuators were limited to a stroking distance of 16 inches.

The attenuators for the Block I CM were sized theoretically to produce the stroking g levels shown in figure 8 for a single-mass (man and couch) system.

Various methods of energy absorption, such as metal cutting, metal bending, tube swaging, and hydraulics, were studied and tested in an effort to meet the original Apollo Program requirements of load, stroke, and repeatability. The first load attenuator proposed for the Apollo CM was an aluminum-honeycomb-core concept (fig. 9).

The honeycomb-attenuator load could be predicted only by testing samples from the same core of honeycomb that was used in the attenuator. Furthermore, the frictional forces of the brake, which was used for return strokes, decreased with time and were not predictable. The result was an attenuator with a questionable load level within large tolerances. This attenuator met the water-landing requirements of the Block I spacecraft and provided the lightest weight strut for the required load levels. Because the water-landing loads were lower than the high-g entry loads, shear pins were provided to ensure that the attenuator would not stroke during entry. The attenuator design remained relatively stable, but design of the lockout device was changed until a crew-operated design (fig. 10) was developed and flown on all missions except the Apollo 7 mission. The honeycomb attenuator was used in all axes on the Apollo 7 mission and for the Y-axis only on all other missions.

During the Block II redefinition, the decision was made to provide crew protection for land landing because the location of the launch pad and the height of the vehicle resulted in a high probability of land landing during a pad or very-low-altitude abort. Because the CM could tumble during a land landing, a requirement for load attenuation in both stroking directions was imposed.

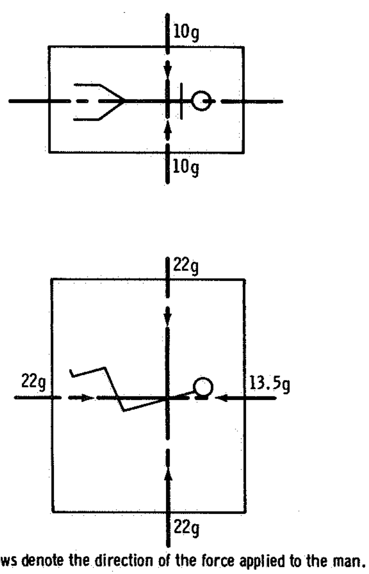


Figure 8.- Block I load-attenuation levels.

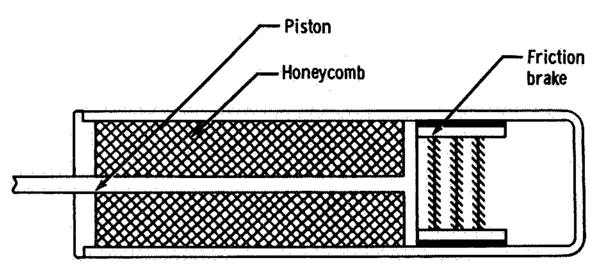
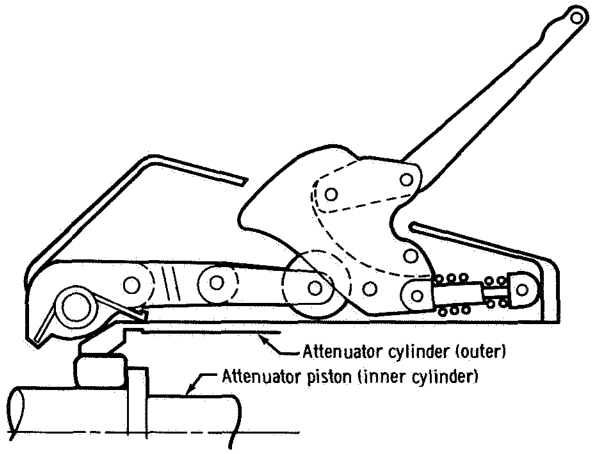
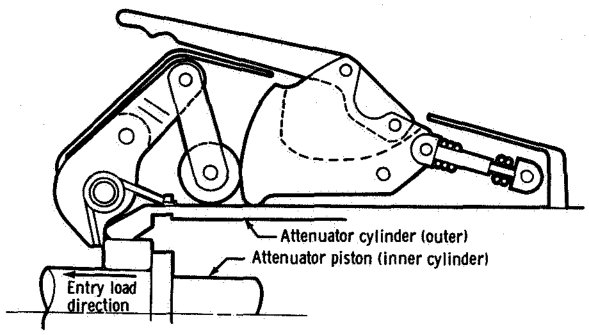


Figure 9.- Aluminum-honeycomb-core load attenuator.



(a) Unlocked position.



(b) Locked position.

Figure 10. - Strut lockout.

The higher energy levels of land landing and the limited stroking distance also resulted in a requirement for an attenuator that would stroke at a predictable level within close tolerance.

A double-acting, repeatable attenuator (cyclic strut) (fig. 11) was developed that fulfilled the spacecraft land-landing criteria. The cyclic strut is based on a unique concept of cyclic deformation of metal to absorb energy (refs. 2 and 3). Simply stated, energy absorption is accomplished by rolling a ring of metal between two surfaces that are located less than the diameter of the ring apart, resulting in continual deformation of the ring as it rolls.

Because the cyclic strut is a constant-load device, load overshoot at the initial stroke of the strut (breakout) is an inherent problem. Because of the small difference between the strut load value necessary to meet the allowable stroking distance and the crew tolerance in the Z-axis, this overshoot could not be tolerated.

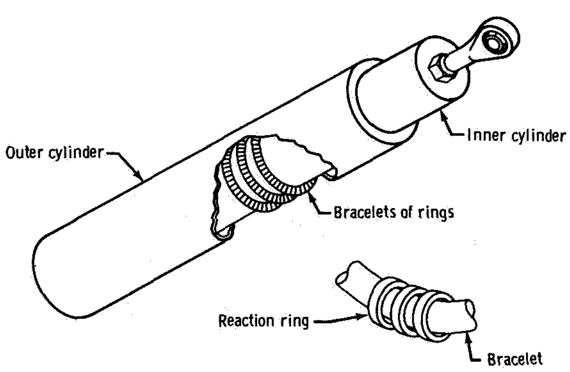


Figure 11. - Cyclic strut.

The couch and man represent a two-mass system with the couch attached to the strut; therefore, the overshoot results in a secondary impact of the man on the couch. Because the couch mass is one-third of the total suspended mass, it does not impose a high enough load on the strut to initiate stroking; as a result, the man impacts the relatively stationary couch with approximately the same velocity as the landing spacecraft. This secondary impact, coupled with the breakout load of the strut, results in a g level that is higher than the stroking level that is designed for a single-mass system. Although this initial-impact g level was not considered dangerous, a softening of the secondary impact was desirable in the Z-axis to decrease the probability of spinal injury.

To reduce the secondary impact level, couch stroking had to start before the secondary impact. This early stroking of the couch was produced by controlling the onset rate of loading that was imposed on the couch system. A low-onset device was developed to control the rate of loading (ref. 3). When this device was added to a Z-axis cyclic strut (fig. 12), the combination strut started stroking at a lower level than the pure cyclic strut, and the rate of loading from breakout to nominal stroke load was controllable. With this application, the maximum load imposed on the crew was never higher than the nominal stroke load, and the secondary impact level was reduced. The low-onset device incorporates the concept of metal-to-metal friction for energy absorption with the frictional load being increased incrementally as the strut strokes.

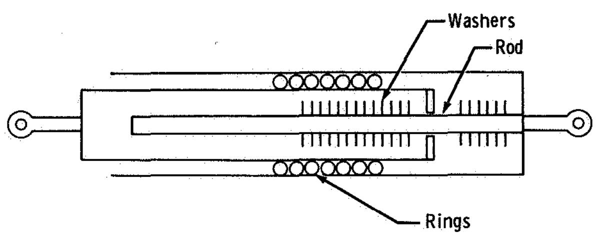


Figure 12.- Ramp-loaded attenuator strut assembly.

Cyclic attenuators were used for the X-axis on all missions starting with the Apollo 8 mission. Cyclic attenuators were used for the Z-axis on the Apollo 8 and 9 missions. On the Apollo 10 and subsequent missions, the Z-axis cyclic attenuator was replaced by the combination attenuator.

SYSTEM DESCRIPTION

Because of the changes in requirements for the Block I and Block II CM and because different equipment was flown on the two command modules, a description of each system is presented.

Block I, Apollo 7 Mission

Couch.- The Block I couch consisted of a unitized, box-beam-construction, three-man platform for the back support. The headrest and the seat/leg-pan assembly for each crewman were attached to this platform. The body of the crewman was restrained by a six-point suspension restraint harness with a single-point-release system. An instep strap that was tightened and released by means of a mechanism actuated by a D-ring located on the seat pan (fig. 4) restrained the feet. This device was replaced by a passive heel restraint (fig. 7) just before the Apollo 7 mission.

The Block I couch headrest was adjustable in flight for two conditions: pressurized suit and nonpressurized suit. Adjustment for crewman size had to be made on the ground before launch. Essentially, the seat/leg-pan assembly was a single unit that pivoted about the hip joint for couch ingress and egress.

Attenuators. - The Block I attenuators consisted of a cylinder and a piston with an aluminum-honeycomb core placed between the piston and cylinder ends. The loads applied to the piston rod were limited to the crushing strength of the honeycomb core, and energy was absorbed by material deformation. Because implementation of this concept would limit the load and would result in energy absorption in the initial stroking direction only, a friction brake was installed on the X- and Z-axis attenuators to provide a limited amount of load attenuation for the return and subsequent stroking and to hold the couch stable after stroking. Because the Y-axis attenuators acted as bumpers between the couch and the CM sidewall and, therefore, stroked in one direction only, a friction brake was not required.

To prevent stroking during high-g entries that would result in attenuator loads higher than the stroking load, a passive lockout was installed. The initial couch loading had to be higher than the breakout level of the lockout before the attenuator would stroke.

Block II, Apollo 8 and Subsequent Missions

Couch. - The Block II couch consisted of three individual body supports that were attached by pip pins and clamps to a supporting framework. The body supports could be folded at the hip joint and knee joint, had provisions for locking the seat pan at two angles other than that of the folded position, were capable of being folded at approximately the shoulder position, and could be detached from the framework for storage (fig. 13). The body supports also could be detached and folded in flight by a crewman in a pressurized space suit. As in the case of side-hatch EVA, the center body support is detached and stowed under the couch of the spacecraft commander. The headrest was adjustable in flight for any size crewman and for any pressure-suit condition. The backpan portion of the body support was constructed of Teflon-coated fiber glass, which would conform to the crewman for comfortable support. Restraint of the crewman was the same as in the Apollo 7 couch with the six-point harness and the passive heel restraint.

Attenuators. - The Block II attenuators (X- and Z-axis) were double-acting or cyclic struts that used the concept of material deformation in the plastic range to achieve energy absorption. Material is deformed by rolling a ring of metal (reaction ring) between an inner and outer tube (fig. 11). When the space between the tubes is less than the diameter of the ring, the ring is forced out of round, thus absorbing energy as it rolls. Because the ring is free to roll in either direction, load attenuation occurs for compression, for tension, and at any position of the strut. The reaction load was controlled by varying the number of reaction rings installed. Heat-treated, high-strength bearing rings are located at each end of the gang of reaction rings to maintain concentricity of the tubes and to control the deflection of the reaction rings. The final design of the cyclic strut was held to a breakout load of 10 percent over nominal and a stroking load of ±5 percent of nominal.

For the Apollo 10 and subsequent missions, the Z-axis cyclic attenuator was replaced by a combination cyclic attenuator, which was basically a cyclic attenuator in combination with a low-onset device. The low-onset device consists of a slender, hard rod of very uniform diameter onto which a series of washers has been pressed. The washers are forced onto the straight portion of the rod, thus causing the washer to be

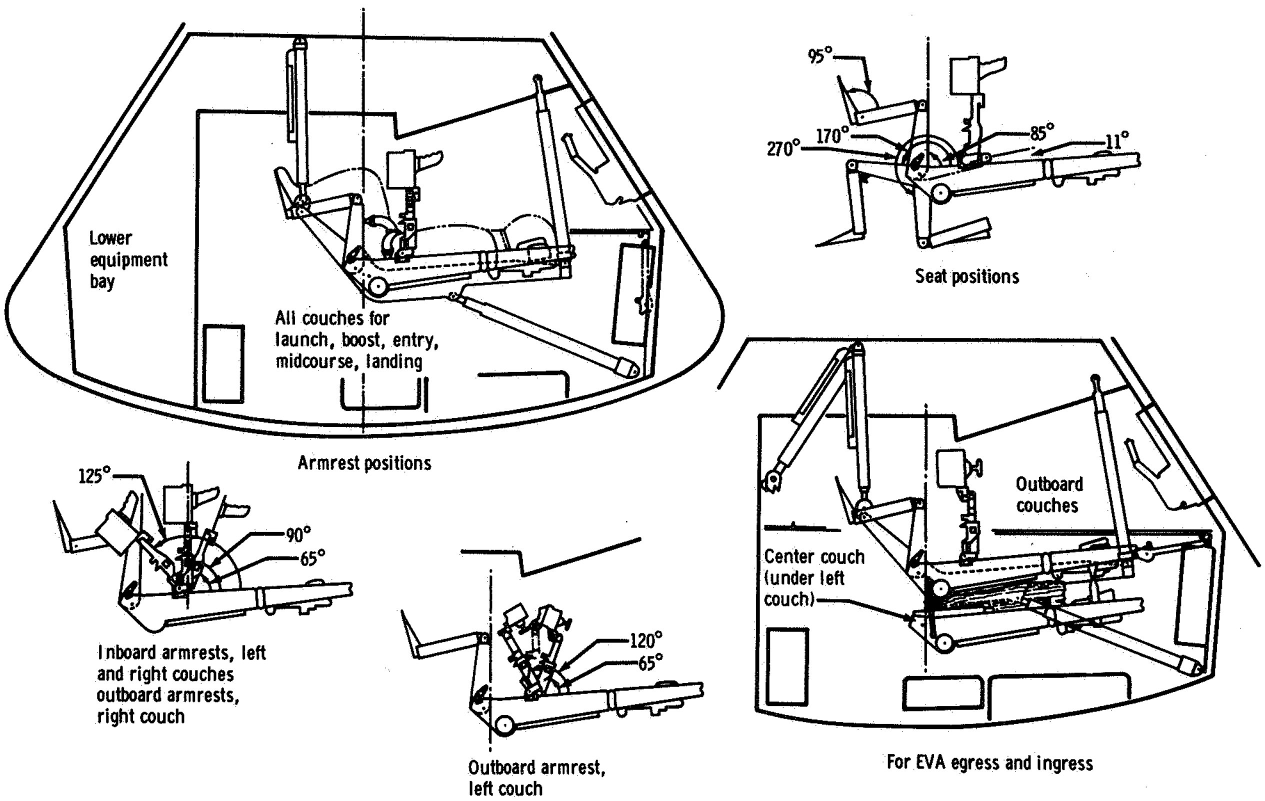


Figure 13.- Foldable-couch flight positions.

deformed plastically and thereby maintaining a squeeze on the rod. When the washer is forced to slide along the rod, drag occurs from metal-to-metal friction and energy is absorbed.

The total load (or total energy consumed) is the cumulative effect of all the washers stroking along the rod. If spaces are left between the washers, the load is increased each time a washer is picked up and pushed along the rod. This incremental loading produces an approximate ramp function of the applied force, which, for a given mass, reduces the deceleration-onset rate. Thus, the deceleration-onset rate of a mass can be controlled by selecting the appropriate washer spacing, and the magnitude of the deceleration can be controlled by selecting the proper number of washers. Characteristic load curves for the cyclic strut and combined strut are shown in figures 14 and 15, respectively. The ramp-loading effect is produced only during the initial stroke of the attenuator, and the attenuator remains a lower level cyclic attenuator for subsequent stroking.

Because a reversible loading in the Y-axis for the Block II vehicle was not needed, the same honeycomb-type attenuator that was used on the Apollo 7 mission was used for all missions.

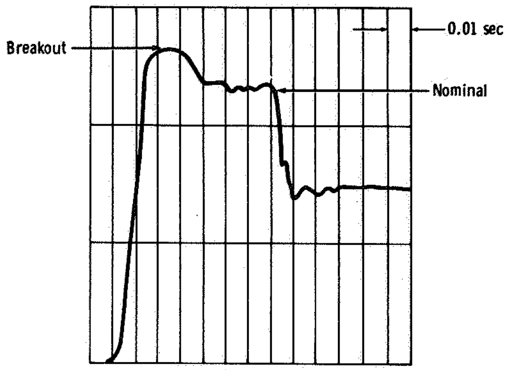


Figure 14.- Cyclic-strut load/time characteristic.

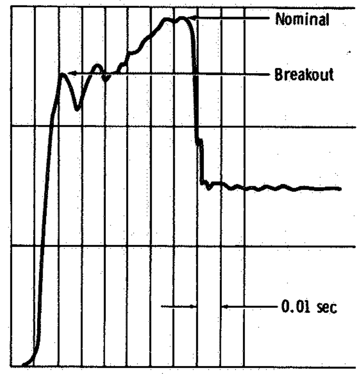


Figure 15.- Combined cyclic-strut and low-onset-device load/time characteristic.

TEST PROGRAMS

The following types of tests were conducted on the crew-couch/restraint and load-attenuation systems.

Basic-Criteria Tests

Couch.- Before the couch could be designed, certain basic questions had to be answered. Crew/couch interface exercises were conducted to determine the couch size that was required to accommodate a crewman in either a pressurized or a ventilated space suit. The location of armrests, hand-controller supports, headrests, and restraint-harness attachments and routings had to be determined. In addition, the couch had to accommodate men ranging in size from the 10th to the 90th percentile with a minimum of adjustments. Also, as part of the basic criteria, human-impact tests were necessary to determine seat angles, methods of restraint, and the g-level tolerance of humans in various directions for the proposed designs.

Before a design could be completed, crewman/couch/spacecraft interface tests were required to determine the mobility of the crewman inside the spacecraft with the couch installed and to determine the capability of the crewman to operate all couch controls and to perform the functions necessary for folding and dismantling the couch.

Attenuators.- The basic design requirement for attenuators is a determination of the load level at which the strut must stroke. This load level is determined from the human tolerance resulting from the couch design coupled with the attenuator geometry within the spacecraft and from the distance the strut is allowed to stroke within the spacecraft. With the basic design requirement in mind, attenuator concepts were reviewed and tested to determine the design that had the best functional performance and the smallest weight-to-load ratio.

Development Tests

Couch.- The development testing of the crew couch consisted primarily of component-structural tests, life-cycle tests, and crew-interface tests. As a result of development testing, some design changes were incorporated. The most significant of these changes were the heel restraint and the headrest.

The snap-in-type heel restraint used on the Gemini spacecraft was determined to be inadequate for the Apollo load conditions and was redesigned to a side-entry, slide-in-type heel restraint that offered better retention. The slide-in-type heel-restraint concept also has been employed in the Skylab Program for restraining a crewman during extravehicular work.

The large, foldable-type headrest that was used on the early Apollo couch was redesigned to a low-profile-type headrest that reduced interference with the crewman during ingress and egress.

Attenuators.- During the development of the cyclic attenuators, test results proved (1) that the inner and outer tubes had to be sized properly to obtain the exact amount of squeeze on the rings to prevent slippage or fatigue, (2) that parts had to be held to very close tolerances to obtain a constant load/stroke curve, (3) that the ring and tube surfaces had to be grit blasted to prevent any slippage, and (4) that spacers separating the rings had to be incorporated to prevent interference between the rings. Results of the corrosion-contaminants test proved that, although the materials used were stainless steel, the attenuators had to be sealed to prevent corrosion. A flexible fluorocarbon boot seal that tore away at a force of 100 pounds was designed for the moving end of the attenuator. The attenuator was flushed with nitrogen, and the boot was installed in a 100-percent-nitrogen atmosphere. Also, the seal kept out foreign particles that might have interfered with the rolling rings.

One significant program milestone was the availability of a complete CM to perform a series of drop tests to understand better the CM dynamics and the dynamics of the couch and attenuation system within the CM. The understanding of the dynamics and test simulation on a drop tower with a full couch/attenuator system permitted refinement of the initial-impact load to an acceptable rate of acceleration for crew tolerance.

The final load/stroke design curve for the low-onset device is shown in figure 16. The load-attenuation levels for each axis flight struts are shown in figure 17.

By using the land-landing g-time curves that were determined from the full-scale-CM impact tests, a series of drop-tower tests with the complete couch/attenuation system was performed to determine the load value of the attenuators

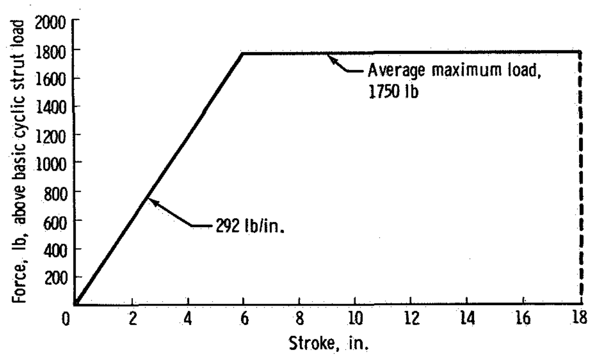


Figure 16.- Ramp-loading device load/stroke curve.

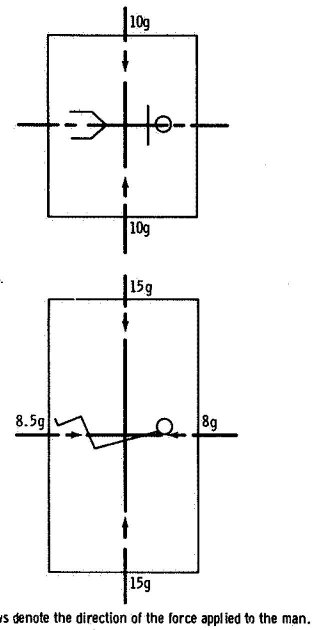


Figure 17.- Block II load-attenuation levels.

that would result in the lowest g level for the crewman within the stroking distance allowed in the CM. Results of the full-system drop tests were invaluable in determining the attenuator load value that was required for the spacecraft, that is, tuning the system. A comparison of figure 17 to figure 8 reveals the reduction in load imposed on the crew that was accomplished.

Because the ramp-loading assembly was essentially a friction device, a number of tests had to be conducted to determine the proper lubricant to be used in assembly. As a friction device, the assembly was velocity sensitive, and development stroke-load tests were programed carefully to produce the proper velocity/time profile.

Certification Tests

Couch.- The CM impact tests and the full-system drop tests were invaluable in certifying the crew couch. Structurally, the couch was designed to the early theoretical attenuator loads when applied statically, but structural failures of the couch were encountered when impact tests were conducted at those theoretical values. Because the attenuator loads were reduced as a result of the full-scale tests, the decision was made to certify the couch to the actual attenuator loads instead of incorporating design changes that would have been required to satisfy the theoretical loads.

Attenuators.- The major certification requirement for the attenuators was to certify that the attenuators would function at the levels established in the full-scale drop tests. Certification was accomplished by stroking each attenuator in both tension and compression on a load/stroke machine and by verifying that the attenuators stroked within ± 5 percent of the nominal load value.

FLIGHT EXPERIENCE

The CM crew-couch/restraint system has functioned satisfactorily during launch, flight, entry, water-landing, and recovery operations. The folding, stowing, and reassembling of the couch in flight have been achieved without problems on all missions except the Apollo 9 mission. The Apollo 9 crewmen experienced some difficulty in reassembling the center body support of the couch. This difficulty proved to be a couch installation problem. When the couch was installed, clearance between the Y-axis-attenuator rubbing pads and the CM sidewalls did not allow for the change in the CM shape in orbit. The decrease in the distance between the CM sidewalls after launch caused a pinching action on the couch structure, making reassembly difficult. A couch-sidewall clearance of 0.040 inch was adequate to eliminate this problem.

No occasion has arisen during any Apollo flight for an evaluation of the CM crew-couch/restraint and load-attenuation systems under abort or land-landing conditions. The two-parachute water landing of the Apollo 15 CM resulted in sufficient crewman/couch loading to stroke the X-axis foot attenuators 0.1 inch. From analysis of data derived from the design qualification and attenuator acceptance tests, an acceleration of at least 15g on the crew was determined to cause the strut to stroke.

CONCLUDING REMARKS

The most difficult couch-development problem was the compromise that had to be made to provide adequate crew protection for a land landing and to satisfy the operational requirements, simultaneously. The couch, restraint, and attenuation interfaces involved controls and displays, pressure-suit connections, helmet and boot-heel designs, human tolerances to impact loads in all directions, human tolerance to prolonged eyeballs-in (forward) acceleration, stowage-compartment configurations to accommodate couch motions on impact, rapid emergency egress for pad abort, inflight stowage for access to the lower equipment bay, and structural integrity for flight and abort conditions.

The use of a full-scale vehicle to determine the landing dynamics of the total couch/attenuation/vehicle system proved to be invaluable in tuning a crew impact-load attenuation system to protect the crewman adequately.

The interface problems that must be considered in the design of crew-couch, restraint-harness, and load-attenuation devices dictate that these components should be considered as an integral subsystem. In addition, the design of the system should not be completed until the most significant interfaces with the vehicle are defined because the basic design concept is limited by the tolerance of the human body to impact loads.

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