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AUGUST 1971 J. AIRCRAFT VOL. 8, NO. 8

Biotechnology Problems Relative to the Space Shuttle Vehicle

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This paper idscusses some of the problems associated with a shirtsleeve, side-by-side crew station as presently proposed for the shuttle vehicle. Experience in the areas of visibility and mission safety from flight programs such as the X-15 are cited as examples that lead to considering design criteria affecting the crew station configuration in the shuttle vehicle. Adequate outside visibility envelopes must be provided for the approach and landing task, and window size must be minimized to prevent breakage as a consequence of high-temperature structural distortion. X-15 experience also indicates the necessity for a pressure backup system when vehicles are repeatedly exposed to the extremes of re-entry conditions.

Introduction

THE shuttle mission presents some unique features which should be investigated to allow engineering tradeoffs on factors affecting the crew station. The space shuttle concepts to date are seriously considering only a side-by-side, shirtsleeve environment for the pilot/copilot crew station. This arrangement has been interpreted from the NASA Statement of Work for Phase B Shuttlecraft Design which specifies a reusable airliner type of vehicle operated by two crewmen in a shirtsleeve environment with high-performance aircraft visibility.

The NASA Flight Research Center, although not directly involved, has followed closely the evolution of the space shuttle and is supporting the program in several technological development areas. In the biotechnology area, investigations of pilot visibility requirements and crew thermal and pressure protection systems are being conducted. It is anticipated that the results of these investigations will contribute to the development of the shuttle. Other contributions of equal or possibly greater importance may be realized as a result of the Flight Research Center's experience with research aircraft. This unique experience, although not acquired in space, is directly pertinent to the shuttle vehicle, because the vehicle will operate as an aircraft once it has entered the atmosphere. The assumption that the shuttle will be manually landed in a conventional manner requires an estimate of the mission-related importance of this task and the concomitant visibility requirements. Our X-15 experience provides information concerning the relative importance of these landing tasks and illustrates some of the practical problems associated with providing the pilot with the direct vision essential for the approach and landing tasks.

The reusable shuttle concept poses some other problems unique to the space community but familiar to aircraft designers and operators. Cockpit pressurization problems encountered in the X-15 airplane are but one example of the kinds of failures to be expected when a vehicle is reused,[1] particularly after being repeatedly exposed to the environmental extremes of space and re-entry.

This paper briefly discusses the Flight Research Center's experience related to biotechnology problems of the space shuttle vehicle and suggests guidelines to satisfy the factors considered.

Presented as Paper 70-1327 at the AIAA 7th Annual Meeting and Technical Display, Houston, Texas, October 19–22, 1970; submitted November 30, 1970; revision received March 22, 1971.

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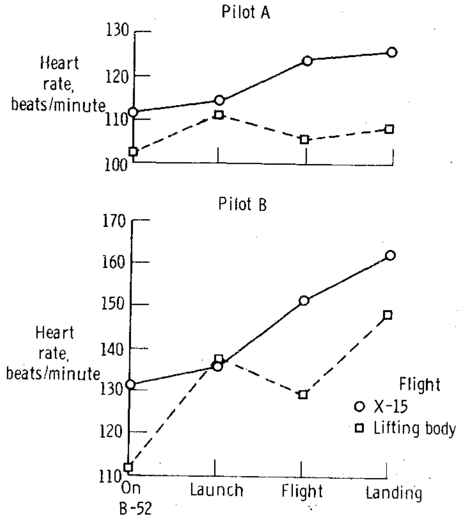


Fig. 1 Average heart rates for X-15 and lifting body flights.

General Discussion

Mission Importance of the Landing Task

Experience pertinent to the reentry and landing phase of the shuttlecraft was obtained in the 199 flights made during the X-15 program. Other experience with shuttle like vehicles has included low-lift-drag-ratio approaches and landings with lifting body vehicles such as the M-2, X-24, and HL-10, which have collectively flown 150 flights.

The X-15 airplane and the lifting body vehicles have similar flight profiles, except that the lifting bodies do not leave the atmosphere. Each vehicle is launched from a B-52 airplane and is unpowered during the approach and landing. The X-15 and lifting body pilots agree that the landing tasks for these vehicles are at least as difficult as other portions of the flight profile. This belief is consistent with their heart rates monitored in flight. Previous investigations have indicated that pilot's heart rates increase with the demands of the tasks encountered.[2] Therefore, heart rates can be used to estimate the portions of the flight that the pilots consider to be most demanding. Figure 1 shows averaged heart rates for two pilots who have flown both types of vehicles. The solid line for pilot A is an average of five flights, and the dashed line is an average of eight flights. For pilot B the solid line is an average of nine flights and the dashed line, four flights. For the lifting body flights, the heart rate at launch is higher than during the flight and then increases for the landings; whereas, for the X-15 flights, the heart rate continues to rise throughout the mission. Although pilots A and B are the only pilots who have flown both types of vehicles, the heart rate trends shown are typical for all the pilots in the X-15 and lifting body programs.

The X-15 and lifting body experience emphasizes the importance of the approach and landing tasks associated with these types of flight vehicles. Special design considerations are required to provide the pilot with adequate means for performing these tasks.

Visibility Envelopes

One design consideration affecting the landing task is the effectiveness of the visibility envelope in allowing the pilot to land the vehicle safely. The visibility envelope depends on the window surface area and eye position. In general, much smaller window areas are required for a single-place cockpit than for a cockpit with a side-by-side arrangement. In this regard, the right viewing angle available to a left-seated pilot during the approach and landing is considerably restricted compared with the visibility available to a pilot in a single-place cockpit. For example, the horizontal and vertical visual angles available from the X-15 airplane and the Boeing 747 airplane are compared in Fig. 2. As shown, the right viewing angle is restricted for the 747 pilot, whereas the X-15 pilot has equally good visibility to the right and left. The ratio of visible envelope areas between the 747 and the X-15 airplanes is 1.36, whereas the window surface ratio is 9.2. That is, the left-seated 747 pilot has only 36% more visibility (primarily to the left) than the X-15 pilot at the expense of nine times the window surface area.

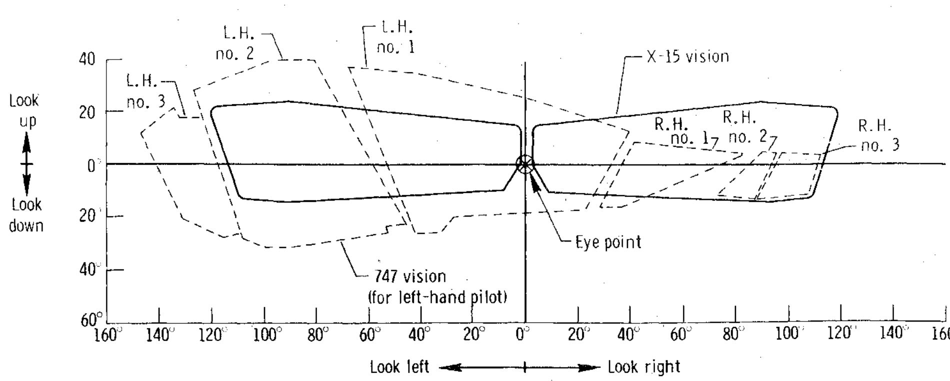
An incident that occurred in the X-15 program relates specifically to the advantages of having equally good left and right vision. During one flight, the right window became completely opaque as a result of windshield glass failure during re-entry. The pilot's comments during debriefing relative to the approach and landing phases are quoted as follows: "The landing was pretty much as usual except for the limited visibility, which came as a surprise. In the landing, I felt I must have been at least two seconds behind in making corrective control inputs. For instance, when the flaps went down and as I flared, and then trim change taking effect and the altitude change, I was two seconds behind on the control to prevent the airplane from ballooning. It ballooned quite a bit higher than it has on previous flights. It's pretty obvious now that both windshield panels are required." In the X-15 airplane the large viewing angle with the small viewing surface area was obtained by placing the pilot close to the window; consequently, the structure holding the window limited head movement. Figure 3, a photograph of a pilot in the X-15 cockpit, illustrates the limited head room which prevents the pilot from leaning toward the left window.

This X-15 experience indicates the desirability of providing equally good visibility to the left and right for approaches and landings at least when go-around capability does not exist.

The Window Areas and the Thermal Problem

Of extreme interest to thermal protection personnel is the window surface area. Any viewing port and particularly the frontal viewing ports are susceptible to various modes of failure, especially during re-entry. The greater the window

Fig. 2 Comparison of X-15 and 747 visibility envelopes.



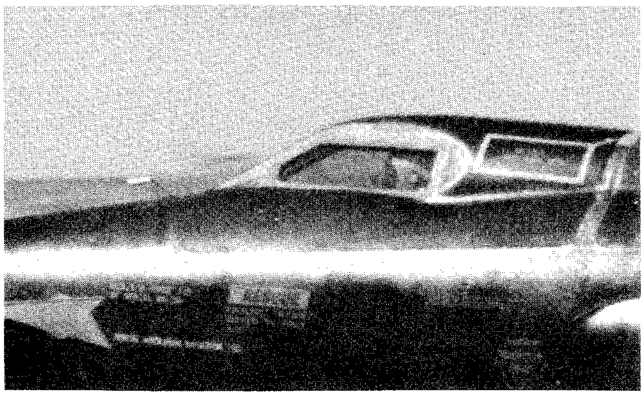


Fig. 3 View of X-15 airplane showing pilot's head position.

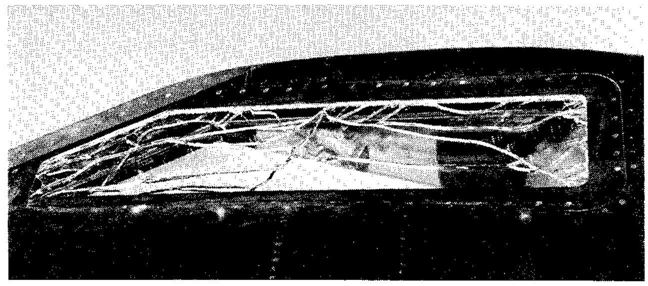


Fig. 5 X-15 severely cracked left-hand outer panel; outside view; flight 2-20.

surface area, the greater will be the possibility of failure. Examples of different window surface areas are the 747 airplane with 29.5 ft^2, the X-15 airplane with 3.2 ft^2, and the two forward or rendezvous windows of the Apollo Command Module with 2.4 ft^2.

Figure 4 is a schematic of the X-15 windshield configuration showing the inner and outer panels. The inner panel is laminated with a heating control between the layers. During several flights, thermal and structural problems resulted in damage to these windows. Table 1 summarizes five flights in which windshield failures occurred. The resultant damage is shown photographically in Figs. 5–9. Soda-lime glass windows were used in early X-15 flights, but this glass was never intended for high-temperature flights. The outer panels were replaced with an alumino-silicate glass window for later flights. This alumino-silicate panel was tested without failure to 1050°F outer-surface temperature, with a ratio of outer-to-inner surface of 790°F, which was 150% of the maximum predicted. The second failure listed in the table was with alumino-silicate glass; the other failures were with soda-lime glass. In each instance, the windows broke because of the interaction between the retaining structure and the glass, not because of the type of glass used. For large window areas, greater thermal expansion and distortion of the retaining structure can be expected, and the potential for glass failure is increased. Therefore, to minimize complexity and weight penalties, it is recommended that a small viewing surface be used in the shuttle vehicle. A large visual angle to the left and right may be provided by placing the pilot close to the viewing windows.

The X-15 experience also shows that a means of providing a backup capability for outside viewing is necessary should visibility be lost or partially obscured. This requirement is further emphasized by the Apollo space flights in which partial loss of visibility has resulted from a hypergolic fuel residue collecting on the windows. One technique that could be used to provide this backup capability would be to incorporate a completely automatic landing system. However, for VFR conditions, an indirect optical viewing system is a candidate for reasons of simplicity and reliability, because the small optical ports may be easily protected. Low-lift-drag-ratio approaches and landings have been made at the Flight Research Center using an indirect viewing system from the rear tandem cockpit of a high-performance aircraft (F-104B). Results of these flight experiments indicated that an optical system of this type can provide the pilot with adequate visual information for the flare and landing.[3]

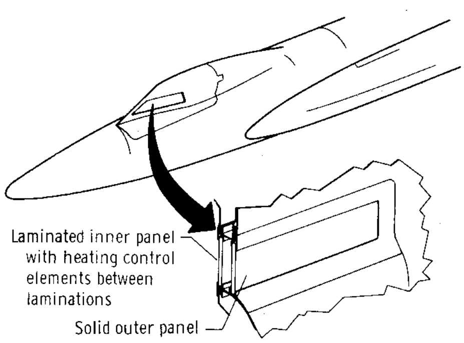


Fig. 4 X-15 windshield configuration.

A Requirement for a Backup Cabin Pressurization System

Of primary interest to a flight crew are provisions for a backup cabin pressurization system. During the X-15 program, partial or total cabin pressure losses were encountered on more than 24 flights. These flights provide the only experience available with a reusable, re-entry vehicle. Table 2 lists examples of these failures. The examples were selected to show a wide variety of failures and/or malfunctions that did not seem to follow a pattern other than that the majority occurred during re-entry. Because the pilots always wore a full-pressure suit as a backup, these failures were not disastrous and the aircraft was safely landed. Several pressure losses occurred early in the program on all three vehicles, thus the program would have terminated very early if pressure suits had not been worn.

This experience with the X-15 airplane points out the necessity of providing a backup system or scheme for pressure protection. The crew should be provided with pressure suits during the high risk portions of the mission such as launch, re-entry, and the terminal phase, or, if a shirtsleeve environment is specified, an alternate solution would be to lay out the crew station to provide cockpit redundancy that allows each cockpit to be independently pressure sealed. This arrangement should reduce the risks to mission safety as a consequence of pressure loss in any given compartment. The safety recommendations considered optimum for the reusable shuttle vehicle would be 1) to provide all passengers and crew with full-pressure suits and 2) for the crew to operate within separately sealed cockpits.

Existing Shuttlecraft-Oriented Flight Experiments

Flight experiments with existing high-performance aircraft are pertinent to studies of a shuttle vehicle cockpit

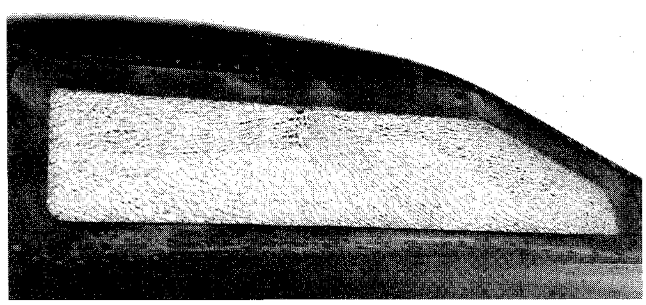


Fig. 6 X-15 cracked right-hand outer panel; outside view; flight 2-21.

Table 1 X-15 windshield failures

Date	Aircraft and flight number	Incident	Cause	Remarks
10/11/61	2-20	Outside panel shattered on left-hand side	Thermally and pressure induced structural distortion	Soda-lime glass. Occurred at approximately 217,000 ft at Mach 5.21. See Fig. 5.
11/9/61	2-21	Right-hand outer panel shattered and became completely opaque	Thermal buckle of the windshield retainer frame during re-entry at Mach 6.04	Alumino-silicate glass. Pilot said, with the limited visibility "... I felt I must have been at least 2 sec behind in making corrective control inputs." See Fig. 6.
5/29/63	3-18	Inner panel cracked on left-hand side	Thermally induced stresses in retainer screws	Soda-lime glass. Heating rates at Mach 3 and low angle of attack. See Fig. 7.
12/5/63	1-42	Inner panel cracked on right-hand side	High structural temperature suspected as cause of structural distortion	Soda-lime glass. Glass broke during re-entry at approximately 100,000 ft. See Fig. 8.
4/29/64	1-47	Inner panel cracked on right-hand side	Faulty heater control during high-temperature portion of flight	Soda-lime glass. An attachment mounted on inside of canopy retainer contributed to failure. See Fig. 9.

arrangement because, for example, investigations of limited visibility flight and indirect viewing methods may be conducted. This information can be generally, and sometimes directly, used in providing design guidelines for a cockpit for both the scaled shuttle prototype and the first full-mission experimental prototype.

The Flight Research Center has initiated a flight program to determine the minimum but adequate viewing angles for shuttle types of approaches and landings. The experiments with high-performance aircraft are designed to evaluate crew performance during standard ILS and low-lift-drag-ratio approaches, which include a family of approach angles from 3° to 18° at speeds from 100 to 300 knots. A family of visibility envelopes is being investigated which ranges from a window surface area of 3.2 ft^2 (X-15) to a maximum of 17.3 ft^2 of viewing surface (high-performance aircraft). The viewing angles will be varied from 7.5° to 240° in the horizontal plane; the vertical angle will remain constant. Information derived from these flights may provide criteria leading to visual and display requirements for the approach and landing phases of the shuttle mission.

Summary

Pilot comments and heart-rate data have indicated that the approach and landing tasks are at least as important as other phases of a mission. The shuttlecraft crew station design guideline suggested to satisfy this important consideration is to provide the pilot with adequate visibility to the left and right. This requirement should also be con-

Table 2 Examples of X-15 flights on which cockpit pressure was lost

Date	Aircraft and flight number	Incident	Cause	Remarks
5/11/59	2-3	Cabin pressure loss; suit inflated	Windshield seal bleed due to thermal stresses	Third powered flight
4/3/61	2-14	Cabin pressure loss; suit inflated	Lost LN_2 system during high buffeting period	High altitude, to 150,000 ft
4/21/61	2-15	Cabin pressure loss; suit inflated	Not able to determine reason for loss	Pressure loss occurred 1 min after burnout, and the pilot said, "Some of the noises that I heard were some good thumps and bumps."
6/23/61	2-17	Quick loss of cabin pressure; suit inflated for duration of flight	General structural deformation of canopy and skin buckled on both wings during re-entry	Pilot commented that he felt much more comfortable using the side-arm controller than the center stick while the pressure suit was inflated
7/11/62	1-30	Cabin pressure loss; suit inflated	Acceleration effects on cabin pressure regulator	Left-hand outer panel also exhibited crazing cracks
7/17/62	3-7	Cabin pressure loss; suit inflated	Continuous running of auxiliary system caused LN_2 to reach the discharge point into the cockpit, and sufficient gasification did not occur	High altitude, to 314,000 ft During re-entry pilot experienced 5*g* acceleration
6/14/65	3-43	Cabin pressure loss; suit inflated	Sticky regulator valve failed to inflate the canopy seal	High altitude, to 240,000 ft
6/29/65	3-44	Cabin did not pressurize; suit inflated	Cycling of ram air door allowed cockpit to pressurize	High altitude, to 280,000 ft
9/8/65	3-47	Cabin pressure loss with a loud pop and hiss; actual pressure loss was slight	O-ring blew out around the stem of the canopy seal regulator	High altitude, to 240,000 ft

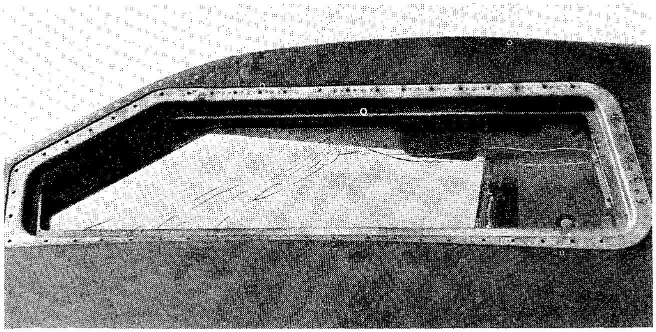


Fig. 7 X-15 cracked left-hand inner panel; outside view; flight 3-18.

sistent with the suggested guideline for a small window to minimize weight, design complexity, and the probability of failure due to structurally induced breakage. These factors suggest that the pilot be placed close to the viewing ports in a one-man cockpit. X-15 experience further shows the desirability of providing a cabin pressure backup system for use with a resuable re-entry vehicle. To satisfy this requirement, separately sealed cockpits are suggested to provide total fail/operational crew capability. The crew station arrangement that would satisfy these guidelines is a tandem configuration; however, after the shuttlecraft configuration is selected and the visibility experiments in progress are completed, other crew station arrangements may be possible within these guidelines.

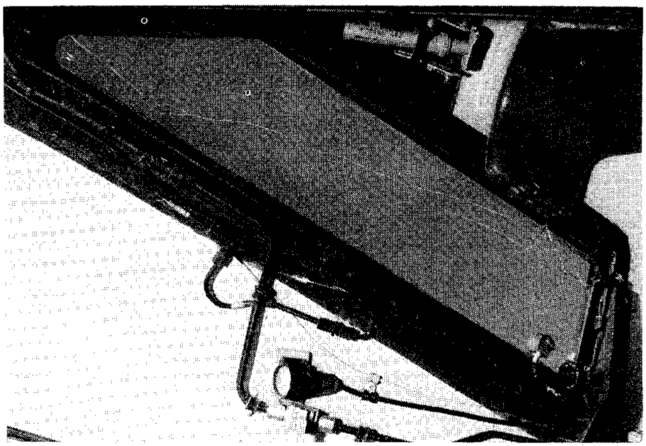


Fig. 8 X-15 cracked right-hand inner panel; inside view; flight 1-42.

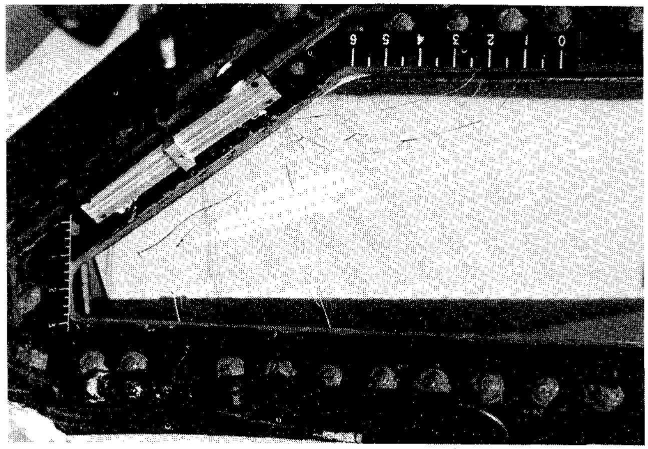


Fig. 9 X-15 cracked right-hand inner panel; inside view; flight 1-47.

High-altitude flights in all experimental aircraft used in Flight Research Center programs have indicated a need for individual crewman backup pressure protection. In this context, a satisfactory arrangement for the first shuttle flights would be to provide all crewmen with pressure suits for use at least during the most critical portions of the mission.

Inasmuch as partial vision loss through the viewing ports has been experienced on X-15 and Apollo flights, a reliable, indirect optical viewing system is recommended for use as a simple backup system for outside viewing.

The suggested guidelines point out a definite need for engineering tradeoffs in the design of the crew station layout for the space shuttle vehicle.

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