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CRASH SURVIVAL EVALUATION OF THE RU-21B

PREPARED BY THE U.S. ARMY SAFETY CENTER, FORT RUCKER, ALABAMA

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CRASH SURVIVAL EVALUATION
OF THE RU-21B

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This report has been approved by the Commander, US Army Safety Center.

ABSTRACT

A crashworthiness assessment of the RU-21B is presented. This assessment was conducted based on Appendix B. Included are the quantative evaluation and a ranking of the crashworthiness factors based on potential for improvement.

SUMMARY

This report contains a USASC assessment of the crash survival potential of the RU-21B. The assessment was conducted using the results of a crashworthy evaluation by USASC personnel in accordance with Appendix B. The assessment provides a point score based against an optimum yardstick whereby an optimally crashworthy aircraft would have a 1.0 rating for each of the six areas of crashworthiness under consideration. The RU-21B rating for each of the six crashworthiness factors is shown below.

	Optimum Number	RU-21B Value
1. Injurious Environment	1.0	.20
2. Evacuation	1.0	.28
3. Troop Retention	1.0	.33
4. Crew Retention	1.0	.38
5. Post-crash Fire	1.0	.39
6. Basic Airframe Crashworthiness	1.0	.80

The areas that require the most improvement for the aircraft to attain minimally acceptable crash survivability levels in their specific areas are Injurious Environment, Evacuation and Troop Retention.

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INTRODUCTION

A system to numerically relate the crash survival potential of a particular aircraft design to what is considered optimum crash survival design is contained in Appendix B. Though developed to be a tool during the preliminary design phase, the system can be used to identify crash-worthiness deficiencies in current aircraft. This report documents the application of this system to the assessment of the crash survivability of RU-21B aircraft.

The aircraft evaluated was an RU-21B belonging to the 1st ASA Co, Ft. Bliss. The goal of the evaluation was to assess the necessary crash-worthiness/requirements to enhance the occupant's chances of survival in an aircraft crash.

Appendix A contains a discussion of the rating used for this evaluation. It and the evaluation are based on the engineering principles and doctrine contained in Reference (1). The data used for this evaluation was obtained by a review of pertinent specifications, Technical Manuals, drawings, and an on-site inspection of the above RU-21B.

OBJECTIVES

The overall objectives of the study were to (1) identify those crash-worthiness deficiencies existing in the RU-21B, and (2) numerically relate the crash survival potential of the RU-21B to what is considered an optimum design and (3) prioritize the crashworthiness factors for potential survivability improvement.

The Rating System and the Overall Rating Results

The approach presented in Appendix B provides for a systematic evaluation of the crash survival potential of an aircraft. In order to focus the proper emphasis on any crashworthiness deficiencies, six basic survival factors are considered when evaluating an aircraft. The six factors along with their hazard potential and optimum number as defined in Appendix B, and the ratings established from the RU-21B evaluation, are as follows:

Factor	Hazard Potential	Optimum Number	RU-21B Value
1. Crew retention system	17.92%	130	50
2. Troop retention system	17.23%	125	41
3. Postcrash fire potential	35.19%	255	99
4. Basic airframe crashworthiness	17.23%	125	100
5. Evacuation	8.29%	60	17
6. Injurious environment	4.14%	30	8
Totals	100.00%	725	315

Prioritizing the Areas of Improvement

In order to prioritize those areas in which improvements are most desirable for improved survivability, an approach was used which considers each of the factors independently. As noted in the above paragraph the evaluation ratings of Appendix B result in an overall rating which is the sum of the factors and does not readily answer the question "what needs to be done first". There is a tendency to view the weighted scores relative to other factors rather than to consider each factor on its own shortcoming. There is a need to present this shortcoming in terms of the percent of attainment of the optimum rating for a given factor. Therefore, each of the six factors scores listed above was normalized to unity, i.e., optimum rating of each factor is 1.0. By taking this approach the more deficient factors reflect lower scores as compared to optimum. This results in the following ranking:

1.	Injurious Environment	.27
2.	Evacuation	.28
3.	Troop Retention	.33
4.	Crew Retention	.38
5.	Post-Crash Fire	.39
6.	Basic Airframe Crashworthiness	.80

This shows the factors, independent of all other factors and hazard potential, which have the greatest need for improvement based on the scores deviation from the optimum score of 1.0.

Discussion of the Results

The goal of crashworthiness improvement effort must consider the survivability of the aircraft as a system and endeavor to enhance survivability with consideration given to cost, mission requirements and practicality of the approach. The various factors and subfactors, although independent, do interact to create a survivable environment. If, as with the RU-21B, the mission equipment creates to some degree an injurious environment which is unavoidable, the total hazard can be minimized if crew/operator restraint systems are greatly improved, e.g., prevent the individuals from contacting injurious objects. On the other hand, if it is deemed impractical to equip the aircraft with crashworthy fuel systems, an excellent emergency exit system would tend to reduce evacuation time and permit rapid egress from a burning aircraft. The use of this approach to enhance crashworthiness of each of the factors within applicable constraints will result in a significant improvement in occupant survivability in the RU-21B as an aircraft system.

The discussions of each subsystems are contained in Appendix A. Specific deficiencies for each factor can be obtained from Appendix A. The more general results of the RU-21B assessment can be summarized by the following:

1. Injurious environment is potentially one of the most serious injury-causing mechanisms.

2. Evacuation is not considered significantly different in priority from injurious environment. It becomes an overriding injury/fatality-causing factor in the more serious accidents. Evacuation coupled with injurious environment poses one of the most serious threats to survival. The ability of injured personnel to egress from the aircraft becomes minimal. Equally the capability to rescue injured personnel is extremely limited.

3. Mission equipment operator retention and seating system is poor. This again compounds injurious environment. Lack of shoulder harness in particular would be the major cause of head, face, and flailing injuries. The lack of neck support or upper restraint will result in neck injuries. Seat tiedown strength is also inadequate.

4. Crew retention is somewhat better than mission equipment operator retention in that shoulder harnesses are provided. However, due to large pull-off angle of the shoulder harness, no lateral restraint for the crew exists. Seat tiedown strength is also inadequate.

5. Post-crash fire and evacuation factors taken together are potentially the biggest cause of fatal injuries. Rigid fuel lines, proximity of ignition sources and lack of crashworthy fuel cells are the principle shortcomings. A review of past U-21 accidents indicates that due to mode of operation post-crash fires do not occur often; however, this does not diminish the lethality of fire once it does occur.

6. Basic airframe crashworthiness is considered good.

CONCLUSIONS

The assessment of the RU-21B crashworthiness provides the following conclusions:

1. The RU-21B in its present configuration does not provide an adequate level of survivability.

2. Improvements to these factors on an aircraft system basis can be accomplished to enhance total occupant survivability.

3. Crashworthiness factors which enhance occupant survivability can be quantitatively evaluated and prioritized to establish most pressing improvement requirements.

4. The top three factors having the most pressing need for improvement are:

   a. Injurious Environment: Elimination of sharp corners, knobs, handles, etc. associated with mission equipment.

   b. Evacuation: The emergency escape system should permit unaided egress without any unusual effort by the occupants, i.e., ability to walk out versus climbing out (overhead hatch). The opening should be large enough to permit the entry of rescue personnel and equipment.

   c. Troop Retention: The mission equipment operators should be provided with an upper torso restraint system.

5. Appendix B in its present form does not readily identify "what needs to be done first." The numerical score tends to be misleading when considering the overall crashworthiness of a current aircraft.

RECOMMENDATION

1. Recommend that the results of this assessment be used to identify and justify improvements to those factors listed in such a manner as to optimize the RU-21B system occupant survivability.

2. Recommend that evaluation criteria contained in Appendix B be updated based on current accident data and scoring be developed to readily reflect the priority of the areas in need of improvement.

REFERENCES

1. USAAMRDL Technical Report 71-22, *Crash Survival Design Guide*, Oct 1971

2. Federal Aviation Regulations, Part 23, *Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes*, June 1974.

APPENDIX A

Crash Survival Evaluation of the RU-21B

This evaluation is based on the probable performance of an aircraft in a severe crash. In less severe crashes some of the ratings may not be quite as important as others. It is assumed that protection of the occupant to the limits of a severe crash is the major goal in aircraft survivability. To develop a reasonable crash survivability rating, weighted values have been assigned to the various factors. The percent of weight assigned to each factor is based on its relative hazard potential.

CREW RETENTION SYSTEM RATING

	Optimum Number	System Rating
Vertical Energy Absorption Capacity	10	2
Restraint Webbing Geometry and Strength	30	21
Seat Longitudinal Strength	15	4
Seat Lateral Strength	5	1
Seat Vertical Strength	5	1
Absence of Casting in Stressed Areas	10	10
Shoulder Strap Guide Width	10	0
Shoulder Strap Pull-Off Angle	10	0
Lap Belt Angle to Seat Cushion	10	10
Lap Belt Tiedown Strap	10	0
Inertia Reel Type	N/A	N/A
Depth of Structure Between Floor and Belly	5	1
Total Points	130	50

TROOP RETENTION SYSTEM RATING

Vertical Energy Absorption Capacity	10	2
Restraint Webbing Geometry and Strength	30	9
Seat Longitudinal Strength	15	6
Seat Lateral Strength	15	5
Seat Vertical Strength	5	1
Absence of Castings in Stressed Areas	10	10
Shoulder Strap Pull-Off Angle	10	0
Lap Belt Angle to Seat Cushion	10	7
Lap Belt or Side Tiedown Strap	10	0
Depth of Structure Between Floor and Belly	10	1
Total Points	125	41

POSTCRASH FIRE POTENTIAL RATING

	Optimum Number	Actual Value
Spillage Control		
Fuel Containment	60**	15
Oil Containment	20	14
Flammable fluid lines	30	0
Firewall	9	7
Fuel flow interruptors	9	7
Ignition Control		
Induction and exhaust flame location	30	25
Location of hot metals and shielding	30	10
Engine location and tiedown strength	15	7
Battery location and tiedown strength	12	3
Electrical wire routing	12	5
Boost pump location and tiedown strength	7	0
Inverter location and tiedown strength	6	1
Generator location and tiedown strength	6	3
Lights location and tiedown strength	5	2
Antenna location and tiedown strength	4	0
Total Points	255	99

BASIC AIRFRAME CRASHWORTHINESS RATING

	Optimum Number	Actual Value
Distance from Nose to Troop/Passenger Area	30	16
Absence of "Plowing" Tendency	15	10
Resistance to Longitudinal Impact Loads	15	14
Resistance to Vertical Impact Loads	10	10
Resistance to Lateral and Roll-Over Impact Loads	15	15
Landing Gear Vertical Force Attenuation	5	3
Landing Gear Location	5	5
Effect of Wing Separation on Cabin Occupants	10	7
Effect of Fuselage Fracture/Separation in Long-Body Aircraft	20	20
Total Points	125	100

EVACUATION RATING

Ease and Reliability of Exit Operation	15	6
Ratio of Usable Exits to Occupants	15	6
Identification of Exits	10	4
Availability of Exits in Rolled Aircraft	10	1
Emergency Lighting	10	0
Total Points	60	17

INJURIOUS ENVIRONMENT RATING

Proximity of Cockpit Controls and Other Structure	10	1
Retention of Interior Equipment	10	4
Rudder Pedal Area	5	3
Absence of Injurious Objects in Cabin	5	0
Total Points	30	8

INDIVIDUAL SYSTEM RATINGS

General

Views of the RU-21B aircraft are shown in Figures 1-3. These views show the cabin entry door, rescue openings, antennae locations, landing gear and overall configurations. The basic fuselage structure is illustrated in Figure 4. The crew seating and cabin configuration is shown in Figure 5.

FIGURE 1

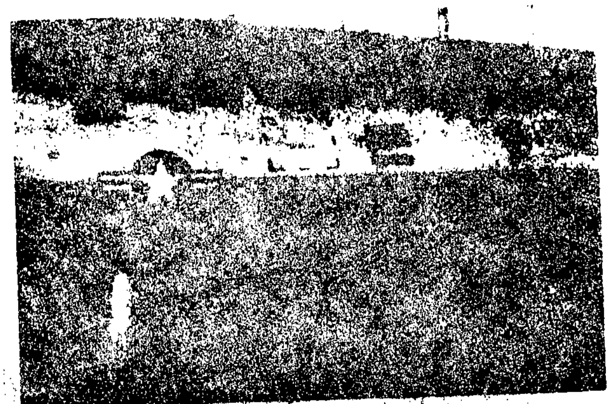


FIGURE 2

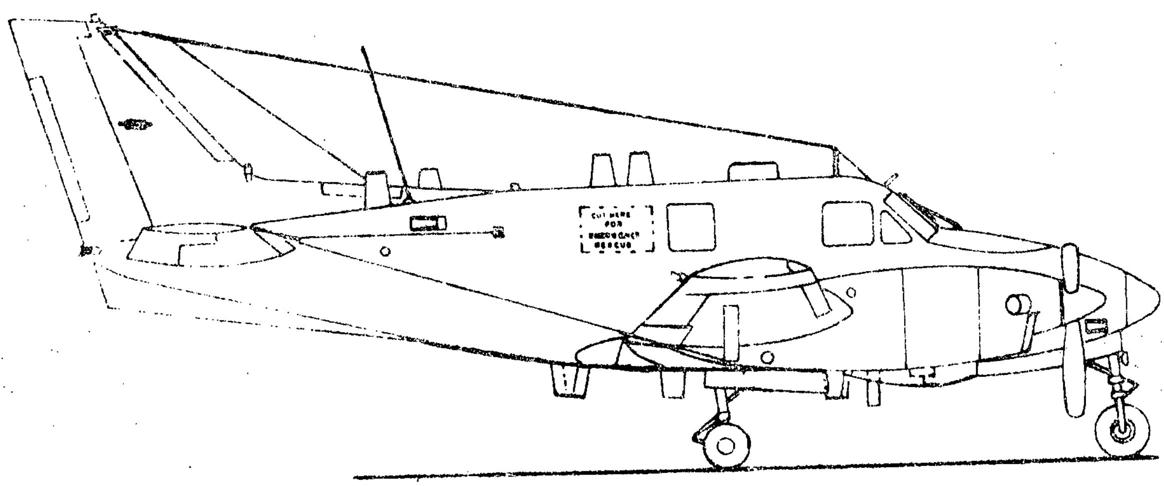


FIGURE 3

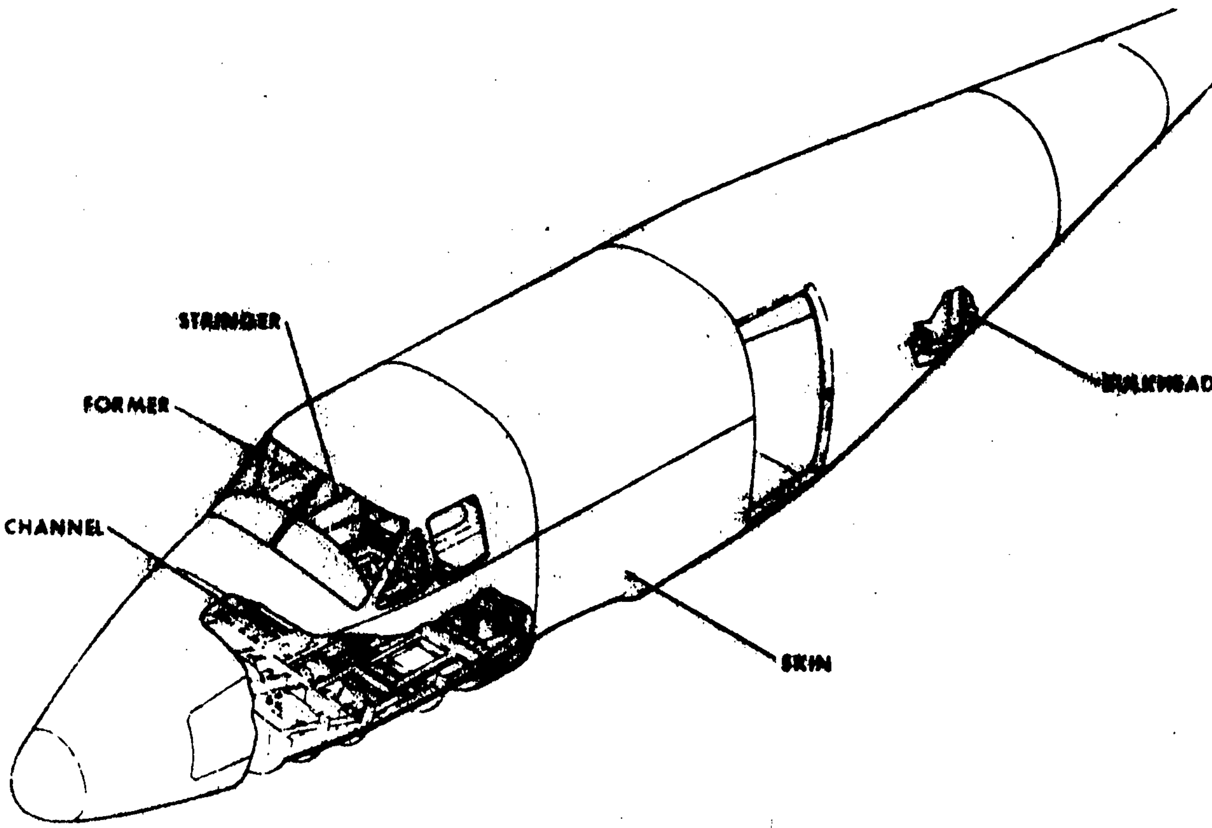


FIGURE 4 – Basic Fuselage Structure

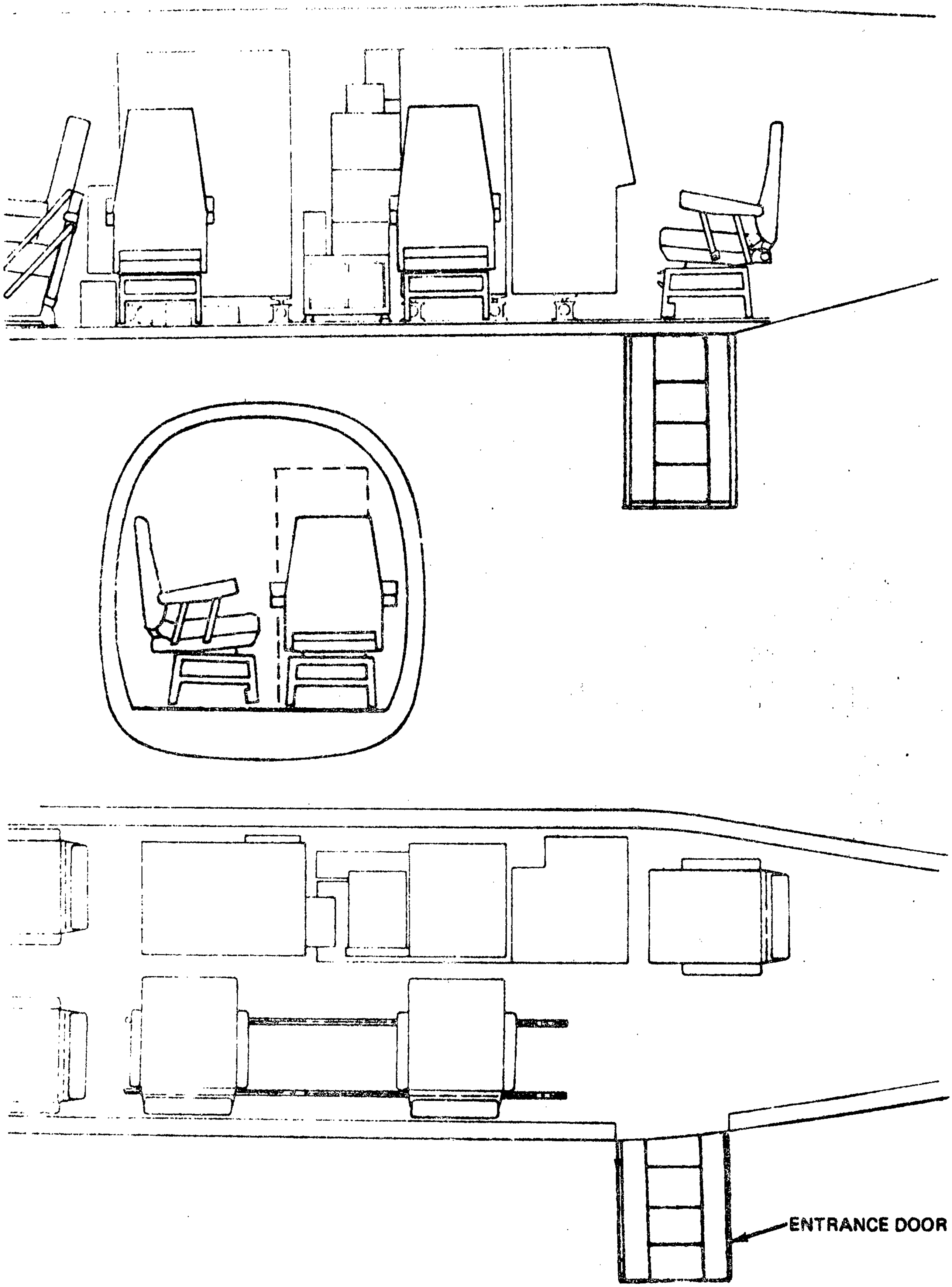


FIGURE 5 —General Interior Arrangement Diagram

The RU-21B is an unpressurized, low wing, all metal aircraft powered by two T74-CP-702 turboprop engines. The primary mission of the aircraft is that of radio reconnaissance.

Crew Retention System Rating

SYSTEM DESCRIPTION

The pilot's and copilot's seats of the RU-21B are arranged in a side by side configuration as shown in Figure 5. The seats are adjustable chair type seats having adjustments vertically as well as fore and aft. They are tabular frame construction and attach to a floor mounted rail. The seat bottom and back consists of foam rubber cushions approximately 4" thick. The seat belts attach to two floor disconnect fittings aft of the seats. The shoulder harnesses attach to a roof mounted inertia reel to provide crash restraint. See Figure 6. The reel will lock automatically under a 2 'G' impact or may be manually locked. Seat design is assumed to conform to Reference 2.

FIGURE 6

	Optimum Points	System Rating
1. Vertical Energy Absorption Capacity		
The design of the seat assembly does not provide for energy attenuation. In addition, buckling of the seat does not appear to provide any significant energy attenuation. The 4" seat cushion will not provide attenuation but could in fact result in higher peak acceleration due to dynamic overshoot.	30	2

	Optimum Points	System Rating
2. Restraint Webbing Geometry and Strength		
The lap belt and shoulder harness webbing is 2 inches wide and .09 inches thick. Ultimate strength of this webbing was assembled to be 5000-6000 pounds. No tie strap is provided in the design.	30	21
3. Seat Longitudinal Strength		
The longitudinal design load factor for the seat is 9G compared to the 35G minimum factor considered to be minimum. Therefore 9/35 of the 15 point optimum is given.	15	4
4. Seat Lateral Strength		
The lateral design load factor for the seat is 1.5G, compared to the 20G factor considered to be minimum. Therefore, 1.5/20 of the 15 point optimum is given.	15	1
5. Seat Vertical Strength		
The vertical design load factor for the seat is 3G compared to the 25G factor considered to be minimum. Therefore a rating of two points are given.	5	2
6. Absence of Castings in Stresses Areas		
No castings are used in stressed areas and the optimum points are given.	10	10
7. Shoulder Strap Guide Width		
No shoulder strap guide is provided; therefore no points are given.	10	0
8. Shoulder Strap Pull-Off Angle		
The shoulder harness is attached to the roof of the aircraft aft of the seat at a distance of 18-20 inches above the shoulders. This results in a pull-off angle of approximately 75° as compared to an optimum of $0-25^{\circ}$. Zero points are given.	10	0

		Optimum Points	System Rating
9.	Lap Belt Angle to Seat Cushion		
	The lap belt centerline projects at an angle of approximately 45° to profile; therefore, optimum points are given.	10	10
10.	Lap Belt Tiedown Strap		
	No points are given since a tiedown strap is not provided.	10	0
11.	Inertia Reel Type		
	Not applicable to fixed wing aircraft.		
12.	Depth of Crushable Structure Between Floor and Belly		
	Approximately 12" of crushable structure is provided as compared to the 24" required. However, since the fuselage bottom is flat rather than circular, only 1 point is given.	5	1

Troop Retention System

Three mission operators seats are mounted in the aft cabin area as shown in Figure 5. A view of the seat is shown in Figure 7. The seats are mounted on tracks near the mission consoles and may be swiveled to allow the operators to face forward, inboard, or aft. The lap belts attach to the seat. No shoulder harness is provided. The seat is assumed to have been designed to Reference 2.

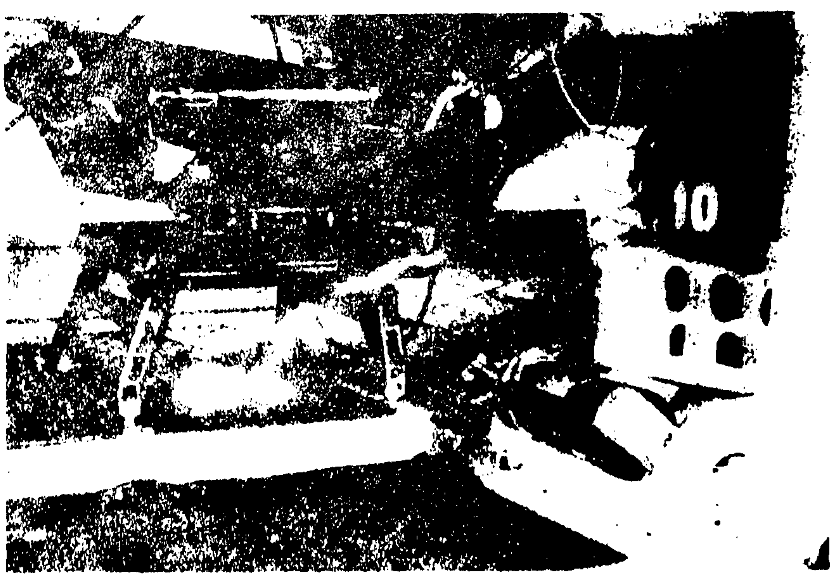


FIGURE 7

		Optimum Points	System Rating
1.	<u>Vertical Energy-Absorption Capability</u> The mission operator's seat structure does not provide for energy attenuation by either design or buckling. Neither is any attenuation provided by the 3" seat cushion. In fact, studies have shown that higher peak accelerations can result due to dynamic overshoot.	10	2
2.	<u>Restraint Webbing Geometry and Strength</u> The lap belt used in the RU-21B is 2 inches wide and .09 inches thick. The ultimate strength was assumed to be 5000 lbs. No lap belt tiedoen or shoulder harnesses are provided. Result is awarding of 9 points to this factor.	30	9
3.	<u>Seat Longitudinal Strength</u> Assuming that the seat complies with Ref. 3, the seat had a longitudinal design factor of 9G.	15	6
4.	<u>Seat Lateral Strength</u> Assuming that the seat complies with Ref. 1, and is a swiveling seat, it has the same strength in the lateral and longitudinal directions, i.e., 9G.	15	5
5.	<u>Seat Vertical Strength</u> Assuming that the seat complies with Ref. 1, it has a vertical design factor of 3G.	5	1
6.	<u>Absence of Castings in Stressed Areas</u> The seat is free of castings in stressed areas. The optimum points are given.	10	10
7.	<u>Shoulder Strap Pull-Off Angle</u> No shoulder strap is provided; therefore; no points are allowed.	10	0

	Optimum Points	System Rating
8. Lap Belt Angle to Seat Cushion		
The lap belt is attached to the seat at the seat back and seat cushion intersection (See Figure 8). The angle is therefore approximately 30° compared to a minimum of 45°, therefore seven points are allowed.	10	7

FIGURE 8

	Optimum Points	System Rating
9. Lap Belt or Side Tiedown Strap		
A lap belt or side tiedown strap is not provided; therefore no points are allowed.	10	0
10. Depth of Structure Between Floor and Belly		
Same as crew retention system.	10	1

Spillage Control

	Optimum Points	System Rating
1. Fuel Containment		
The RU-21B containment system consists of 2 identical systems in each wing connected by a crossfeed manifold. Fuel in each system is contained in a nacelle tank and gives interconnected wing tanks. (See Figure 9)	60	15

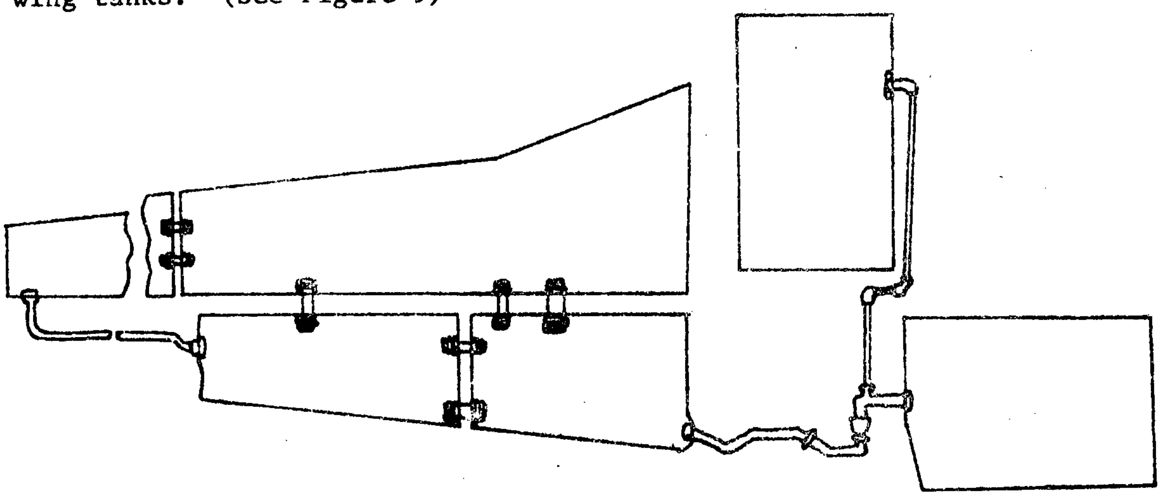


FIGURE 9 –RU-21B Fuel Containment System (Some interconnecting lines removed for clarity.)

Fuel can be transferred between the two systems by electrically operated transfer pumps located on the bottom of the fuselage (See Figure 10). Total usable fluid for both systems is 396 gallons (2574 pounds). The nacelle and inboard main wing tanks are self-sealing (bullet-resistant) type. The other tanks are constructed of a rubberized material, but are not self-sealing. They are connected by metal couplings. The two nacelle tanks are equipped with a submerged, electrically driven boost pump located on the bottom of the engine nacelle (See Figure 11).

FIGURE 10

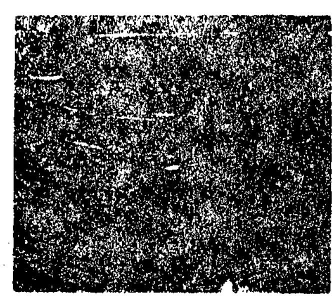


FIGURE 11

	Optimum Points	System Rating
a. Location		
Because of their location in the wings, the tanks are highly susceptible to damage/rupture/puncture in a crash, especially in rough terrain.	12	3
b. Vulnerability		
The fuel tanks located in the wings are highly susceptible to crash damage. Many locations such as the filler areas, fuel quantity indicators and vents are rigidly attached to the wing structure and the fuel tank. The tanks are connected by metal coupling. Any deformation in an accident can result in the fittings being torn from the tanks and fuel spillage.		
c. Construction Technique		
The nacelle tank being located behind the engine and above the wheel will result in a tank configuration as shown in Figure 12. The wing tanks are essentially flat with square corners, no irregularities. The nacelle is constructed of a self-seating (bullet-proof) material and the wing-mounted tanks are constructed of rubberized material.	30	9

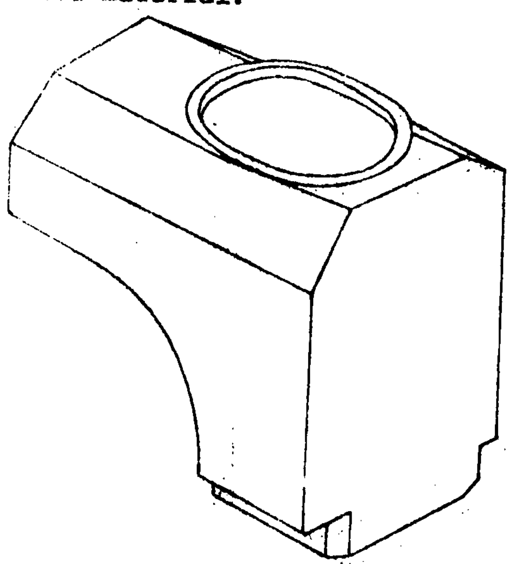


FIGURE 12 -Nacelle Tank Configuration.

	Optimum Points	System Rating
d. Fuel Boost System		
The electrically driven fuel boost pumps are located in the bottom of the nacelle mounted tanks. This area is highly susceptible to damage in a fire resulting in spilled fuel and an ignition source.	6	0
Oil and Hydraulic Fluid Containment		
The engine oil system is the only oil system on the aircraft. The engine oil tank is integral with the air-inlet casting located forward of the engine accessory gear box. The capacity of each of these oil tanks is 9.2 quarts.	20	14
1. Location		
The location of the oil tank is poor. Severe crashes can result in the engine separation and rupture of the tank. The hot engine surfaces can ignite the oil. Though this would represent only a small fire, it is located near the main fuel tanks and could ignite the fuel spillage. Points are therefore granted only for the location away from occupiable areas.	7	2
2. Vulnerability		
The oil tank is not likely to be damaged by other aircraft components; however, the scavenge lines from the propeller reduction gearbox to the tank run under the engine and is vulnerable to impact damage.	7	6
3. Construction and Tiedown Accuracy		
The casting type construction should offer excellent resistance to puncture and should contain the fluid in all accidents except those with severe impacts. Its integral construction to the engine insures excellent support during typical crash impacts.	6	6

Flammable Fluid Lines	Optimum Points	System Rating
The flammable fluids transported through lines to various parts of the aircraft include oil and fuel. These fluids are extremely flammable and pose a serious threat should spillage occur.	30	0
a. Construction		
All lines transporting the fluids are rigid metallic lines with a large number of couplings. Small airframe deformation can result in line separations and fluid spillage. No breakaway fittings are provided.	10	0
b. Routing		
The fluid lines are routed under the engine and through the airframe structure where they can get cut, trapped or pulled. No flexible hoses with extra lines exist; therefore, deformation of the structure through which the lines are passed will result in separation and fluid spillage.	10	0
c. Breakaway Fittings		
No breakaway fittings are provided in any of the fluid lines.	10	0
4. Firewalls		
A firewall is mounted between the nacelle fuel cell and accessory gearbox on both engines preventing the flow of spilled fluid from reaching the hot engine components (See Figure 13). There is a hazard, however, from oil spilled from the engine oil system.	9	7

FIGURE 13

	Optimum Points	System Rating
5. Fuel Flow Interrupters		
Fuel flow interrupters are not included in this aircraft design. However, certain components tend to serve as interrupters preventing the flow of fluid into occupiable areas and near hot components in moderate crashes. These components are the firewall in the engine nacelle and the box beam construction of the wings.	9	7
Ignition Control		
1. Induction and Exhaust Location The engines are located in wing mounted nacelles on the wings of the aircraft. Since fuel tanks are located in the wings and nacelles, ingestion of spilled fuel is highly probable, resulting in ignition of the spilled fuel. The exhaust parts are directed backward toward the wings. Exhaust would be directed toward spillage from the wing and nacelle tanks resulting in ignition.	30	25
2. Location of Hot Metals and Shielding		
The engine is inclosed by a shroud protecting the engine (hot metal) from external spillage; however, the engine is unprotected from internal spillage. Solid fuel lines are routed around the engine and solid oil lines are routed under the engine. Spillage from separation of these lines will impact on the hot engine surfaces.	30	10
3. Engine Location and Tiedown Strength		
The engine location which is near the area of anticipated flammable fluid spillage is very undesirable. Separation of the engine is not expected except in severe impacts; however, separation of the inboard wing will result in spillage near the engine. In this case, the engine location is more important than retention. Seven points are therefore granted.	15	7

4. Battery Location and Tiedown Strength

Optimum Points	System Rating
12	3

The battery is located in the right wing inboard section in the forward part of the wing (See Figure 14). Displacement is not expected except in severe crashes. The location is in the area of anticipated flammable fluid spillage and in the area where deformation will result in separation of attached wiring resulting in ignition sources in the area of the fuel spillage.

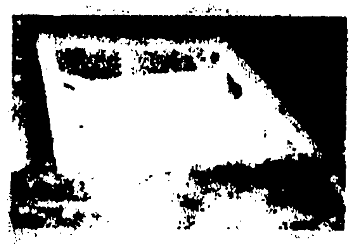


FIGURE 14

5. Electrical Wire Routing

Optimum Points	System Rating
12	5

The wiring is generally routed fairly high up in the fuselage in cable ducts where minimum structural deformation is expected. In the other areas they are routed along and through structural members where deformation can be expected. The wires are pulled tight and no extra length is available to accomodate deformation. No breakaway couplings or wire shieldings are used. With the exception of high fuselage routing, the routing is considered poor.

6. Fuel Boost System

Optimum Points	System Rating
7	0

Electrically driven fuel boost pumps are located in the bottom of each nacelle fuel tank. Electrically driven boost pumps, especially those located in an area susceptible to damage, are undesirable.

7. Transformer-Rectifier and Tiedown Strength

Optimum Points	System Rating
6	1

The two inverters are located in the outboard portion of the center wing section. They are susceptible to crash damage and are in the areas of anticipated fuel spillage. One point is therefore allowed.

8. Generator Location and Tiedown Strength

Optimum Points	System Rating
6	3

Two 300 amp-started generators are installed on the air[illegible], one on each engine. They are subject to impact damage, are mounted in front of the nacelle fuel tanks, and are near areas of flammable fluid spillage.

	Optimum Points	System Rating
9. Lights (Beacon, Search and Navigation)	5	2

There are two navigation lights and two rotating beacons located on the aircraft. The navigation lights are located on the leading edge of the wing tips. The beacons are located on the top of the aft section of the fuselage and the fuselage bottom near the wing center line. The upper beacon poses little problem; however, the navigation and lower beacon lights could cause arcing in a moderate impact. Both are located in an area of possible fuel spillage.

	Optimum Points	System Rating
10. Antennae	4	0

The aircraft has numerous antennae located on the bottom and top of the main fuselage (See Figure 3). The lower antennae are highly susceptible to crash damage with resulting arcing near areas of anticipated fuel spillage.

	Optimum Points	System Rating
BASIC AIRFRAME CRASHWORTHINESS	125	
1. Distance From Nose to Troop/Passenger Area	30	16

The distance from the nose of the aircraft to the crew seat in the cabin is approximately 8 feet. The approach speed is approximately 113 knots (190 fps). Assuming a 20G crushing strength, the velocity which can be tolerated without crushing of the occupiable space is:

$$
\begin{aligned}
V &= 8 \; Gd \\
&= 8 \quad 20(8) \\
&= 8 \quad (12.7) \\
&= 101 \text{ fps}
\end{aligned}
$$

This is lower than the normal approach speed; therefore, 101/190 of the points are given.

	Optimum Points	System Rating
2. Absence of "Plowing" Tendency	15	10

The fuselage is of an all metal semi-monocoque construction. The bottom portion forward of the crew compartment is made of aluminum bulkheads with aluminum formed sheet metal stringer. Two keep assemblies along either side of the nose wheel wall

	Optimum Points	System Rating
compartment strengthen that section. The aft portion of the fuselage is made up of aluminum bulkheads with aluminum formed sheet metal stringers. These areas are covered by skin plating varying from 0.025" to 0.040", and provide a smooth surface without any irregularities. Plowing should be eliminated in all but the severe impacts.		
3. Resistance to Longitudinal Impact Loads		
As noted above the fuselage is a semi-monocoque construction consisting of aluminum bulkheads and sheet metal formers and stringers. These and the keel beams in the floor should prevent the floor from buckling in a moderate crash. Resistance to roof collapse is provided by the curved roof members, stringers, and additional longeron above and below the windows on either side of the aircraft.	15	14
4. Resistance to Vertical Impact Loads		
The absence of high mass items in the low wing design coupled with the ring and stringer construction results in excellent resistance to vertical loads.	10	10
5. Resistance to Lateral and Roll-Over Impact Loads		
Since the aircraft is a high speed aircraft, high resistance to lateral crushing is assumed. Due to the low wing design, rollover and lateral impacts are not expected to occur frequently.	15	15
6. Landing Gear Vertical Force Attenuation		
No energy attenuation is provided by the landing gear.	5	3
7. Landing Gear Location		
The landing gear is located under the wing nacelles . the forward area of the nose. These locations prevent the intrusion of the gear into occupiable areas in the event of gear displacement.	5	5

	Optimum Points	System Rating
8. Effect of Wing Separation on Cabin Occupants		
Separation of the outboard wing sections can occur with significant effect on the occupants of the aircraft; however, complete separation of the inboard section will probably result in damage to the cabin floor. This could cause seat separation.	10	7
9. Effect of Fuselage Fracture/Separation in Long Body Aircraft		
The ring/stringer construction of fuselage coupled with the longerons in the upper portion of the fuselage and keel beams in the low section make separation in the occupiable area remote. Mishap data to this point do not reveal a significant problem in this area.	20	20

EVACUATION

	Optimum Points	System Rating
1. Ease and Reliability of Exit Operation		
The main cabin door located in the rear of the fuselage (Figure 5) is used for normal or emergency exit. The door is simple to open requiring only a turning motion of the internal or external handle. A removable window is located on the right side of the cabin section but is blocked by mission equipment. Should the main door be blocked or jammed, exit can only be accomplished by breaking out the windshield or cutting a hole in the fuselage at the location shown in Figure 15. Evacuation of the aircraft is greatly handicapped by the internal configuration of the aircraft (Figures 16,17,18). The pilot, copilot, and mission crew members in the forward portion of the cabin have to climb/crawl over seats and/or occupants to exit the aircraft.	15	6

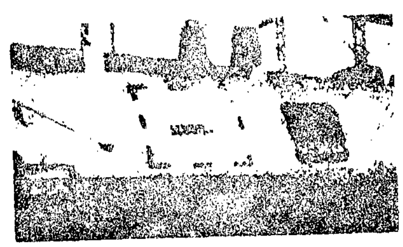


FIGURE 15

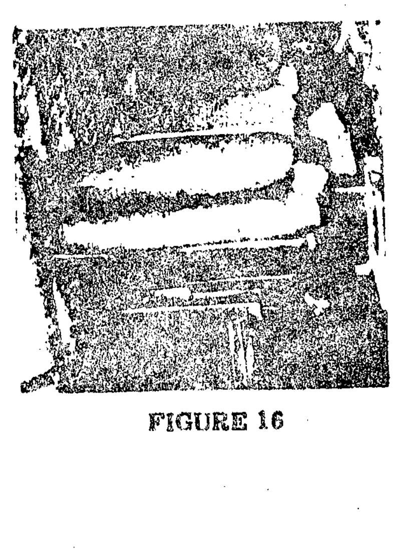


FIGURE 16

FIGURE 17

FIGURE 18

This effort is hampered by all of the protruding objects and small openings between the seats and fuselage/mission equipment, which tend to "catch" the evacuatees' extremities and clothing. Though not specifically addressed in this factor, removal/rescue of injured personnel was considered. Removal of injured from the forward area cannot be accomplished in a timely manner since only one person can traverse the evacuation route at a time. Removal of injured through other routes, i.e., windshield or fuselage opening, is also extremely difficult and time consuming.

	Optimum Points	System Rating
2. Ration of Usable Exits to Occupants	15	6

Though the aircraft meets the suggested ratio of 1 exit to 10 passengers, i.e., 1 to 5, this exit is not always necessarily usable to all occupants. The single exit can be blocked by injured personnel or loose mission equipment, thus preventing use by crew members in the forward area of the cabin. No forward exits are available for the crew in the cockpit area. NOTE: An escape hatch has been developed for the U-21 cockpit area; but has not been installed in this aircraft due to conflicting requirement with the mission required hardware. This would improve the evacuation of uninjured personnel; however, exit by injured personnel or rescue of injured would not be greatly enhanced.

	Optimum Points	System Rating
3. Identification of Exits		
The single exit (and "cutaway" rescue hatch) is not clearly marked; however, its location is evident. Operating instructions are readily readable under lighted conditions; however, neither the exit location or the operating instructions are illuminated by an emergency light. Location and operation in a darkened, confused condition is, therefore, hampered.	10	4
4. Availability of Exits in a Rolled Aircraft		
Rollover in this aircraft is not expected to occur frequently; however, rollover on the left side or inverted position could block or hamper exits for those positions respectively. A final position on the left side would block the only single exit, while an inverted position would require the occupant to support the weight of the door while exiting.	10	1
5. Emergency Lighting		
No emergency lighting system is provided; therefore, no points are allowed.	10	0

INJURIOUS ENVIRONMENT

	Optimum Points	System Rating
1. Proximity of Cockpit Control Panels and Other Structures		
There are numerous injurious objects which can be contacted. They include the objects in the instrument panel, steering yoke and fuselage structure. Lateral movement is not prevented by the shoulder harness thus allowing contact with the structure.	10	1

	Optimum Points	System Rating
2. Retention of Interior Equipment	10	4

The tiedown strength of the mission equipment is 9G's. The tiedown configurations are shown in Figures 19 and 20. The required strength is 25G's.

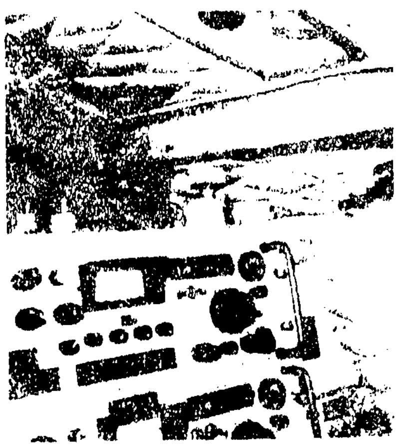


FIGURE 19

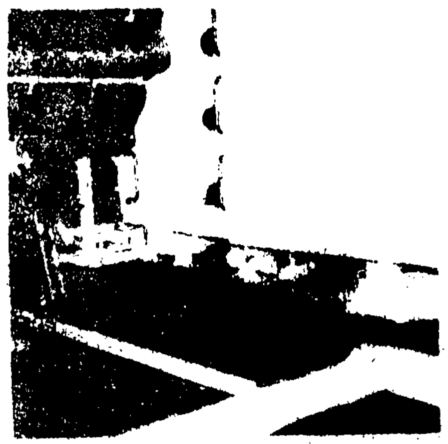


FIGURE 20

	Optimum Points	System Rating
3. Anti-Torque Pedal Area (Rudder Controls)	5	

The rudder control pedals design provides a large area for support of the feet; however, the feet can become trapped behind the pedals and between the pedals and structure. See Figure 21.

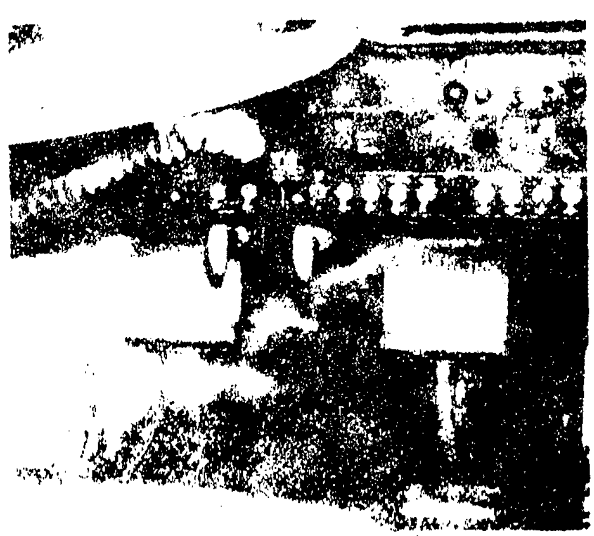


FIGURE 21

4. Absence of Injurious Objects in Cabin

	Optimum Points	System Rating
The numerous injurious objects consisting of sharp equipment corners, control knobs, and rails (See Figures 22, 23, 24, and 25) coupled with the lack of proper seating and restraint, present a serious hazard to occupants in the cabin area.	5	0

FIGURE 22

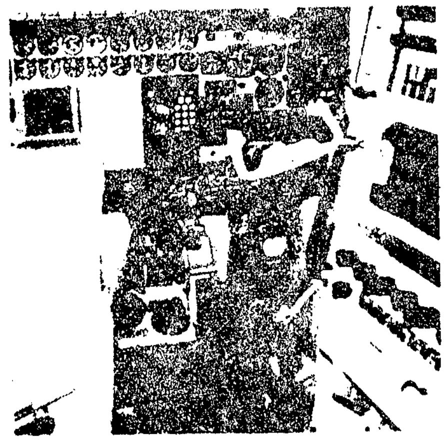


FIGURE 23

FIGURE 24

FIGURE 25

APPENDIX B

Rating System Criteria

The Dynamic Science Division of Marshall Industries developed this crash survival evaluation system under Contract DAAJ02-69-C-0030 for the U.S. Army Research and Technology Laboratories (formerly U.S. Army Aviation Materiel Laboratories).

FIXED-WING AND ROTARY-WING AIRCRAFT CRASH SURVIVABILITY RATING

When evaluating any aircraft from a crash survival point of view there are six basic factors that should be considered. These are (1) Crew Retention System, (2) Troop Retention System, (3) Postcrash Fire Potential, (4) Basic Airframe Crashworthiness, (5) Evacuation, and (6) Injurious Environment.

In order to develop a reasonable Crash Survivability Rating, weighted values have been assigned to the various factors. The percent of weight assigned to each is based on their relative hazard potential. The six factors along with their hazard potential are as follows:

	Hazard Potential	Optimum Number	Actual Value
1. Crew Retention System	17.92%	130	
2. Troop Retention System	17.23%	125	
3. Postcrash Fire Potential	35.19%	255	
4. Basic Airframe Crashworthiness	17.23%	125	
5. Evacuation	8.29%	60	
6. Injurious Environment	4.14%	30	
Totals	100.00%	725	

To make the job of rating easier, the hazard potential percentage has been converted to an optimum numerical value where a perfect score on all six factors would equal 725. For existing aircraft inadequate restraint systems and postcrash fire have been equally responsible for injuries and fatalities in accidents so they were weighted at approximately 35% each. A poor score on either of these important items could indicate a critical situation from a crash survival point of view - depending on such variables as number of personnel carried, operating terrain, and rescue facilities.

Each of the six factors is in turn broken down into sub-factors against which a hazard potential percentage has been assigned and converted to an optimum numerical value. The person conducting the evaluation simply selects that portion of the optimum numerical value that each sub-factor is worth and lists it opposite the optimum value in the space provided under "Actual Value".

CREW RETENTION SYSTEM RATING

	Optimum Number Fixed-Wing	Optimum Number Rotary-Wing	Actual Value
Vertical Energy Absorption Capacity	10	30	
Restraint Webbing Geometry and Strength	30	20	
Seat Longitudinal Strength	15	10	
Seat Lateral Strength	15	10	
Seat Vertical Strength	5	10	
Absence of Casting in Stressed Areas	10	10	
Shoulder Strap Guide Width	10	10	
Shoulder Strap Pull-Off Angle	10	5	
Lap Belt Angle to Seat Cushion	10	5	
Lap Belt Tiedown Strap	10	5	
Inertial Reel Type	N/A	5	
Depth of Structure Between Floor and Belly	5	10	
Total Points	130	130	

TROOP RETENTION SYSTEM RATING

	Optimum Number Fixed-Wing	Optimum Number Rotary-Wing	Actual Value
Vertical Energy Absorption Capacity	10	30	
Restraint Webbing Geometry and Strength	30	20	
Seat Longitudinal Strength	15	10	
Seat Lateral Strength	15	10	
Seat Vertical Strength	5	10	
Absence of Castings in Stressed Areas	10	10	
Shoulder Strap Pull-Off Angle	10	10	
Lap Belt Angle to Seat Cushion	10	10	
Lap Belt or Side Tiedown Strap	10	5	
Depth of Structure Between Floor and Belly	10	10	
Total Points	125	125	

POSTCRASH FIRE POTENTIAL RATING

	Optimum Number	Actual Value
Spillage Control		
Fuel containment	60**	
Oil containment	20	
Flammable fluid lines	30	
Firewall	9	
Fuel flow interruptors	9	
Ignitition Control		
Induction and exhaust flame location	30	
Location of hot metals and shielding	30	
Engine location and tiedown strength	15	
Battery location and tiedown strength	12	
Electrical wire routing	12	
Boost pump location and tiedown strength	7	
Inverter location and tiedown strength	6	
Generator location and tiedown strength	6	
Lights location and tiedown strength	5	
Antenna location and tiedown strength	4	
Total Points	255	

**If a range extension system is included in the evaluation, allow 40 points for primary fuel system and 20 points for the range extension system.

BASIC AIRFRAME CRASHWORTHINESS RATING

	Optimum Number Fixed-Wing	Optimum Number Rotary-Wing	Actual Value
Distance from Nose to Troop/Passenger area	30	10	
Absence of "Plowing" Tendency	15	15	
Resistance to Longitudinal Impact Loads	15	15	
Resistance to Vertical Impact Loads	10	30	
Resistance to Lateral and Roll-Over Impact Loads	15	30	
Landing Gear Vertical Force Attenuation	5	20	
Landing Gear Location	5	5	
Effect of Wing Separation on Cabin Occupants	10	N/A	
Effect of Fuselage Fracture/Separation in Long-Body Aircraft	20	N/A	
Total Points	125	125	

EVACUATION RATING

	Optimum Number	Actual Value
Ease and reliability of exit operation	15	
Ratio of usable exits to occupants	15	
Identification of exits	10	
Availability of exits in rolled aircraft	10	
Emergency lighting	10	
Total Points	60	

INJURIOUS ENVIRONMENT RATING

	Optimum Number	Actual Value
Proximity of cockpit controls and other structure	10	
Retention of interior equipment	10	
Rudder pedal area	5	
Absence of injurious objects in cabin	5	
Total Points	30	

RATING SYSTEM CRITERIA

GENERAL

Each of the subfactors listed previously are discussed briefly on the following pages. In rating an aircraft, the subfactors should be given a point value proportional to the desirable qualities outlined in the discussion.

CREW RETENTION SYSTEM

Vertical Energy Absorption Capacity

Fixed-Wing — Optimum = 10 points

Some method should be provided in the seat structure to attenuate vertical impact forces to a value of about 20G on the seat occupant. This decelerative loading must be maintained through a minimum stroke of three (3) inches in order to offer protection in the majority of fixed-wing aircraft accidents. If the energy-absorbing device is a fixed load type, it should stroke at a load of approximately 3000 pounds. This value makes an allowance for the following parameters: (a) a 15-pound seat bucket weight, (b) only 80 percent of total occupant weight rests on the seat, and (c) allowance for the 5th percentile (136-pound) pilot to insure a 25G maximum deceleration.

The seat vertical energy-absorption capacity can be rated as follows:

A.	A seat bucket energy-absorber with a minimum 3-inch stroke	100%
B.	A crushable honeycomb, non-resilient cushion of minimum 4-inch thickness	70%
C.	A crushable, expanded foam cushion of a minimum 4-inch thickness	50%
D.	A slow-rebound foam ("Ensolite" or"Ethafoam") of 4-inch thickness	20%
E.	Elastic foam rubber cushion or no attenuating material	0%

Rotary-Wing — Optimum = 30 points

The same comments apply as for the fixed-wing aircraft, with the exception that a stroke of 8 inches at a level of 3000 pounds is required. This factor can be rated as follows:

A.	A seat bucket energy-absorber with a minimum 8-inch stroke	100%
B.	A crushable honeycomb, non-resilient cushion of minimum 4-inch thickness	40%

C. A crushable, expanded foam cushion of a minimum 4-inch thickness — 30%

D. A slow-rebound expanded foam ("Ensolite" or "Ethafoam") of a minimum 4-inch thickness

E. Elastic foam rubber cushion or no attenuating material — 0%

Restraint Webbing Geometry and Strength

Fixed-wing Optimum = 30 points
Rotary-wing Optimum = 20 points

All webbing should be a minimum of 0.09 inch thickness to insure low elongation and minimum "creasing" under load. Padding material in the abdominal and collarbone area is desirable. The strength and width of the lap belt, shoulder strap, and tiedown strap are listed below:

Item	Width (In.)	Strength (Lb)
Lap Belt	2.5	8000 (loop)
Shoulder Straps	2.0	4000 total
Belt Tiedown Strap	1.5	2500

Each of the above factors on restraint webbing can be rated as a percent of the total points as follows:

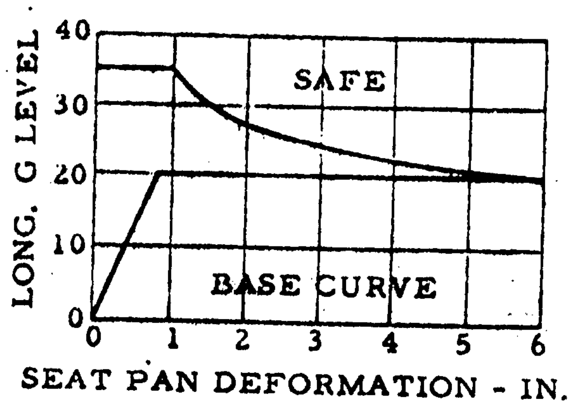
Webbing thickness	10%
Strength and width of lap belt	40%
Strength and width of shoulder straps	40%
Strength and width of belt tiedown strap	10%

The strength is more important than the width of the webbing; therefore, the number of points allowed should be proportional to the strength values.

Seat Longitudinal Strength

Fixed-wing Optimum = 15 points
Rotary-wing Optimum = 10 points

The desired G-level versus deformation is shown:

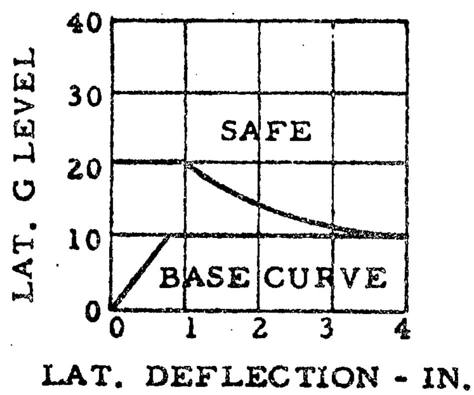


To be acceptable, a seat must have a load deflection curve which rises to the left and above the base curve and extends into the region beyond the upper curve. Load deflection curves must be obtained from static tests of the complete seat units.

Seat Lateral Strength

Fixed-wing Optimum =15 points
Rotary-wing Optimum = 10 points

The desired G-level versus deformation is shown:



Seat Vertical Strength

Fixed-wing Optimum = 5 points
Rotary-wing Optimum = 10 points

The seat should attenuate vertical forces as noted above under lateral energy absorption capacity and should also be able to sustain 25G before failure.

Absence of Castings in Stressed Areas

Optimum = 10 points

Since castings are noted for poor ductility, this item requires no explanation. If castings are used in two or more critically stressed areas, the rating should be zero, unless it is known that the casting material has been treated to insure ductility.

Shoulder Strap Guide Width

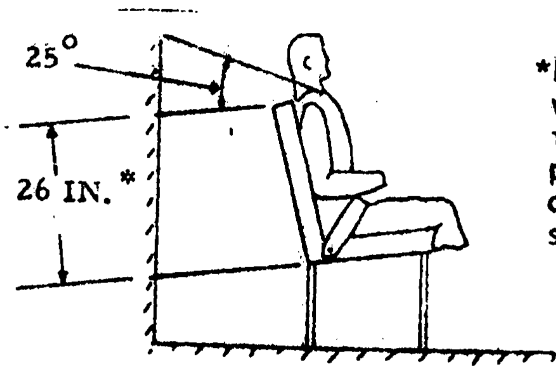
Optimum = 10 points

The width of the guide at the top of the seat back should not be more than 3.0 inches.

Shoulder Strap Pull-Off Angle

Fixed-wing Optimum = 10 points
Rotary-wing Optimum - 5 points

The shoulder strap guide should be located a minimum of 26 inches above the undeflected seat cushion. If the shoulder harness is connected to structure of the seat back, the angle of the strap with respect to the seat cushion should be between zero and 25 degrees upward as illustrated.



*For each one inch of variance from the 26-inch dimension, 20 percent should be deducted from the optimum score.

Lap Belt Angle to Seat Cushion

Fixed-wing Optimum = 10 points
Rotary-wing Optimum = 5 points

The lap belt centerline should project an angle of 45-55 degrees to profile with respect to the seat cushion. This angle requires that the centerline be approximately 3 inches forward of the back seat and seat cushion intersection.

Tiedown Strap

Fixed-wing Optimum = 10 points
Rotary-wing Optimum = 5 points

The lap belt should be retained in place on the pelvis by some kind of tiedown strap. Preferably, the strap should be attached between the center of the belt and the seat pan. A less optimum method consists of two straps attached at either side of the seat pan and the frontal portions of the lap belt. The side straps should be rated only half as effective as the center tiedown strap.

Inertia Reel Type

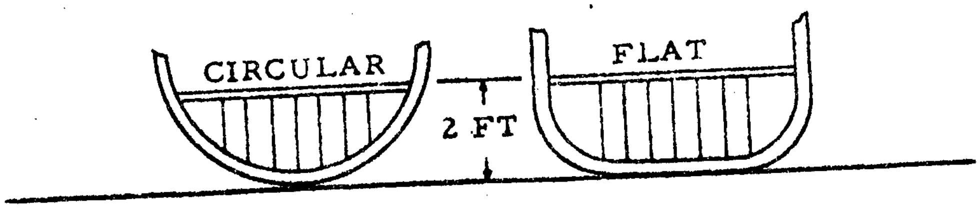
Rotary-wing only - Optimum = 5 points

All rotary-wing aircraft should utilize a rate-of-extension type reel only (MIL-R-8236, type MA-2, MA-4, or MA-6). This type reel should be checked by a quick jerk to determine locking ability.

Depth of Crushable Structure Between Floor and Belly

Fixed-wing Optimum = 5 points
Rotary-wing Optimum = 10 points

A fuselage of circular cross-section with a crushable depth of two (2) feet minimum between the floor and the belly skin is ideal. If a flat belly structure is used, a higher deceleration onset rate will result and less deformation will occur than with a circular fuselage. Thus, for two aircraft of equal crushable depth, the flat belly aircraft would be rated only half as much as the circular belly.



TROOP RETENTION SYSTEM

The rating criteria for this section is identical to that for the Crew Retention System with some exceptions as noted:

Vertical Energy-Absorption Capacity

Fixed-wing Optimum = 10 points
Rotary-wing Optimum = 30 points

Same as Crew Retention Criteria

Restraint Webbing Geometry and Strength

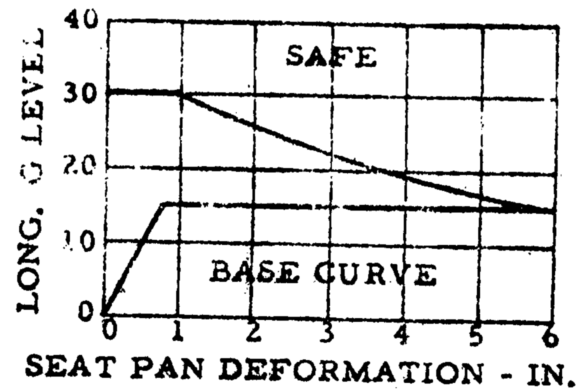
Fixed-wing Optimum = 30 points
Rotary-wing Optimum = 20 points

Same as Crew Retention Criteria with exception that a side tiedown strap of 1500 pounds capacity can be used instead of a belt tiedown strap for side-facing personnel.

Seat Longitudinal Strength

Fixed-wing Optimum = 15 points
Rotary-wing Optimum = 10 points

e desired longitudinal G level versus deformation is shown:

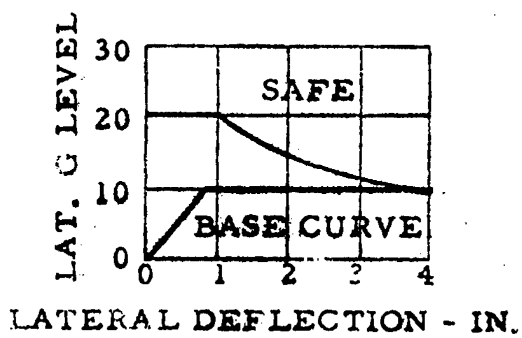


It should be noted that this is a sideward loading on a side-facing seat.

Seat Lateral Strength

Fixed-wing Optimum = 15 points
Rotary-wing Optimum = 10 points

The desired lateral G level versus deformation is shown:



Seat Vertical Strength

Fixed-wing Optimum = 5 points
Rotary-wing Optimum = 10 points

Same as Crew Retention Criteria.

Absence of Castings in Stressed Areas

Optimum = 10 points

Same as Crew Retention Criteria.

Pull-Off Angle

Optimum = 10 points

Same as Crew Retention Criteria.

Lap Belt Angle to Seat Cushion

Optimum = 10 points

Same as Crew Retention Criteria.

Lap Belt or Side Tiedown Strap

Fixed-wing Optimum = 10 points
Rotary-wing Optimum = 5 points

Same as Crew Retention Criteria with the exception that a side tiedown strap is equally acceptable with a center belt tiedown for side facing troops.

Depth of Structure Between Floor and Belly

Optimum = 10 points

Same as Crew Retention Criteria.

POSTCRASH FIRE POTENTIAL RATING

Spillage Control

Optimum = 60 points

Fuel Containment

Location (20% of total value) - 12

The location of the fuel tank should be evaluated with respect to the anticipated impact area, occupiable area, large weight masses, and primary ignition sources.

Vulnerability (20% of total value) - 12

The vulnerability of a fuel tank should be evaluated with respect to possible tank ruptures caused by various aircraft structural failures, such as landing gear failure and vertical column deflection. Tank failures associated with structural displacement, such as ruptures around the filler neck, the fuel line entry and exit area, the quantity indicators, and the tiedown devices should also be considered.

Construction Technique (50% of total value) - 30

The construction technique is evaluated for two primary considerations. One is tank geometry and the other is tank construction materials.

Tank Geometry - 10

Smooth contoured shapes are given the highest number of points, whereas irregular shapes and interconnected multicell tanks are given the lowest number of points.

Cell Material - 20

The tank is given a certain number of points, depending upon its construction.

1.	Crash Resistant Fuel Tank	20
2.	Cal. .50 bullet proof, self-sealing	15
3.	Cal. .30 bullet proof, self-sealing and crash resistant	10
4.	Pliocell	5
5.	Metal canister	2
6.	Integral	0

Fuel Boost System (10% of total value)- 6

The fuel boost pump should be evaluated according to its potential for causing fuel spillage due to fuel cell rupture or line failure. This includes location and method of fuel cell attachment.

Oil and Hydraulic Fluid Containment

Optimum = 20 points

Location (34% of total value) - 7

The location of the oil tank should be evaluated from the standpoint of its proximity to the anticipated impact area, occupiable area, large weight masses, and primary ignition sources.

Vulnerability (34% of total value) - 7

Evaluate from the standpoint of rupture resistance from other aircraft structure; e.g., control linkage failures causing puncture to the tank.

Construction and Tiedown Adequacy (32% of total value) - 6

Construction Methods - 3

Construction methods are evaluated in descending order of oil containing ability.

1. Crash Resistant - 3 points

2. Bladder - 2 points

3. Sheet Metal - 1 point

Tiedown Adequacy

Tiedown should be evaluated primarily on the adequacy of the system to support the tank during typical crash accelerations.

Flammable Fluid Lines

Optimum = 30 points

Construction (33% of total value) - 10

The construction of fuel lines should be judged in accordance with the hose material and couplings. Experience has shown that rigid lines fail before the flexible type; thus, flexible lines with a steel braided outer sheath are given the most points. Also included in this phase of the evaluation are the couplings. The fewer the couplings the better. Ninety degree couplings are less desirable than the straight type. Any coupling is less desirable than an uncut hose. Aluminum fittings usually fail before steel ones.

Routing (33% of total value) - 10

The routing of the fuel lines is an important consideration. The lines must not pass through areas where they can get trapped, cut, or pulled. Extra hose length (20-30% in areas of anticipated structural deformation) should be provided. Holes through which the fuel lines pass should be considerably larger than the O.D. of the hose.

Breakaway Fittings (33% of total value) - 10

Breakaway fittings should be installed on each fuel line that enters and exits the fuel tank. It is also advisable to have them installed at strategic locations throughout the system.

Firewall

Optimum = 9 points

Evaluate the firewall from the standpoint of how well it will function as a shield between crash induced fluid spillage and the various engine ignition sources.

Fuel Flow Interrupters

Optimum = 9 points

Fuel flow interrupters are devices that block or divert the flow of spilled flammable fluids. There are many different methods to perform this function; the fire curtain in the H-21 helicopter is a good example.

Ignition Control

Induction and Exhaust Flame Location

Optimum = 30 points

Evaluate from the standpoint of:

1. Location of expelled flames in relation to location of spilled flammable liquids.

2. Fuel ingestion.

Location of Hot Metals and Shielding

Optimum = 30 points

Evaluate from the standpoint of how well the hot items (temperatures above 400°F)are shielded or protected from fuel spillage. Components included are:

Engine (external and internal)

Exhaust System

Heater

Engine Location and Tiedown Strength

Optimum - 15 points

Consider consequences of engine separation. Where will the engine go and how will it effect the fuel cell, exhaust system, electrical wiring, and fuel and oil lines? Will the engine come into contact with spilled flammable fluids?

Retention strength is more important for helicopters in which the engine may be located above or just behind the fuel cell; it is of less consequence for pod-mounted engines.

Battery Location and Tiedown Strength

Optimum = 12 points

Evaluate from the standpoint of tiedown strength and of vulnerability of the battery and attached wiring to damage during a crash. Location should also be as far as possible from fuel and oil tanks and anticipated areas of flammable fluid spillage.

Electrical Wire Routing

Optimum = 12 points

Evaluate from the standpoint of crashworthiness of routing and vulnerability to damage during crash. Some excess length (20-30%) should be provided to allow for airframe deformation during a crash.

Fuel Boost System

Optimum = 7 points

The fuel boost system should be evaluated with respect to its function as an ignition source. The following items should be considered:

Power Supply (An air pressure system is best, a hydraulic system is is next best, and an electrical system is least desirable.)

Pump Location. (A suction system with the pump located on the engine is best. A pump located outside the tank is next best and an internal tank mounted pump is least desirable.)

Transformer-Rectifier and Tiedown Strength

Optimum = 6 points

Evaluate from the standpoint of tiedown strength and of vulnerability of the inverter and attached wiring to damage during crash. Location should be as far as possible from fuel and oil tanks and anticipated areas of flammable fluid spillage.

Generator Location and Tiedown Strength

Optimum = 6 points

Evaluate from the standpoint of tiedown strength and of vulnerability of the generator and attached wiring to damage during a crash. Location should be as far as possible from fuel and oil tanks and anticipated areas of flammable fluid spillage.

Lights (Beacon, Search and Navigation)

Optimum - 5 points

Are the light filament and/or the wires immediately surrounding the light attachments in the area of possible flammable fluid spillage?

Antenna Location

Optimum = 4 points

Evaluate the antenna systems and their respective wiring from the standpoint of vulnerability to damage and location in areas of possible flammable fluid spillage.

BASIC AIRFRAME CRASHWORTHINESS

Distance from Nose to Troop/Passenger Area

Fixed-wing Optimum = 30 points
Rotary-wing Optimum = 10 points

This item will obviously affect the crashworthiness of any aircraft, whether rotary-wing or fixed-wing, as long as the crash force acts generally along the longitudinal axis. Thus, some method is needed to grossly evaluate the advantage of increased crushable structure forward of the front row of cabin seats. It is assumed that aerodynamic requirements as well as visibility requirements will continue to dictate that the crews of 200+ mph, multi-engine aircraft will be located in the nose of the aircraft and that only a limited amount of crushable structure can be provided between them and the point of probable impact. Thus, the evaluation must be aimed at the cabin section where the majority of the aircraft occupants are located. For most general aviation type aircraft, the cockpit and cabin must be considered as one unit.

The amount of crushable structure ahead of the passengers should logically be related to the airport approach speed of the aircraft since most survivable accidents will occur at or less than this velocity. Thus, for an aircraft with a very slow stall/approach speed, the crushable structure needed can be less than for an aircraft with a very high approach/stall speed.

The optimum length of crushable structure or deforming distance can be calculated for various velocity changes by using the formula

$$d = \frac{V_2^2 - V_1^2}{64G}$$

where d = total deforming distance

V_2 = aircraft impact velocity - ft/sec

V_1 = aircraft velocity after major impact - ft/sec

G = fuselage crushing strength

Experimental test results indicated that a 20G fuselage crushing strength is reasonable value. It is assumed that about 75 percent of fuselage structure is compressible longitudinally while the remaining 25 percent is "incompressible." For purposes of this gross calculation, it seems reasonable to further assume that the terrain deformation offsets the incompressible portion of the fuselage. Thus, the calculated deforming distance (d) is assumed to be the length of the aircraft from its nose to the first row of passenger/troop seats. The most severe crash is the complete stop from approach speed in a single pulse; for this situation, the term V_1 is zero and the desired distance (d) can be computed for various approach (impact) velocities.

Samples of crushing distances required are calculated below:

Impact Velocity (mph)	Impact Velocity (fps)	Crushable Distance Required (d) (feet)
40-55	60-80	$\frac{V^2}{64G}$ = $(70)^2$ 64 (20) = 3.8
55-68	80-100	= 6.3
68-82	100-120	= 9.4
82-95	120-140	= 13.0
95-109	140-160	= 18.0
109-122	160-180	= 23.0
122-136	180-200	= 28.0
136-150	200-220	- 34.0

With the above values available as a guide, any aircraft can be grossly evaluated on a comparative basis with other aircraft.

Absence of "Plowing" Tendency

Fixed-wing Optimum = 15 points
Rotary-wing Optimum = 15 points

The primary objective here is obvious. The nose and belly of the aircraft should be smooth enough and have structural members of sufficient strength underneath to prevent it from plowing a furrow in the earth. The lower skin should be thick enough to resist tearing, thus providing a skidding surface for the aircraft.

Resistance to Longitudinal Impact Loads

Fixed-wing Optimum = 15 points
Rotary-wing Optimum = 15 points

The primary objective is to provide sufficient strength to prevent the roof of the aircraft from moving forward and downward with respect to the floor of the aircraft. Continuous beams running from the nose of the aircraft under the floor for the entire length of the occupied section is preferable since this type design will probably prevent the floor from buckling upward. It is obvious that enough wall structure must be available on either side of the aircraft to prevent collapse due to inadequate shear strength. In this respect, a fuselage with many large openings is undesirable. All concentrated masses, which may become a hazard to occupants in a crash, should be restrained to a level of 20G.

Resistance to Vertical Impact Loads

Rotary-wing: Rotary-wing Optimum = 30 points

The structure must be evaluated by its resistance to collapse due to vertical impact loads. This requires a simultaneous evaluation of resistance to longitudinal impact loads, since the resultant may be the critical loading. For example, the UH-1A helicopter might not come "unglued" by a purely vertical impact, but accident statistics indicate that a longitudinal load is usually present and the resultant load is the cause of the roof failure on this aircraft.

If the engine and transmission are located over the cabin or just aft of the cabin, it is recommended that the design tiedown strength be not less than 20G in the longitudinal and vertical directions to prevent cabin penetration. Regardless of tiedown strength, the fuselage shell should contain peripheral frames at a spacing not to exceed 20 inches in order that a maximum amount of energy is absorbed before a mass will penetrate the structure.

This item will necessarily have to be evaluated in a gross manner; however, some pertinent design criteria are available. For example, the vertical strength of the fuselage shell is usually determined by the retention strength of the engine and rotor transmission, and their retention strength is stated in the aircraft model specification. For example; the Kaman UH-2 fuselage structure is designed to sustain a 20G downward loading from the engine and rotor transmission; thus, the fuselage is very strong.

Fixed-wing: Fixed-wing Optimum = 10 points

Resistance to vertical impact loads is usually very good in low wing designs since no heavy components are located above the seated occupants. High wing aircraft, however, can be hazardous because the entire weight of the wing structure, fuel and engines (two-thirds of aircraft weight) is pressing downward at one point on the fuselage which is not designed for such a loading. High-wing aircraft with fuselage-mounted landing gears (which have fuselage reinforcement to sustain normal landing loads) are much more resistant to vertical crash forces than high-wing aircraft with wing-mounted landing gears.

Resistance to Lateral and Roll-over Impact Loads

General:

Evaluate in regard to the probability of cabin collapse during a roll-over or lateral impact. Even though the evaluation of this point is difficult, some design features will be obvious as discussed below:

Rotary-wing: Rotary-wing Optimum = 30 points

When the entire side of the cabin consists of a door, as in the UH-1A aircraft, it is obvious that this structure will be very weak during a roll-over crash and it should be evaluated accordingly. As an extreme contrast, a circular fuselage with few large openings will have maximum integrity during a roll-over. All concentrated masses, which could become a hazard to occupants in a crash, should be restrained to a level of 15G. A 15G retention strength is always recommended for the transmission and rotor system.

Fixed-wing: Fixed-wing Optimum = 15 points

It is probable that most high-speed (150+ mph) aircraft will have rather strong fuselage structures because of high aerodynamic loads, and will not collapse laterally in most aircraft accidents. The slower speed aircraft, however, are less rugged and should be evaluated more closely. For example, the dual doors of several high-wing, single engine aircraft are more likely to be thrown open during a cartwheel-type accident than would the doors of a competitive low-wing design. Obviously, any opening in the fuselage permitting the occupant's extremities to be thrown outside is a potentially hazardous situation.

Landing Gear Vertical Force Attenuation

Rotary-wing Optimum = 20 points

The landing gear will ideally exert an upward force of 10-15G through its maximum travel to the point at which the fuselage structure impacts the ground and begins to absorb energy. Various kinds of energy-absorbing methods can be utilized to achieve the desired result. For example: the Bell OH-4A Aircraft utilizes tapered wall lateral support tubes which absorb energy by bending; whereas, the presidential Sikorsky Aircraft utilizes a telescopic principle in which honeycomb material is crushed.

The amount of force required to deform the gear vertically until fuselage belly contact is made should be known in order to evaluate this factor. The standard aircraft oleo strut is a poor energy-absorbing mechanism because it cannot stroke rapidly enough in most severe accidents.

Fixed-wing: Fixed-wing Optimum = 5 points

Although the same principles apply here as for the rotary-wing situation, accident statistics indicate a lesser percentage of fixed-wing aircraft accidents with high sink rates than for helicopters. An exception is the small four place, single-engine aircraft which is involved in many stall/spin accidents; provision for vertical attentuation in this type aircraft certainly appears to be worthwhile.

Landing Gear Location

Optimum = 5 points

Evaluate the damage which will be caused by this large mass as it is displaced during a crash. For example, if the gear is located directly under the cabin floor, the probability of its being driven upward into the occupiable area must be evaluated. No consideration need be given to the relationship of ignition sources to the landing gear since these items are evaluated under Postcrash Fire Potential.

Effect of Wing Separation on Cabin Occupants

Optimum = 10 points

Evaluate as to whether the tearing away of the wing will be hazardous to the cabin occupants. The poor accident record of the L-19 Army aircraft in this respect well illustrates the point. The complete separation of the C-131E (CV-440) wing in an Air Force accident without effect on the seat occupants illustrates good performance in this respect.

Effect of Fuselage Fracture/Separation in Long-Body Aircraft

Optimum = 20 points

A primary consideration is the manner in which the fuselage fails due to a load perpendicular to its longitudinal axis. If it appears obvious that the break in a fuselage will occur underneath a seat row, it is an undesirable design. The performance of the Martin 404 aircraft in the 1963 Rochester, New York accident illustrates the advantage of a clean fuselage break exactly perpendicular to the longitudinal axis. In this accident, the break occurred just aft and just forward of the wing spars and none of the seat rows were affected. Evaluate to determine whether the passenger seat structure and occupants are affected significantly by the fuselage break.

EVACUATION

Ease and Reliability of Exit Operation

Optimum = 15 points

Evaluate from a standpoint of simplicity of operation. Include the regular entrance doors. Look for a "single motion" jettison feature on all doors and their capability of being opened from the outside. Check for possibility of jamming during a crash due to fuselage distortion, etc. Check equal distribution of emergency exits throughout aircraft to insure that all passengers move about the same distance from their seats to an exit.

Ratio of Usable Exits to Occupants

Optimum = 15 points

When computing a ratio, include only those exits that are available to those occupants; i.e., do not include cockpit exits in the ratio for cabin occupants. Assign a rating to this ratio for cabin occupants. Assign a rating to this ratio which reflects an evacuation time of 30 seconds for all occupants. Assume that one occupant requires approximately 1.5 seconds to egress an emergency exit and that 50 percent of the exits may be blocked if the aircraft comes to rest on its side. Thus, on this basis one exit is required for each ten passengers. An additional exit is required if the capacity is not evenly divisible by 10 (e.g., 21 passengers would require three exits.)

Identification of Exits

Optimum = 10 points

Emergency exits should be clearly marked and readily identifiable as such. The identifying letters should be a minimum of 3/4 inch high, and they must be lighted by the emergency lighting system. Operation instructions should be readily readable; should be a minimum of 1/3 inch in height; and color should be offset, as red on white or vice versa. Do not use optimum unless a method is used whereby the passenger is instructed as to the exit he should use for his particular seating position. This may be accomplished by suitable markings on the wall or seat back ahead; this method is considered necessary to alleviate panic and confusion in case of an emergency. An aircraft with up to nine passengers would not need to abide by the requirements instructing the passengers to specific exits, since at least one entry door would be provided and its location and method of approach would be obvious.

Availability of Exits in Rolled Aircraft

Optimum = 10 points

Use the above ratio considering the aircraft rolled on either side, thereby blocking a certain number of exits. Take into account the size of the available exits (at least 22 inches square) and the height above the opposite wall. A fuselage width of 5 feet or more is considered too great for an occupant to climb in order to reach an exit.

Emergency Lighting

Optimum = 10 points

Check for system used: impact switch (G limit) or hand operated; a combination of the two is preferred. Check retention strength for 25G design factor for power supply. Keep in mind that any system is better than none. Check for independent power supply.

INJURIOUS ENVIRONMENT

Proximity of Cockpit Control Panels and Other Structure

Optimum = 10 points

Check if cockpit occupant is able to contact control panels when restrained with lap belt and shoulder straps. Check if shoulder straps allow lateral movement and what structure can be contacted in this manner. Evaluate this throughout the adjustment range of the seat.

Retention of Interior Equipment

Optimum = 10 points

Check the tiedown design strength of equipment such as fire extinguishing bottles, tool boxes, etc. and evaluate against an optimum of 25G.

Anti-Torque Pedal Area

Optimum = 5 points

Evaluate the possibility of trapping the feet between the rudder pedals and adjacent structure. Check if area may collapse easily onto the feet during crash. Rudder pedal should support both the ball of the foot and the heel. A simple bar-type pedal is unsatisfactory.

Absence of Injurious Objects in Cabin

Optimum = 5 points

Check for sharp corners, protrusions, etc., in the vicinity of the seated occupants.