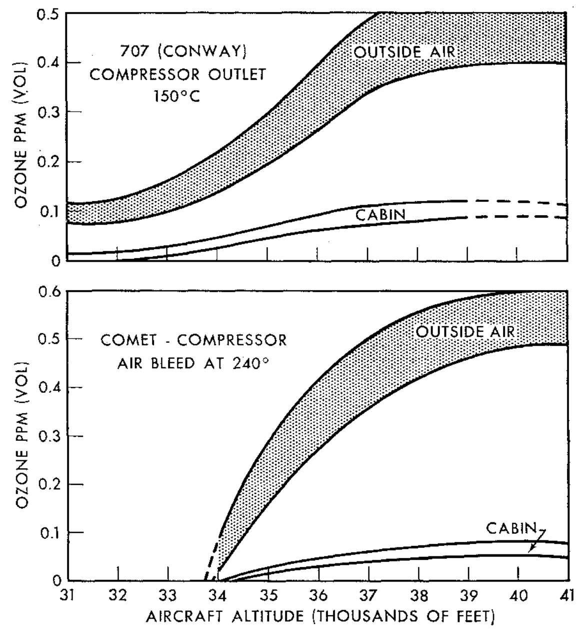

Fig. 2 Ozone concentration.[4]

ambient air for pressurization purposes of the SST contains 5–10 ppm, and using the 75–90% degree of destruction of ozone shown by Bennett[4] in Fig. 2 in passage to the cabin, the projected predictable cabin ozone content in the SST would probably fall within the range of 0.5–2.25 ppm, unless special means were to be taken to destroy or reduce this high concentration to a tolerable level.

It is believed that the heat generated in the high-speed compressor necessary to maintain cabin pressure at altitudes of 70,000–80,000 ft would destroy a large portion of the ambient ozone. Unfortunately, the very efficiency of these compressors depends on their speed, thus reducing the contact time of ambient air with the heat. It is probable that the ozone concentration present in the planned SST will reveal an environmental health hazard unless some means is used or an adequate dwell time is engineered in the compressor system to destroy or reduce the ozone to an acceptable level.

There are a number of ways of destroying or substantially reducing the ozone level in an aircraft, including the use of manganese dioxide-cupric oxide, cobalt, nickel wool, silver or other metal or metallic oxide types of catalytic filters, and other gas phase thermal decomposition methods.[6] Military aircraft have successfully used catalytic filters to destroy cabin air contaminants which include aldehydes, ketones, and ozone. A lighter weight filter to destroy ozone alone can no doubt be developed. Consequently, although ozone may represent a potential environmental health hazard, its control does not impose serious difficulties for engineers in design of the SST.

References

[1] Clamann, H. G. and Bancroft, R. W., "Toxicity of ozone in high altitude flight," *Ozone Chemistry and Technology* (American Chemical Society, New York, 1959), p. 352.

[2] Ernsting, J., "Physiologic aspects of the significance of ozone in pressurized cabins." I.A.M Memo. 8–20, Royal Air Force, Inst. Aviation Med., Farnborough (September 1959).

[3] Young, W. A., Shaw, D. B., and Bates, D. V., "Presence of ozone in aircraft flying at 35,000 feet," Aerospace Med. **33,** 311 (1962).

[4] Bennett, G., "Ozone contamination of high altitude aircraft cabins," Aerospace Med. **33,** 969 (1962).

[5] Jaffe, L. S. and Estes, H. D., "Ozone toxocity hazard in cabins of high altitude aircraft, a review and current program," Aerospace Med. **34,** 633 (July 1963).

[6] Boberg, J. E. and Levine, M., "Catalytic filtration of ozone in airborne application," J. Eng. Ind. (Trans. Am. Soc. Mech. Engrs., Ser. B) **84,** 42 (1962).

Structural Energy Absorption

Ralph Winthrop Johnson*
Consultant, San Diego, Calif.

Introduction

VARIOUS target drones (Ryan Firebee) and escape capsules (Mercury) have in the past been recovered by parachute systems. Many of them have been using decelerating devices, such as inflated impact bags (Radioplane XQ-4), nose spikes (Lockheed X-17), or spring and shock absorbers. These impact absorbers have been designed to absorb the kinetic energy of descent (K.E. $= \frac{1}{2}mV^2$), with minimum loads transmitted to the vehicle itself. In this paper an inquiry is made into the best material to use for a vehicle structure (the airframe) which does not have any shock-absorption device. The best structural shapes to use for this purpose are not investigated here.

Discussion

The criterion for the best material is the amount of energy that can be stored in the material within the elastic limit. It is assumed that the vehicle is undamaged upon touchdown and may be used again, perhaps even for 20 flights, without any permanent set in the material. Within the elastic limit, the stress-strain diagrams are essentially linear, and the energy absorbed (or rather stored) by the structure is equal to $P\delta/2$, where δ is the maximum deflection of the airframe. By equating energies, $mv^2/2 = P\delta/2$ and $P = mv^2/\delta$. This simple equation can be used to compare the structural load developed by, for example, an impact-bag ($\delta = 10$ in.) system vs no impact bag ($\delta = \frac{1}{4}$ in.).

It is shown here that the absorbing device reduced the structural load about 40 times. However, it is not the purpose of this paper to compare systems but only to compare materials. It is nevertheless pointed out that the best energy-absorbing material, either in combination with other available shock-absorbing devices or without, can be used for the airframe structure.

Comments on Shape

Stress concentrations at notches in a structure subject to impact will tend to fail the material at the notch before the full energy-absorption capability of the remaining volume of material is attained. The shape, the length L, and the volume of the material are important in the design of impact-absorbing structures:

1) A larger volume can absorb more energy.
2) A longer part can absorb more axial energy because at the same *strain* ($\epsilon =$ in./in.) it has a larger *deflection*, $\delta = \epsilon L$, and the external energy absorbed is $P\delta/2$.
3) Notches tend to absorb too much energy.
4) Constant cross sections are best for columns. This is another way of saying that the most efficient energy storage is obtained by maintaining a high constant stress throughout.

Plastic Energy Absorption

The material inelastic range may be used for "one landing only" designs. Here, in the plastic range, there is available a large energy reservoir of ductile materials, which may prove to be superior to the brittle ones. Also, energy-absorbing sandwich cores may be used. In either case, the parts are permanently deformed or crushed and must be replaced.

Elastic Energy Stored

The strain-energy density is defined as the strain energy per unit volume. Below the elastic limit, this is sometimes referred to as the modulus of resilience.[1]

Typical materials are chosen in order to compare their elastic-energy contents, using the uniaxial elastic-energy[2]

Received May 4, 1964.
* Structures Specialist. Associate Fellow Member AIAA.

Table 1 Stored energy[a] vs unit volume or unit weight

Material	Ref.	Compression data, $\sigma\epsilon/2$	Energy density U, in.-lb/in.^{3}	Weight density w, lb/in.^{3}	Energy/lb, U/w	Wt. compared to 4340 steel
Epoxy-unidirectional glass fiber laminate	3	$\frac{(95,000)(0.0165)}{2}$	784	0.07	11,200	0.278
Epoxy-181 glass fabric laminate	4	$\frac{(60,000)(0.018)}{2}$	540	0.07	7710	0.403
7075-T6 aluminum	5	$\frac{(77,000)(0.008)}{2}$	308	0.101	3050	1.02
8 Mn titanium	6	$\frac{(120,000)(0.008)}{2}$	480	0.171	2800	1.11
Inconel X steel	7	$\frac{(92,000)(0.003)}{2}$	138	0.304	454	6.85
4340 steel	8	$\frac{(220,000)(0.008)}{2}$	880	0.283	3110	1.0
AM-350 (SCT)	9	$\frac{(150,000)(0.0052)}{2}$	390	0.282	1380	2.25
17-7 PH (TH 1050)	10	$\frac{(170,000)(0.006)}{2}$	510	0.276	1845	1.69
ZK-60A-T5 magnesium	11	$\frac{(35,000)(0.006)}{2}$	105	0.0695	1510	2.06

[a] Room temperature values.

equation $U = \sigma\epsilon/2$ (see Table 1). For comparison, compression stress-strain diagrams[3-11] are used for all the examples herein.

Energy-Weight Comparison

The maximum stored energy per pound is obtained by dividing the strain-energy density U by the weight density w of each material:

$$\text{Specific Energy} = \frac{U}{w} = \frac{\text{in.-lb/in.}^3}{\text{lb/in.}^3} = \text{in.-lb/lb}$$

The values are tabulated in Table 1. For the same energy content, the results show that the no. 181 fabric epoxy laminate is much lighter than 4340 steel heat-treated to 260,000 psi tensile ultimate. The reinforced plastic weight is 3110/7710 = 0.403 lb to absorb the same amount of energy as 1 lb of the 4340 steel. The last column in the table compares the weight required to absorb the same energy as the 4340 steel.

Caution should be used in comparing the unidirectional laminate, because it is weak in other ways, which may rule out its practicability in some cases.

Conclusions

Two conclusions can be made:

1) Reinforced plastics are excellent energy absorbers and should be considered early in any design where energy absorption is needed.

2) The use of auxiliary shock-absorbing devices may add weight, cost, and complexity. The use of primary structure to fulfill energy absorption requirements, as well as ordinary load requirements, may lower weight, cost, and complexity. Over-all system reliability may be increased as a by-product.

References

[1] Maleev, V. L., *Machine Design* (International Textbook Co., Scranton, Pa., 1939), p. 25.

[2] Wang, Chi-Teh, *Applied Elasticity* (McGraw-Hill Book Co., Inc., New York, 1953), p. 34.

[3] "Fatigue properties of plastic laminates reinforced with unwoven glass fibers," Armed Services Technical Information Agency ASD-TDR-62-464, p. 10.

[4] *Plastics For Flight Vehicles* (Government Printing Office, Washington, D.C., November 1959), MIL-HDBK-17, Part I, Fig. 2-63.

[5] *Metallic Materials and Elements For Flight Vehicle Structures* (Government Printing Office, Washington, D.C., August 1962), MIL-HDBK-5, Fig. 3.2.7.1.6(b).

[6] Ref. 5, Fig. no. 5.2.2.1.6(a)

[7] Ref. 5, Fig. no. 6.2.2.1.6(a)

[8] Ref. 5, Fig. no. 2.3.1.2.6(c)

[9] Ref. 5, Fig. no. 2.7.1.3.6(b)

[10] Ref. 5, Fig. no. 2.7.2.3.6(b)

[11] Ref. 5, Fig. no. 4.2.14.2.6(b)

Simulator Study of a Turn Procedure for Reducing Airspace Requirements for Supersonic Transports

RICHARD H. SAWYER*
NASA Langley Research Center, Hampton, Va.

THE flight of the supersonic transport along airways will differ from present jet-transport flight in the greater airspace that is swept out in making turns at the ground-based radio-navigation facilities which supply bearing and distance information [Very High Frequency Omnidirectional Range, Tactical Air Navigation (VORTAC) stations]. For example, the turning radius for a bank angle of 30° at a Mach number of 3.0 at cruise altitude is greater than 75 naut miles. Also, continuation of present piloting practice of proceeding through the zone of ambiguity created by the cone of silence over the VORTAC station before initiating the turn will further increase airspace usage. At cruise altitude for the supersonic transport, the zone of ambiguity can vary from 5–25 naut miles depending on the antenna design. An investigation to study the airspace requirements for the supersonic transport in making changes in heading at a VORTAC station and to determine improved operating techniques to reduce the airspace requirements and pilot workload has been made and is reported.[1]

In this investigation, the supersonic transport was simulated by a fixed-based single-place cockpit and an analog computer arrangement. The equipment in the cockpit included the usual aircraft controls, with the exception that a side-arm controller was used for longitudinal and lateral control. The usual flight and navigation instrumentation was provided, and, in addition, for some tests an oscilloscope was

Received February 20, 1964.

* Aerospace Engineer.