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TESTS ON THE BIRD IMPACT RESISTANCE OF POLYURETHANE FOAM†

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SUMMARY

Recent incidents have shown that bird impact can cause catastrophic damage to an aircraft tail unit. One of the proposals for minimizing this damage was the filling of the tailplane structure with a deep layer of plastic foam. A small gun was available for throwing "birds" at structures and this was used to investigate the impact absorption properties of foam and the protection it would offer to a tailplane.

It was concluded that the direct impact of a 2 lb. bird at 240 mph on the nose of the tailplane tested could cause catastrophic internal damage. When the tailplane was filled with the foam described, the internal damage was greatly reduced, but the energy transmitted to the tailplane mounting was increased to a degree which raised the possibility of failure of the tailplane attachments to the fuselage.

It is concluded that other methods should be sought to protect the tail unit from bird impact damage.

INTRODUCTION

In a general discussion on the protection of aircraft structures against bird impact, it had been suggested that a deep layer of plastic foam might form a good protection. Samples of plastic foam were, therefore, tested against 1 lb. and 2 lb. dummy "birds", fired from an airgun at 420 and 350 ft./sec., respectively, the foam being both in the open and enclosed in an aircraft tailplane. The results of these experiments show how much protection was offered by the arrangements tested.

DETAILS OF FOAM TESTED

The foam tested was a polyurethane foam[a], cast into frames, to a density of 3 lb./ft." Since it would be difficult to cast more than a 5" depth of foam, the samples were made up in stout wooden frames 9" x 12", of 5" depth, whose top and bottom were removed after the casting operation was complete. Three of these frames clamped together thus gave a total thickness of 15" of foam, of 9" x 12" cross-section, as shown in Figure 1. This would reasonably represent a unit of foam cast between the upper and lower skins and a pair of ribs, in a tailplane or small aircraft wing, by way of example. No parting agent was used in casting, so the foam adhered firmly to the inner walls of the frames.

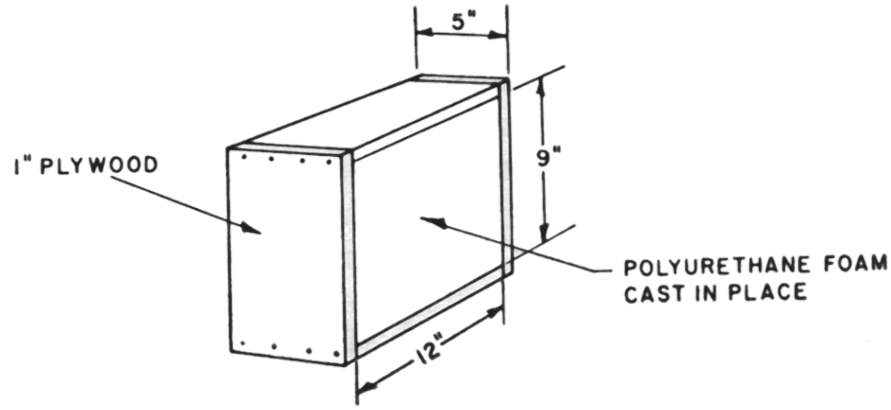

Figure 1. Foam target boxes

DETAILS OF GUN AND DUMMY "BIRDS"

The gun used (Figure 2) was a simple 3.75" bore brass tube, 12 ft. long, in the breech end of which the dummy "bird" was placed. Behind this, and separated from the barrel by a .004" brass diaphragm, was a 5½ft.^{3} reservoir. This was charged to a suitable pressure, in this case 60 psig, and the gun fired by pricking the diaphragm by a pointed steel rod from within the reservoir. The diaphragm then split and the bird was accelerated up the barrel. Its muzzle velocity was established by photographing the run with a Fastax movie camera, at 4000 frames/sec., and counting the frames needed for the "bird" to pass a marked 12" distance in the 4 ft. gap between muzzle and target. These films also demonstrated that the bird arrived intact at the target. The 350 ft./sec. velocity was used as being the lowest speed consistently obtainable with this gun.

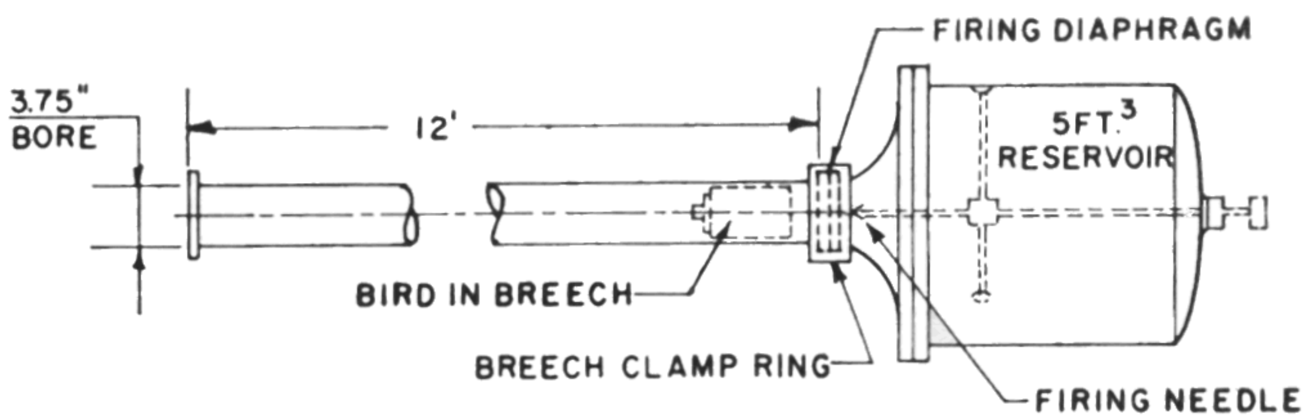

Figure 2. Airgun for firing dummy "birds"

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[a]No. 402 A & B Vibrathane Rigid Urethane Foam. Normally 2 lb./ft.^{3} density, but in this case restrained to produce 3.0 lb./ ft.^{3} density, 95 to 98% closed cell. Approx. 35 psi compressive strength; 55 psi tensile strength.

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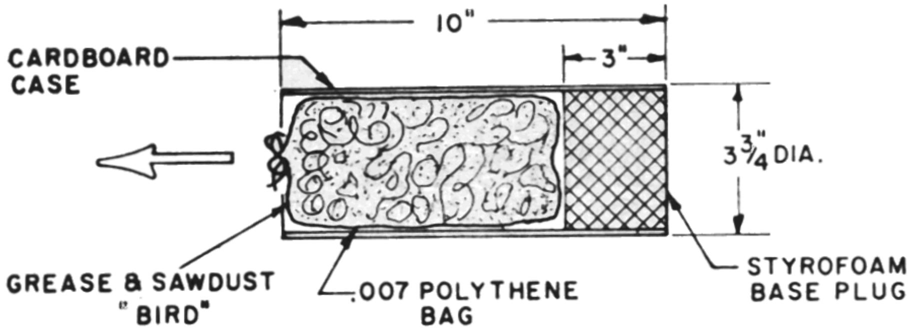

Figure 3 Dummy "bird"

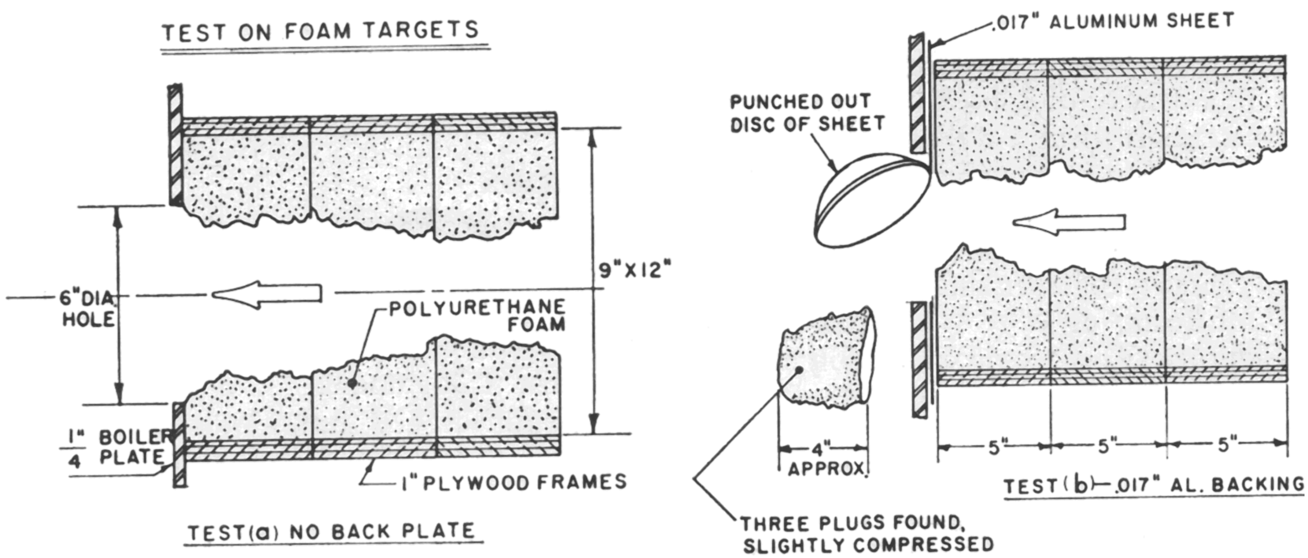

Figure 4 Damage to foam targets

The "birds" used were made of a mixture of X4P Grease M. of a vaseline consistency, and sawdust, of 47 lb./ft." density, wrapped in .007" polythene film, and placed in a sabot (Figure 3) for firing. The sabot consisted of a block of very light styrofoam 3" thick, and a one-ply case of thin (.016") cardboard. The weight of the sabot (.10 lb.) is included in the 1.0 lb. weight of the "bird"

Many different dummy "birds" have been tested, with the object of standardizing the projectile, and avoiding the offensive nature of organic remains splattered about the target area. High speed movies have shown that the real bird behaves as a thick fluid during high-speed impact, and the targets do not show damage traceable to hard bone structure. It has therefore seemed reasonable to simulate the bird by a viscous paste or fluid, contained in some form of bag which will not rupture under the acceleration forces in the gun, or from air-loading in the short flight from gun to target. Wax, rubber, gelatine-oil mix, clay and putty have all been tested by various workers. A very detailed discussion of this subject is to be found in Reference (1), in which it is shown that putty and clay "birds" give an energy transfer to the target almost identical to that of a real bird up to speeds of 320 kt. (540 ft./sec.), with a slow divergence above this. It was felt that the grease used, with an addition of sawdust to correct the density, would give a fair simulation of these materials, and was a reasonable bird simulation for the present tests.

The character of damage inflicted on aluminum sheet structures by the grease-sawdust "birds" has been observed by the writer to be identical to that of meat "birds" fired under the same conditions, in this speed
range.

Various wrappings and sabots were tested by the writer before settling on the type described; the strong polythene sheet was the only material found which combined sufficient tensile strength to resist the rupturing forces during launching with enough flexibility to avoid falsifying the impact behaviour of the "bird"

THE TESTS

Isolated foam

The three 5" frames of foam, presenting a total thickness of 15", were clamped in front of the heavy rigid target mounting. The back surface of the foam was against 1/4" boilerplate, in which a 6" d. hole had been cut, centred on the line of flight of the "bird". A 1 lb. "bird" was fired at the foam at 420 ft./sec. (288 mph).

After firing, the target was completely undisturbed, except for a ragged hole through its centre. This hole was about 4" d. at entry, and increased gradually to 6" d. at exit, as shown in Figure 4. The sides of the hole were ragged and torn, showing no sign of compacting due to any lateral pressure. The material removed from the hole was visible only as fine powder and small fragments, No grease from the "bird" was found in the hole, so it must have passed through without rupturing.

Foam backed with .017" dural sheet

The target was arranged as before, but with a .017" dural sheet against its back face, to see if the temporary trapping of the plug of compressed foam on the nose of the "bird" would affect the mode of failure. A 1 lb. "bird" was fired at the foam at 420 ft./sec. (288 mph).

After firing, the foam target was found to have a hole through it, exactly similar in nature to that of the previous shot. The backing had made no difference. The backing sheet had been forced against the boiler plate, and punched cleanly round the 6" d. hole in the plate, although the hole through the foam was only about 4"/5" d. The "bird" was found in the tank behind the plate, in a relatively undamaged condition, and three plugs of foam were found with it. These had been driven through the target in a practically uncompressed condition, showing that the foam shears out at extremely low compressive stress.

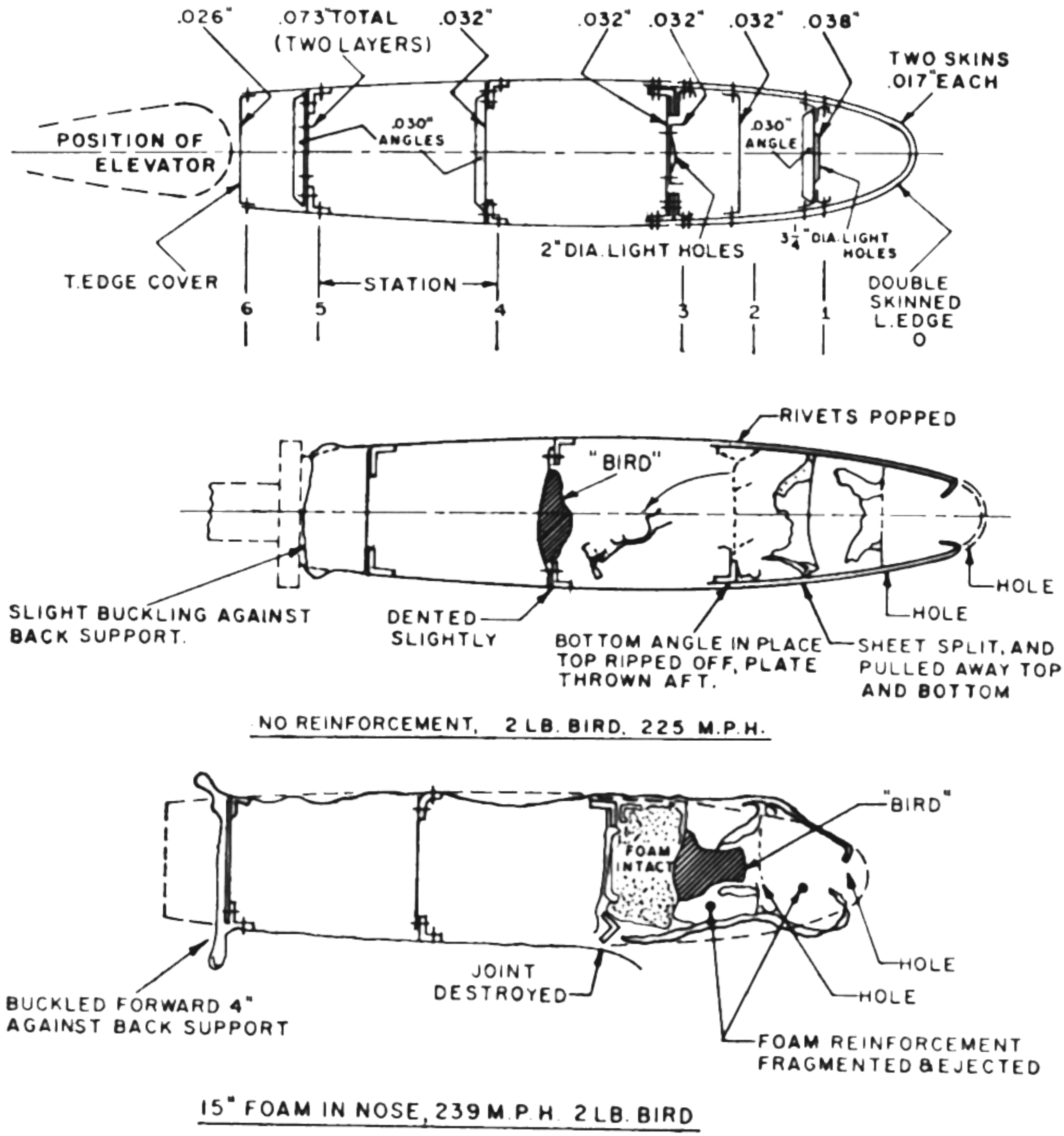

Figure 5 Horizontal stabilizer tested

Unprotected aircraft tailplane (horizontal stabilizer)

The horizontal stabilizer (see Figure 5) from a twin-turboprop passenger transport aircraft was available for testing. It was held rigidly in a heavy wooden cradle, with weights on top of it, and with its trailing edge supported solidly by 6" x 6" timber props from a heavy concrete wall. The elevator was removed.

A 2 lb. dummy "bird" was fired at the leading edge, at 330 ft./sec. (225 mph).

The results of the shot are seen in Figure 5. The "bird" made a 5" d. hole in the leading edge, a 5" d. hole in the plate at station 1, split and pulled away the plate at station 2, pulled out and broke off the top angle, smashed the main spar, and tossed the remains from station 3 into the space aft, and came to rest against the dented spar at station 4. The wrecked area extended over a good 12" length of structure in the spanwise direction.

It is the writer's opinion that the stabilizer would have failed under normal flight loads, after this strike. The load imposed on the stabilizer mountings can be surmised from the 1/2" or so of buckling at the trailing edge, where the main impact load was transmitted to the ground in this target set-up.

Protected tailplane

Another part of the same stabilizer was filled with foam to see what protection this would afford against a bird-strike. If one wished to put the 15" of foam referred to previously into this tailplane, it could be put in the leading edge, or trailing edge. The shot just described penetrated only partway through the tailplane, so that 15" of foam in the trailing edge would not have affected the results at all, as the "bird" would not quite have reached it.

The foam filling, of the type already described, was therefore placed in the leading edge, to a distance of 17" back. In fact, the space back to the main spar, at station 3 (Figure 5) was filled very tightly with blocks of foam, already described, which were cut out of their wooden frames and sawn to exact shape to fit each cavity in the wing, being forced in in a spanwise direction.

A 2 lb. "bird" was fired at the leading edge, at 350 ft./sec. (239 mph). Referring again to Figure 5, the entry hole in the leading-edge was exactly similar to the case without foam packing, and the "bird" again penetrated the plate at station 1 in the same way. The foam packing between stations 0, 1, and 2 was completely fragmented and flew in all directions, in pieces varying from 2" d. to fine powder.

The unit formed by the plate at station 2, the main spar at station 3, and the block of foam between, stopped the "bird". However, in doing so the attachment of the main spar to the skin was completely destroyed and the skin joint split open, with all rivets popped, over an 18" length (spanwise) of tailplane. Furthermore, the trailing edge of the tailplane was crumpled about 4" against its supports by the impact, and the whole plane was badly distorted.

Owing to the local detachment of the main spar, the writer again feels that the tailplane would have failed under flight loads. The crumpling of the support surface shows that the impact load imposed on the stabilizer mountings would have been much greater in this case than in the previous case.

CONCLUSIONS

In the test on an unprotected tailplane, a "bird" impacting on the leading edge at about 230 mph penetrated a little over half the chord of the tailplane, destroying all internal spar structure in its path. The tailplane would probably have folded up in flight.

When the same tailplane had its front 17" packed with foam plastic, a similar "bird" penetrated only about half this distance. The impact loads tore the main spar partly away from the skin, some serious internal damage still resulted, and the shock on the tailplane attachment was far greater, with crumpling over the whole structure.

Reference (2) contains a much more complete account of experiments in this field, and it is interesting to note that the results of the present experiments appear to agree completely with the findings reported in this reference.

ACKNOWLEDGMENT

This paper is reproduced by permission of Mr. M. S. Kuhring, Chairman of the NRC Associate Committee on Bird Hazards to Aircraft, at whose instance the experiments were carried out.

REFERENCES

(1) Sommers, J. -- Test of Materials and Packaging Methods for Use in Aircraft Windshield Bird-Impact Simulation, FAA Tech. Rept. XDS-23, 1963.
(2) Ahlers, R. H. -- Stability of Structure Following Bird Strike, FAA Tech. Rept. ADS-60, 1966.

APPENDIX I

IMPACT LOADS ON TAILPLANE
--a simplified calculation

The 2 lb. "birds", travelling at 330 and 350 ft./sec. penetrated 33 and 13 in. into unprotected and foam-filled structures, respectively.

Assuming uniform deceleration of the "bird", we have that:

(A) Unprotected structure

From $v^2 = u^2 + 2fs$
$0^2 = 330^2 - 2f\ 33/12$
.'. f = 19800 ft./sec.^{2} deceleration
= 19800/32.2 = 615 g
"Bird" weighs 2 lb.
.'. Force = 615 x 2 = 1230 lb. on tailplane during deceleration

(B) Protected structure (foam filled)

$0^2 = 350^2$ _ 2f 13/12
= 56,500 ft./sec.^{2} deceleration
= 56,500/32.2 = 1760 g
"Bird" weighs 2 lb.
.'. Force = 1760 X 2 = 3520 lb. on tailplane during deceleration

For a 4 lb. "bird" impacting at 300 mph, these figures would increase, at a first approximation, to 4370 lb. and 11050 lb., respectively.

This confirms the conclusion that while the presence of foam will alter the character, and may reduce the extent of damage to the internal tailplane structure, it will do this by increasing the forces transmitted to the supporting structure.