

BIRD STRIKE COMMITTEE EUROPE

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TESTS OF A DEVICE FOR THE PROTECTION OF AIRCRAFT GAS TURBINE ENGINES
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ENGLANDINTRODUCTION

Damage to engines from collision with birds is a problem to which a solution has yet to be found, although for the last 30 years efforts have been made in this direction with no sign of success. Bird impact on the rotating first axial compressor stages has resulted in deformation of individual blades leading to shedding of metal debris and severe damage to the entire compressor assembly.

Steps to prevent these occurrences have included strengthening of the engine itself and redesigning the compressor first stage blades to have adequate strength and stiffness and thus to avoid structural failure. However this runs counter to modern compressor design trends where the blade sections are tending towards a lower t/c ratio and a more flexible component.

Many proposals have been advanced that would prevent the bird carcass from reaching the engine whole, and some of these are shown on Fig. 1. In general these schemes were intended to slice up the bird, dispersing the individual pieces of debris and thus reducing the impact load on individual compressor blades. Whether this dispersion would occur is open to doubt, and testing that has been done has shown that the sliced

portions of the carcass do not disperse but travel on a substantially undisturbed course. Furthermore, the presence of slicing grids across the intake carry with them aerodynamic penalties which significantly reduce the efficiency of the intake. More serious still are the dangers of fatigue failure of the grid structure itself and the possibility of ice accretion.

THE DEVICE

The device to be described in this paper has been devised by British Aerospace (Warton Division) and depends on the principle of attenuating and spreading the bird carcass so that the debris can be safely ingested by the engine whilst minimising the performance, structural and icing problems. It consists of placing over an appropriate area of the intake duct a suitably shaped surface located so that bird impact on, or passing across it is likely.

Initial ground tests have been completed in which birds have been fired against a variety of damaging surfaces. The results of these tests have been analysed by Rolls Royce Limited, with a view to estimating potential engine damage.

THE DAMAGING MECHANISM

The philosophy behind this approach has been to find a mechanism which, taking advantage of the kinetic energy of the bird will impale it to a sufficient extent to precipitate a significant degree of evisceration resulting in a break up of the carcass, decanting its body fluid, and spreading the resulting debris both in the direction of motion and laterally, (Fig. 2). Damaging surfaces of various types were designed. These ranged from an emery-cloth covered surface to surfaces made of expanded metal, a cheese grater type of arrangement, and a bed of nails cut off square and protruding a short distance above the surface of the duct.

THE TEST PROGRAMME

The test installation is shown diagrammatically in Fig. 3. Freshly killed chickens were fired from a conventional air operated gun which was trained on the specimen damager surface. The surface was set at angles of 10° and 25° to the approach vector of the bird, these angles being representative of swan-necked intakes in current military aircraft.

Beyond the damager test piece and perpendicular to the direction of the approaching bird a large plate representing the engine intake was set up whose front face consisted of a honeycombe of square tubes arranged to catch the debris. This assembly is known as the debris plotter. Three slow motion cameras (3000 frames/sec) using colour film were employed to record the tests, one viewing the bird before impact and two the passage of the debris between the damager and the debris plotter, both from the side and from above. Marker boards were positioned

in the field of view of the cameras so that the velocity of the bird and the spread of the debris could be ascertained.

Chickens with a mass of $1\frac{1}{2}$ lb were fired and were chosen to be representative of the smaller gulls, pigeons, crows, curlews and mallards likely to be encountered. It was planned to achieve a velocity for the tests of about 150 knots since analyses of bird strikes in the United Kingdom for military aircraft show that some 40% of all strikes occur at speeds at or below that figure and these have been found to inflict particularly severe engine damage.

Rolls Royce cooperated with British Aerospace by carrying out the test analysis which was accomplished with the aid of a mathematical model that has been developed for the purpose. The analytical data required for this is based on the time history of the mass distribution of the debris arriving at the engine face. After each bird firing the debris was recovered from the plotter cells and masses and distribution recorded.

The damager types were as shown on Fig 4: A plain aluminium plate was used as a control case.

- i) A rough emery cloth
- ii) A coarse expanded metal grid
- iii) A fine expanded metal surface
- iv) $\frac{1}{8}$ " dia nails set at a pitch of $\frac{3}{4}$ ". Two variants of this were tested and were cropped off square at heights of $\frac{1}{8}$ ", and $\frac{1}{2}$ " above the face of the base plate, which represented the surface of the intake duct.
- v) A perforated metal sheet having scoop shaped protrusions similar to a domestic cheese grater.
- vi) A section of steel tread plate frequently found in engineering factories, power stations etc.

By reference to the slow motion films it was possible to observe the attenuation of debris caused by various damager types and to identify the timewise distribution of discrete masses entering the debris plotter. From these films and with reference to the debris plot individual masses were assigned to these pieces of debris and their velocities calculated. It was also possible to assign a spatial impact position for those pieces of debris which had rebounded from the plotter and whose masses had been recorded subsequent to the test firing. In some instances the debris had been retarded by the damager to such an extent that it fell short of the plotter, and where this was the case it was neglected during the subsequent analysis.

has thus been possible to calculate " $m \bar{v} h$ " terms for the damaged blades involved in these incidents and assess the percentage stress in them compared to the datum which related to a known level of damage.

Three categories of damage have been allocated:

- Category 1 Major primary and extensive secondary damage, resulting in failure of engine to continue to run.
- Category 2 This is a category between 1 and 3 for which no operating experience is currently available and is one in which the damage would be expected to be somewhat less severe than in Category 1.
- Category 3 Minimal engine damage, ranging from small nicks to tears in blades. In all cases the engine would continue to run in a satisfactory manner.

By combining the test results with those from service incidents it has been possible to assess the effectiveness of each damager type investigated, and Fig. 7 shows the average stress for all shots against a particular type of damager clearly indicating the relative merits of each type.

Of the 8 types tested, 7 fell within 28% to 50% of the datum stress implying moderate damage, and the possibility that the engine would fail. However the damager consisting of $\frac{1}{2}$ " high rails, produced stresses at the category 3 level implying only minor damage and continued operating capability.

CONCLUSIONS

It is seen that a successful damager is one which breaks up the bird and attenuates the debris in an axial direction. Fig. 8 shows diagrammatically the effect the dagagers have in dispersing the bird debris. Several of the dagagers tested are likely to reduce engine damage, whilst one showed a significant reduction in blade impact stress level estimated to allow the engine to continue to operate satisfactorily. It is concluded on this evidence that a $1\frac{1}{2}$ lb bird might safely be ingested at 180 knots by the engine under consideration when protection devices of the foregoing type are fitted. It is recommended that further firing tests might be contemplated to cover other test conditions and perhaps some ad hoc installations. Test firings against real engines would also add confidence to the analyses.

In conclusion I would like to thank British Aerospace for permission to present this paper, and to thank my colleagues for their help in preparing it.

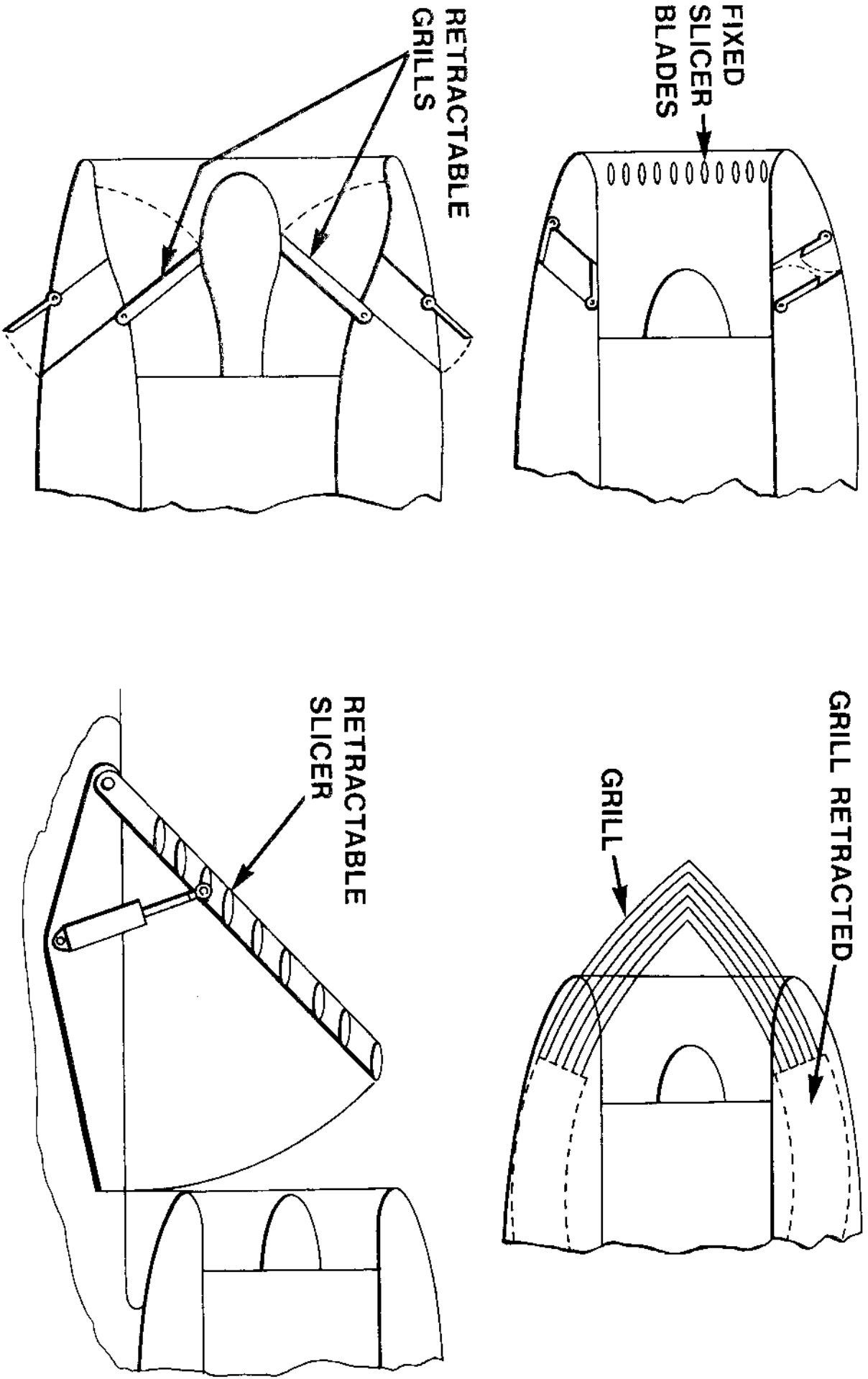


Fig. 1 Some Other Proposals for Protecting Engines

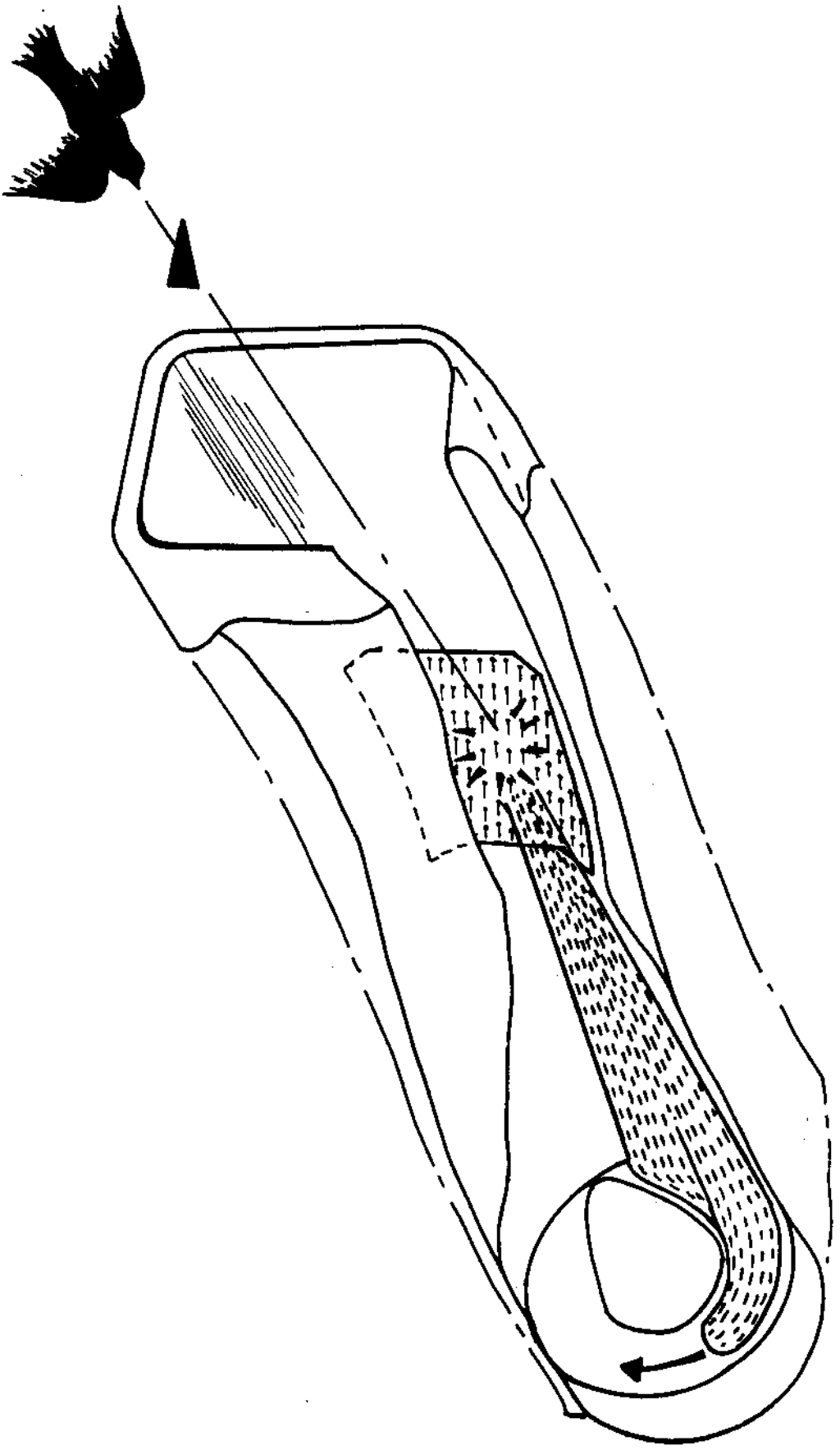


Fig. 2

Illustration of Bird Damager

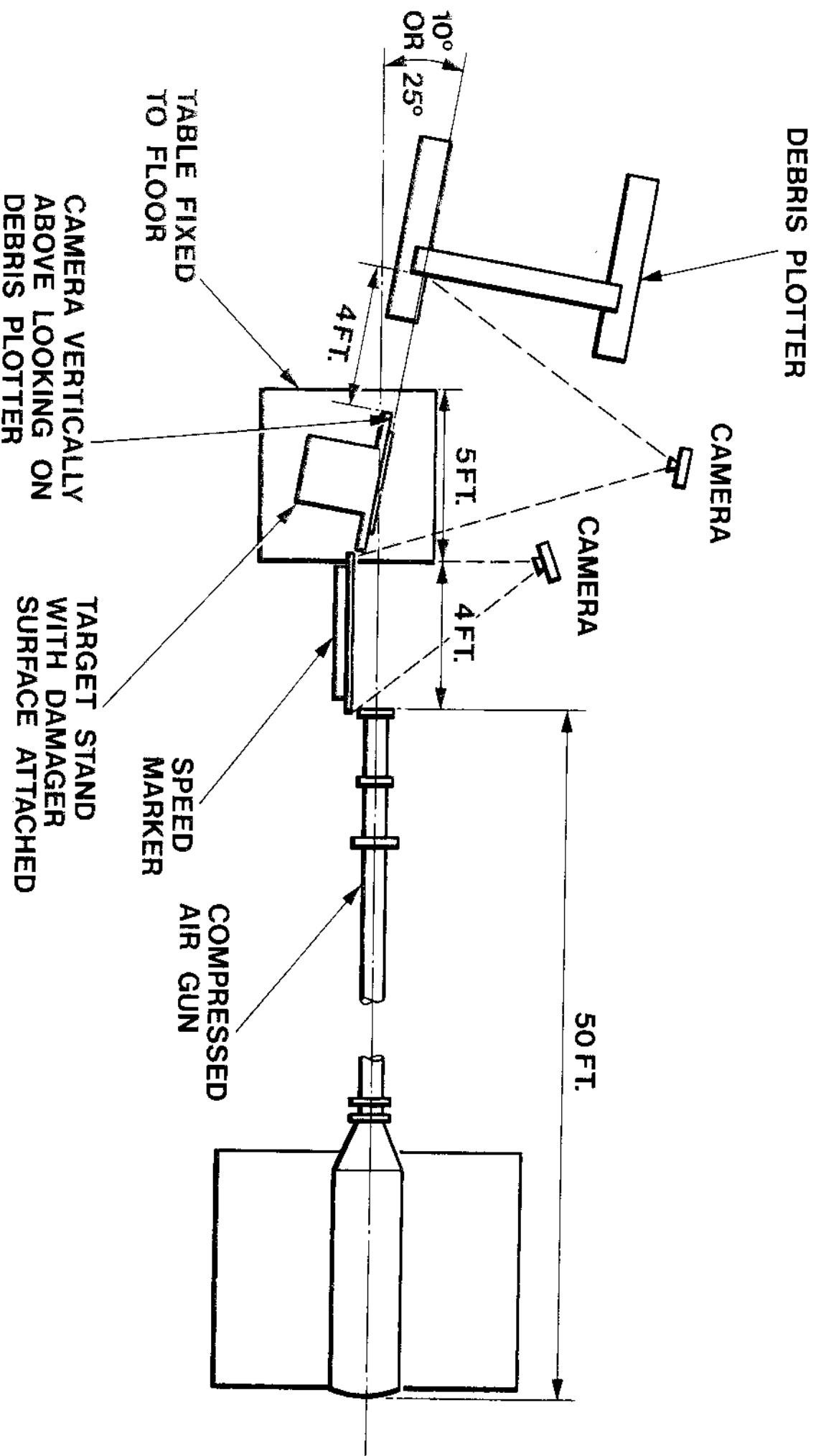
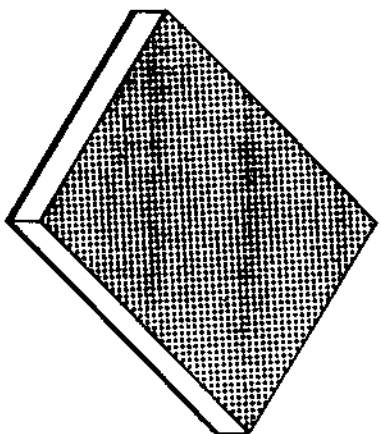
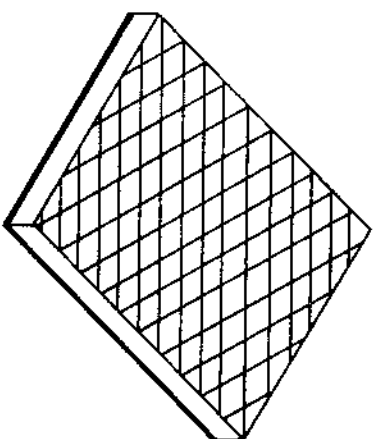


Fig. 3

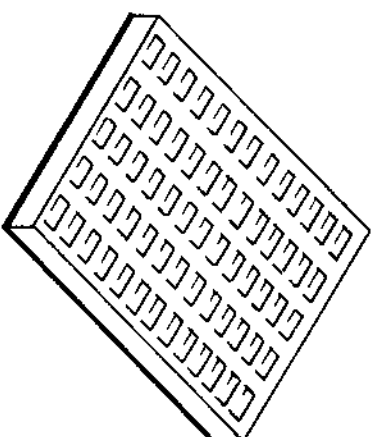
Diagrammatic Test Installation Arrangement



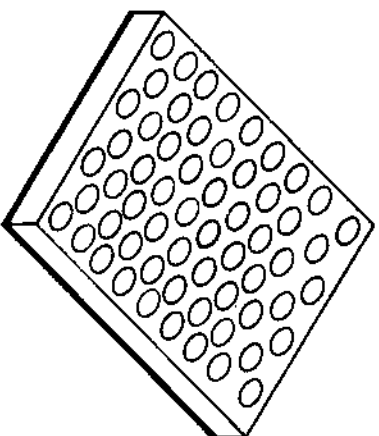
ROUGH EMERY CLOTH



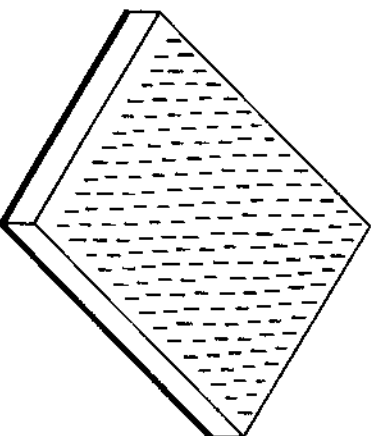
COARSE EXPANDED METAL



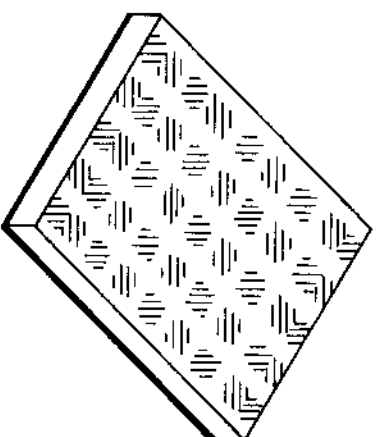
FINE EXPANDED METAL



PERFORATED METAL SHEET



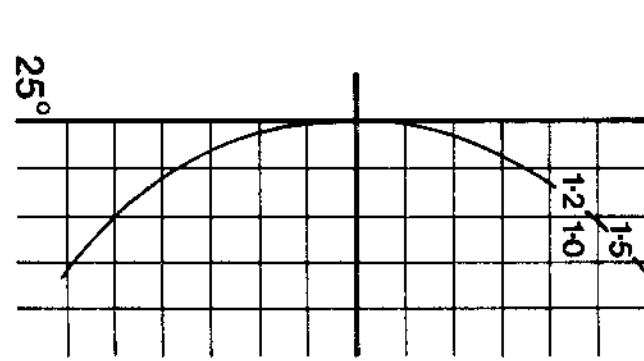
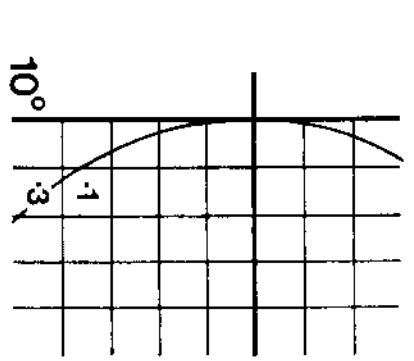
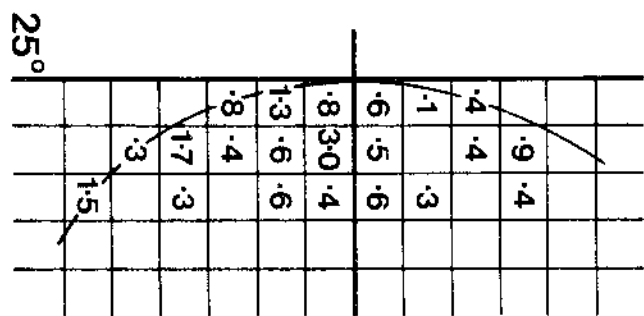
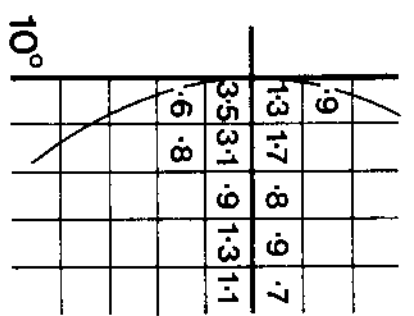
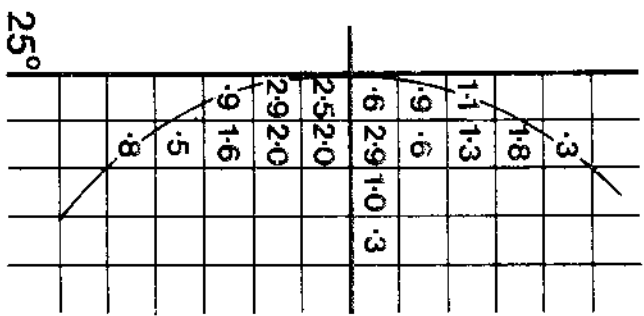
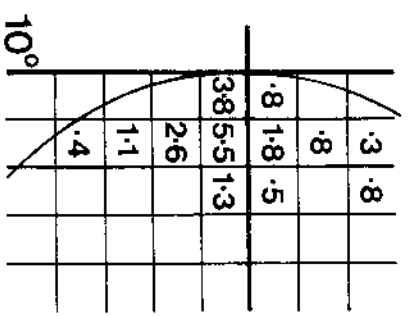
NAILS $\frac{1}{8}$ " AND $\frac{1}{2}$ " HIGH



TREAD PLATE

Fig. 4

Ramager Surfaces Tested



ALUMINIUM SHEET

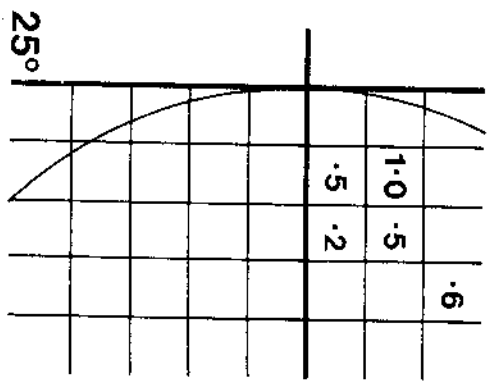
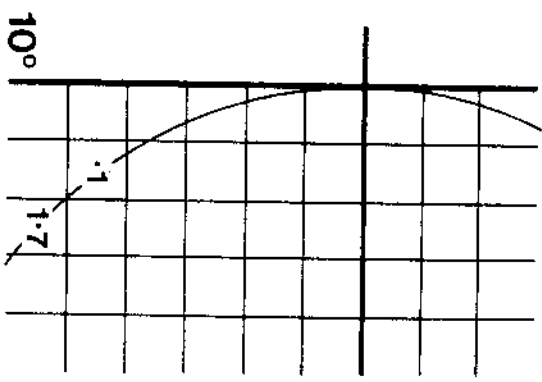
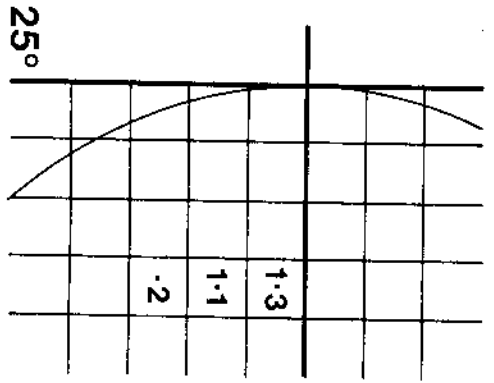
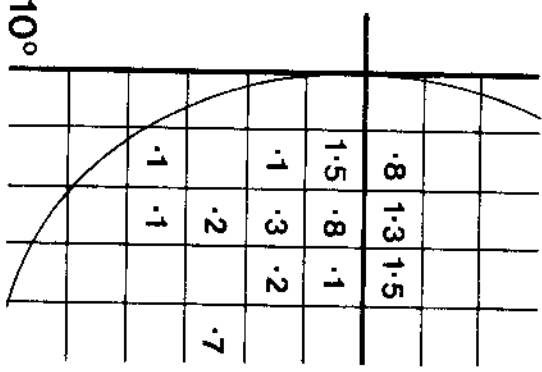
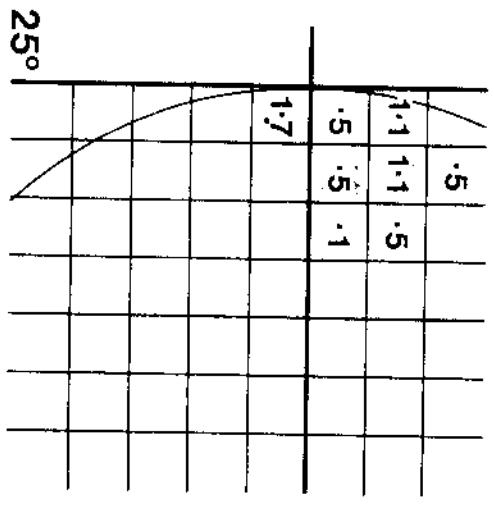
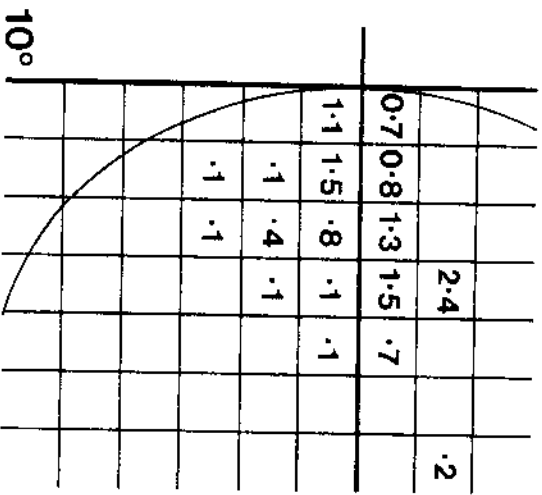
PERFORATED METAL

Fig. 5

Adjusted Debris Plot

10 M. SEC. AFTER IMPACT

12 M. SEC. AFTER IMPACT



5 M. SEC. AFTER IMPACT
 1/8" NAILS x 1 1/2" HIGH

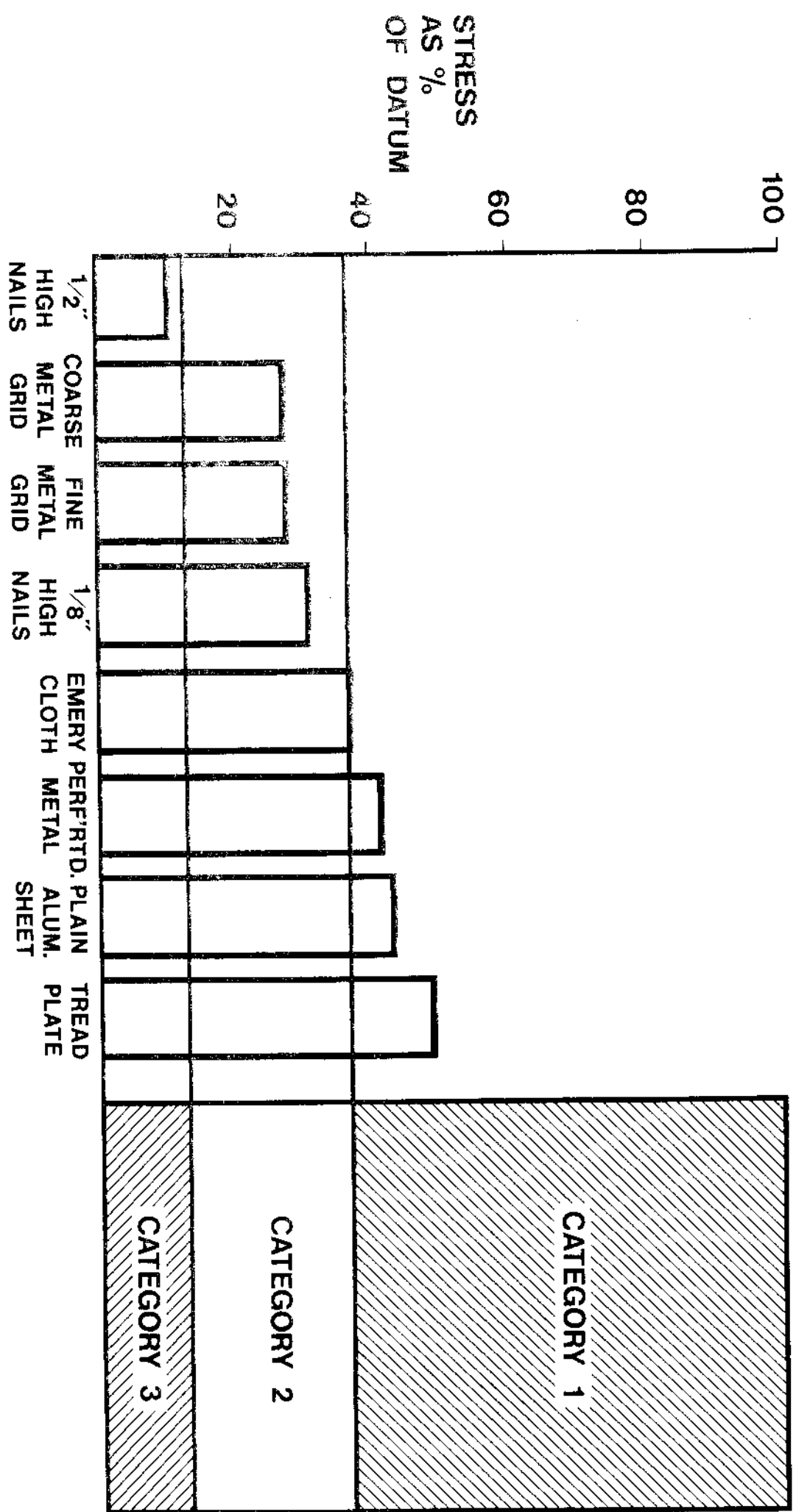
10 M. SEC. AFTER IMPACT

10 M. SEC. AFTER IMPACT

23 M. SEC. AFTER IMPACT

Fig. 7

Calculated Average Stress for Various Damager Surfaces



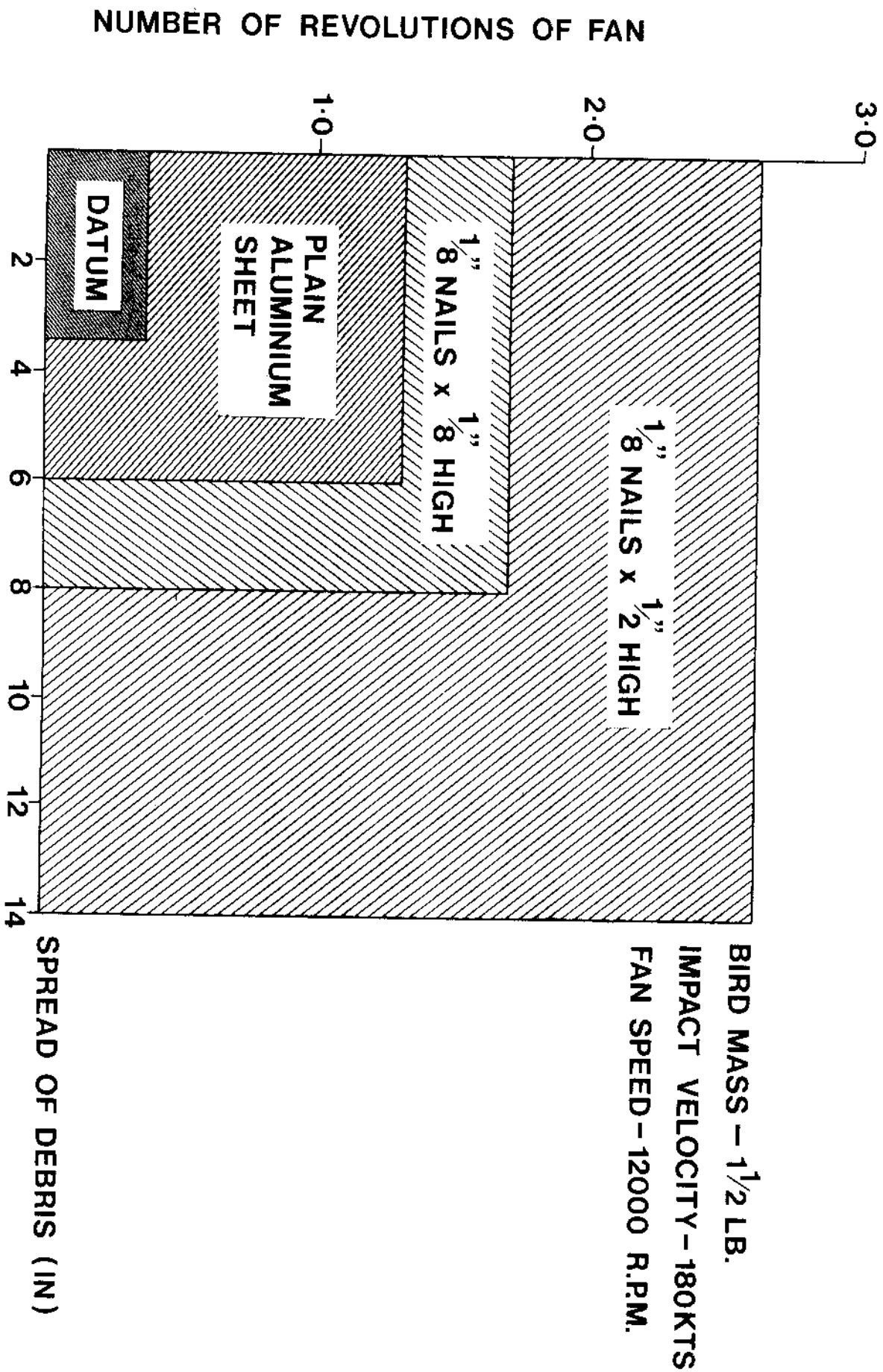


Fig. 8 Dispersal of Debris for Various Damager Types