GENERAL SESSION V

ENGINEERING EXPERIENCE AND RELATIVE IMPORTANCE OF VARIOUS PARAMETERS IN ACOUSTICAL FATIGUE

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DESIGN CONSIDERATIONS FOR MINIMIZING ACOUSTIC FATIGUE IN AIRCRAFT STRUCTURES

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INTRODUCTION

Considerable effort has been expended by various organizations to improve the noise resistance capabilities of aircraft structures. Although much of this effort has been directed toward solutions of specific problems, a considerable amount of general know-how has resulted. Some of this information is available in references 1-13; however, much is still unpublished and is only evident in many successful present-day aircraft designs. Although it is recognized that noise fatigue problems may be influenced by overall vehicle configurations, the present paper contains a brief summary of the available published information relating to the more detailed design procedures for minimizing noise-induced structural fatigue. In particular, past damage experience is reviewed, descriptions are given of some ways in which specified designs may be made less vulnerable to noise damage, and some discussion is directed toward the possible problems of the future.

AREAS OF NOISE DAMAGE

Before getting into a discussion of structural design details, it is helpful to indicate first the locations on the aircraft where damage is most likely to occur. In the case of propellers and turbojet engines, the damage areas are usually localized, as indicated by the shaded areas of figure 1. The conventional propeller airplane is subject to greatest damage from noise-induced vibration in or near the plane of the propeller. Very little damage has been encountered in the region of the wing except in the case of pusher propellers operating close to the relatively weak wing trailing-edge structure.

The jet airplane is subject to greatest damage in an area to the rear of the engine exhaust exits. For external or pod-mounted engines, these areas may extend to the wing trailing edge and, to some extent, spanwise along the wing. Of particular concern are the control-surface areas such as trailing-edge flaps which, at times, may be deflected near to or even into the jet exhaust stream. Fatigue failures may occur in the secondary fuselage structure for installations having internally mounted engines near the wing-fuselage junctures. For both external and internal engine locations, primary and secondary structures of tail assemblies are also subject to damage. To date, damage has been a minimum in configurations of airplanes and missiles having the jet or rocket engines located at the aft end of the vehicle. In future airplane, missile, and space vehicle designs involving the use of very high-performance engines, the damage areas may extend far forward of the engine exit nozzle and may thus include a larger part of the vehicle structure and equipment.

TYPES OF FAILURES ENCOUNTERED

A qualitative indication of the types of failures encountered in a large number of aircraft due to acoustic excitation is shown in figure 2. The data which apply to both propeller and jet multiengine aircraft were combined from reports of manufacturers. Failures due to propellers and jets are differentiated by the coding of the figure to indicate skin structure, wing primary structure, fuselage primary structure, and miscellaneous equipment damage. For instance, of the total number of jet airplanes having failures due to acoustic excitation, 86 percent of these had failures of the skin surface panels and only about 10 percent had failures of fuselage rings and longerons. A relatively large number of both jet and propeller aircraft encounter damage either to the skin panels or the skin support structure, and a smaller number to the wing ribs and stiffeners and fuselage rings and longerons. The locations where damage occurs vary with the aircraft configurations and the type of propulsion, as indicated in figure 2. For example, it is shown that for propeller aircraft, fuselage damage is more probable than wing damage.

Various types of equipment trouble also develop in aircraft, and particularly in missiles, as a result of acoustic-induced vibrations. In some cases the frames to which equipment is attached vibrate in such a manner that the equipment malfunctions. In others, the attachment brackets fail or the equipment itself fails. Items such as hydraulic lines, electrical lines, and conduits are particularly susceptible to this type of trouble. Sensitive equipment, such as gyros and various kinds of electronic gear having vacuum tubes and other sensitive components, are also susceptible. The weak points in many pieces of equipment are the gussets, brackets, and clamps for attaching the equipment to the frames. Bolts without lock nuts and other safety devices are also potential sources of trouble. The design of such items as equipment brackets and clamps is beyond the scope of this paper, which will deal mainly with the problems associated with the airplane skin surfaces.

CONTEMPORARY AIRCRAFT SKIN CONSTRUCTION

Contemporary aircraft skin panels include the three general types for which sectional views are sketched in figure 3. The design of a given skin surface element is influenced largely by its primary mission on the aircraft. For example, surface elements of wings are designed to carry large aerodynamic loads, whereas fairings may carry relatively small loads. The simple skin panel at the top, as the name implies, contains no stiffeners and is supported only at its edges. This type of construction is used mainly where the distance between main supports is small. For larger span openings the skin stiffener panel is useful. It contains intermediate stiffener elements between its main supports. These stiffeners, which can be of various sizes, shapes, and spacings, are used to increase the local stiffness of the panel and allow it to carry large steady loads. Another form of construction which has a very high local stiffness is the honeycomb sandwich. This construction incorporates two relatively thin outside skin surfaces bonded to an inner core material containing a large number of small cell structures, the longitudinal axes of which are perpendicular to the skin surfaces.

The following discussion will be devoted to the manner in which these three types of skin surface panels respond to noise loads and, in particular, the nature of the noise fatigue problem for each type of design. Some attention will be given to the manner in which failures occur, the reason for failures, and some indication of ways in which fixes can be applied. Attempts will be made to indicate which designs are superior for applications to intense noise loadings. The simple skin surface panels, the skin stiffener panels, and the honeycomb sandwich panels will be discussed in order.

Simple skin panels.- A convenient manner in which a given area of the airplane surface may be covered is with the use of simple skin panels. Their fatigue characteristics have been studied for both random and discrete noise loadings in reference 13, and a summary of those results is given in figure 4. The beneficial effects on time to failure, of increased panel thickness, increased panel curvature, and increased differential pressure across the panel surface are shown. These data refer to 11-inch by 13-inch aluminum-alloy panels attached only at discrete points along the edges and to relatively rigid frames for purposes of the test. The fatigue cracks first appeared near the attachment points and then progressed generally parallel to the attachment line. In the extreme cases, these edge cracks turned inward toward the center of the panel and eventually joined up in such a way that large pieces of the skin dropped out. The time to failure of figure 4 is defined as the time of exposure required to generate the first perceptible crack. Doubling of the thickness of the flat skin resulted in about a twentyfold increase in the fatigue life. An increase of the curvature of the panel was also beneficial; a panel of 4-foot radius gave a fatigue life on the order of

100 times that of a flat panel of the same size and thickness and the same noise pressure loading. A relatively small pressure differential across the surface of a curved panel resulted in a further significant increase in the fatigue life.

Skin-rib designs.- As a contrast to the preceding results for rigid edge supports, data are presented in figure 5 for a different type of edge supports. A tentative design chart for plain skin on bent flange ribs, a type of design suitable for trailing-edge flap and aileron construction, is shown (refs. 3 and 4). Three structural variables are involved; namely the skin thickness which is the ordinate, the rib spacing as indicated by the solid lines, and the rib thickness as indicated by the dashed lines. The chart indicates the combinations of these three variables which are satisfactory for resisting damage to various noise pressure loads referred to spectrum level (unit band width), as indicated on the abscissa. The chart is based on theoretical analyses and has been confirmed generally by experimental results. If a rib structure were designed according to this chart to withstand a given noise loading, it would be possible to use any convenient skin thickness within the range of the chart and then adjust the rib thickness and spacing to conform to the requirements of the design. Likewise, for given rib spacings, the rib and skin thicknesses could be varied to meet the requirements. The chart also gives an indication of the manner in which an unsatisfactory design for a given noise loading could be altered to make the design satisfactory. Thus information of this type is useful for applying fixes to damage areas on existing aircraft as well as in the planning of structural designs for proposed aircraft.

Skin-rib junctures.- The manner in which the skin and ribs are fastened together is also very important. Further details of skin-rib construction are illustrated in figure 6, for which the numerical data were taken from reference 1. The top row of numbers represents and fatigue life in minutes for these various configurations at a noise level of 160 db (RE 0.0002 Dynes per cm^2). The data on the second row apply to a noise level of 170 db though it should be noted that only one design was tested. The design on the left, which consists of a skin and bent-flange rib, has a very short life on the order of a few minutes. If a doubler strip were added to this configuration, the life span may be increased by about a factor of 10. A further change of the rib configuration to make it more symmetrical would give a further significant increase in the fatigue life. Then, finally, the use of bonding instead of riveting in order to decrease stress concentrations results in a further increase of life span.

If the design on the right, which is considered satisfactory for noise levels of 160 db, were exposed to a noise level of 170 db, it would then have a relatively short fatigue life. This illustrates the fact that the structure has to be designed to withstand the particular noise environment that exists at that location and that designs suitable for low-intensity applications may not be suitable for high-intensity applications.

Stiffener configurations.- With regard to the design of skin stiffener type panels, the configuration of the stiffener, its method of attachment, and the manner in which it is terminated are also very important with regard to the fatigue life of the panel (refs. 1 and 5). Some cross-sectional views and methods of termination are indicated schematically in figure 7. At the top of the figure are shown sketches of some stiffeners that are in common use. It will be noted that some of these are not symmetrical about the lines of attachment to the skin, whereas others are symmetrical. From experience, it has been found that the stiffeners which have symmetrical sections are superior to those having unsymmetrical sections. In this respect, the stiffener shape, which is most convenient for its attachment to the other structural elements of the airplane or to equipment items, may not be acceptable from the standpoint of acoustical fatigue. A difficult problem in terminating the stiffener at the edge of a panel is that of reducing local stress concentrations at the termination. At the bottom of the figure are shown four sketches of terminations commonly used for hat section type stiffeners. The two configurations at the right represent attempts to change the shape of the hat section stiffener at its end in order to form a gradual transition to a flat attachment surface in the region of the doubler strip at the edge of the panel. In the sketches on the left the hat section stiffener is mainly joggled up over the doubler strip. It is not known which of these latter four schemes is the better although all of these are in use to minimize the stress concentrations at the termination of the stiffener and to eliminate abrupt changes of local stiffness in these areas. The use of bonded joints in place of the rivets indicated in the figure might further reduce these stress concentrations.

Honeycomb sandwich.- Because of its high impedance to noise loading and because of more uniform stressing of the material, the sandwich type of construction as illustrated in figure 8 is being used successfully for many high-intensity noise applications (refs. 1, 9, 12, and 14). At the top of the figure is a sketch showing the main structural features and possible damage areas due to acoustic fatigue. The sketches at the bottom indicate some of the various schemes being used for attachment of these panels to the main structural members or for making local attachments of other items to honeycomb sandwich panels (ref. 15).

Three general areas of possible damage are indicated in the figure. Damage may occur at the attachment points at the edge of the panel as in the case of other types of construction already discussed. A further source of trouble in the particular design shown in the sketch is the bend radius of the edge-former of the panel. Fatigue cracks starting at this location can spread rapidly throughout the panel. A third area in which damage may be anticipated is the core section (refs. 9 and 12). Local faults may develop because of poor bond joints of the core cell walls with the skin surfaces, thus resulting in local loss of strength. Acoustic fatigue damage may also occur in the cell wall structure itself which, in some cases, has eroded away due to the detrimental effects of the noise.

One of the problems in the use of sandwich type material for skin surfaces is that of attaching the skin panels to the main members of the aircraft. Some ways in which this may be done are illustrated in the sketches at the bottom of the figure. The upper left of these involves the crushing of the core material at the edge of the panel. From a fatigue standpoint, this has not been satisfactory because there exist many faults of the cell structure, from each of which fatigue cracks may be initiated. A more satisfactory method than this involves the use of a formed doubler at the edge, as indicated in the upper right-hand sketch.

As a matter of convenience, in some applications the attachment schemes illustrated in the lower sketches may be used. In order to increase the local strength in the region of the attachment points, the core may be "densified" or may be replaced by a high strength insert. Many schemes of attachment are under study, some of which are variations of the ideas suggested in the sketches in this figure. These same principles of edge treatment are also being applied to increasing the local strength of the panel in the regions where attachment is made to other structural members and items of equipment (ref. 15).

FUTURE AIRCRAFT SKIN CONSTRUCTION

Several trends are evident in the present evolution of high-temperature construction, and these are illustrated by the sketches of figure 9. These include truss core sandwich, open face sandwich, waffle grid, and insulated heat shields. The first three of these are characterized by a high stiffness under loading normal to the plane of the panel. In the case of sandwich type panels the stiffness is roughly comparable to solid plates of equal thickness, but because of the reduced mass the natural frequencies are much higher. These high-temperature sandwich constructions incorporate a large number of tiny weld joints which are potential sources of fatigue cracks and could be sources of trouble that require very good production quality control to eliminate. Spot and seam welding, in particular, are believed to result in stress concentrations and in altered material properties. These sandwich constructions depend, for their strength, on their overall structural integrity and hence small faults in construction cannot be tolerated. This imposes a very severe problem of quality control. Another source of difficulty can again be the edge attachment problem. The edge reinforcement required to transmit high static loads across panel boundaries generally leads to an undesirable discontinuity in bending stiffness.

This waffle grid panel is made from a thick piece of stock and is milled out to the form shown in the sketch, either by chemical or mechanical means. The design is so arranged that no abrupt changes in local stiffness occur in the region of the stiffening elements and the edge fastening, and promises to be very useful for high-intensity noise applications.

The sketch in the lower right-hand corner of the figure illustrates a type of heat shield construction which is being considered for the Project Mercury manned space capsule. It consists of a thin outer skin into which a series of dimples are stamped, and which is separated from the main skin surface structure by an airspace and a thermal insulating blanket, as indicated in the sketch. The objective here is to keep the inner construction cool even though the thin outer skin may be operating at a very high temperature. This type of construction is being considered for reentry type space vehicles and for more conventional aircraft having interior personnel and equipment compartments that need to be insulated from the high exterior temperatures. Of particular concern here is the very thin outside skin which may have inherent stress concentrations due to the stamping procedures and which is attached to flexible spacers at many points.

CONCLUDING REMARKS

In summary, the nature of the noise damage problem has been discussed with particular emphasis on structural designs. It has been shown that damage due to noise occurs largely in the skin surface structure in the vicinity of the power plant. Some detailed acoustic fatigue data were presented for simple skin and skin rib types of construction. Such parameters as skin thickness, panel surface curvature, and differential pressure across the panel as well as rib spacing, rib thickness, and rib attachment details were noted to be significant. Some general principles for design of noise resistant skin-stiffener and honeycomb panels, particularly with regard to edge treatments, were also included. Finally, brief descriptions were given of some proposed surface designs for high-temperature application, along with a discussion of some noise fatigue problem areas.

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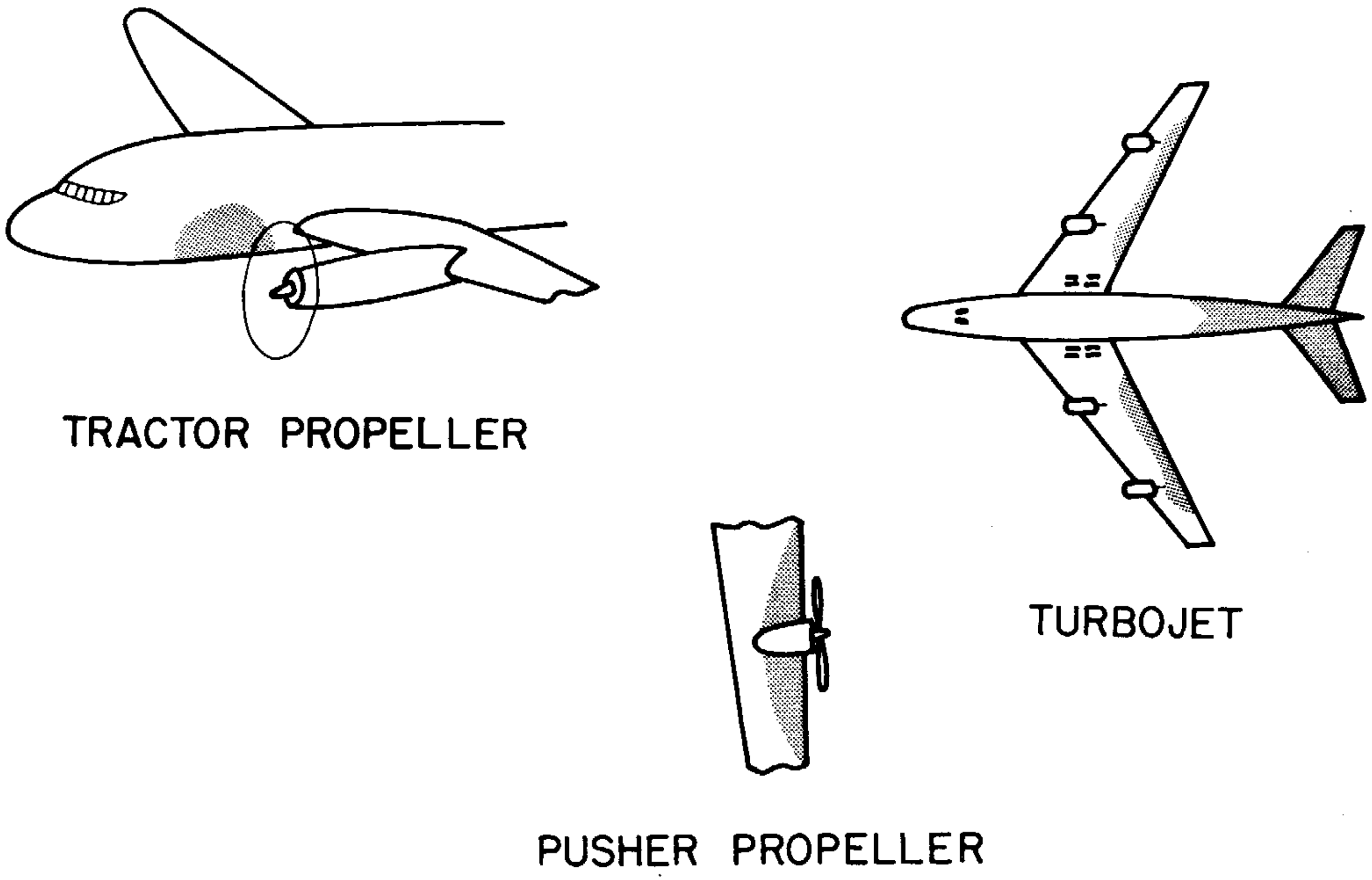

NASA

Figure 1.- Areas of possible damage on aircraft due to acoustic excitation from power plants.

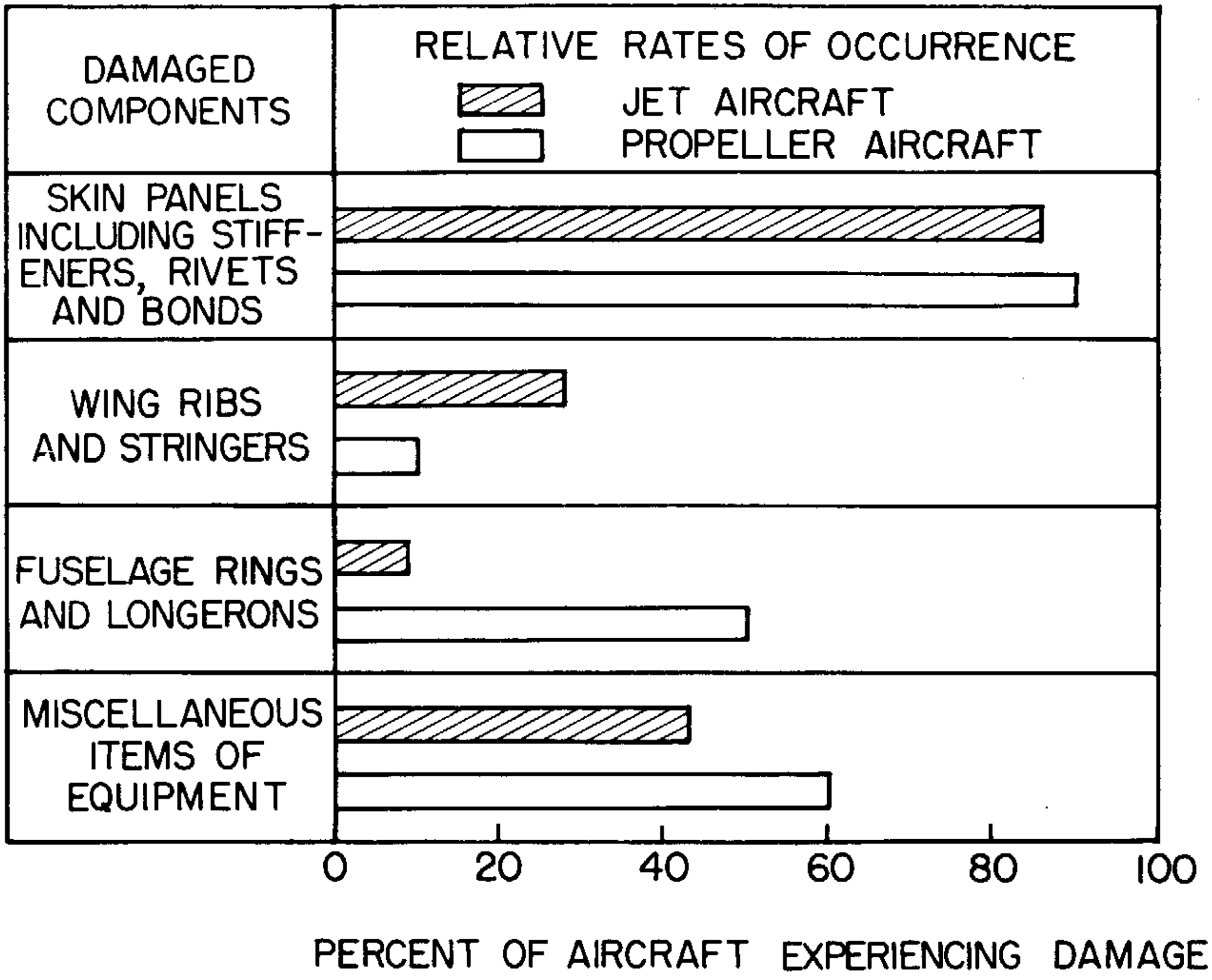

Figure 2.- Structural components affected in acoustically damaged aircraft.

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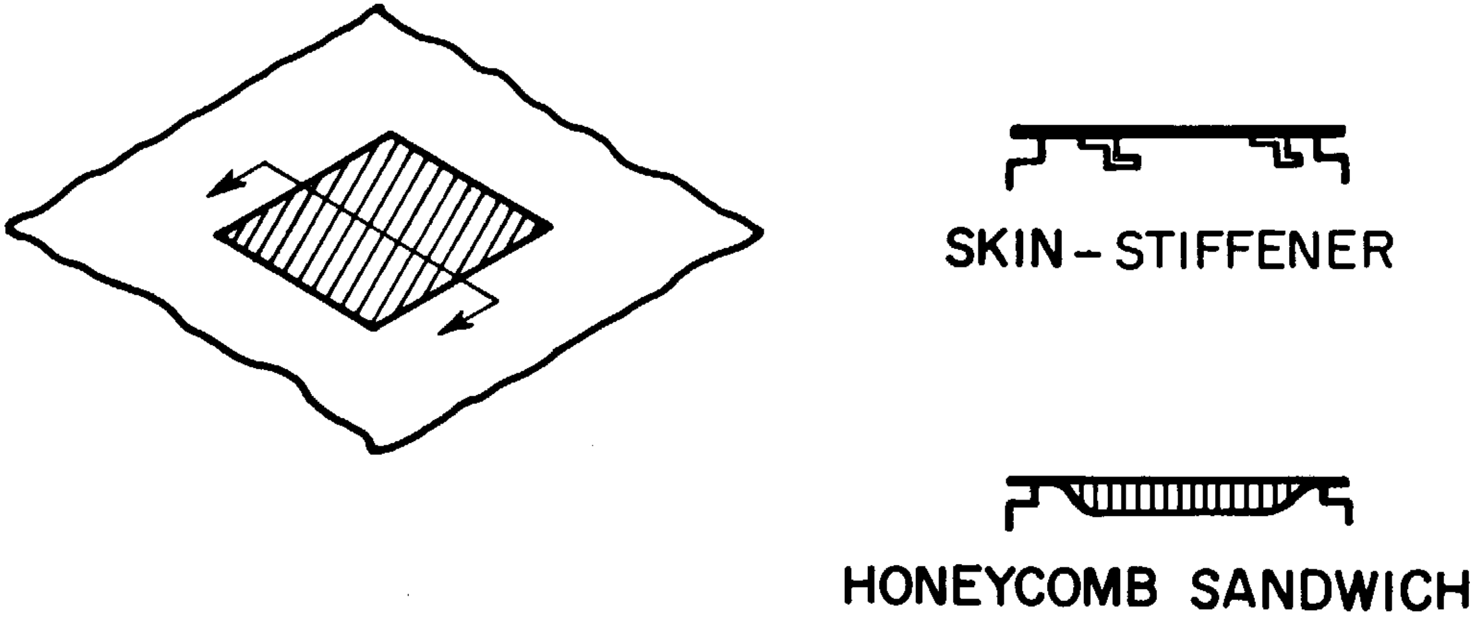

Figure 3.- Three types of skin-surface panels used in contemporary aircraft construction. NASA

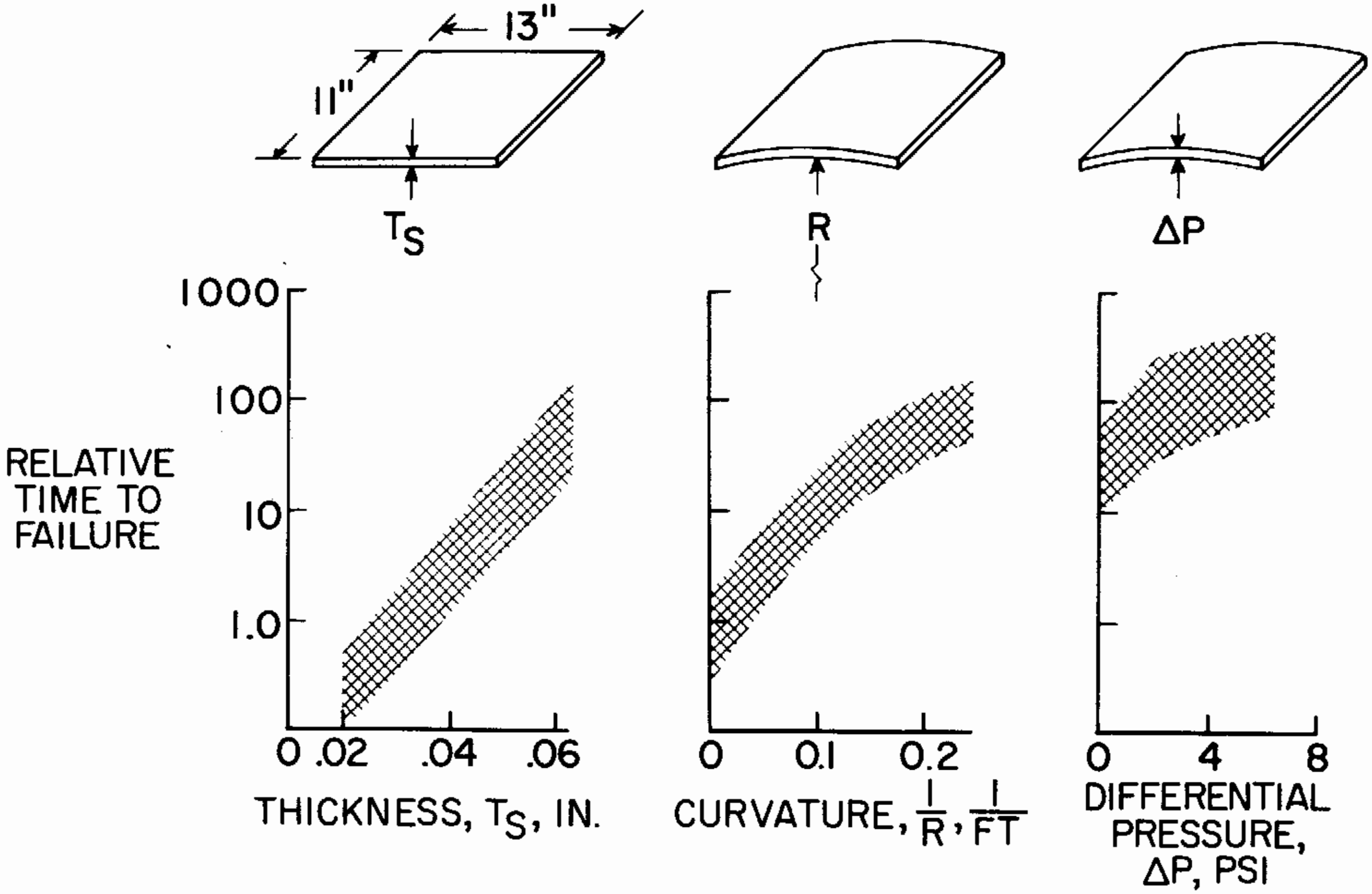

Figure 4.- Three factors affecting the acoustic fatigue life of simple skin panels. (From Ref. 13) **NASA**

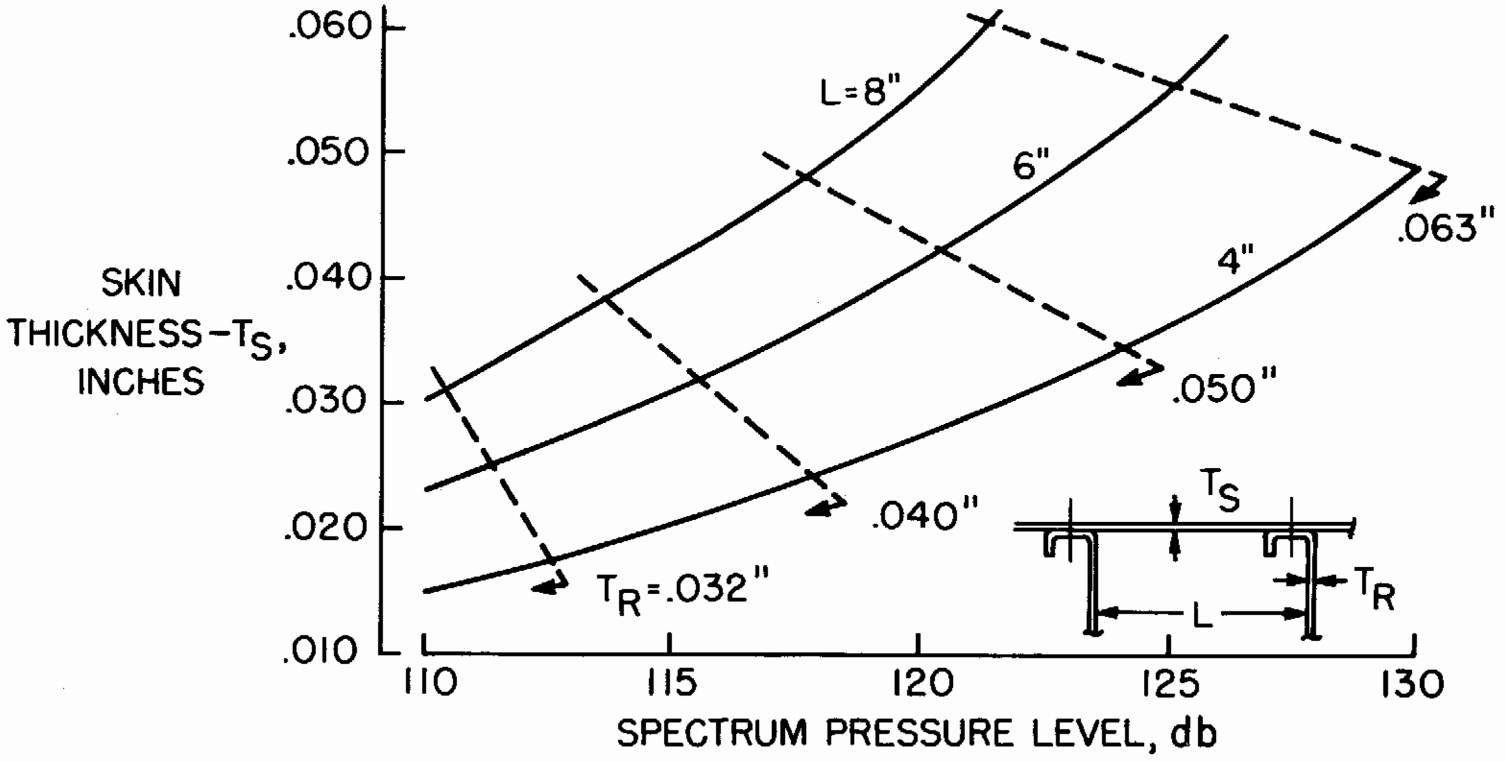

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Figure 5.- Tentative design chart for permissible acoustic loading of skin-rib construction. (From Ref. 4)

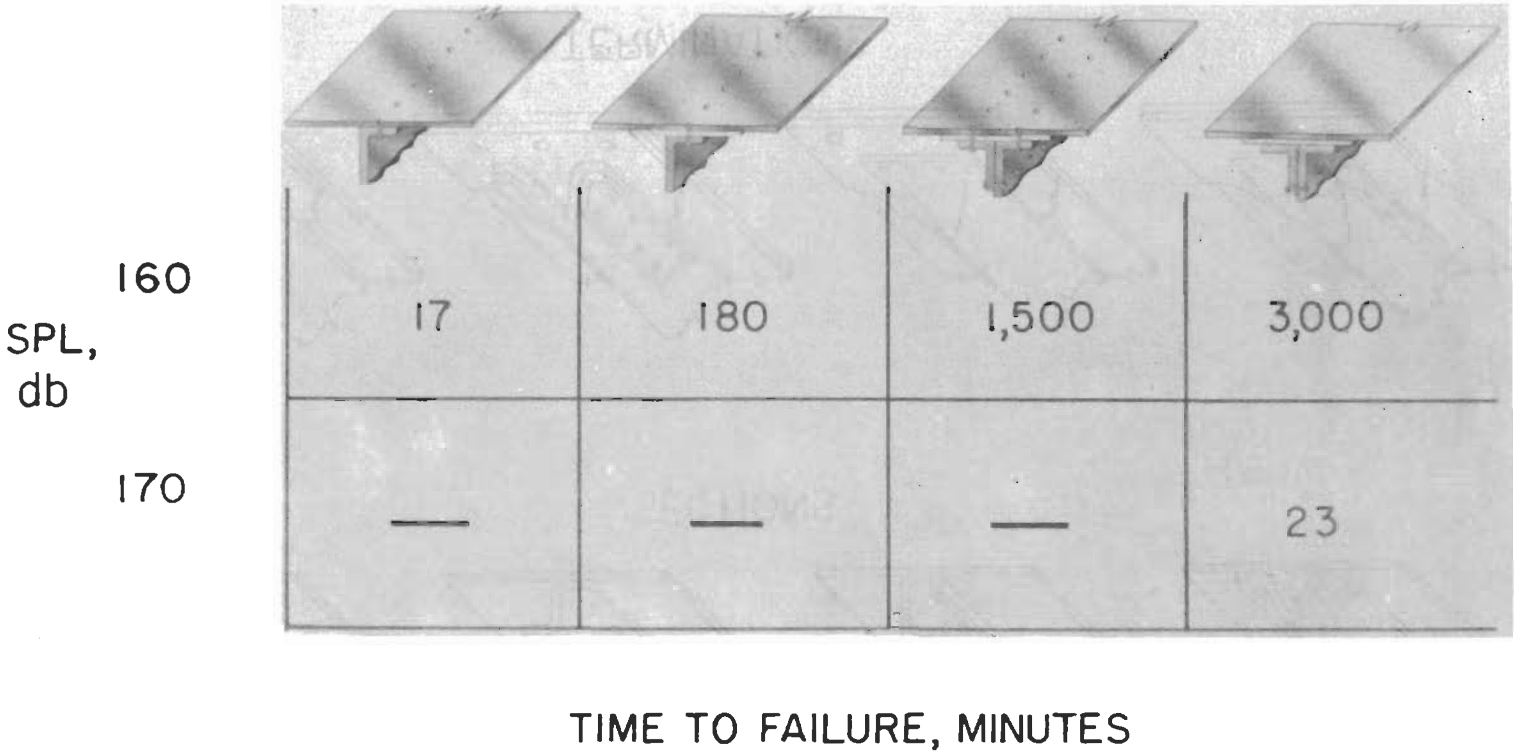

Figure 6.- Time to failure for four types of skin-rib junctures during siren tests. (From Ref. 1) NASA

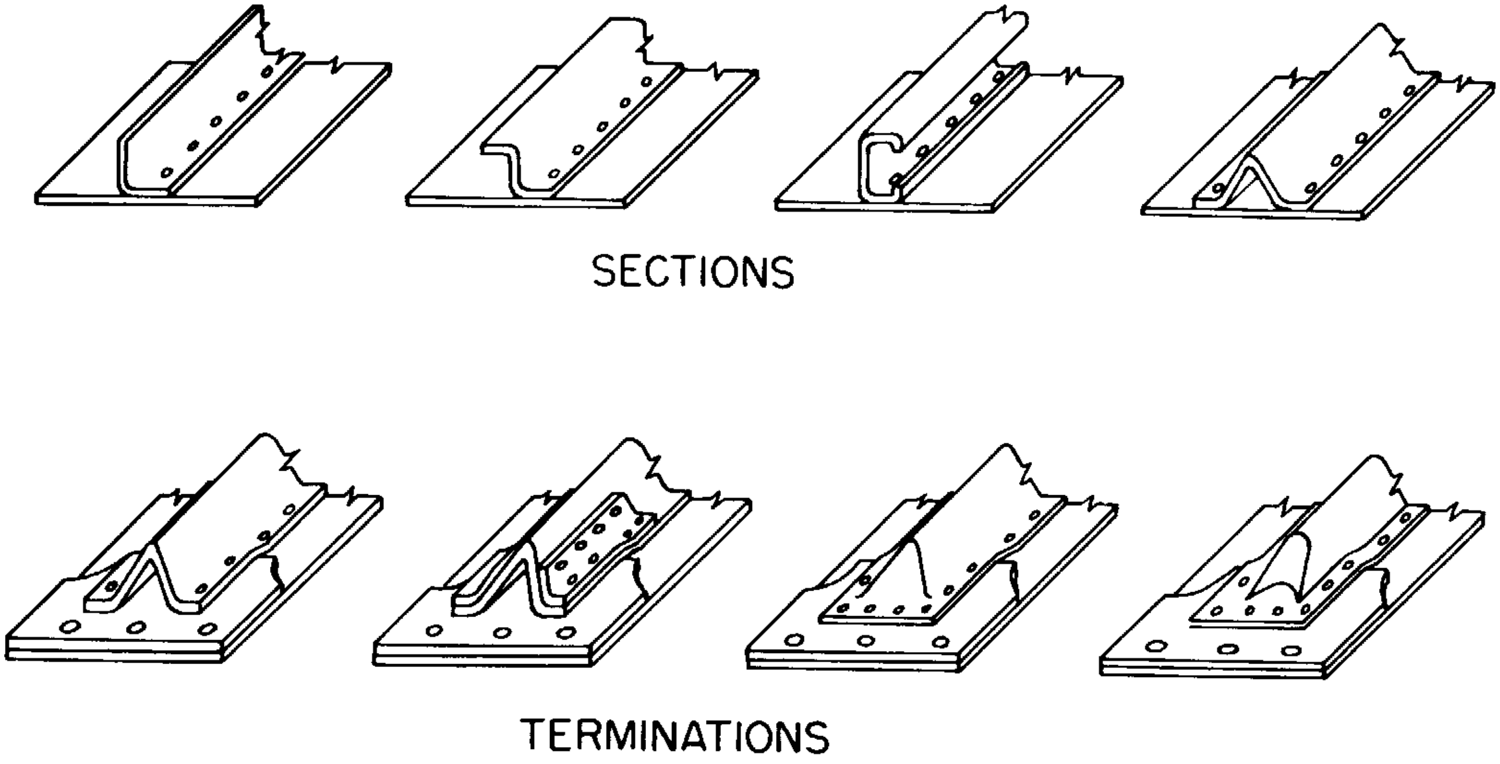

Figure 7.- Some skin-stiffener configurations. NASA

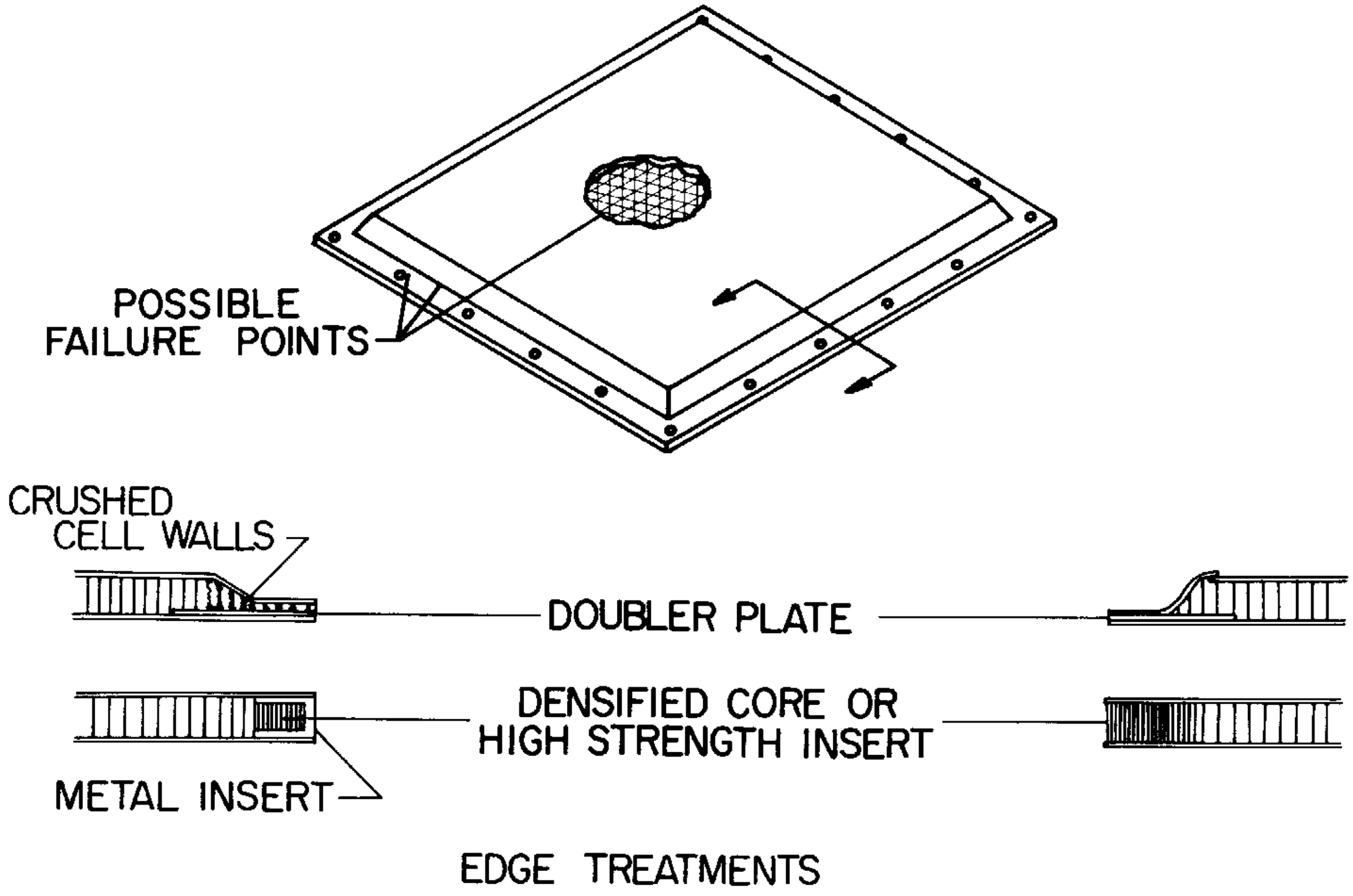

Figure 8.- Honeycomb-panel configurations. (From Ref. 15) NASA

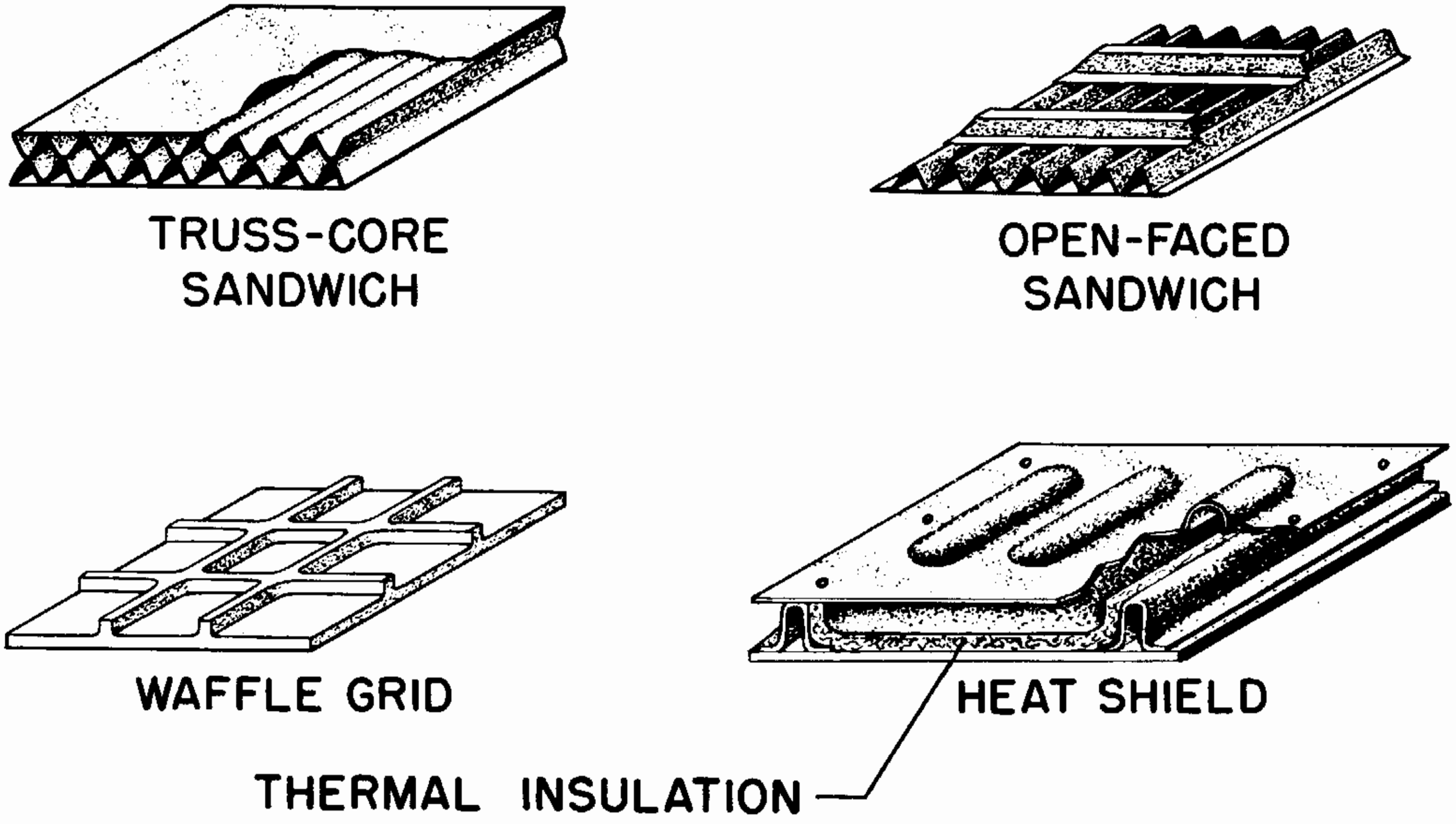

Figure 9.- Some types of skin-surface construction for high-temperature applications.