N74 30926

TITANIUM HONEYCOMB STRUCTURE

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INTRODUCITON AND BACKGROUND

During initial engineering design studies for a commercial supersonic transport, titanium was shown to provide the lowest weight structure to carry a given payload. A summary of this data compared to aluminum and stainless steel is shown in Figure 1. The lowest structural weight has a favorable impact on the operating economics of a commercial transport airplane. As design refinements occurred based on aerodynamic, propulsion, pressure loads, flutter, and range / payload developments, a mach. 2.7 fixed wing titanium airplane evolved.

The major impact of this final configuration on structures and materials technology was to require development of a titanium honeycomb sandwich system for wing cover panels. There were basically three technical reasons for a sandwich structure. First, spanwise and chordwise and loadings (Figure 2) were generally low and sandwich material provided the most efficient structure. Second, flutter testing showed that high wing stiffness was required and again sandwich structure was most efficient. Third, liquid fuel was carried in direct contact with the wing structure in integral fuel tanks and sandwich structure provided thermal insulation for the fuel.

Figure 3 shows the temperature profile for the prototype supersonic transport. Generally the basic structure would be operating at 450°F with some local areas reaching peaks of 500°F under special flight conditions. For the basic wing sandwich material the maximum operating temperature would be 450°F. Figure 4 shows the major structural concepts planned for construction of the prototype aircraft. Titanium honeycomb sandwich applications were also expanded to the power plant pod and empennage structure for improved structural efficiency. Additionally, resistance to relatively high sonic levels (160 dB) was required in portions of the empennage structure and honeycomb sandwich met this requirement. Titanium honeycomb sandwich was not planned for the most highly loaded center section of the wing nor the relatively deep (up to 11 inches) wedge structure on both leading and trailing edges of wing and tail structure of the prototype airplane because process development could not be carried out in time to meet the planned prototype manufacturing schedule.

PROCESS DEVELOPMENT

The criteria of concern in development of a brazed titanium system involved three major areas; (1) metallurgical compatibility, (2) manufacturing feasibility, and (3) design viability. Process development, although concerned primarily with metallurgical parameters, had to consider concurrently both manufacturing and design aspects.

The initial step was to assess and selectively test brazing alloy systems for compatibility with titanium, for processing parameters, and for preliminary strength properties. Table 1 shows a summary of the various brazing alloy systems and their pertinent characteristics. As a result of this assessment, the aluminum base alloys were selected for further evaluation and subsequently aluminum alloy 3003 was chosen as the best alloy. This choice was based on brazing temperature range, foil availability, flatwise tensile strength and corrosion resistance.

A primary concern was the formation of any embrittling effects as a result of the formation of titanium aluminide ($TiAl_3$) during the brazing cycle. The brazing cycle temperature envelope was developed to limit titanium aluminide formation by restricting the holding time above 1175^{o}F to one hour maximum. With this control, an aluminide layer of .0003 inches maximum is formed. This thin layer has no noticeable effect on static properties of the basic titanium 6Al-4V face sheet alloy. Fatigue properties may be reduced by approximately 20%, however, due to difficulties in specimen preparation, the available data are inconclusive. Figure 5 shows the final high temperature portion of the braze cycle envelope used for process control.

Another major concern was galvanic coupling effects resulting from exposing aluminum and titanium to a corrosive environment. From a theoretical standpoint based on single electrode potentials of the two alloys, aluminum should preferentially corrode when in contact with titanium. Extensive accelerated laboratory testing and commercial airline fleet exposure showed that no galvanic accelerated corrosion effects occurred. Figure 6 shows an unprotected honeycomb sandwich panel installed on the mud flap of a Boeing 727 model airplane for service evaluation. Approximately three years of airline service exposure have been carried out with no corrosive attack occurring.

Although all corrosion testing indicated that galvanic acceleration would not be a problem, a conservative approach was taken by stipulating that non-perforated core would be used exclusively. With this approach each individual cell cavity would be hermetically sealed and any progression of moisture through a panel would have to progress a cell at a time.

In 1969 at the time of initiation of development of brazed titanium honeycomb sandwich, the state-of-the-art structural sandwich system which existed was silver brazed PH 15-7Mo stainless steel. This system had been used extensively on the B70 supersonic bomber. A comparison of the stainless steel and titanium honeycomb sandwich processes is shown in Table 2. Several items are noteworthy. First the brazing temperature of the titanium system is much lower and this fact simplifies both tooling and heat source requirements. Secondly, the titanium system requires no post brazing thermal cycle. Finally, a generous amount of aluminum braze alloy is used during the process to produce a .030" fillet at the core to face sheet junction. With the standard .002" thick one-quarter inch cell size and optimum braze conditions, this amount of braze alloy provides enough strength to break the 3Al-2.5V core foil during a flatwise tensile test.

MECHANICAL PROPERTIES

As process development progressed, firm requirements were developed for basic honeycomb panel strength. The standard honeycomb core consisted of .002" thick one-quarter inch cell produced from 3Al-2.5V foil (density = 5 pounds per cubic foot). Cell walls were corrugated for added stiffness. Static mechanical properties were developed for the basic honeycomb panels from tests of flatwise tension, flatwise compression, plate shear, beam shear, and edgewise compression specimens. Figure 7 contains a summary of the mechanical property data.

In addition, creep behavior was of concern and a simple single cell tubular test specimen was developed for evaluation. This specimen permitted easy mechanical loading for data gathering. The data were later confirmed using standard 2 inch square honeycomb sandwich specimens. Figure 8 contains a summary of both single cell and multiple cell test specimens for both 450°F and 600°F. All test fractures that occurred were of a stress rupture nature. No perceptible creep occurred with any of the test specimens.

DESIGN DEVELOPMENT

Basic panel strength requirements could be met with five pound per cubic foot core. At load transfer areas however, where mechanical fasteners were used to fasten panels to spars and ribs, higher density core was used. This high density core provided both increased resistance to environmental effects at panel edges as well as capability to withstand fastener loads. Table 3 shows an approximate distribution of the various types of core planned for use on the supersonic transport prototype. Edge designs utilizing the higher density core are schematically shown in Figure 9.

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One of the major developments involved utilization of appropriate non-destructive testing techniques to ascertain that brazed panel quality was acceptable. Figure 10 shows schematically the techniques utilized to determine panel quality. The eddy current scan technique would be applied 100% to each panel to check for the proper distribution of the aluminum braze alloy within the panel. Radiographic inspection was used selectively to determine node flow, shear tie integrity and the extent of core crushing

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if any. The Ultrasonic C-Scan technique was used 100% on each panel to determine braze alloy fillet size and the location of any sheet-to-core voids. Figure 11 shows an ultrasonic trace representing three levels of fillet size.

SCALE-UP

Although many fine ideas can be satisfactorily demonstrated in the laboratory, the final proof of acceptability for aerospace structural usage consists of full scale hardware fabrication and testing. Concurrent with the design phase of the prototype program, a major effort was devoted to building three foot by twenty foot panels representative of both wing and empennage designs. The philosophy behind this approach is that there are generally technical problems encountered with fabrication of full scale hardware that are not revealed in small scale fabrication. This fact was also true with this aluminum brazed system. Considerable effort was expended in tooling development, temperature control, retort purging, panel restraint, core machining and non-destructive testing.

The simplified tooling concept used for face sheet forming and panel brazing is shown in Figure 12. This concept was devised to minimize production costs of the process. In fact masonite side walls were found to be acceptable as side wall retainers for the braze fixture. Figure 13 shows a successfully completed 20 foot wing panel.

SUMMARY

At the time of the SST cancellation, the development and evaluation of the system was essentially complete for the planned applications. Design criteria and properties were established. Subsequent extensive testing has shown that neither corrosion nor creep rupture would be a problem for the proposed applications. Process and material specifications and quality acceptance criteria and inspection methods were established as demonstrated by the successful fabrication of 3' x 20' production wing panel. At the present time, further development work sponsored by the Department of Transportation is underway to extend the process for broader applications such as more highly loaded structure, wedge configurations, and acoustic panels.

TABLE 1

BRAZE ALLOY SYSTEM COMPARISONS

ALLOY SYSTEM	CHARACTERISTICS				
	COST	BRAZE TEMPERATURE	CORROSION RESISTANCE	STRENGTH	METALLURGICAL COMPATIBILITY
Silver Base (Ag, Ag-Al)	High	Moderate	Poor	High	Good
Noble Metals (Au, Pd)	Very High	High	Good	High	Good
Ti-Cu-Ni	High	High	Excellent	High	Embrittling
Ti-Zr-Be	High	High	Excellent	High	Embrittling
Copper Base	Low	High	Good (if Diffused)	High	Embrittling
Al	Low	Low	Good	Moderate	Good

TABLE 2

COMPARISON - STAINLESS STEEL & TITANIUM H/C SANDWICH

ITEM	PH 15-7 Mo/Ag	Ti-6Al-4V/Al
Braze Temperature	1900°F	1250°F
Faying Surface Joints	Used	Not Used
Intercell Hermetic Seal	No	Yes
Post Braze Heat Treatment	Required	Not Required
Braze Alloy Cost	High	Low
Braze Alloy Quantity	Small	Large
Fillet Size	.010 Inch	.030 Inch
Quality	Moderate	High
Corrosion Resistance	Fair	Good
Flatwise Tensile Strength	900 psi	1500 psi

TABLE 3

CORE TYPES

DESIGNATION	CELL SIZE Inch	WALL THICKNESS Inch	DENSITY lbs/cu. ft.	SST % USAGE
4-20	1/4	.002	4.9	70
4-30	1/4	.003	7.3	12
2-20	1/8	.002	9.3	10
2-30	1/8	.003	14.0	3
2-60*	1/8	.006	28.5	5

* Ti-6Al-4V - All Others Ti-3Al-2.5V

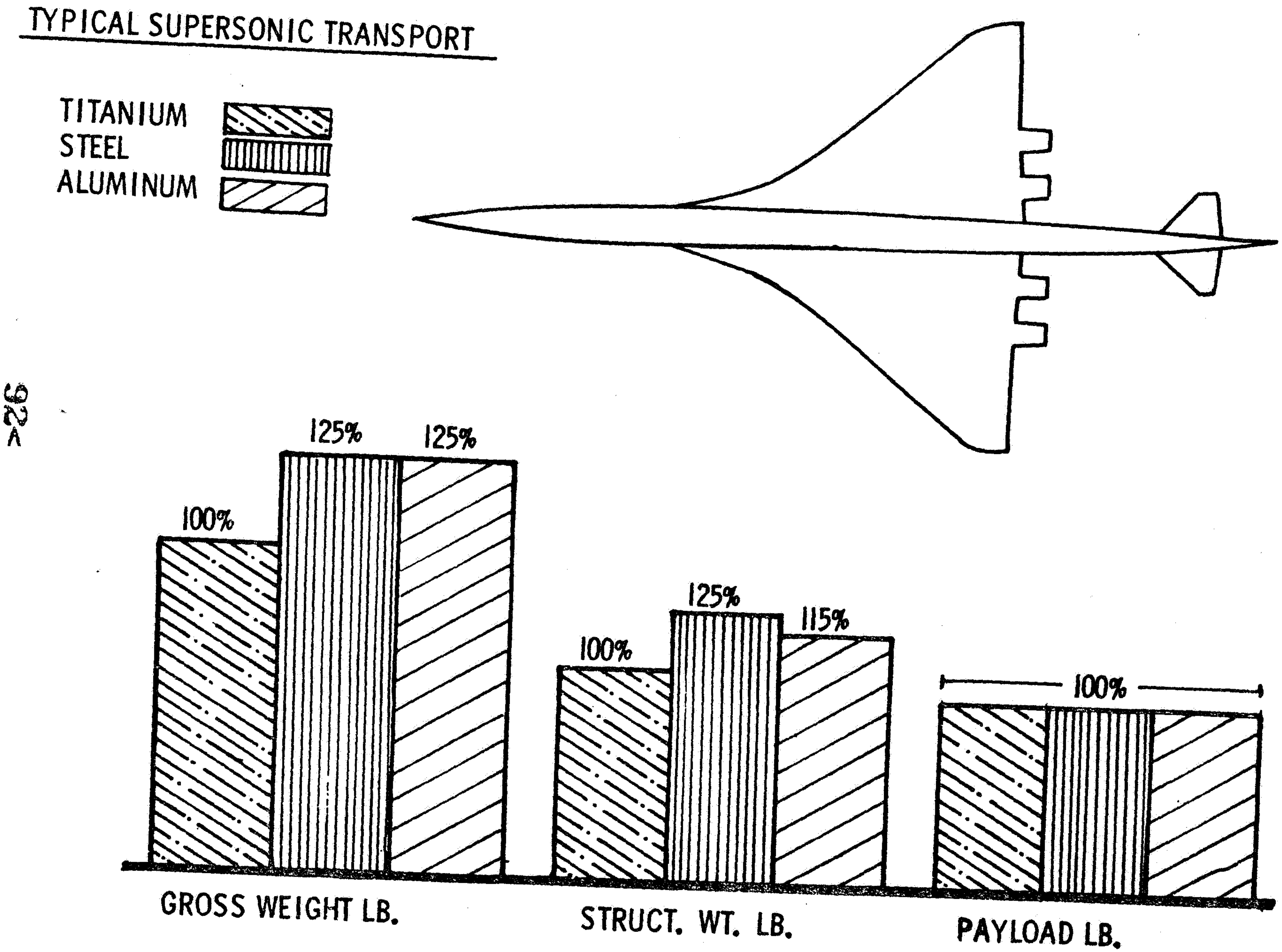

FIGURE 1 WEIGHT COMPARISON FOR DIFFERENT STRUCTURAL METALS

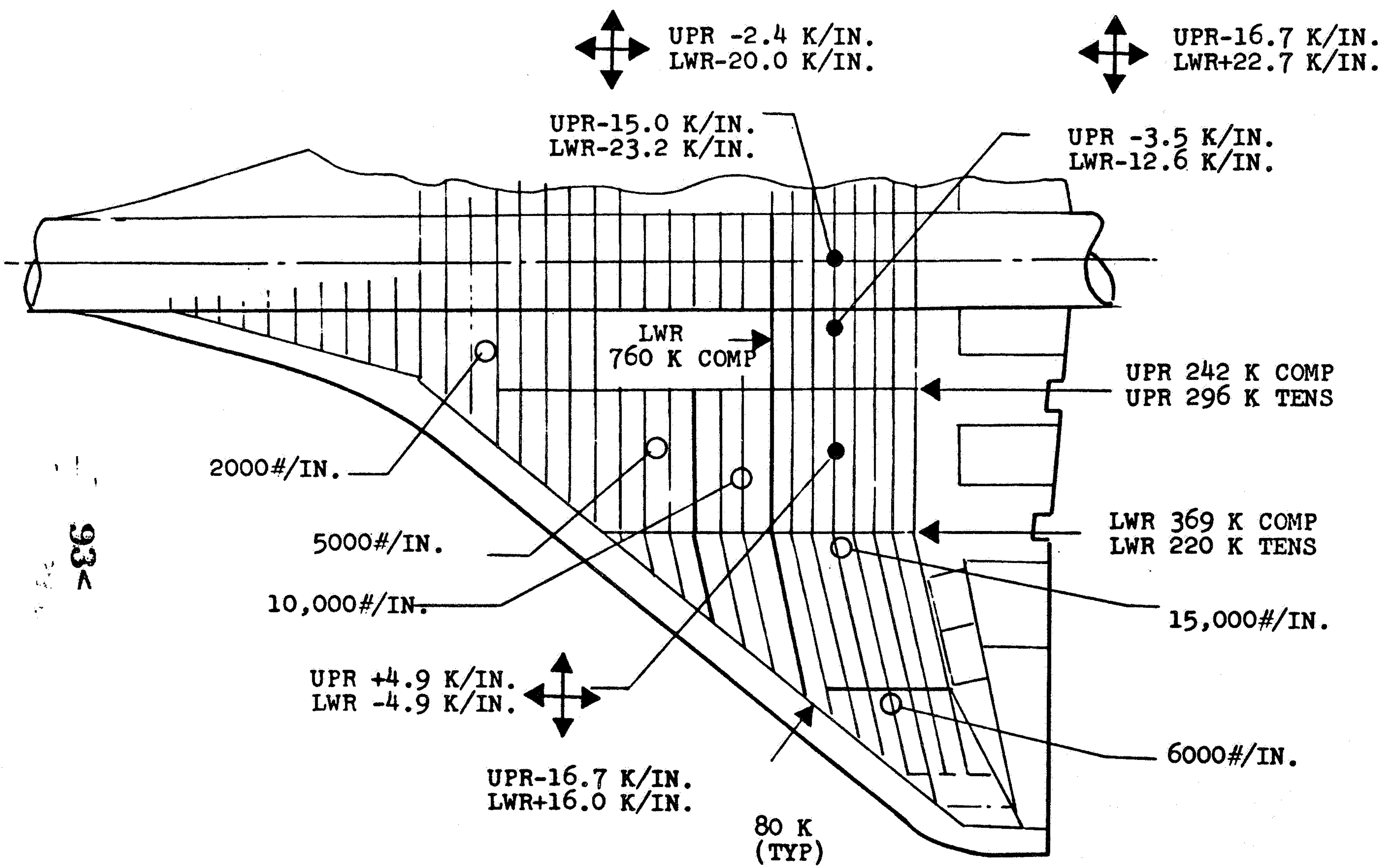

FIGURE 2 TYPICAL WING END LOADS

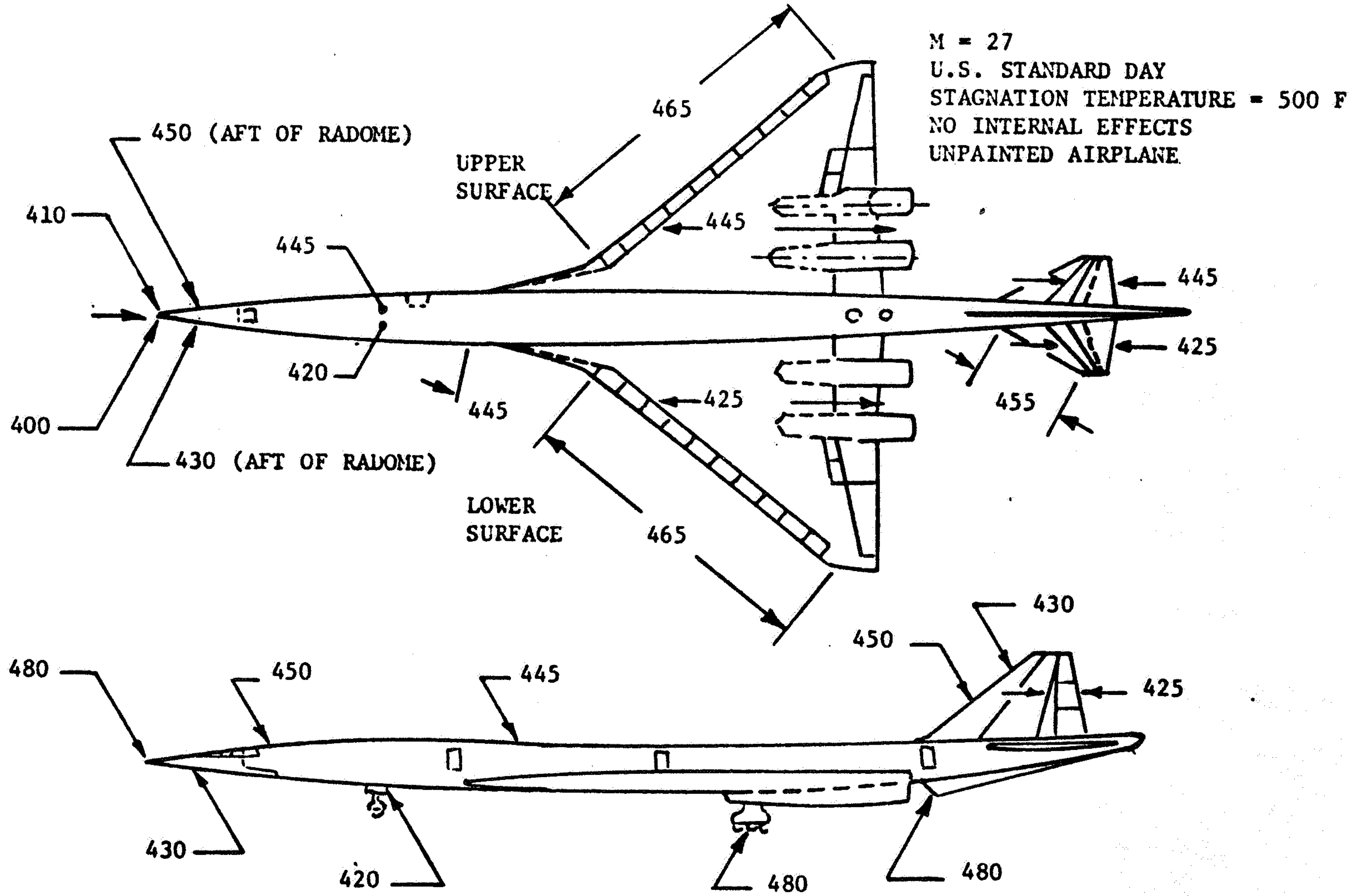

FIGURE 3 SST SURFACE TEMPERATURE, °F.

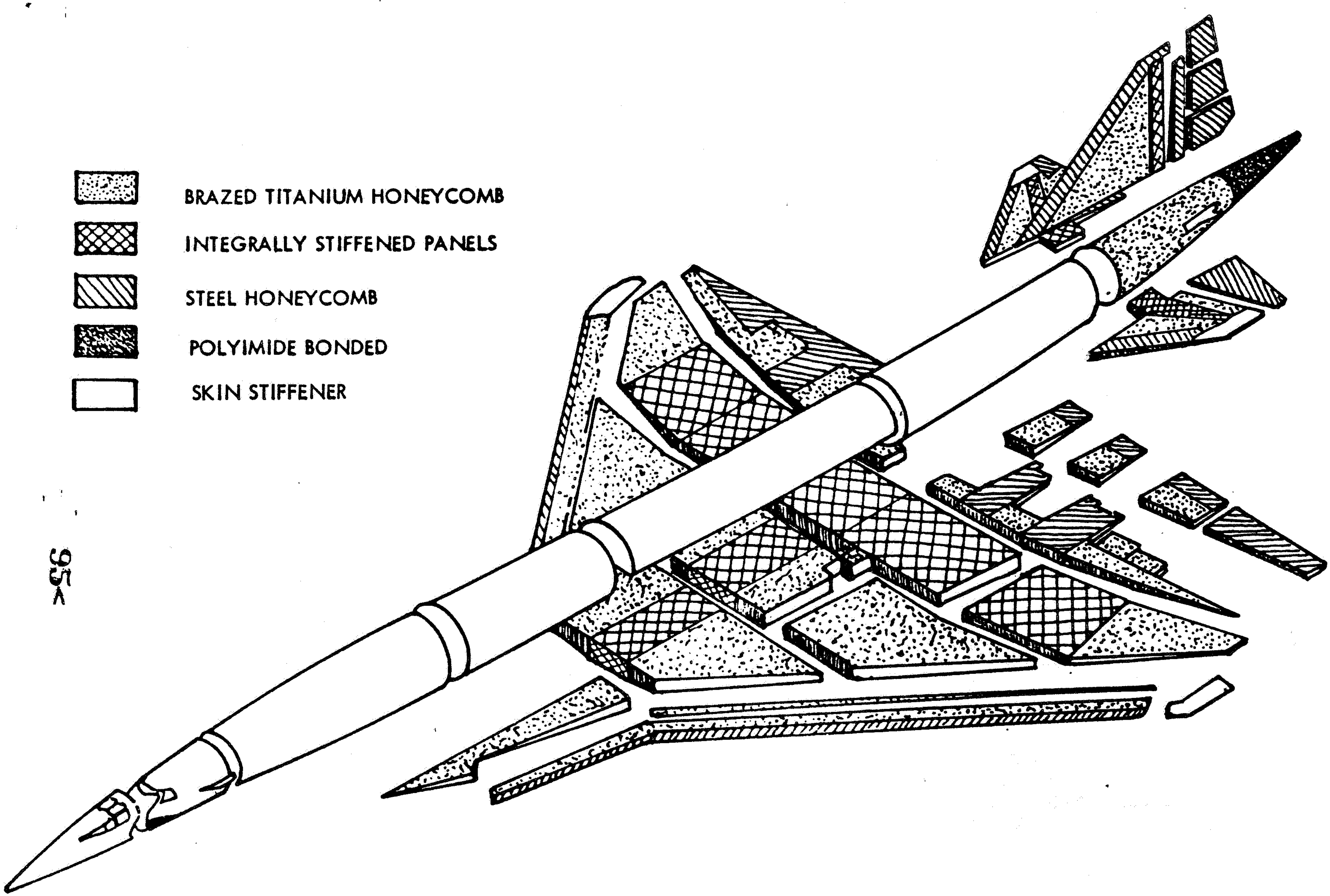

FIGURE 4 SST STRUCTURAL CONCEPTS

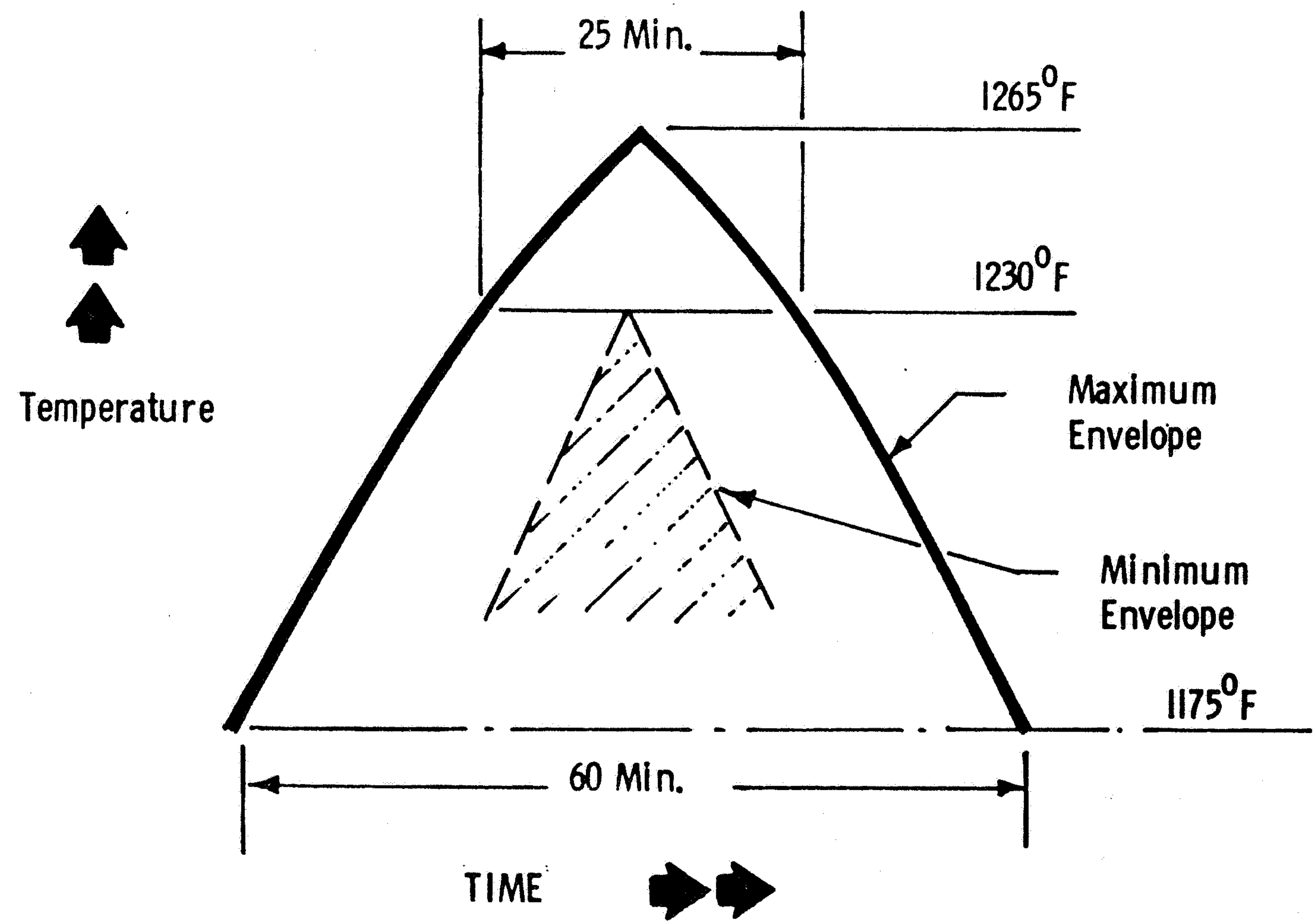

FIGURE 5 BRAZE CYCLE ENVELOPE

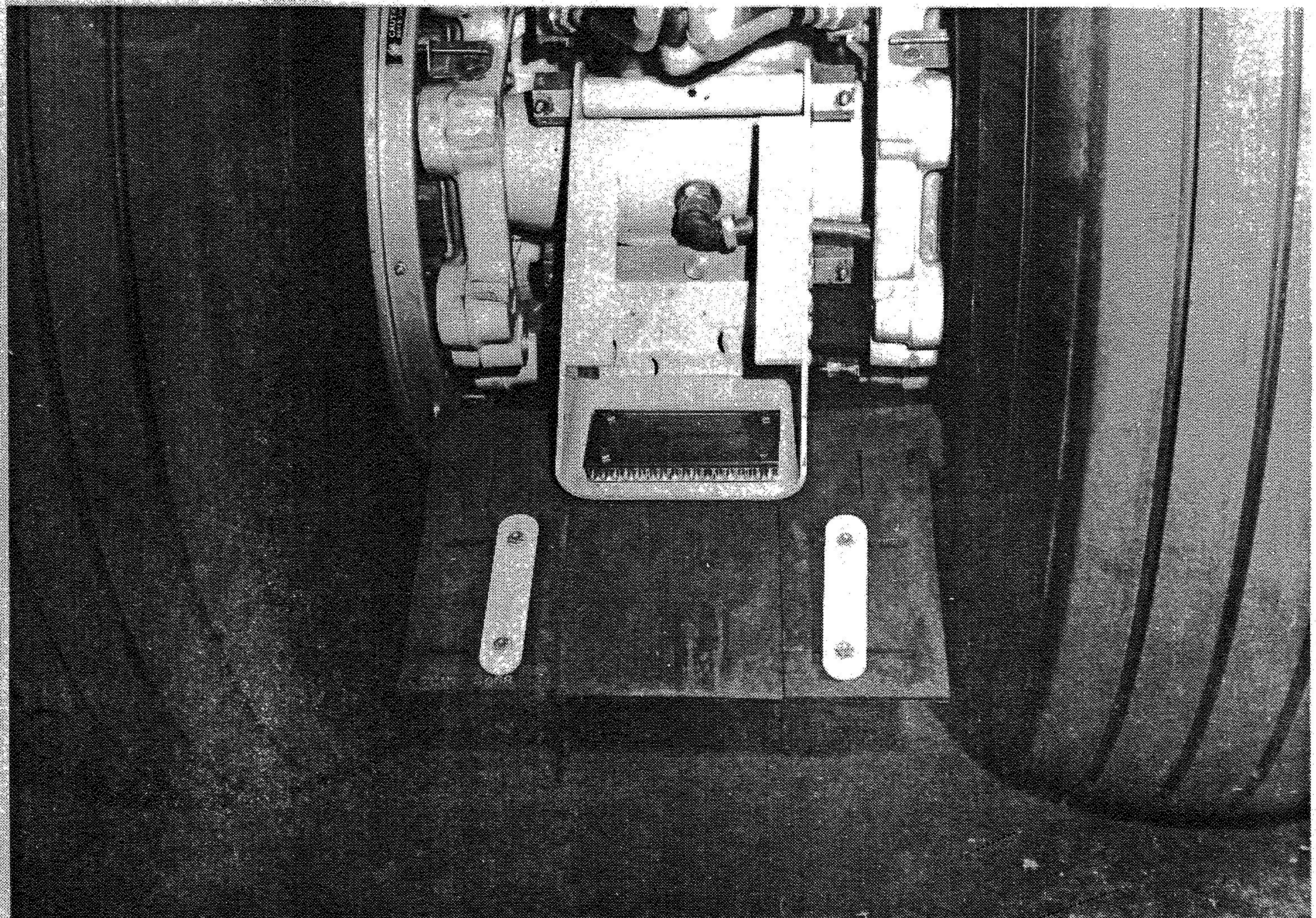

FIGURE 6   727 LANDING GEAR CORROSION TEST INSTALLATION

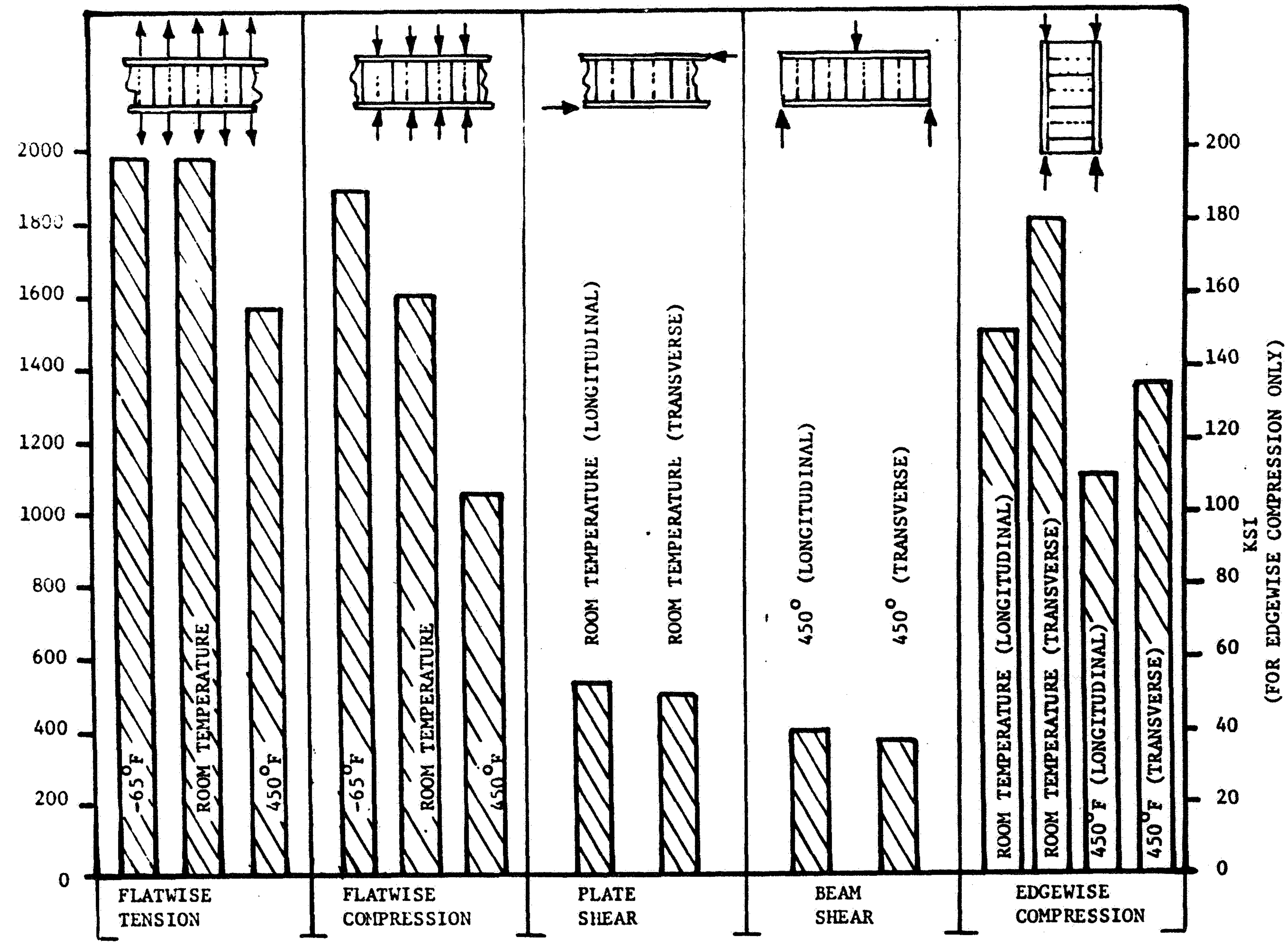

FIGURE 7 AVERAGE STRENGTH OF HONEYCOMB PANELS WITH 4-20 CORE

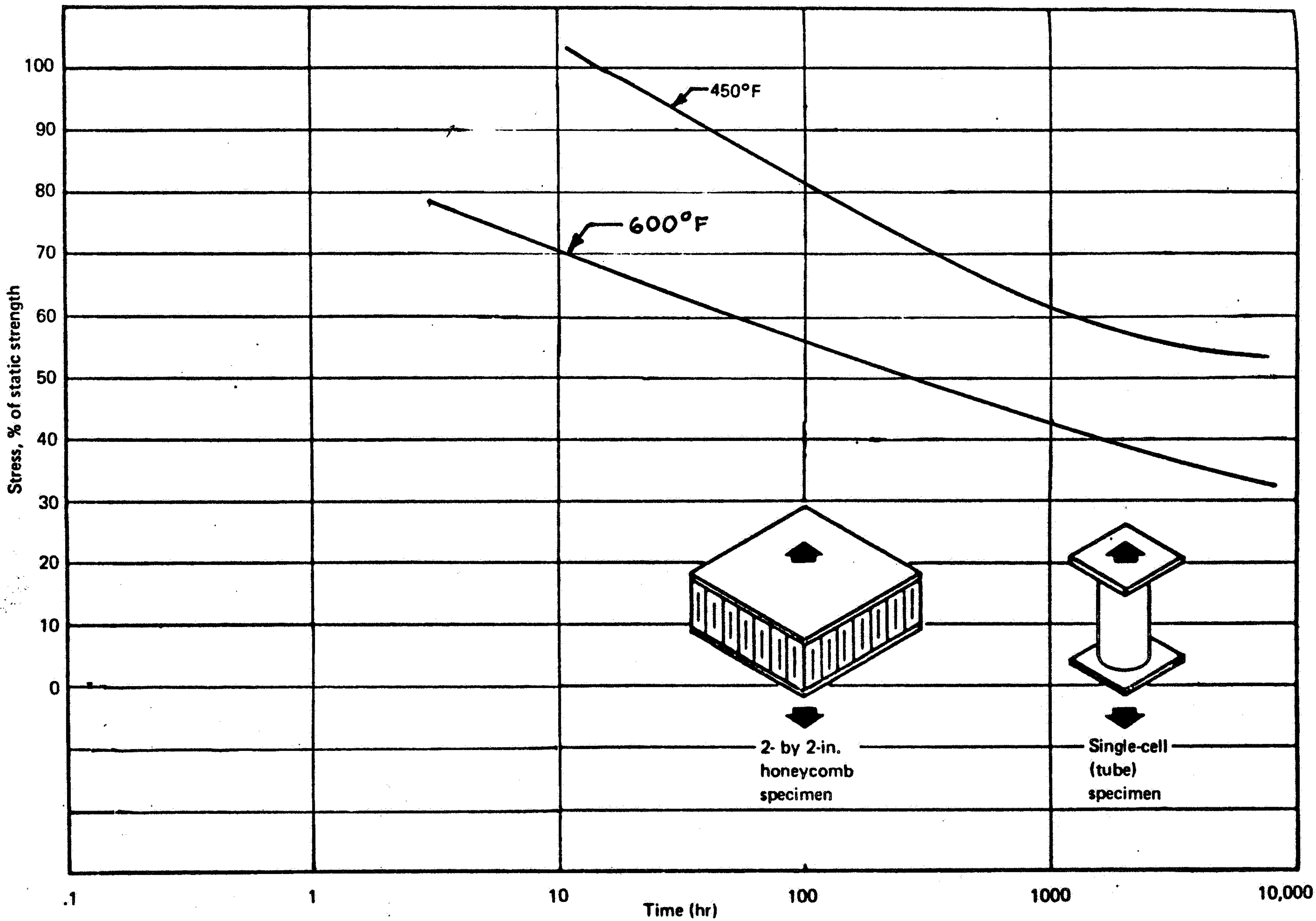

FIGURE 8 STRESS -RUPTURE STRENGTH

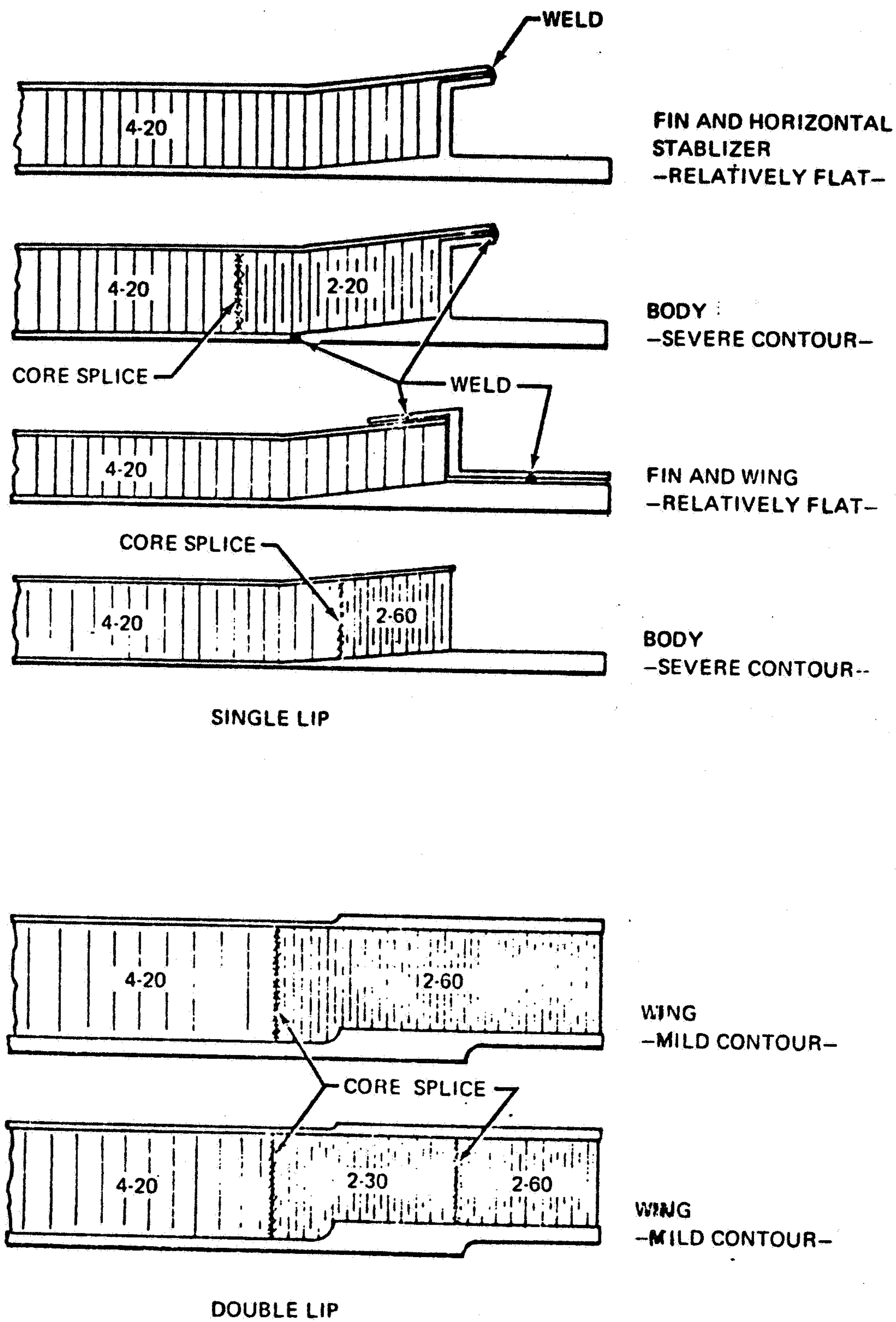

FIGURE 9 TYPICAL EDGE DESIGNS

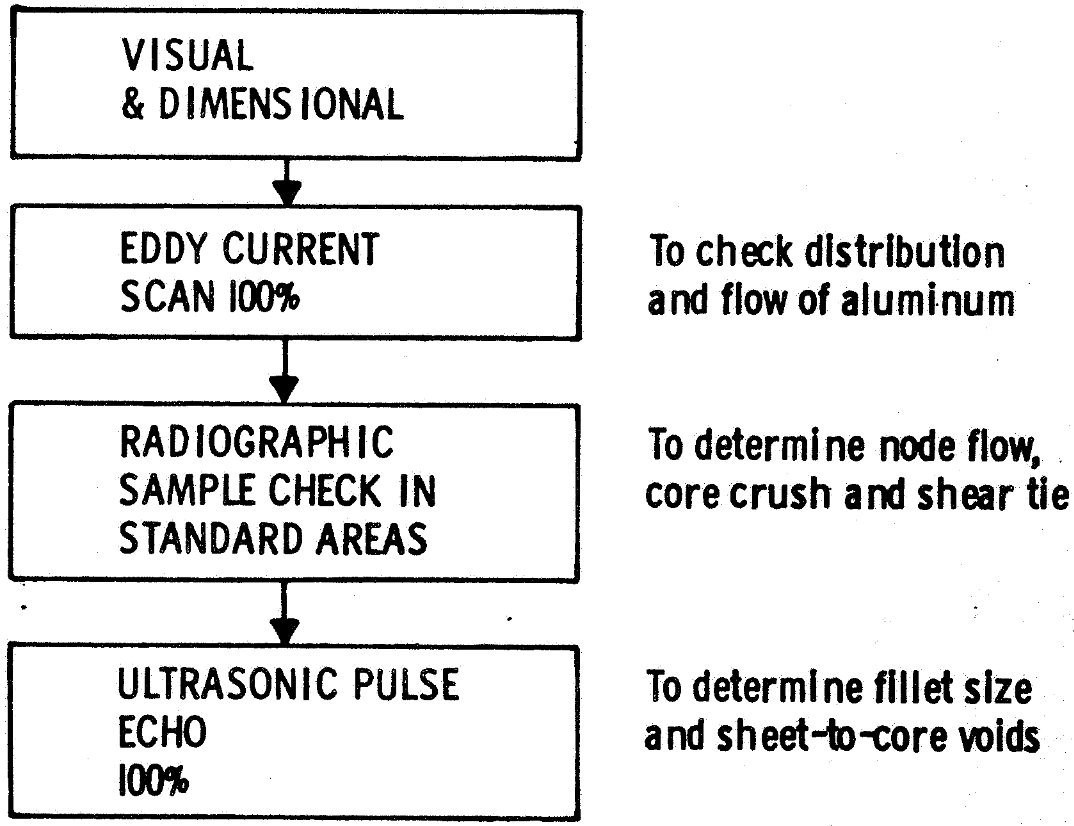

FIGURE 10 NON DESTRUCTIVE TESTING

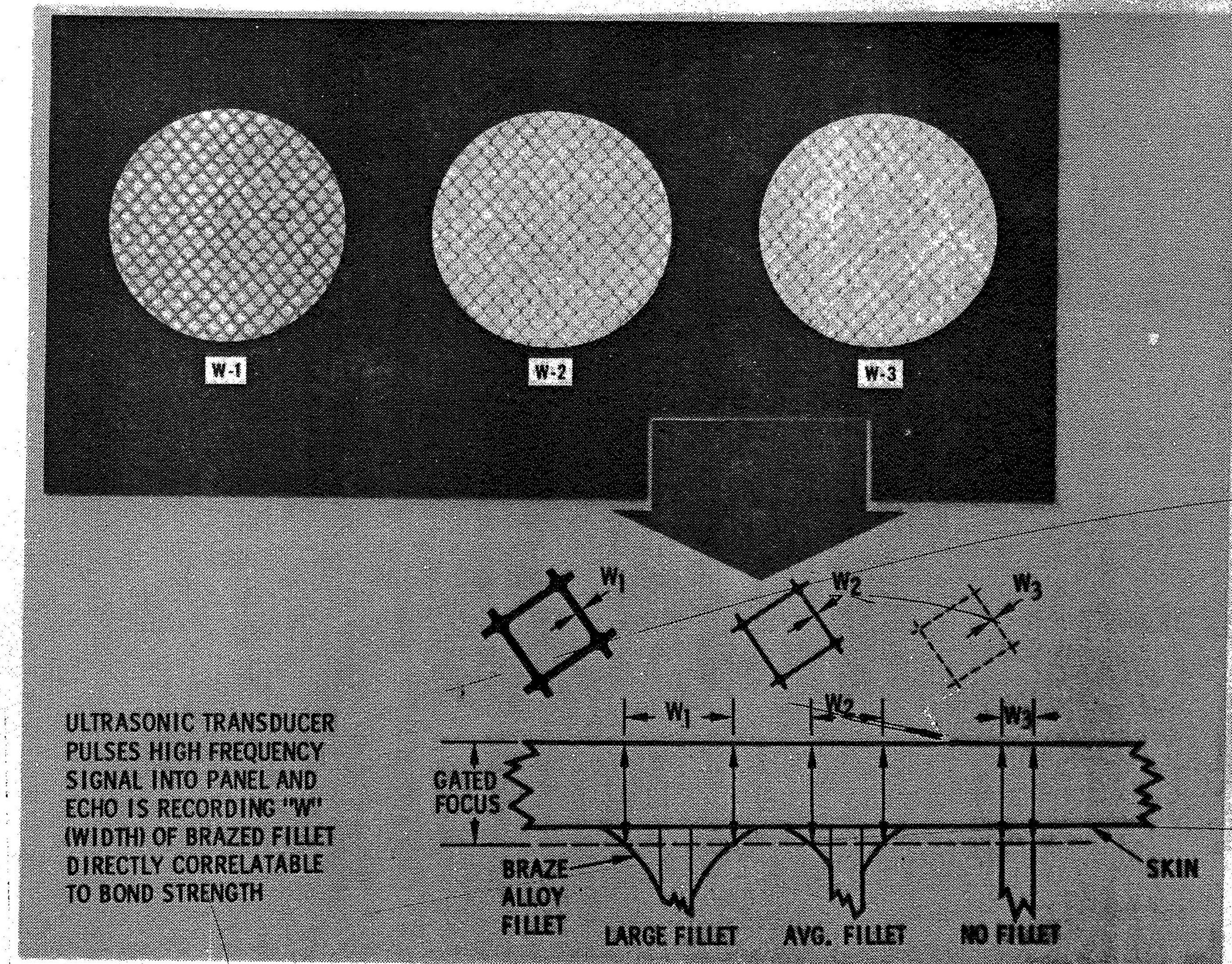

FIGURE 11 ULTRASONIC INSPECTION FOR BRAZING OF CORE TO SKIN

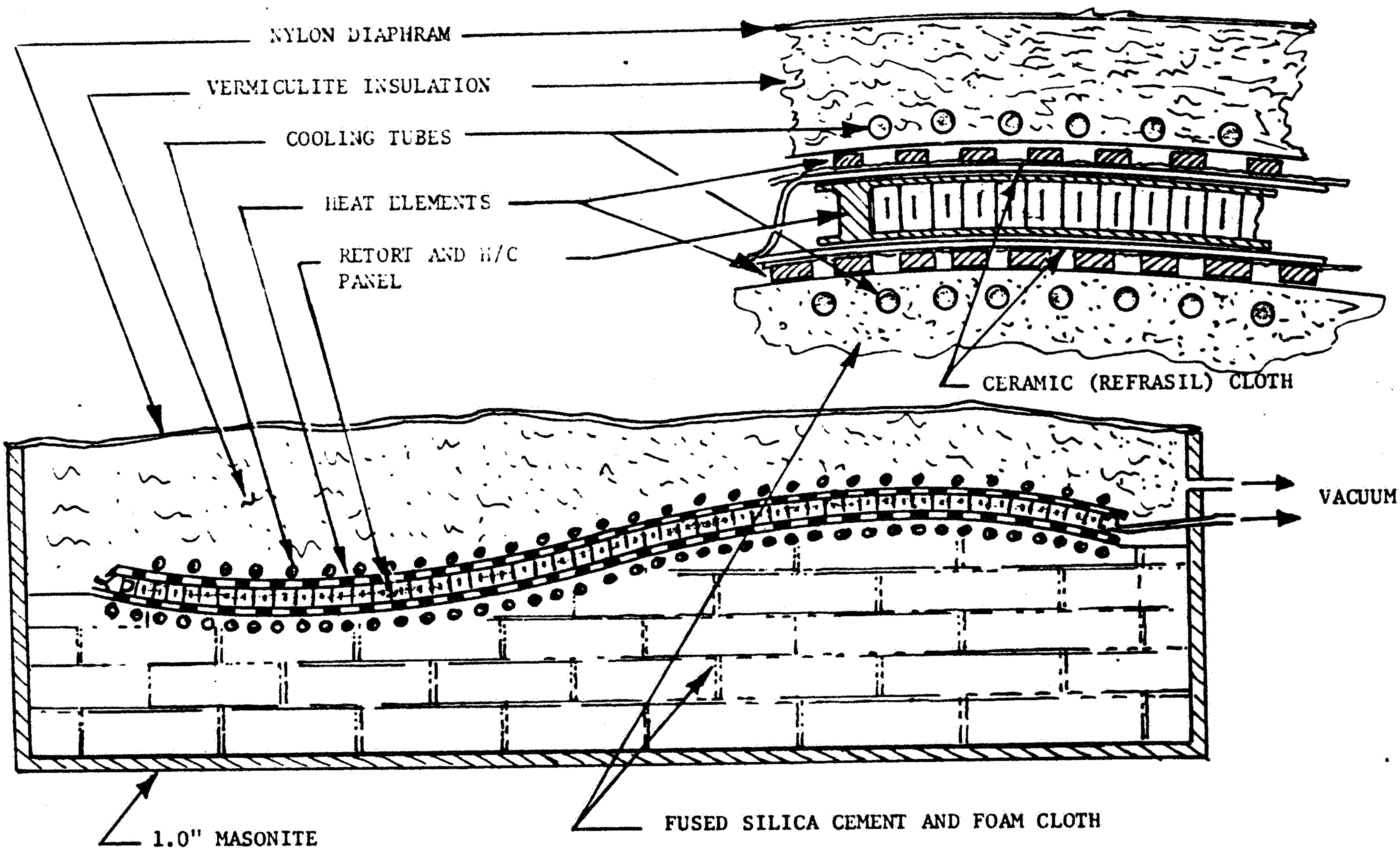

FIGURE 12 SOFT TOP BRAZE TOOL

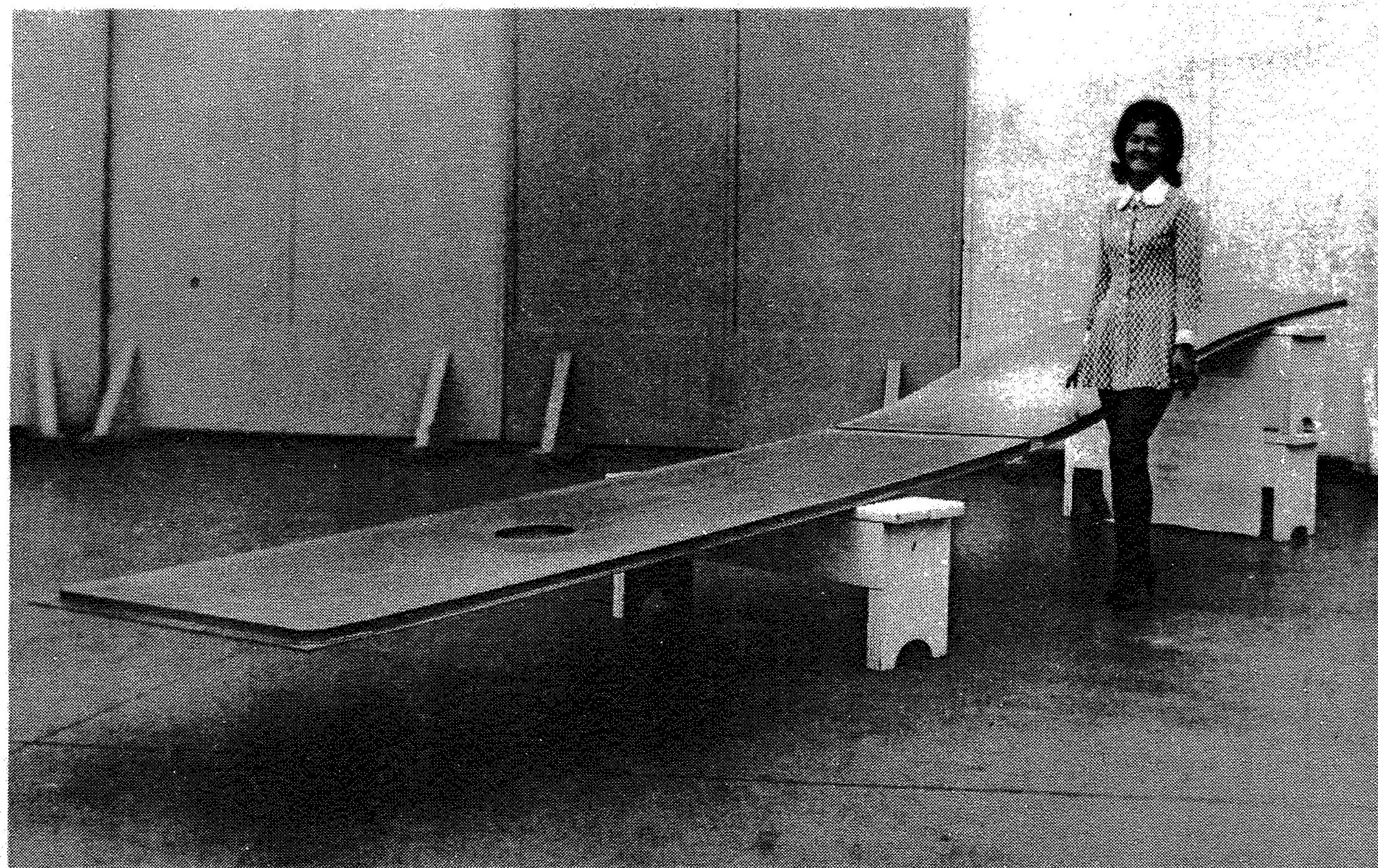

FIGURE 13 3' x 20' WING PANEL