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NON-HONEYCOMB F-16 HORIZONTAL STABILIZER STRUCTURAL DESIGN

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Abstract

Thin "wedge" and airfoil-shaped structure for high performance aircraft wing and empennage control surfaces have historically used bonded full-depth honeycomb construction because of its inherent stiffness properties and weight efficiency. However, these structural benefits have been paid for with high initial cost and long-term in-service problems.

The F-16 non-honeycomb horizontal stabilizer, manufactured by General Dynamics, Fort Worth, uses a construction technique unique to the industry.

The primary components of this construction method are graphite/epoxy skins mechanically fastened to a one-piece sheet aluminum "corrugated" substructure and a machined aluminum pivot fitting. The skins and substructure are tooled to a common inside-mold-line surface to facilitate assembly.

The fabrication cost of this method is less than that of a hypothetical bonded honeycomb baseline, but a slight weight penalty is incurred by its use. This construction method avoids the causes of the long-term in-service problems associated with bonded honeycomb construction.

Ground test and flight test programs with the new stabilizer have been successfully completed in the spring of 1981. The stabilizers are currently in full production and being delivered on the F-16 Fighting Falcon.

I. Background

Bonded honeycomb sandwich construction was developed in the 1950's to meet the demands for stiff, lightweight structure called for in the new generation of high performance aircraft. This type of structure is extremely efficient for thin airfoil-shaped structures such as wing and empennage control surfaces where aeroelastic considerations often dictate the design. This construction method became the standard throughout the industry during the 1960's and 1970's for small components such as leading-edges and rudders as well as relatively large articles such as complete horizontal stabilizer assemblies.

However, the attractive properties of sandwich structure did not come without a price. The initial fabrication cost of this type of structure is traditionally higher than that of more conventional structure due to costly materials, demandingly precise fabrication techniques, stringent processing requirements, and costly inspection procedures.

More recently, the existence of long-term in-service problems with this type of structure has become apparent. Honeycomb core corrosion and subsequent skin-to-core delamination have become major problems in some aircraft. The inspection procedures to locate and quantify these problems are time consuming and require specially trained personnel, and the repair procedures are often expensive. In general, honeycomb sandwich structure costs the user more to maintain than conventional "built-up" structure from both a maintenance man-hour per flight-hour and a dollar per flight-hour standpoint.

The aircraft performance benefits gained with the use of bonded sandwich construction are real, but the cost, both short-term and long-term, is high.

The F-16 non-honeycomb horizontal stabilizer, designed and manufactured by General Dynamics/Fort Worth, reduces fabrication costs and eliminates in-service difficulties experienced with honeycomb structure while maintaining good weight efficiency.

II. Geometry

The F-16 non-honeycomb horizontal stabilizer has 30 percent more planform area than the original F-16 horizontal stabilizer. Various details of geometry and aerodynamic data are given in Figure 1. The maximum contour-to-contour thickness is only 5.7 inches at the root and 1.3 inches at the tip.

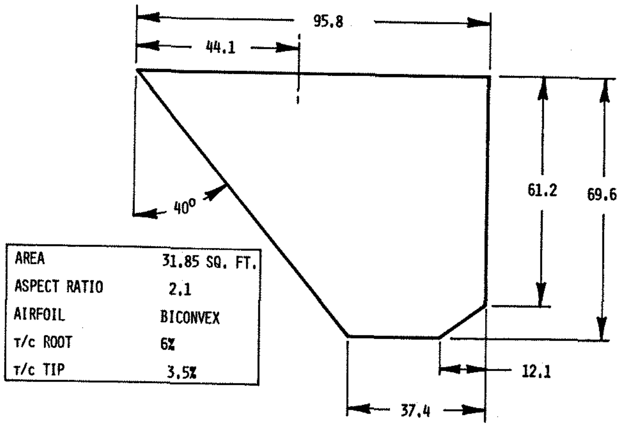

FIGURE 1
F-16 NON-HONEYCOMB
HORIZONTAL STABILIZER
GEOMETRY

III. Design Criteria

The primary stabilizer design criteria are stiffness related and consist of stabilizer flutter, panel flutter, and basic panel stability. Local areas of the stabilizer, the most prominent being the skin-to-pivot fitting bolted joint, are strength designed.

Stabilizer flutter configured major portions of the graphite skin as well as the shaft portion of the pivot fitting.

Each of the skin panels was checked for panel flutter and basic panel stability. All panels remain stable to ultimate load.

This same stability criteria was applied to the webs of the corrugated substructure, which dictated basic gauge requirements and integral stiffener configuration and location.

In addition to the skin-to-pivot fitting joint, local areas in the corrugated substructure-to-pivot fitting joint, the corrugated substructure-to-skin joint, and the leading-edge assembly-to-box joint were strength designed.

IV. Structural Description

The F-16 non-honeycomb horizontal stabilizer (Figure 2) is characterized by its minimum num-

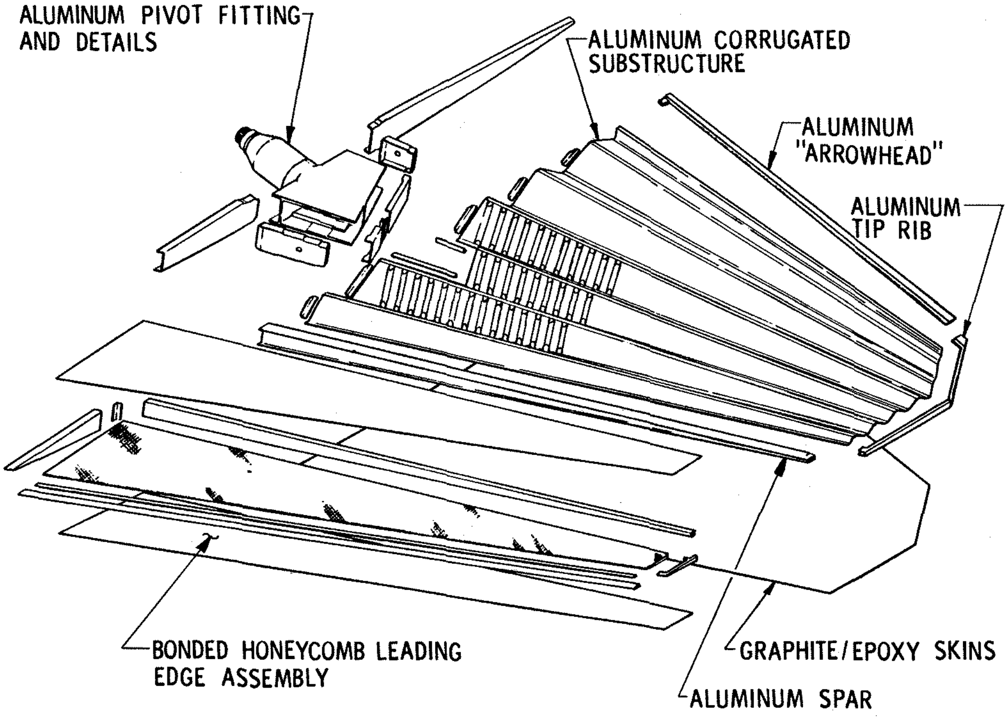

FIGURE 2
F-16 NON-HONEYCOMB
HORIZONTAL STABILIZER
STRUCTURAL ARRANGEMENT

ber of detail parts, the relative simplicity of these parts, and the ease with which they are assembled. The stabilizer consists of two components, the major structural box assembly and a removable leading edge.

The decision to use a removable, interchangeable leading edge was made early in the design process for two primary reasons. The first was to retain a leading-edge design proven to be tolerant of both ground-handling and inflight damage. Secondly, experience has shown that most damage sustained by the horizontal stabilizer is on the leading-edge, and providing a removable leading edge will allow the customer to spare relatively inexpensive leading-edge assemblies and a few relatively expensive box assemblies as opposed to a relatively large number of expensive one-piece stabilizer assemblies.

The stabilizer box assembly consists of thirteen primary components and an assortment of small structural shear clips and brackets.

The box is framed by the formed aluminum root rib segments and the pivot fitting at the inboard end, the spar, the tip rib, and the trailing-edge wedge. The corrugated aluminum substructure is inserted into this frame and tied structurally at the root and tip with shear clips. The forward flange of the corrugated substructure overlaps the corresponding spar flange, and is connected to it with the same row of mechanical fasteners which attach the skin to the spar (Figure 3). The graphite/epoxy skins are subsequently mechanically fastened to the substructure assembly at each of the nodes of the corrugated substructure.

The heart of this structural concept is the one-piece formed aluminum corrugated substructure (Figure 4). In the spanwise direction, it reacts load as a conventional spar. In the chordwise direction, and any direction between chordwise and spanwise, the corrugated substructure in combination with the skins transfer load to the pivot fitting as a truss. The webs of the corrugated substructure are integrally stiffened with beads over the inboard two-thirds of the structure. The upper portion of the bead is formed to a "flat-top" configuration such that the local secondary bending moment caused by the eccentric load path is reacted by heel-and-toe action of the bead. (Figure 4).

The corrugated substructure is formed from 2024 aluminum sheet in a two-stage drop hammer process. A flat pattern in the "O" condition is formed to an approximate shape in a starter die. This piece is heat treated, and while still in the "W" condition it is formed to its final configuration. The part is subsequently artifically aged to its final temper of T62.

The skin faying surfaces of all the substructure components, including the corrugated substructure, are tooled to an inside-mold-line (IML) surface. The inside surface of the graphite/epoxy skins is also tooled to this same IML surface. This tooling concept was chosen to minimize mismatches in the substructure assembly and thus minimize the amount of shimming required to obtain proper fit of the skins.

The graphite/epoxy skins (Figure 5) are optimized from both a performance and a fabrication standpoint. At the outboard end and in

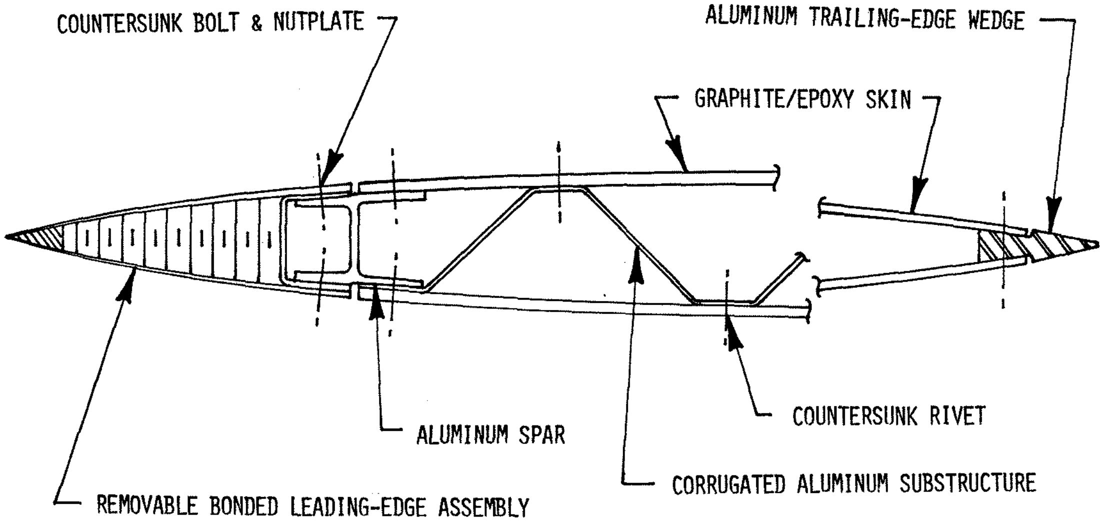

FIGURE 3
F-16 NON-HONEYCOMB
HORIZONTAL STABILIZER
STRUCTURAL CROSS SECTION

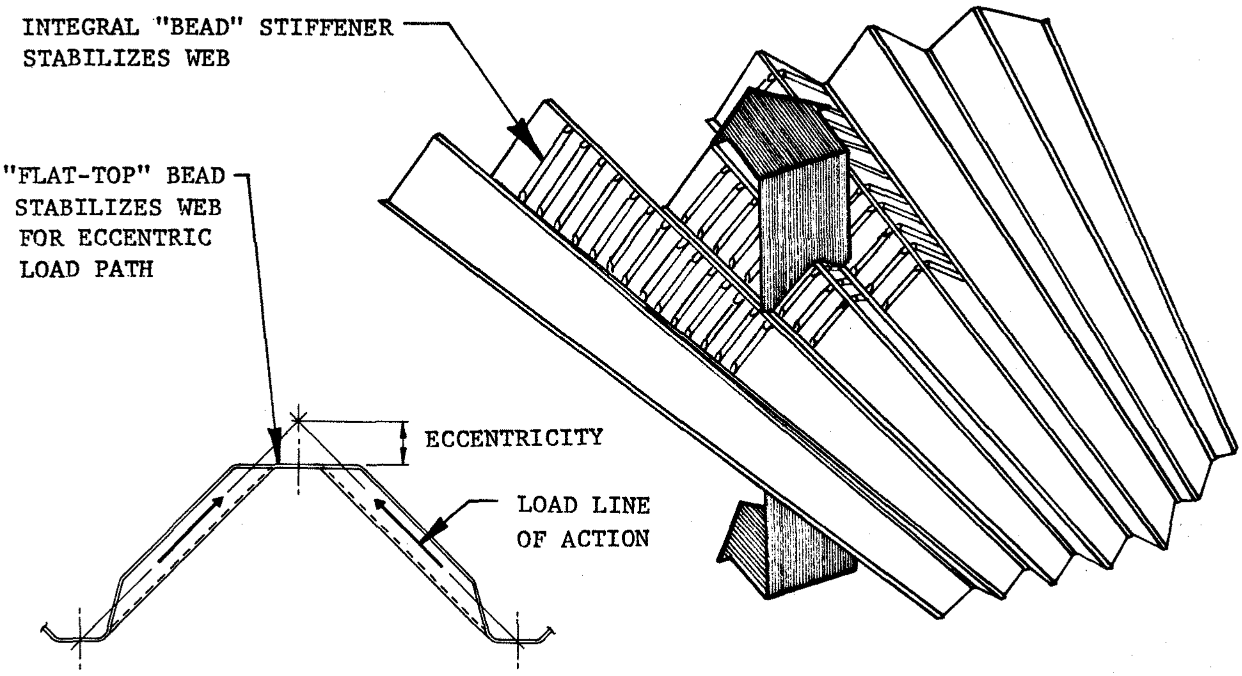

FIGURE 4
INTEGRALLY STIFFENED
CORRUGATED SUBSTRUCTURE

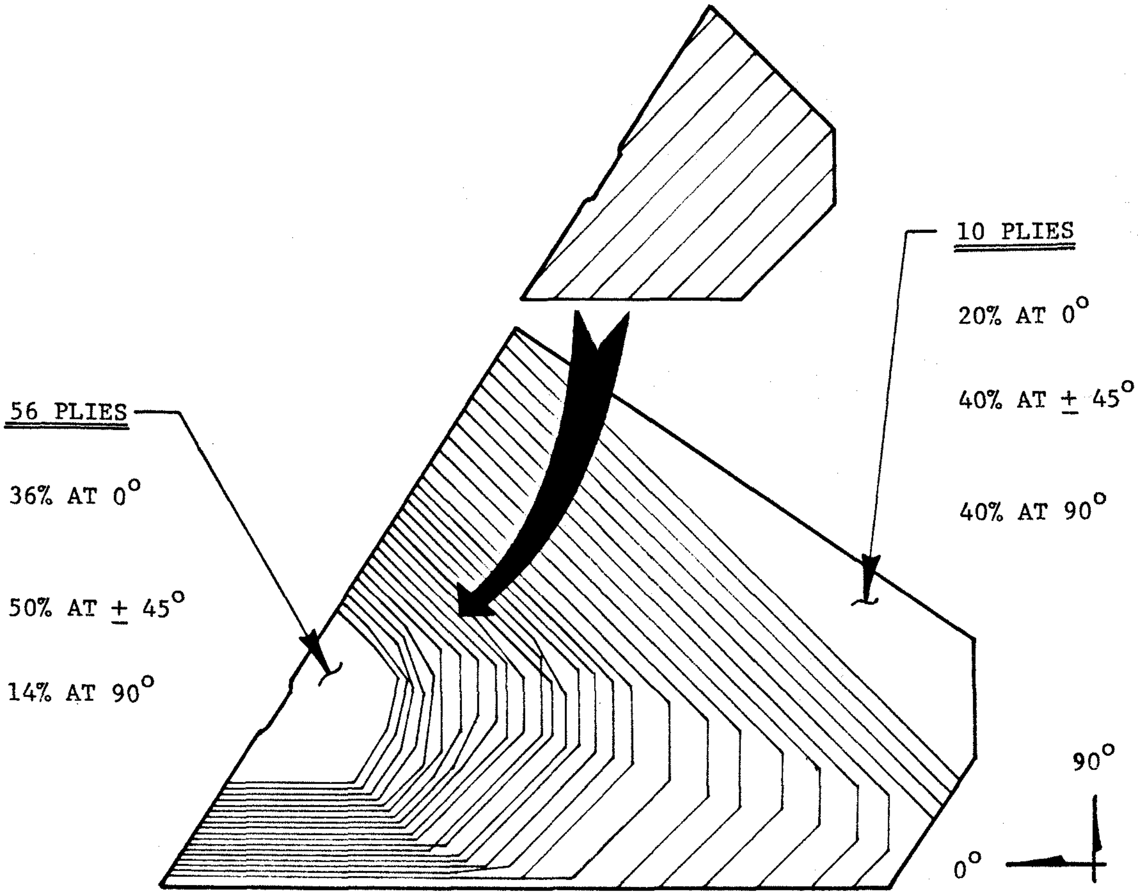

FIGURE 5
GRAPHITE/EPOXY
STRUCTURAL
BOX SKIN

the trailing-edge areas, the ply orientation is optimized for panel flutter and panel stability. At the inboard end, the orientation is optimized for bolted joint strength.

Even though the skin is cured with its inside surface against the bond-form, a smooth aerodynamic surface is obtained with the use of a metallic caul sheet placed over the outside surface during the curing process. To enhance this procedure, the skin is configured such that only two plies terminate at any given point, and the ply drop-off pattern is nearly linear. Also, each of the plies is configured for efficient lay-up with automated tape laying equipment, using either 3-inch or 6-inch wide tape. This is accomplished by defining ply termination angles compatible with the alignment capabilities of the tape laying head of the machine and by defining ply termination lines which are exact multiples of the tape width.

The pivot fitting (Figure 6), machined from 2124-T851 aluminum plate, is also designed to be structurally efficient and producible. The inboard portion of the fitting is configured to interface with existing fuselage structure, while the outboard portion provides the structural joint with the skins, corrugated substructure and root rib. The fitting surfaces at the joint with the skins was stepped in thickness to be strain compatible with the graphite skins, but the steps were oriented to minimize the number of milling machine set-ups required.

Four closure webs complete the pivot fitting assembly. With these webs in position, the outboard portion of the pivot fitting becomes a closed two-cell box.

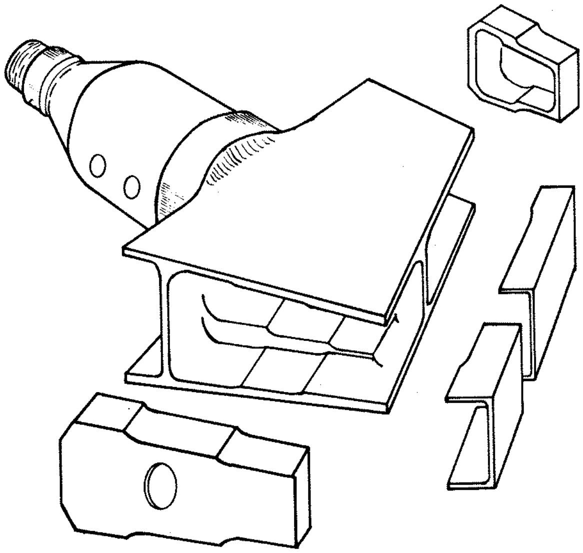

FIGURE 6
PIVOT FITTING AND
CLOSURE WEBS

The removable, interchangeable leading-edge assembly (Figure 7) employs a design proven in the field by numerous existing F-16 components including the vertical stabilizer leading-edge, the rudder, and the previous, smaller bonded honeycomb horizontal stabilizer used on earlier F-16's. Experience has shown that this configuration is capable of withstanding in-flight impacts, as well as ground handling damage, and yet remain basically intact and structurally sufficient. This design has also been shown to be readily repairable.

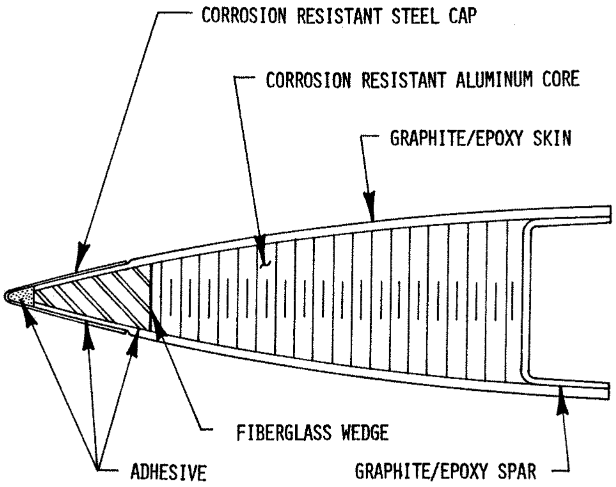

FIGURE 7
LEADING-EDGE
ASSEMBLY CROSS SECTION

Low density corrosion resistant aluminum honeycomb core is bonded to thin graphite skins producing an extremely light, stiff structure. The extreme leading-edge consists of a fiberglass wedge and a corrosion resistant steel cap. The leading-edge assembly attaches to the box assembly with countersunk bolts and nutplates.

Great care has been taken to provide corrosion protection and dissimilar material isolation throughout the stabilizer. Each leading-edge assembly is sealed, inspected and leak checked prior to acceptance to ensure that moisture can not enter the core cavity. All aluminum detail parts are anodized and receive two coats of an epoxy base primer. The graphite/epoxy skins have a ply of fiber glass on the inner surface to isolate the graphite from the aluminum substructure. In addition, a layer of an epoxy-base liquid shim and a layer of a polysulfide base sealant are applied in all skin/substructure faying surfaces. Corrosion resistant steel fasteners are used in all graphite-to-aluminum joints. Water drainage holes are provided at the outboard/aft tip of the stabilizer so that any moisture which forms in the box can drain.

V. Structural Weight

A weight study was performed comparing the non-honeycomb stabilizer to a hypothetical stabilizer of the same size constructed with graphite/epoxy skins and aluminum honeycomb core. The results of this comparison are presented in Table 1.

As expected, the skins of the non-honeycomb stabilizer are heavier than those of its honeycomb counterpart. However, the substructure of the non-honeycomb stabilizer weighs substantially less than the honeycomb core and adhesive which it replaces.

The total structural weight of the non-honeycomb stabilizer is approximately 5% more than that of its honeycomb counterpart, but this is judged to be a small price to pay when compared with the substantially lower initial fabrication costs (presented in Section VI) and the lower in-service costs expected with the non-honeycomb design.

VI. Fabrication Cost

The use of this structural concept provides significant reductions in fabrication cost when compared to the same hypothetical bonded honeycomb stabilizer utilized for the previous weight comparison. This relative ease of fabrication can be attributed to the low number of detail parts and the IML tooling concept which minimizes mismatch between adjacent parts.

The results of a fabrication cost study comparing the non-honeycomb design to the bonded honeycomb version of the stabilizer are presented in Figure 8. This study demonstrated a 75% increase in initial fabrication cost if the new stabilizer had been designed as a bonded honeycomb structure, and the honeycomb fabrication cost is twice that for the corrugated design at article 600.

TABLE I
WEIGHT COMPARISON
NON-HONEYCOMB VS. HONEYCOMB
HORIZONTAL STABILIZER

HYPOTHETICAL HONEYCOMB STABILIZER		
SKINS (GRAPHITE/EPOXY)		45.9
CORE (ALUMINUM)		21.9
ADHESIVE		19.4
INTERNAL SPAR	(TITANIUM)	2.6
PIVOT FITTING	(TITANIUM)	35.9
ROOT RIB	(TITANIUM)	4.6
TIP RIB	(TITANIUM)	1.1
FRONT SPAR	(TITANIUM)	6.9
TRAILING EDGE WEDGE		1.5
LEADING EDGE ASSEMBLY		14.5
FASTENERS, SEALANT, MISC.		3.5
		157.8 LB./STAB.

F-16 NON-HONEYCOMB STABILIZER	
SKINS	60.4
CORRUGATED SUBSTRUCTURE, CLIPS, BRACKETS, AND RELATED SUBSTRUCTURE	29.5
PIVOT FITTING AND WEBS	43.3
ROOT RIB	1.4
TIP RIB	.7
FRONT SPAR	4.5
TRAILING EDGE WEDGE	1.9
LEADING EDGE ASSEMBLY	14.5
FASTENERS, SEALANT, LIQUID SHIM, MISC.	9.7
	165.9 LB./STAB.

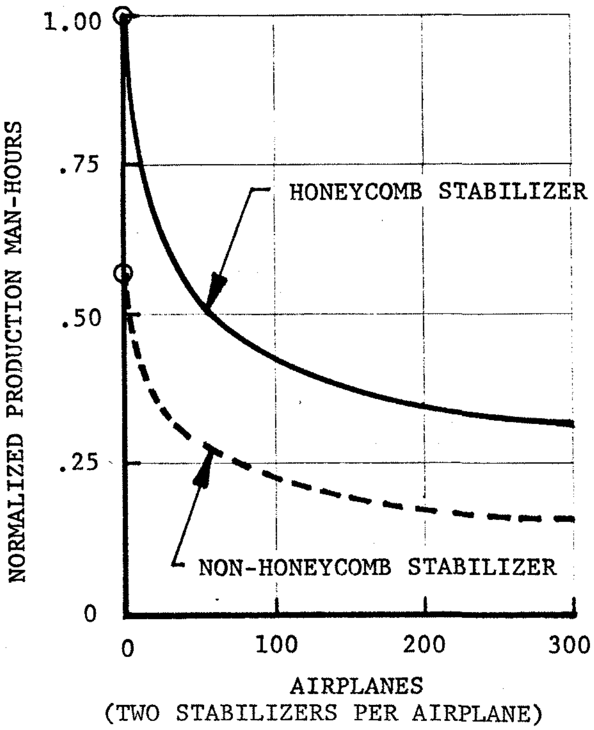

FIGURE 8
FABRICATION COST COMPARISON
HONEYCOMB VS NON-HONEYCOMB
F-16 HORIZONTAL STABILIZER

VII. Current Status

The F-16 non-honeycomb horizontal stabilizer successfully completed both ground structural tests and flight tests during early 1981. Deliveries of USAF F-16's equipped with the non-honeycomb stabilizers commenced in late 1981, and deliveries to other customers started in early 1982.

VIII. Summary

In recent years within the aircraft industry a requirement for structure with the stiffness and weight attributes of bonded honeycomb assemblies, but with low fabrication cost and good long-term serviceability has come about. The non-honeycomb F-16 horizontal stabilizer has met the first three of these requirements and is well on its way to meeting the fourth.

Though only in the production mode for approximately a year, this stabilizer has already proved itself to be exceptionally producible, durable, and repairable. Variations of this structural concept can be adapted for many aircraft components ; and in an environment where total aircraft life cycle cost is becoming increasingly important, they will be.