Integrally Formed Structures: A New Stiffened Panel Concept

J. C. McQueen,* S. W. McClaren,† and A. P. Martin‡
LTV Aerospace Corporation, Dallas, Texas

Analytical and experimental results of research efforts on the evaluation of a new stiffened panel concept, integrally formed structures, is described herein. These efforts have been directed toward the compression stability evaluation of the new concept. Comparisons of this concept with conventional Z and integrally machined panel concepts are presented for two materials, namely, 7075-T6 aluminum and 6Al-4V titanium (annealed). These comparisons are based upon compression efficiency (column and crippling) and manufacturing costs. Both experimental and analytical data demonstrate the potential of the integrally formed concept. Its potential, as related to metallic structures reinforced by composite materials, is also discussed. The results indicate that the integrally formed panel is a highly attractive design concept in terms of manufacturing cost, strength, weight and adaptability to meeting failsafe standards and employing new materials of construction.

I. Introduction

MAJOR factors associated with the introduction of advanced technologies into future aircraft systems will be the impact of cost and weight of the structure. To this end numerous studies have been initiated within the last several years to secure a lightweight low-cost compression panel. Results of some of these studies have been reported by Hickman,[1] Yusuff,[2] and Catchpole,[3] who investigated the integrally machined and conventional Z stiffened compression panels. The effort reported here in the development of an "integrally formed compression panel" concept[4] had the same objective. The concept developed is illustrated in Fig. 1.

The integrally formed structure is a stiffened panel consisting essentially of two sheets of material. The outer or face sheet is bonded or spot welded to an inner sheet which has stiffeners formed into the sheet. Two integrally formed concepts are illustrated in Fig. 2. A panel fabricated in this manner offers a significant increase in the strength-weight index as compared to the riveted conventional Z panels of the same material and design conditions.

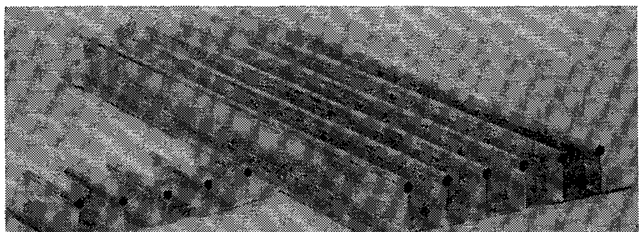

Fig. 1 Typical integrally formed compression panels (curved crippling specimen and flat buckling specimen).

Under this program, several types of integrally formed panels were analyzed and compared to various conventional stiffened panel designs. Of the many panel designs analyzed, six integrally formed types and two conventional types of stiffened panels were selected for test. The materials used for the test panels were aluminum (7075-T6), titanium (6Al-4V), and steel (Ph 15-7Mo). During the program 328 crippling panels were tested. Two integrally formed panel designs of 7075-T6 aluminum and 6Al-4V titanium were selected from all those tested to compare to the conventional stiffened panel for this paper. The two types of integrally formed panels selected are compared to two conventional panel designs shown in Fig. 2.

II. Technical Approach

The optimum failing stress of a compression panel is the stress at which local crippling and Euler column buckling are calculated to be the same. The optimization procedures used were developed in Ref. 5 which combine the panel geometries and the related column and crippling curves. An average failing stress was first assumed for the entire cross section. The panel was then optimized at this stress using the crippling stress analysis (flat element, one edge free, etc.). In order to form a standard base for comparing the buckling stress of all the various panel concepts, a panel length of 20 in. was employed with simply supported end ($C = 1.0$) conditions assumed. The radius of gyration(ρ) was calculated, and divided into the effective column length [$L' = L/(C)^{1/2}, L' = 20$ in.]. This calculated L'/ρ (Point A_1, Fig. 3) was then compared to the L'/ρ on the Euler curve (Point B_1, Fig. 3) at the assumed average failing stress, material, and temperature conditions. If the values were unequal, the average failing

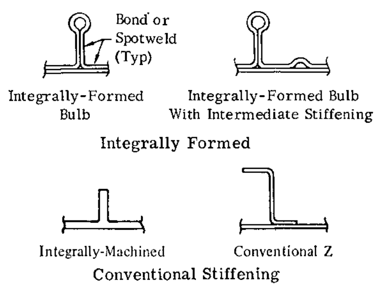

Fig. 2 Structural panel concepts.

Received July 14, 1969; presented as Paper 69-760 at the AIAA Aircraft Design and Operations Meeting, Los Angeles, Calif., July 14–16, 1969; revision received January 28, 1970. The authors gratefully acknowledge the direction and support of J. R. Marsh and J. O. Snyder of the Fabrication Branch, Manufacturing Technology Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. The authors also appreciate the assistance of J. H. Best, Chief of Structures; G. A. Starr, Chief of Applied Research and Development; W. W. Wood, Chief of Manufacturing Research and Development; D. W. Truelock, Project Engineer and J. A. Fouse, Manufacturing Research Engineer Specialist of LTV Aerospace Corporation. This work was supported by Air Force [Contract AF33(615)-3756] and LTV Aerospace Corporation, Vought Aeronautics Division, Dallas, Texas, company-sponsored IR and D programs.

* Structures Design Engineer.
† Supervisor, Structures Research and Development.
‡ Supervisor, Structures Design. Associate Fellow AIAA.

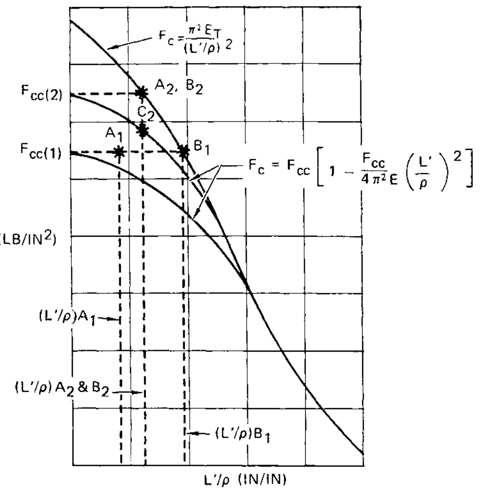

Fig. 3 Column curve.

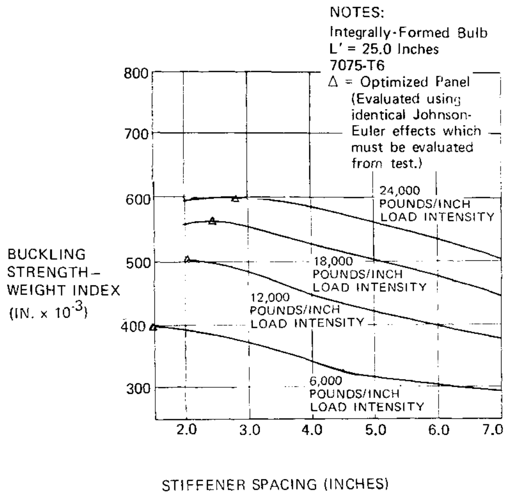

Fig. 4 Strength-weight index of integrally formed bulb for various stiffener spacings.

stress was either raised or lowered and the process repeated until the values were equivalent (Points A_2 and B_2, Fig. 3). The crippling stress was adjusted using the Johnson-Euler equation for determining the column failing stress in the transition region (Point C_2, Fig. 3). Buckling in the transition region involves both over-all elastic bending instability

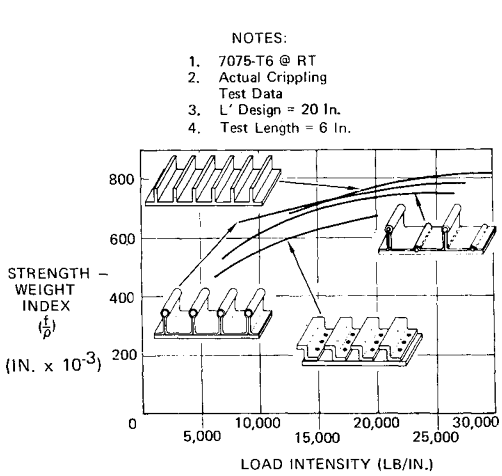

Fig. 5 Aluminum structural efficiency comparison for selected tested panel concepts.

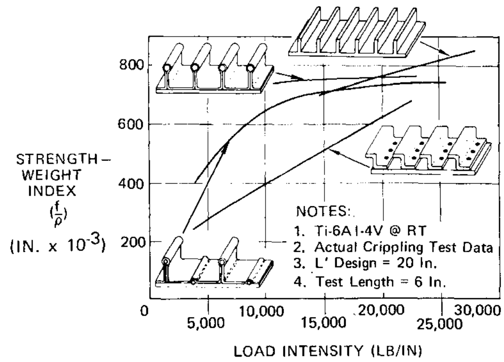

Fig. 6 Titanium structural efficiency comparison for selected tested panel concepts.

plus local buckling which becomes more extensive as the stress increases.

The initial computer routines for each panel concept were written for a crippling condition, but they were revised and updated to optimize for a buckling load intensity and also to allow the designer to set specific stiffener spacings. When the stiffener spacing was varied from the optimum dimension, an important relationship was noted for the critical stress. The strength-weight index change in the vicinity of the optimum point was small with variations of stiffener spacing. This point is illustrated in Fig. 4. In most design cases, the larger stiffner spacing would be selected since it would be the most favorable from a cost consideration.

III. Comparative Results

The results of the pertinent crippling panel tests are illustrated in Fig. 5 for aluminum (7075-T6) and Fig. 6 for titanium (6Al-4V). The test panel dimensions were optimized utilizing an effective column length of 20 in. The test panel length was chosen as 6 in. to force a crippling failure mode. Each curve is based on approximately nine test points. The results verify the integrally formed panel as a very efficient design for compression loading. The integrally formed panels are attractive compared to both conventional Z panels, which have a comparable cost, and to machined panels which are considerably more expensive. The integrally machined panel failed at a stress level that was approximately double the predicted stress level.[2] The stiffener legs were observed to rotate torsionally at the predicted initial failing stress. Also the integrally formed panel failure, as illustrated in Fig. 7, was typically in the nature of a noncatastrophic failure as compared to the more catastrophic type failures experienced with the integrally machined panels as illustrated in Fig. 8. The variation between the predicted and actual crippling strength-weight index is illustrated in Fig. 9 and 10.

IV. Manufacturing Cost

The cost analysis for each of the three panel design concepts is presented in Figs. 11 and 12. The cost analyses were based

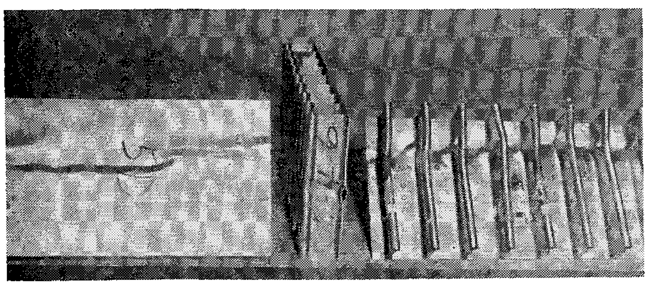

Fig. 7 Tested titanium integrally formed bulb (spot welded) panels.

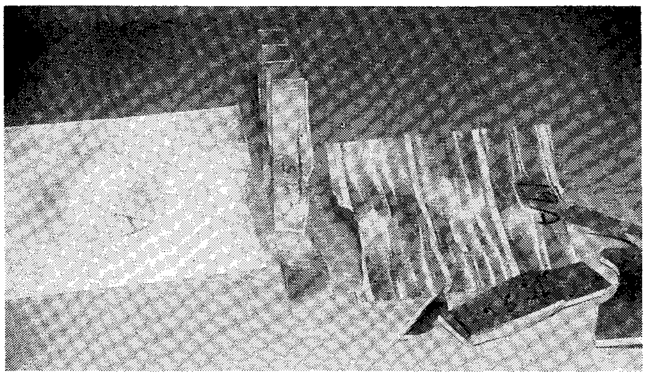

Fig. 8 Tested aluminum integrally machined straight leg panel.

on a careful study of the fabrication requirements for producing each of the panel types and includes all recurring and nonrecurring costs. The costs are predicated upon a 1000 of production run of 2-ft by 5-ft panels and include the major operations related to forming, joining, machining, and heat treatment.

V. Manufacturing Procedure

It is evident, as a result of the program that the integrally formed structures can be mass produced at a competitive cost. The forming of the inner skin takes place in three simple operations as illustrated in Fig. 13. It is anticipated that 50-ft-long panels can be manufactured rather easily with double contours.

VI. Potential Application Areas

There are a wide variety of potential applications for integrally formed panels in aerospace vehicle structures. These panels can in fact be used anywhere that a skin-stringer type of construction can be employed. This would include fuselages, wings, tail sections, space boosters, and flooring, to name some of the more obvious. Panels can be contoured, stiffener spacings and heights can be tapered, bulb radii can be varied, and the stiffener gage can be tapered.

The integrally formed panels have been fabricated with considerable success with boron composite inserted between the inner and outer sheet materials. The metal surrounding the composite solves several problems generally associated with all composite materials, such as joining structural members and providing environmental protection. The inner and outer metal face sheets also lend stability to the composite. Composite can be placed between the sheet material as shown in Fig. 14. A boron-aluminum test panel with a 50% volume of boron/epoxy is shown in Fig. 15. The panel

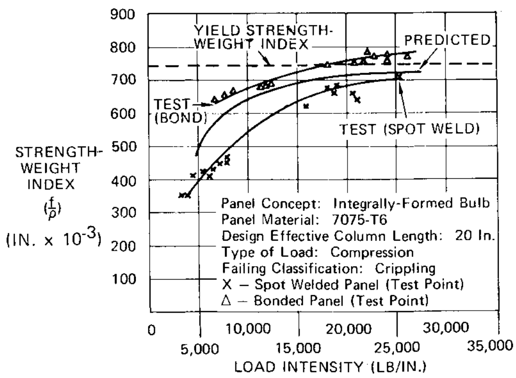

Fig. 9 Comparison of predicted and experimental test data for 7075-T6 aluminum for 6-in. crippling specimens.

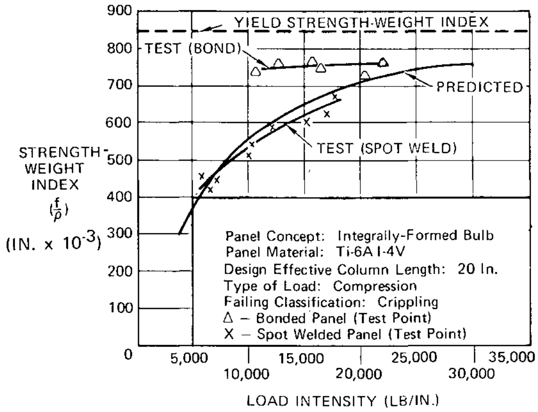

Fig. 10 Comparison of predicted and experimental test data for 6Al-4V titanium for 6-in. crippling specimens.

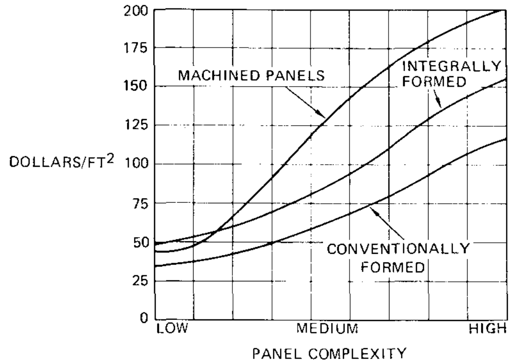

Fig. 11 Effects of structural complexity on the fabrication cost of 7075-T6 aluminum panels.

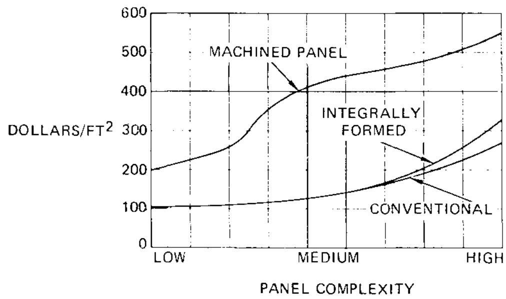

Fig. 12 Effects of structural complexity on the fabricaton cost of 6Al-4V titanium panels.

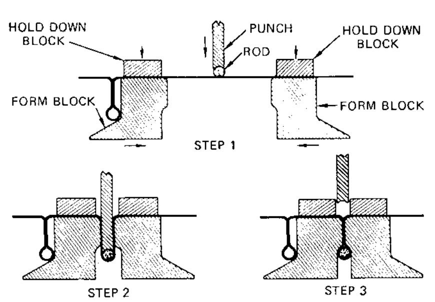

Fig. 13 Schematic of preforming and final sizing operations for integrally formed structures.

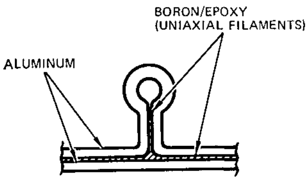

Fig. 14 Integrally formed aluminum-boron configuration.

exhibited a strength-index of 1,106,000 as compared to a strength-weight index of 700,000 for a comparable aluminum panel. This represents a 51.4% increase in strength-weight index. The aluminum-boron integrally formed panel demonstrated a 61.4% increase of strength-weight index over a comparable riveted conventional Z panel. The predicted results along with the test points are presented in Fig. 16. The design and manufacturing methods can possibly be improved to obtain higher failing stresses.

VII. Conclusions

1) Integrally formed panel design concepts appear to have the desirable attributes for improving aerospace structures in terms of low manufacturing cost, high-strength capability, and low weight. 2) Integrally formed panel design concepts tend to emphasize the use of both the material properties and section stability characteristics to obtain improved compression loading capabilities. 3) Panel dimensions may be varied so it can easily be adapted to an optimum design. 4) The integrally formed panels can be readily designed to incorporate reinforcement by composite materials. 5) Integrally formed panels have inherent fail-safe characteristics.

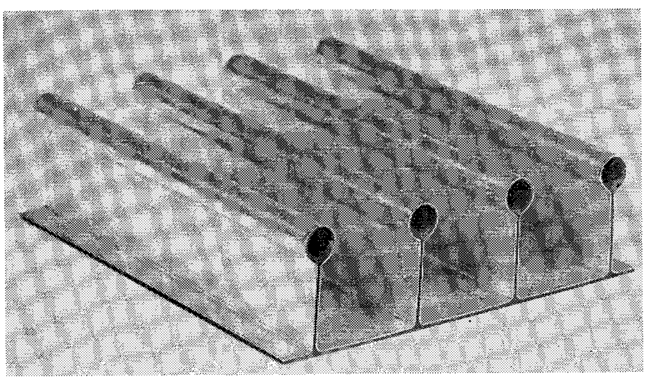

Fig. 15 A 50% boron-50% aluminum (by volume) integrally formed panel.

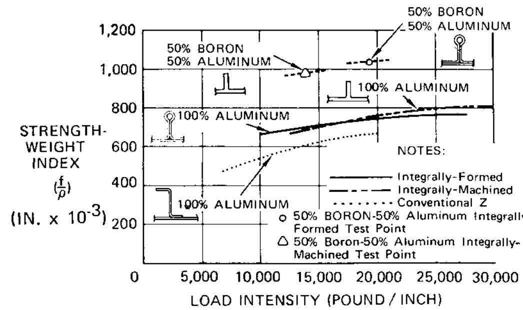

Fig. 16 Comparison of 100% aluminum and 50% boron-50% aluminum (by volume) integrally formed and integrally machined test results.

References

[1] Hickman, W. A. and Dow, N. F., "Direct-Reading Design Charts for 755-T6 Aluminum-Alloy Flat Compression Panels Having Longitudinal Extruded Z-Section Stiffeners," TN 2435, Feb. 1952, NACA.

[2] Yusuff, S., "Primary Instability of a Panel of Integral Construction With Unflanged Stiffeners," *Journal of the Royal Aeronautical Society*, Vol. 58, Dec. 1954, pp. 808–812.

[3] Catchpole, E. J., "The Optimum Design of Compression Surfaces Having Unflanged Integral Stiffeners," *Journal of the Royal Aeronautical Society*, Vol. 58, Nov. 1954, pp. 765–768.

[4] Truelock, D. W., McClaren, S. W., and Fouse, J. A., "Development of Design and Manufacturing Technology for Integrally Formed Structures," AFMF-TR-67-404, Dec. 1967, Vought Aeronautics Division, Dallas, Texas.

[5] McClaren, S. W., McQueen, J. C., and Martin, A. P., "Comparison of Integrally Formed Compression Panel Efficiencies with Other Aerospace Panel Concepts," *AIAA Bulletin*, Vol. 4, AIAA, New York, 1967, p. 108.