of those having reverse curves. Sections that have reverse curves usually are exceptionally rigid in bending.

These remarks have been directed toward structures subjected to pure bending. In the case of a fuselage where the rudder is mounted on top, a torsional load is applied as well as a shear load. The form again is an important item. In a perfectly round section or in the eliptical fuselage section, the structure will have great torsional rigidity but in a flatter section or one in which there are reverse curves the rigidity is not so great. It has been the authors experience in testing a number of sample sections of various forms and cross sections that a torsional load in addition to a shear load which carries bending, will not materially reduce the fiber stress and consequently will not greatly reduce the total load carried.

This monocoque type of structure has proved to be very interesting and the results of the effects in its direction have been very gratifying. With the presentation and confirmation of a few new basic formulas and a way of predicting accurately a form factor for this type of structure, no reason can be seen why, in the future, the monocoque type will not become extremely popular, and there will be better airplanes carrying bigger pay loads with a faster service.

## Discussion

Joseph S. Newell.[2] The writer hesitates to discuss this paper because his own ideas as to the merits of all-metal airplanes are in such a turmoil that he finds it difficult to present them to his own satisfaction. Within the past three months he has discussed the relative merits of various materials and various types of construction with designers in the East while his colleague, Professor Niles of Stanford University, made similar inquiries in the West. The results obtained were compared during the recent aircraft show at St. Louis.

The following opinions, all of which were obtained from engineers and designers of considerable repute, will indicate the reason for the writer's hesitation and they will, he feels sure, indicate the almost total lack of dependable facts on which to base all-metal airplane designs.

Regarding durability of materials it was found that aluminum alloy properly heat treated plus anodic treatment plus an oxide primer plus enamel or varnish was as good as alclad, if not better. From another source it was found that aluminum alloys could not be protected against corrosion in service by any means so far discovered, and the opinion was expressed that stainless iron would be the solution for the durability problem. On the other hand it was stated that salt-spray tests on the thin-gage sheets of stainless iron, which were required to give a structure of practicable weight, indicated that its rate of corrosion was very nearly the same as for the aluminum alloys. The most definite opinion came from one of the most experienced designers in the industry. His idea was that for durability and economy of maintenance Sitka spruce was most suitable for aircraft.

Regarding the efficiencies of different types of construction some engineers advocated the use of stiffened flat sheets, some offered corrugated sheets. Opinions as to the behavior of flat sheets with stiffeners also varied. Some engineers maintained that the skin carried most of the load, others said that it was extremely inefficient and that the stiffeners were the structural members that actually carried the loads. The writer has test data from which one may draw either conclusion, and until the preliminary tests now being conducted by some of his students at Massachusetts Institute of Technology are completed he reserves his opinion.

He does, however, wish to differ with the author on the subject of metal permitting a closer degree of accuracy in design than wood. He admits that wood has varying properties, but he would like to emphasize the fact that the variations are such that the strengths average above rather than below the specified values for wood that passes Army and Navy specifications. It is true that a great deal of understrength spruce has been purchased by various commercial manufacturers during the past three years, but that is less the fault of the material than the inspection. The admirable work of the U. S. Forest Products Laboratory which has given form factors, allowable stresses, and specifications for spruce and other woods, all of which contribute to dependability and lightness in conventional design, can be nullified neither by statements regarding the difficulty of obtaining test specimens in wood nor by expatiating upon the dependability of metal due to the fact that the physical properties are carefully controlled throughout its manufacture and treatment. At least it hardly seems possible that such should be the case so long as mild-steel tubes will show up satisfactorily in chemical tests yet have a modulus of elasticity as low as 18,000,000, nor while the properties of stainless steels vary over so wide a range as they do at present. The modulus of elasticity of one set of specimens with which the writer has become acquainted varied from 26,000,000 to 34,000,000 lb. per sq. in., and the modulus of elasticity, it is hardly necessary to remark, is usually regarded as the most constant of the properties of metals.

As for the virtues of full-monocoque versus semi-monocoque construction it is again difficult to state which is the better. A recent set of tests indicates that flat sheets stiffened along the edges, but having no intermediate stiffeners will carry practically the same load in compression regardless of their width. This is contrary to elastic theory. These tests were fairly comprehensive as they were run on four different materials, various gages were used, and widths ranged from 4 in. to 24 in. in 4-in. increments. All specimens were 24 in. in length along the axis of loading. Very meager data on stiffened sheets, on the other hand, indicate that with a 4-in. spacing of stiffeners, a flat sheet 12 in. wide will carry the same load that would be taken by three 4-in. sheets stiffened along the edges plus the load which would be carried by the stiffeners acting as columns. These data are extremely meager and further tests may necessitate revising the above conclusions, but if it is true one is forced to conclude that full-monocoque structures involving flat sheet in compression are impracticable. Here again nothing can be established definitely due to lack of test data.

Such data are sorely needed and until aeronautical engineers possess allowable stress data comparable to that now available for the design of spruce members or of steel tubular members it is doubtful that efficient all-metal structures can be proportioned without involving expensive tests on minor parts and on major assemblies. Civil engineering practice from which most methods are derived, has nothing to assist with the thin-gage, highly stressed materials. The author states that tests must be made to determine the strength of individual sections that make up the skin. They most certainly must. The Army Air Corps has recently completed a series of tests on corrugated sheet carrying compression, and has done some work to determine relative torsional stiffnesses of box-shaped structures simulating the spars, ribs, and skin of a metal wing from which the leading and trailing edges have been removed. It is expected that these data will be published shortly and they will be of great utility since they will furnish some allowable stress data. Parallel studies of stress distribution in similar box structures subjected to torsion have been made on Zylonite models in the photo-elastic laboratories at the Massachusetts Institute of Technology. The results are now being prepared for publication.

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