A DESIGN NOTE ON HONEYCOMB SANDWICH CONSTRUCTION

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A common radome material is the plastic sandwich type structure composed of two faces or skins of dense material separated by and bonded to a honeycomb core (see Figure 1). The question often arises of how to calculate the elastic and thermal properties of such a section. Simple methods for estimating the moment of inertia of a sandwich beam, its associated modulus of elasticity, and the thermal conductivity value should be very useful in preliminary design work.

Elastic Beam Properties

Consider first the problem of estimating the moment of inertia and the associated modulus of elasticity for a sandwich beam construction. A first approximation would be to assume only the skins contribute to the moment of inertia, that they are held apart a distance equal to the core thickness, and that they develop their full modulus of elasticity. To check this simplified analysis, four sample sandwich materials with different skin and core thicknesses were tested as beams and their deflections measured under load.

The four sample beams were of constant cross section, simply supported, with a concentrated load applied at the center of the span. For these conditions, the ratio of load W to mid-span deflection d can be written (Reference 1)

$$\frac{W}{d} = \frac{48\,E\,b\,t\,c}{L^3}\left(t + \frac{c}{2}\right) \qquad (1)$$

where E is the modulus of elasticity of the skin material, L is the span length of the beam, and the other symbols are defined as shown in Figure 1. The sample beams were five inches wide with thirty inches between supports; skin and core thicknesses were as given in Table I. The skin material was made of combinations of 181 and 113 glass fabric with 114 finish, impregnated with polyester resin (Selectron 5003). The core was 1/4 inch cell size polyester fiberglass honeycomb with a density of approximately eight pounds per cubic foot. The skins were bonded to the core with polyester resin. All samples were cured at room temperature. A flexural modulus of elasticity of 3.4×10^6 psi (obtained by experimental measurement) was used for the skin material.

For each sample beam, mid-span deflections were measured with a dial indicator over a range of loads from three to thirty pounds. A plot of load versus deflection could then be made and the slope (load-deflection ratio) determined for each sample. These plots were linear for all samples with data scatter less than 5 percent. A comparison of the results of the calculations using equation (1) and the test measurements are given in Table I.

Table I illustrates that the simplified approach of calculating the moment of inertia for a sandwich beam by neglecting the core and assuming the skins develop their full modulus of elasticity gives answers that are within 10 percent of the measured results. This simplified analysis should be applicable to all long sandwich type beams in bending where the skin thickness is small ($t < 1/5\ c$) compared to the thickness of the core and where the core is sufficiently strong in shear to prevent collapsing of the two skins.

Thermal Conductivity

An expression for the equivalent thermal conductivity k of a sandwich honeycomb such as shown in Figure 1 can be written

$$\frac{(2t + c)}{k} = \frac{2t}{k_s} + \frac{1}{C} \qquad (2)$$

where k_s is the thermal conductivity of the skin material, C is the conductance associated with the core, and the other symbols are as previously defined. If C in equation (2) is considered to be made up of conduction through the solid part of the honeycomb and convection through the air cell of the honeycomb, the following can be written:

$$C = \frac{xh}{2} + (1-x)\frac{k_c}{c} \qquad (3)$$

where h is the film coefficient for the honeycomb air cell, k_c is the thermal conductivity of the core material, and x is that fraction of the core area that is air.

The first term in equation (3) represents the heat transfer through the air cell. When such an air space forms part of a wall construction, an additional resistance to heat flow is introduced at each added surface. Because of the difference in temperature on the two sides of the air space, some degree of air movement is set up within the space unless the space is unusually narrow. Heat is transferred across the space by convection currents and by radiation. The resistance of the air space is, therefore, approximately the sum of the two individual surface resistances h, or 2/h. Consequently, the term xh/2 appears in equation (3) for that fraction of core area that is air.

The value to use for h in equation (3) could be expected to lie between two limiting values. The lower limit would be the h value equivalent to the conductivity of an air space equal to the core thickness. The upper limit would be the equivalent value obtained for an air space infinite in two dimensions, but of thickness equal to the core thickness (reference 2). The true value for the h would be greater than the value for the lower limit as air movement is present, yet less than the upper limit since the air space is of finite dimensions. Consequently, an average value of the two limits appears reasonable for an approximate answer.

An experimental determination was made* of the thermal conductivity for two honeycomb sandwich samples. The samples had .034 inch skins made of combinations of 181 and 112 glass fabric with Garan finish, impregnated with polyester resin (BRS 142). Sample A had a four-pound per cubic foot nylon phenolic honeycomb core .309 inches thick, sample B a six-pound per cubic foot CTL (glass fabric) phenolic honeycomb core .311 inches thick. Both cores had 1/4 inch cell size honeycomb and were bonded to the skins with epoxy resin. The thermal conductivity of the skin material k_s was taken as 2 BTU/hr-sq.ft.-°F/in., the value for the core material k_c, 1.5 BTU/hr-sq.ft.-°F/in. The cross sectional core area for sample A was 94.5 percent air, 5.5 percent solid material; for sample B, 93.5 percent air, 6.5 percent solid. Substituting in equations (2) and (3), the values shown in Table II are obtained; the experimentally measured values are given also.

Since the thermal conductivity values used for the skin material and core were approximate values ($\pm$15 percent) and the value for h is an approximation, as explained, the excellent agreement shown in Table II should not at present be taken as an indication of the accuracy of the method. However, it does substantiate the method as a good approximation, the accuracy of which can be fully established when more experimental evidence is available. Moreover, from Tables I and II it can be seen both the k approximation and that for the elastic beam properties are of sufficient accuracy for preliminary design work when honeycomb sandwich construction is employed.

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* Using standard apparatus at the Massachusetts Institute of Technology.

References

1. Mark, M., "Moments of Inertia and Deflection of Plastic Sandwich Beams", Modern Plastics, Vol. 32, No. 7, 1955, p. 146.

2. Rowley, F. B. and Algren, A. B., "Thermal Resistance of Air Spaces", A.S.H.V.E. Transactions, Vol. 35, 1929, p. 165.

TABLE I

	Thickness, in.		Load - Deflection Ratio, lb/in.	
Sample	Core	Skin	Measured	Calculated
I	0.204	0.029	21.8	23.4
II	0.228	0.022	20.5	20.6
III	0.275	0.014	17.4	17.5
IV	0.180	0.029	19.6	18.0

TABLE II

		Thermal Conductivity, k, BTU/hr.-sq.ft.-°F per inch	
Sample	Temperature °F	Measured	Calculated
A	61°F	0.463	0.45
A	114°F	0.486	0.50
A	150°F	0.509	0.53
B	63°F	0.493	0.46
B	107°F	0.512	0.51
B	140°F	0.538	0.54

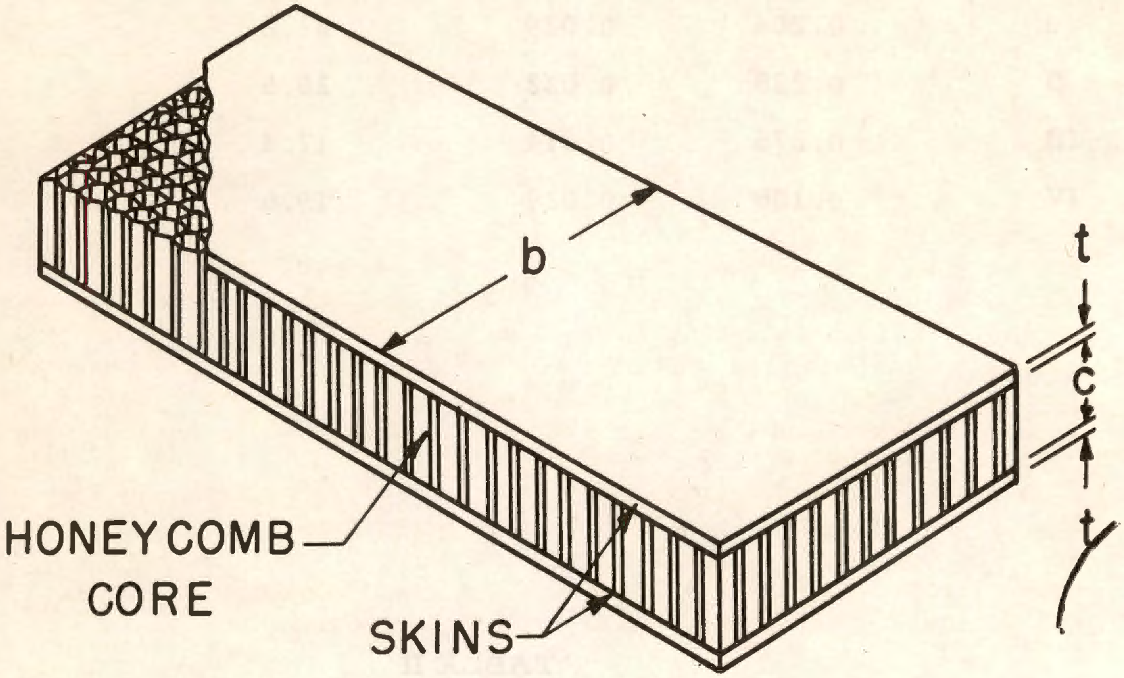

FIGURE 1

HONEYCOMB SANDWICH