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Axially Compressed Optimum Cylinder— Comparison of Stiffener Configurations

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VARIOUS authors have worked on the optimum design of waffle cylinders[1-8] with orthogonal and spiral stiffener configurations. This Note presents results of minimum weight design studies on six types of stiffener configurations for a given load intensity, cylinder length and radius (including a cylinder with bonded shell-wall construction). In the bonded construction thin sheets are folded so as to give a series of unidirectional stiffeners. Two such sheets are then bonded on either side of another thin sheet so that the stiffeners are placed orthogonally. Assuming perfect bonding such a cylinder can be treated as orthogonally stiffened.

The optimum equivalent thickness of a cylinder has been obtained through structural synthesis. The interior penalty function method[9] has been used with multiple starting points. The failure modes considered are: gross buckling,[10,11] buckling between circumferential stiffeners, local buckling of skin,[10,12] local buckling of axial and spiral stiffeners,[7,13] and yielding of the cylinder material. For a meaningful comparative study of the designs, the upper and lower limits of the design variables have been prescribed on a uniform basis (Table 1).

The fixed parameters for the designs have been taken as: cylinder length = 406.4 cm (160 in.), cylinder radius = 152.4 cm (60 in.), design load = 1755.55 N/cm (1000 lb/in.), $E = 7.326 \times 10^6$ N/cm^2 (10.6×10^6 psi), Poisson's ratio = 1/3, and yield stress = 49,763.6 N/cm^2 (72,000 psi). The results of the design studies are given in Table 2. For orthogonal stiffening the designs of Ref. 6 are lighter than those of the present study. The differences are due to the fact that in Ref. 6 the axial and circumferential stiffeners have unequal depths whereas in the present study the depths are equal. Stiffener depth is the most effective parameter in increasing gross buckling load. In automated design procedure, therefore, the stiffener depths tend to be large. With a large axial stiffener depth being restricted by stiffener buckling, circumferential stiffener depth tends to be large. This behavior can be observed in design study 6 (see Table 2) where d_c has moved very close to the prescribed upper limit. Since in the present study axial and circumferential stiffener depths are the same, skin thickness, the second most effective praramete in increasing gross buckling load, tends to be large making the designs heavier. For spiral type outside stiffening the design of the present study is lighter than that of Ref. 6. The reason may be attributed to the higher estimation of skin buckling load in the present study.

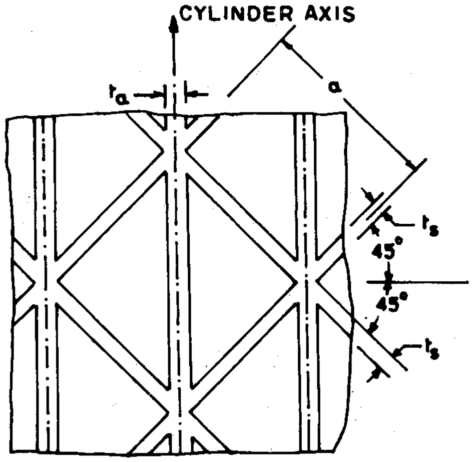

Fig. 1 Spiral-cum-axial type stiffening.

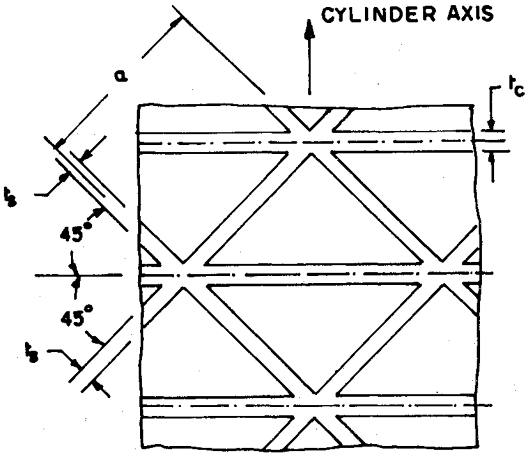

Fig. 2 Spiral-cum-circumferential type stiffening.

Outside stiffened waffle cylinders are found to be lighter than inside stiffened cylinders. Spiral-cum-axial (Fig. 1) and spiral-cum-circumferential (Fig. 2) stiffener configurations resulted in designs heavier than those with spiral stiffener configuration. For outside stiffener location, spiral type stiffening gives the lightest design followed by spiral-cum-circumferential type stiffening. For inside stiffener location, spiral-cum-orthogonal type (Fig. 3) stiffening gives the lightest design followed by spiral type stiffening. Among all the stiffener configurations considered for the waffle cylinder studied, spiral type outside stiffening gives the lightest design.

Folded sheet stiffening (Fig. 4) with axial stiffener on the inside (and circumferential stiffener on the outside) gives a design lighter than that with axial stiffener on the outside. It is also seen that folded sheet stiffening with axial stiffener on the inside gives a design which is only 0.85% heavier than that for spiral type outside stiffening.

Although the design studies have been limited to one cylinder and one load intensity, the studies demonstrate the significant effects of stiffener configurations and stiffener location on the minimum weight of a waffle cylinder. The result of the design study on folded sheet stiffening, the construction of which is likely to be cheaper than waffle construction, is encouraging.

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Index categories: Structural Design; LV/M Structural Design (including Loads).
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Table 1 Design variables and their limits (in mm)

Type of stiffening		a	b	t_s	t_a	t_c	d	h	
Orthogonal	X^u	101.6	101.6				25.4		
	X_l	25.4	25.4		0.254	0.254		0.254	
Spiral	X^u	76.2					25.4		
	X_l	25.4		0.254				0.254	
Spiral-cum-axial	X^u	76.2					25.4		
	X_l	25.4		0.254	0.254			0.254	
Spiral-cum-circumferential	X^u	76.2					25.4		
	X_l	25.4		0.254		0.254		0.254	
Spiral-cum-orthogonal	X^u	76.2					25.4		
	X_l	25.4		0.254	0.254	0.254		0.254	
Folded sheet					d_a	d_c	h_m	h_0	h_i
	X^u	101.6	101.6		25.4	25.4			
	X_l	25.4	25.4				0.0254	0.0254	0.0254

Table 2 Design studies

Study	Type of stiffening	Stiffener location	Design variables, mm							Equivalent thickness, mm
			h	d	t_a	t_c	t_s	a	b	
1	Orthogonal	Outside	0.699	9.861	0.756	1.435	...	27.75	97.219	1.1087
		Inside	1.067	12.605	0.826	0.813	...	48.3	98.876	1.3840
2	Spiral	Outside	0.711	10.49	...	...	0.518	32.379	...	1.0444
		Inside	0.775	13.24	...	...	0.599	36.83	...	1.2022
3	Spiral-cum-axial	Outside	0.451	10.033	0.711	...	0.635	32.766	...	1.1356
		Inside	0.61	10.795	0.711	...	0.737	35.814	...	1.3439
4	Spiral-cum-circumferential	Outside	0.617	10.287	...	0.254	0.533	31.176	...	1.082
		Inside	0.813	12.954	...	0.267	0.622	45.34	...	1.272
5	Spiral-cum-orthogonal	Outside	0.533	9.258	0.686	0.445	0.47	39.402	...	1.1011
		Inside	0.572	8.589	0.66	0.787	0.445	41.923	...	1.1138
			h_m	h_i	h_0	d_a	d_c	a	b	
6	Folded sheet	Axial outside	0.719	0.292	0.051	8.649	22.987	25.573	51.829	1.3025
		Axial inside	0.276	0.343	0.165	8.598	24.664	31.11	101.574	1.0533

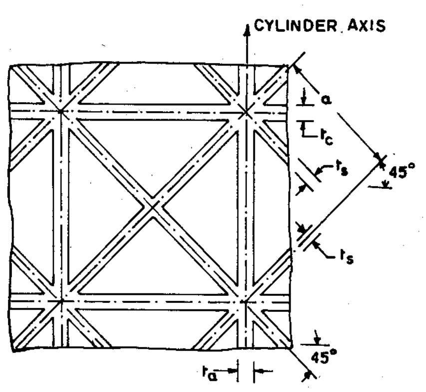

Fig. 3 Spiral-cum-orthogonal type stiffening.

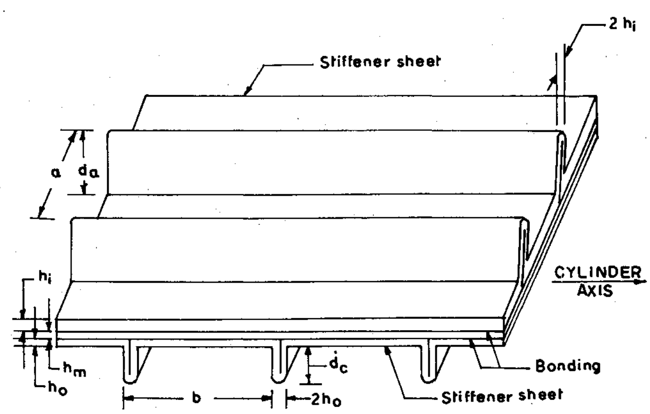

Fig. 4 Folded sheet stiffening.

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Impact of the Space Environment on Spacecraft Lifetimes

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Introduction

THIS paper examines whether space is a benign environment insofar as spacecraft life is concerned. This topic should be of concern to planners who must assure that adequate numbers of satellites are available on orbit to perform specific missions, yet not at the expense of gross over-procurement of satellites. Taylor[1] has stated that the environment is benign and thus spacecraft lifetimes, once faulty satellites are weeded out by early failures, are very long.

We have examined data compiled by the NASA[2,3] on 57 typical satellites, both at the black box and total spacecraft levels. The data, analysis, and conclusions are presented below.

Data

Data[2] relating to spacecraft failures as a function of time in orbit are given in Fig. 1. A failure is defined as the loss of operation of any spacecraft function, part, component, or subsystem irrespective of its effect on total spacecraft mission performance, which is monitored by telemetry. Infant failures,[3] that is, failures occurring at or near initial spacecraft activation, have been removed from the raw data since these failures represent malfunctions introduced by the harsh launch environment and are not indicative of the effects of the space environment on spacecraft. Of the 57 spacecraft sampled, 54 survived launch.

The data were fit with a Weibull cumulative failure distribution[4]

$$W(t)=A[1-\exp(-t^{\beta}/\alpha)] \tag{1}$$

by a least-squares fit. The estimated values of the parameters are

$$A=2.1\times10^{2} \qquad \alpha=1.9\times10 \qquad \beta=5.4\times10^{-1} \tag{2}$$

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and the fitted line is shown in Fig. 1. This differs from the standard Weibull distribution by the factor A which must be included here because it is unknown *a priori* how many failures could occur. The derived value of A indicates approximately 4.0 malfunctions per spacecraft for the 54 spacecraft. The rms difference between the Weibull distribution and the data is 2.0 which indicates a very good fit.

Figure 2 shows the number of spacecraft surviving as a function of time. A spacecraft failure is defined as problems of sufficient nature as to cause operation of the spacecraft to be discontinued. These data are fitted with a Weibull distribution of the form

$$F(t)=54\exp(-t^{\beta}/\alpha) \tag{3}$$

with the results

$$\alpha=7.0\times10^{2} \qquad \beta=8.7\times10^{-1} \tag{4}$$

The fitting curve is shown in the figure, and the rms error is 1.2 indicating a good fit.

Discussion

The mean life for an object following the Weibull failure distribution is given by

$$\mu=\alpha^{1/\beta}\Gamma(1/\beta+1) \tag{5}$$

For $\beta=1$, $\mu=\alpha$. Based on this sample, the mean lifetime for components in space is 410 days and the mean lifetime for spacecraft is 2000 days.

Of considerable interest is the hazard rate, the instantaneous failure rate as a function of time $z(t)$,

$$z(t)=f(t)/R(t) \tag{6}$$

where $f(t)$ is the failure distribution function and $R(t)$ is the reliability function, or $F(t)/N$ where N is the number of cases in the notation of Eq. (3). Furthermore, $f(t)=-R'(t)$, so that for Weibull distributions

$$z(t)=(\beta/\alpha)t^{\beta-1} \tag{7}$$

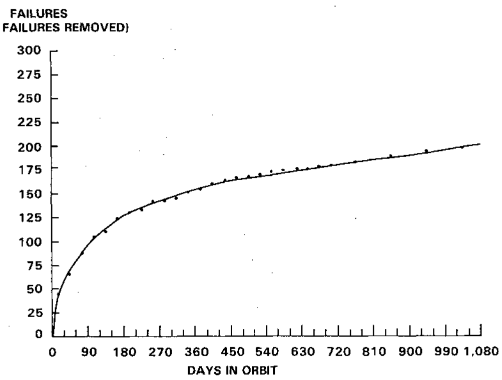

Fig. 1 Spacecraft failures in orbit.

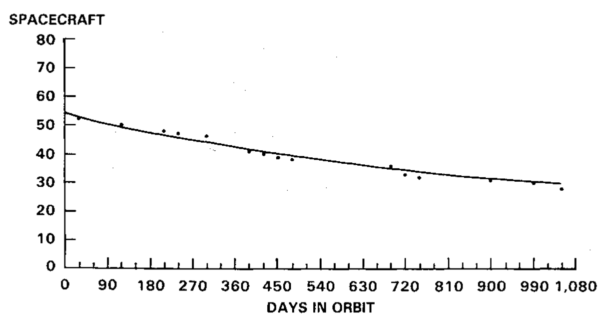

Fig. 2 Number of spacecraft still operating.