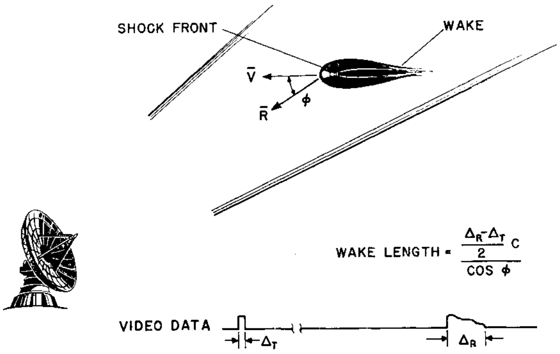

Fig. 5 Radar video during re-entry for measurement of wake length.

application of real (or near-real) time radar video processing might be an osbital attitude sensing system, which would provide a means for evaluating the accuracy of the spacecraft's self-contained guidance and attitude sensors. Other possible applications include an orbiting vehicle identification system and penetration-aid study programs. Results obtained from wake analysis will aid re-entry studies relating to communication blackout, since radar returns are also similarly affected by the ionization.

Design of Cylinder-Cone Intersections

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The basic theory for stresses at coaxial intersections of uniform thickness cones and cylinders has been developed. In the procedure to be described below, the structural and geometric requirements are revealed for a uniform stress intersection. However, an intersection fabricated to meet these requirements would be impractical. An arbitrary simplification has been made to obtain a low stress ("optimum") intersection of a more practical character. The principal features of this intersection are the absence of stress concentration and the ability to withstand internal forces without exceeding a stress level equal to the cylinder circumferential membrane stress.

Nomenclature

C = stress ratio, $\sigma t_0/pR$
D = bending rigidity of shell, $Et^3/[12(1 - \nu^2)]$, in-lb
E = Young's modulus, lb/in.^{2}
M = bending moment per inch of circumference, lb
p = pressure, lb/in.^{2}
Q_0 = transverse shear per inch of circumference at intersection, lb/in.
R = mean radius of cylinder, in.
t = thickness of shell, in.
t_0 = thickness of cylinder away from intersection, in.
t_1 = thickness of intersection at springing line, in.
α = cone semiangle
λ = attenuation length of cylinder, $\{R^2t^2/[3(1 - \nu^2)]\}^{1/4}$
ν = Poisson's ratio
σ = stress, psi

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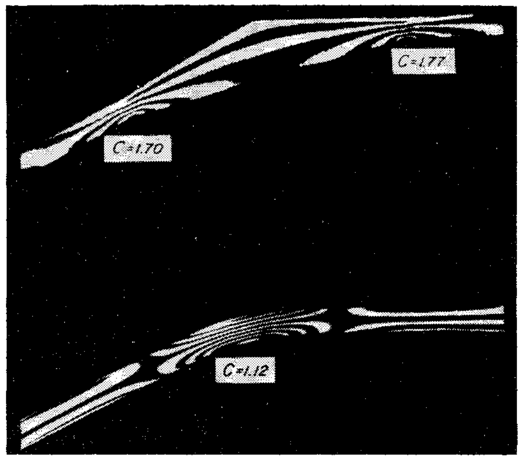

Fig. 1 Stress ratios for two types of intersections.

Design Procedure

An investigation of stresses at cone-cylinder intersections with various types of reinforcement rings revealed that the simpler designs were accompanied by lower stress fields. It was also found that the character of the stress field in an axial cross section could be reproduced in a two-dimensional model of the cross section loaded by the internal forces that were computed using standard three-dimensional (or axisymmetric) shell theory. Therefore, the design procedure discussed herein is based upon the two-dimensional analysis of a beam-like strip of the cone-cylinder axial cross section loaded by the internal forces at the intersection of the cone-cylinder pressure vessel subjected to internal pressure.

Examination of mathematical data[1] and photoelastic studies[2, 3] revealed striking symmetry of the stress distribution about the interior angle bisector of the cone-cylinder intersection. This is depicted in Fig. 1 by the fringe patterns on two models. The first has a low stress level at the intersection springing line but has concentrations at the tangent points, whereas the second is essentially free of tangent concentrations but is overstressed at the springing line. This symmetrical stress distribution suggested that for design purposes the interior forces at the intersection of a cylinder with a cone of half-angle α could be replaced by those for an intersection consisting of two cones each of half-angle $\alpha/2$, as shown in Fig. 2. The problem was simplified further by as-

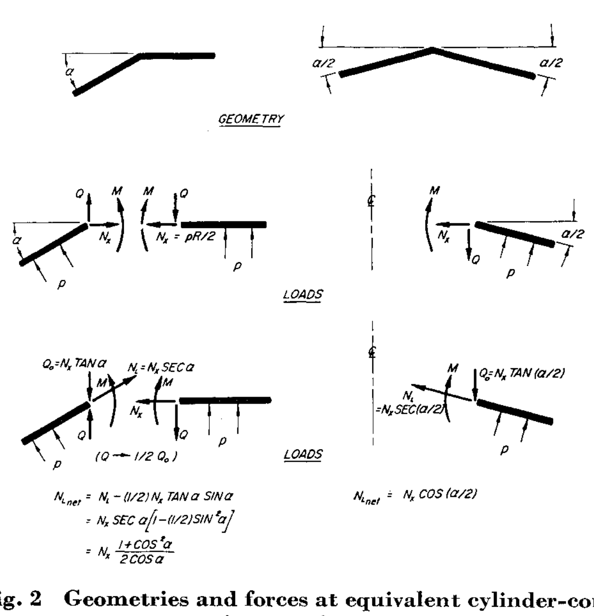

Fig. 2 Geometries and forces at equivalent cylinder-cone intersections.

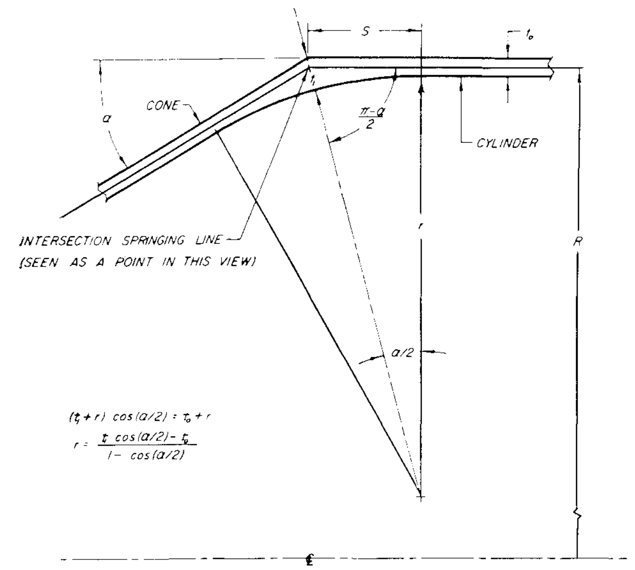

Fig. 3 Geometry of optimum intersection.

suming that 1) the structural properties of the cones are equal to those of the cylinder of the original intersection, and 2) the distribution of internal moments would not be affected by the modifications that would eventually be made to the intersection in order to attain the optimum configuration.

The design criterion requires that at any section of the intersection the bending moment and net membrane force produce a total stress equal to pR/t_0, the circumferential membrane stress in the original cylinder:

$$\sigma = 6M/t^2 + (pR/2t)\cos(\alpha/2) = pR/t_0 \tag{1}$$

The bending moment at any station must be determined from an interaction calculation together with shell theory. The thickness t at any station of the intersection region may be found from Eq. (1) after M is found. The data of Watts and Lang[1] show that the axial stresses are critical for designing the intersection; hence there is no need to check circumferential stresses.

The intersection moment M is determined from equality of the slopes due to M and Q_0 (Fig. 2) at the double cone intersections, because rotational symmetry must be preserved about the centerline[4]:

$$M\lambda/D = Q_0\lambda^2/2D = (pR/2)\tan(\alpha/2)\lambda^2/2D \tag{2}$$

or

$$M = (pR\lambda/4)\tan(\alpha/2) \tag{3}$$

If the attenuation length λ is computed for the basic cylinder (with $t = t_0$) disregarding the thickening near the intersection, then

$$M = pR^{3/2}t_0^{1/2}\tan(\alpha/2)/4[3(1-\nu^2)]^{1/4} \tag{4}$$

Once M is found, the moment at any distance x from the intersection may be found using basic cylinder theory; let $\xi \equiv x/\lambda$, then

$$M(x) = e^{-\xi}(M[\cos\xi + \sin\xi] - Q_0\lambda\sin\xi) \tag{5}$$

and the design moment $M(x)$ at any station x would be less than M at the intersection. Therefore, only M is important in the design procedure. Substituting Eq. (4) into Eq. (1) where $t \equiv t_1$ at the intersection springing line, gives

$$\frac{3}{2}\,\frac{pR^{3/2}t_0^{1/2}\tan(\alpha/2)}{t_1^2[3(1-\nu^2)]^{1/4}} + \frac{1}{2}\,\frac{pR}{t_1}\cos(\alpha/2) = \frac{pR}{t_0} \tag{6}$$

Multiplying by t_1^2/pRt_0 and substituting

$$A \equiv \cos(\alpha/2)/2$$
$$B \equiv \frac{3}{2}\left(\frac{R}{t_0}\right)^{1/2}\frac{\tan(\alpha/2)}{[3(1-\nu^2)]^{1/4}} \tag{7}$$

into Eq. (6) gives

$$(t_1/t_0)^2 - A(t_1/t_0) - B = 0 \tag{8}$$

or

$$t_1/t_0 = [A + (A^2 + 4B)^{1/2}]/2 \tag{9}$$

For moderate $\alpha(\leq 30°)$, reasonable simplifications† are $\cos(\alpha/2) = 1$, and $\tan(\alpha/2) = \alpha/2$. Typical values for ν are 0.3 for metals and 0.5 for stress freezing plastics, so that $[3(1-\nu^2)]^{-1/4}$ would be between 0.778 and 0.816, which is a variation about the mean (0.797) of 2.4%. Using a value of 0.80, the preceding simplifications lead to

$$t_1/t_0 = 1 + [1 + 9.6\alpha(R/t_0)^{1/2}]^{1/2}/4 \tag{10}$$

A limitation to Eq. (10) occurs when $t_1/t_0 = 1$ or $\alpha = (\frac{5}{6})(t_0/R)^{1/2}$.

A practical optimum intersection would consist of straight external boundaries on the cone and cylinder and a circular arc interior longitudinal transition such that t_1 from Eq. (10) exists at the springing line. Studies have shown that for $\alpha = 30°$ this will encompass the thickness envelope that will satisfy Eq. (5). The geometry of the intersection is shown in Fig. 3 together with the relation among r, t_0, t_1, and α, which permits construction of design charts for various cylinder proportions.

Tests Tending to Substantiate Design Procedure

During the period of development of the design procedure described in the preceding paragraphs, a pressure vessel was fabricated with the intersection of Fig. 3, with $R = 2.91$ in. and $t_0 = 0.030$ in., so that $R/t_0 = 97$. The cone semiangle α was 30°, which requires that $t_1/t_0 = 2.03$ or $t_1 = 0.061$ in. and $r = 0.86$ in. The photoelastic fringe pattern observed for this vessel is shown in Fig. 4, for which the stress ratio $C = \sigma t_0/pR$, was found to be 0.99. This indicates that increased thickness at the springing line does effectively reduce the local moment, and the relatively crude design procedure already outlined provides a reasonably accurate representation of the structural behavior of the intersection.

Additional tests were performed on such intersections with stiffening frames added; first with a T frame at the intersection springing line, and then with a pair of T frames straddling the intersection. In both cases, all of the simplifying assumptions were retained despite the orientation of the frame webs in a plane perpendicular to the cylinder axis. In the case of the single frame the same cross-sectional geometry was used as previously, except that all dimensions were doubled. It was found that $C = 0.90$, indicating overdesign furnished by the addition of the frame. For the pair of straddling frames, the radial support furnished by the frames was considered in the analysis, resulting in slightly smaller values of t_1/t_0 and r/t_0. This yielded $C = 0.94$. Details appear in Ref. 3.

This simplified design procedure appears to offer simple transitions without stress concentrations. However, because

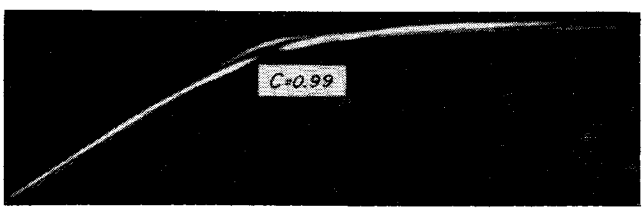

Fig. 4 Stress ratio for optimum intersection.

† For example, use of these trigonometric approximations leads to an error of 0.5% in t_1/t_0 for $R/t_0 = 100$.

of limited experimental data the range of applicability requires further investigation.

References

[1] Watts, G. W. and Lang, H. A., "Stresses in a pressure vessel with a conical head," Trans. Am. Soc. Mech. Engrs. **74**, 315–326 (1953).

[2] Smith, L. W. and Cooper, C. K., "Photoelastic investigation of stresses in a conical head pressure vessel," Soc. for Experimental Stress Analysis **XIII**, no. 2, 7–20 (1956).

[3] Becker, H., Gurtman, G., and Colao, A., "Study of cone-cylinder intersections," New York Univ. TR SM 62-6 (1962).

[4] Timoshenko, S., *Theory of Plates and Shells* (McGraw-Hill Book Co., Inc., New York, 1940), p. 393.

Atmospheric Toxicants in Manned Space Stations

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THE occurrence of toxic hazards in space environmental systems is recognized, but suitable methods of amelioration have not been postulated. As such, it is necessary to establish criteria, develop techniques, and design performance parameters for the control and evaluation of undesirable vapors and particulate materials with which man will be confronted in his future extended space missions. Several pitfalls are encountered when an attempt is made to apply the existing available knowledge, since these are based on eight-hour work days and five-day week exposures. Bioastronautics is not concerned with such studies but rather with longterm exposures of a continuous nature with what is hoped will be relatively low concentrations. Direct extrapolation of the industrial-compiled exposures to space requirements are, of course, not feasible. Perhaps the greatest discrepancies will be found in the interactions and resultant formations of the low-level contaminants within the environment.

In a previous paper[1] compilations were made of the effluents produced by man. Similar lists are also available which indicate what compounds might be produced in a particular industrial operation or in a specific facility. What pathways these substances might follow is problematical, and the listing of the materials per se is of an academic nature and serves as a baseline, but is probably not definitive with respect to procuring a suitable habitat.

The interaction among vaporous components may operate synergistically or antagonistically; i.e., the final aggregate product may be more or less toxic than the precursors. An example of that is the interaction of hydrogen chloride and ethyl alcohol, both of which have been identified as occurring in restricted atmospheres.[2] The resultant ethanol is much less toxic than its precursors. Numerous examples with opposite results may be cited, however. For reactions involving the major atmospheric gases, the final composition within the orbital space station must be specified. To date, this has been a controversial topic. If a single gaseous system of oxygen is utilized there will be pertinent basic oxidation processes, whereas the addition of nitrogen may lead to the formation of toxic nitrogen oxides or other such derivatives. The inert gases have been implicated in certain biological reactions especially from a neural aspect.[3] The difficulties in analysis of these evasive materials further complicate their interactions.

Traversing space will lead to radiation of the capsule and its sealed environment. The radiation may come from artificial sources, the inner and outer Van Allen belts, solar flares, or galactic sources. The reaction of radioactive materials may profoundly alter the profile of the atmospheric components and it must be assumed that such interactions will be deleterious. Extensive investigations are being conducted on the direct effects of radiation on man but the indirect, insidious interplay with his habitable atmosphere have been largely neglected. Likewise, photochemical reactions and the effects on the formation of undesirable elements must be considered. Photochemical processes are now assigned as one of the major roles in the formation of the smog. The scope of these physiochemical complexes is magnified in the small confined area of a space station and further compounds the problems facing the astronauts. Chemical reactions of a diverse nature will be involved with lighting aboard and will be affecting the formed contaminants.

Particulate matter is an all-inclusive entity for such things as dust, sprays, fumes, and living organisms. Classification is based largely on the particle size and has not been adequately characterized. It may, however, react with the spacecraft atmosphere to become atmospheric dispersoids. A problem which can be solved only in a weightless or reduced gravitational environment is the change in settling rate which has been to date a principal criterion in characterizing these materials. As man enters space, living particulates, his microbiota, will accompany him. Such materials will react with the trace components to present another facet in the field of microbiology and possibly exobiology.

The chemistry of surfaces is receiving a new impetus as more of the critical properties of micro particles are uncovered. Such constituents, although of minor magnitude, have in earth-bound stations exhibited their potency by causing corrosion and other physical phenomena on surfaces of instrumentation and living areas of submarines.[4] Consider that metal surfaces become pitted and corroded; then the mucous membranes and other sensitive surfaces of man are also affected, probably to a greater degree. A normal atmosphere consists of a mixture of ions of varying size; each moving with a variable speed dependent upon their size. Beneficial results have been ascribed to them in regards to asthmatic and upper respiratory conditions, the negative ions showing a therapeutic effect, whereas the positive ions have been assumed to be innocuous. These, it would appear, could easily be attached to trace materials if their ionized state is retained for a suitable duration. As such, this would present another facet to the complex space station atmosphere.

Water will be present in the orbiting space capsule for drinking purposes, personal hygiene, cooking, and other uses. It is also present in large amounts as ambient humidity in the atmosphere. The interaction of the micro materials with that of water constitutes a large science in itself and might well change the profile of the mission. Aerosols and condensation nuclei are resultant products. Aerosols will play an integral role in the atmosphere of space stations. Toxicologists have shown that the formation of an aerosol greatly increases the damage done to man after ingestion, as compared with the same material before being placed in colloidal suspension. The formed particle is of significance, since particles of different sizes are retained to a different degree in the lungs. Condensation nuclei resemble aerosols in that they are liquid or solid, submicroscopic airborne particles, each of which can act as a nucleus for the formation of a water droplet. These materials are formed, however, only by supersaturated water vapor. The moisture content is important as well as the particle size in the necessary condensation process. The various operations involved in life support instrumentation aboard a manned space vehicle should present numerous opportunities for the formation of such nuclei.

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