Wind Loads for Bar-Truss Structures

M. S. Katow
DSN Engineering Section

When a computer model of a bar-truss structure exists for analysis by the NASTRAN or IDEAS computing programs, it can also be used to calculate the wind loadings. By using the cross-flow principles and vector analysis, a software was generated for computing the wind loads on the nodes or joints of the computer model. Detailed descriptions of the algorithms used and probable accuracy of the solution are included.

I. Introduction

The subreflector of the 64-meter antenna is supported by a quadripod using a truss-type structure (Fig. 1) for the legs and apex. With the multiplicity of square tubes in the wind stream at odd angles to the wind direction, a simple method of calculating the wind drag of a truss structure should enhance the wind loading analysis for stresses and deflections.

In the analysis method to be described, the existing structural analyzing NASTRAN or IDEAS model consisting of the CBAR element and the GRID coordinate cards defining the locations of the joints of the truss structures are used as inputs to the wind forces calculating software. Presently, the truss is assumed to use round bars that are an approximation to the actual square tubes used for the 64-meter quadripod.

The algorithms used to calculate the drag and lift of single cylindrical bars at angles to the wind direction axis are described (Ref. 1) with data showing excellent confirmations of the predicted values by experimental results.

For the nominal wind velocities, the viscous pressure drag caused by boundary-layer separation resulting in varied distribution of forces normal to the body surface is the dominating effect. The skin friction effects are low (approximately 2 or 3 percent).

The drag (C_D) and lift (C_L) coefficients of a cylindrical bar as defined in Ref. 1 by the cross-flow principle are:

$$C_D = C_D\text{-Basic} (\sin^3 \alpha)$$

$$C_L = C_D\text{-Basic} (\sin^2 \alpha \cos \alpha)$$

Using angle α as defined in Fig. 2, C_D-Basic is the drag coefficient value with the axis of the cylindrical bar normal to the wind direction. It follows that vectors C_D and C_L will lie in the same plane defined by the axis of the bar and the wind direction vector even if the bar is at any angle to the basic coordinate system.

Thus the wind force vectors at the end nodes of the cylindrical bar (Fig. 2) are:

$$\text{lift}/2 = \mathbf{C_L} \cdot \text{diameter} \cdot \text{length} \cdot q \qquad (1)$$

$$\text{drag}/2 = \mathbf{C_D} \cdot \text{diameter} \cdot \text{length} \cdot q \qquad (2)$$

$$q = \frac{pV^2}{Z} = \text{dynamic pressure}$$

$$p = \text{air density}$$

$$v = \text{wind velocity}$$

II. Solution Description

The coordinate system defining the structural model will be used as the basic system since the wind-load vectors must be compatible to it.

Defining a bar **OA** by the basic coordinate system in the second quadrant (Fig. 3) and the wind vector **OB** to lie in the fourth quadrant (quadrants defined in plane XOZ), the angle α between the bar vector and the wind vector is calculated by the dot or scalar product as:

$$|\mathbf{OA}| \cdot |\mathbf{OB}| \cos\alpha = \mathbf{OA} \cdot \mathbf{OB}$$

where

$$|\mathbf{OA}| = \sqrt{a_1^2 + a_2^2 + a_3^2}$$

$$|\mathbf{OB}| = \sqrt{b_1^2 + b_2^2 + b_3^2}$$

$$\mathbf{OA} \cdot \mathbf{OB} = a_1 b_1 + a_2 b_2 + a_3 b_3$$

$$a_i = \text{components of } \mathbf{OA}$$

$$b_i = \text{components of } \mathbf{OB}$$

The drag vector for a bar will always be in the same direction as the wind vector; however, the lift vector **OC** will be normal to the drag vector and also lie in the plane defined by the bar vector and the wind vector.

Thus the drag value for each end of the bar can be calculated using Eq. (2) and its unit vectors are the same as for the wind direction.

The lift vector can be calculated using the vector triple product (Ref. 2)

$$\mathbf{OB} \times (\mathbf{OB} \times \mathbf{OA})$$

The vector product **OB** × **OA** defines a vector **OD** (not shown in Fig. 3), which is perpendicular to both **OB** and **OA**. Then the vector product **OB** × **OD** defines a vector **OC**, which is perpendicular to both the wind vector **OB** and **OD**. Thus the life vector **OC** lies in the plane determined by the bar vector **OA** and the wind vector **OB**.

In vector analysis terms, the components of the vector product **OB** × **OA** are:

$$d_x = a_y b_z - a_z b_y$$

$$d_y = a_z b_x - a_x b_z$$

$$d_z = a_x b_y - a_y b_x$$

Then the components of the cross product **OB** (**OB** × **OA**) are:

$$c_x = a_y d_z - a_z d_z$$

$$c_y = a_z d_x - a_x d_z$$

$$c_z = a_x d_y - a_y d_x$$

III. Conclusions

(1) The circular cylinder was used in the solution algorithm because of its insensitivity to the axis rotation. The basic drag coefficients for a circular cylinder from Ref. 1 is shown in Fig. 4. For the wind velocities of normal interest, the curve is flat at approximately 1.2 C_D.

Figure 5 illustrates the drag coefficients for a standard square tubing (Ref. 1); as there is a drag rise for the orientation shown as (b), an average value used for computing the wind load should result in an accuracy within 10 percent.

(2) The circular and square tubings used in truss structures are normally assembled by welding, using close fitting joints. This results in smooth joints so that the actual lengths between the centerline intersections can be used for the drag and lift calculations.

(3) There will be interference effects resulting from turbulence created by air passing by the joints and bars before striking the next rows of joints and bars. This action should reduce slightly the drags and lifts of the trailing structure because of the sparseness of the normal trusses.

IV. Software Description

The program was coded for the 1100-81 computer to read the free-field columns integer used for NASTRAN or IDEAS structural model data; these data consist of GRID and CBAR information. Since the CBAR cards define a PBAR card (bar property data), an equivalent card was read in to input the diameter and the basic drag coefficient.

After checking for duplicate GRID and no match between the grid nodes in the CBAR card and the GRID listings, the drag and lift components are computed using the algorithms previously described. For each GRID node, the three-component drag and lift values for all bars connected to a grid joint are listed, followed by the wind loading as vector sum.

The wind loading values in three components are output as standard NASTRAN or IDEAS force cards in file 10 and also listed in the output. These force cards can be directly input into the structural analyzing program.

References

1. Hoerner, S. F., *Fluid-Dynamic Drag*, University Microfilm International, Ann Arbor, Michigan, 1958.
2. Wylie, C. R., Jr., *Advanced Engineering Mathematics*, McGraw-Hill Book Co., Inc., 1960.

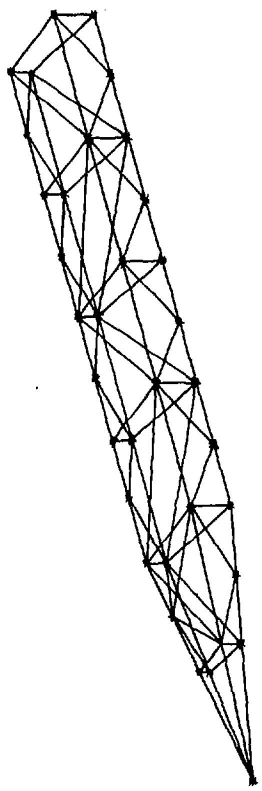

Fig. 1. Isometric view of bottom part of 64-m quadripod leg

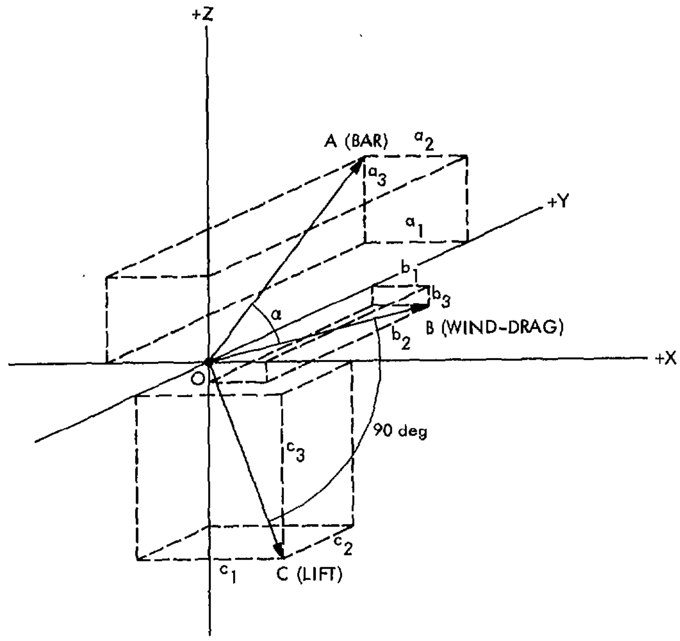

Fig. 3. Bar-wind vectors

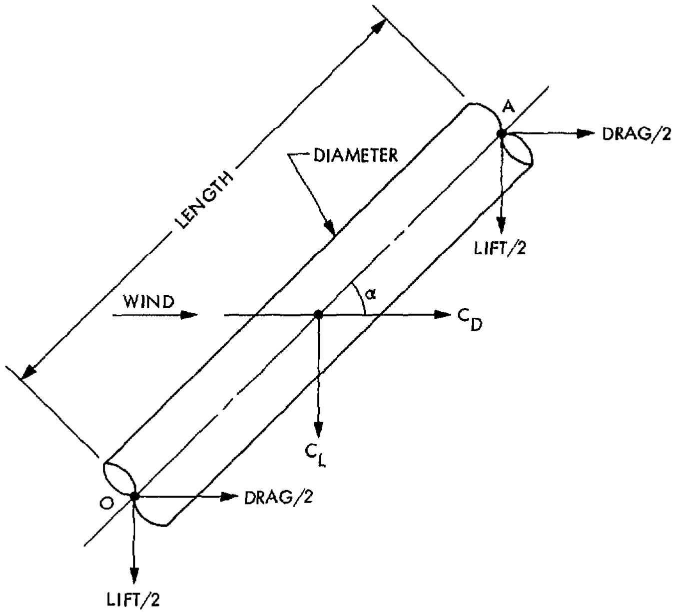

Fig. 2. Cross-flow notations

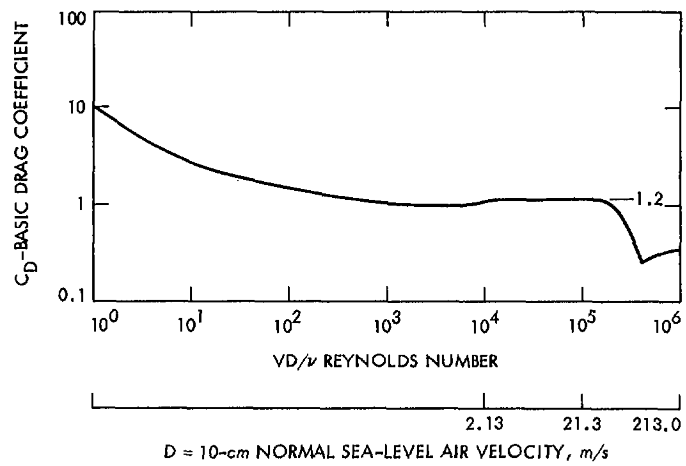

Fig. 4. Basic drag coefficient of circular cylinder (between walls)

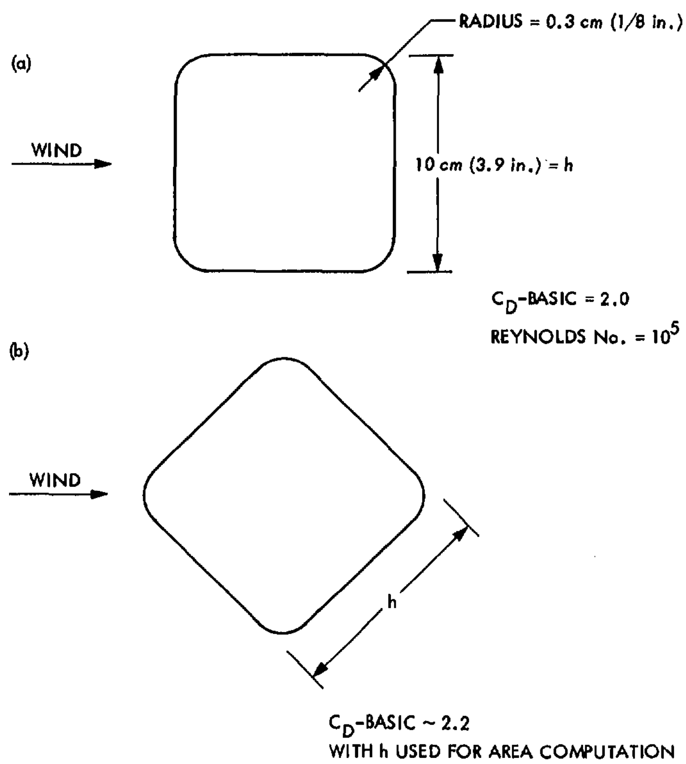

Fig. 5. Basic drag coefficient-square tubing