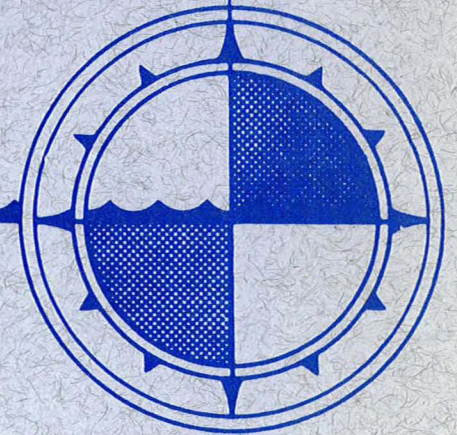


**THE USE OF EXTRUDED PLASTIC FAIRING
FOR A SUBSURFACE MOORING**

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ABSTRACT

Vertical excursions of instruments suspended beneath a subsurface buoy, resulting from hydrodynamic drag forces on the cable, cause problems in oceanographic data acquisition and analysis. In an effort to alleviate the problem, a plastic cable fairing was evaluated in a field experiment. An empirical value for the fairing drag coefficient was obtained using a mathematical simulation of the mooring. Then, again using the mooring model, comparisons were made of instrument excursions resulting from the use of unfaired cable, faired cable and additional system buoyancy.

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Introduction

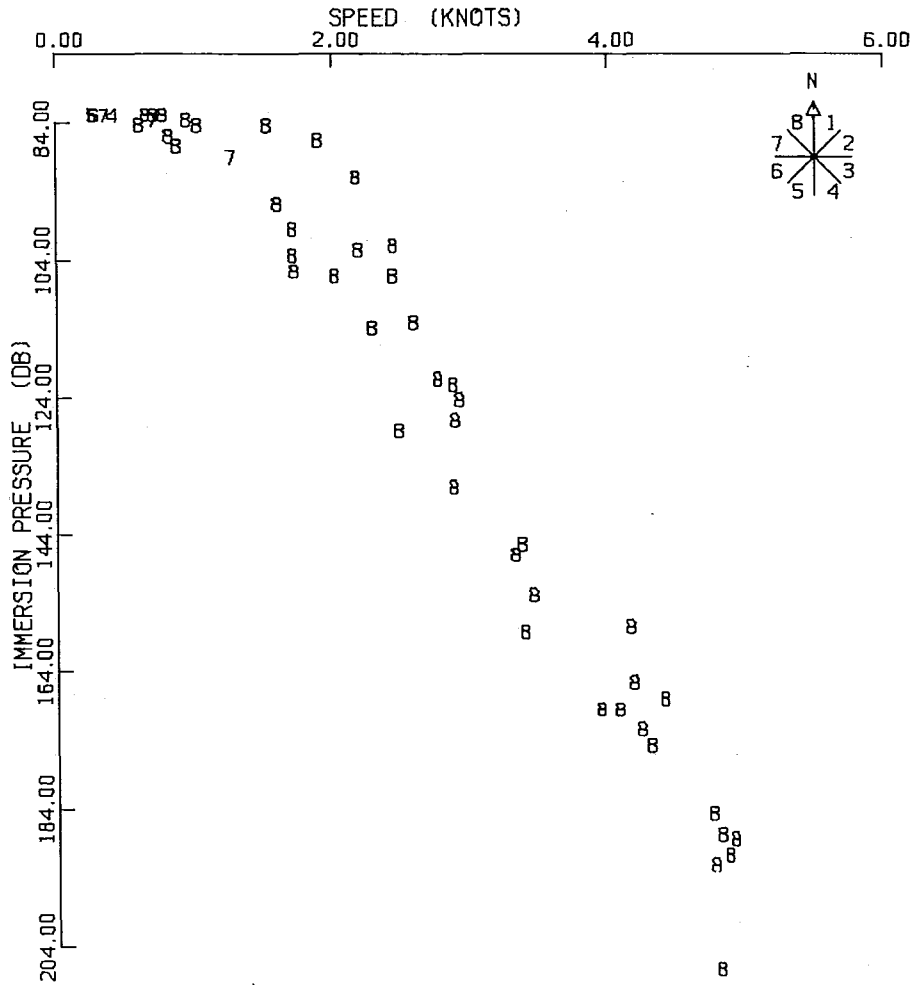
Hydrodynamic drag forces on cables used for mooring an array of current meters or other instruments, where the array is supported by a subsurface buoy, result in excursions of the instruments over some interval of depth as the current varies in strength. These excursions are undesirable inasmuch as they prevent measurements from being obtained at the desired vertical positions at all times and they make the task of correlating measurements from different stations more difficult. Figure 1 shows such a case, where sequential samples from current meter sensors show the vertical position *vs* the current speed at that position over a period of about 8 hours. In this particular case, the current meter was suspended 60 m below a spherical buoy whose rest position was at a depth of 40 m. Total length of $\frac{1}{4}$ -inch diameter wire rope mooring line was 275 m. Note that the maximum vertical displacement shown is equivalent to about 120 m in depth as the current speed approached 5 knots. The numbers used to denote the data points in Figure 1 refer to direction octants.

One means of reducing the effect of the cable drag is to increase the buoyancy of the system. Another possibility for improving the situation is to reduce the actual drag by fairing the cable to produce a more streamlined profile. An extruded plastic fairing for $\frac{1}{4}$ -inch diameter cable is made by Fathom Oceanology Limited of Port Credit, Ontario, marketed under the trade name of "Rigstream" fairing. It was decided to try a field experiment to evaluate this product in actual use. A contract was let to Dobrocky Seatech Ltd. of Victoria, B.C. to deploy and retrieve a test mooring utilizing three current meters on a faired cable and, subsequently, to provide the Institute of Ocean Sciences, Patricia Bay with the resulting data tapes for analysis, together with a report describing the mooring activities (Dobrocky Seatech Ltd., 1977). The drag coefficient for the fairing was unknown, but was to be estimated by using the data in conjunction with a numerical computer model (Bell, 1977).

Field Program

The site chosen for the test mooring was in Haro Strait at the position $48^{\circ}35.6'N$, $123^{\circ}15.5'W$. Prior experience suggested that the velocity profile at this location was quite uniform in both amplitude and direction, especially during periods of large tidal range. The condition of uniformity over depth facilitates subsequent analysis. The water depth at the site is approximately 720 ft.

The mooring was deployed on October 22, 1976 and remained in position until November 1, when it was retrieved. Because of some handling difficulties during installation of the system, the exact amount of fairing applied to the cable was not recorded. The fairing segments were each 2 feet long and it was known that a few segments were left off so that the personnel involved could grip the cable more easily to restrain its motion during deployment. It was also noticed, as the cable moved overboard, that a few segments of fairing were improperly installed. It is suspected that these fell off the cable shortly thereafter. Upon retrieval, the remaining length of fairing was obtained and corresponded to approximately 93% of the total wire rope length.



SCATTER DIAGRAM - PRESSURE VS. VELOCITY

Figure 1. Vertical excursion of a current meter. System buoyancy - 800 lb, length of line between current meter and anchor - 215 m, sample interval - 10 min, tidal range - 2.5 m.

The current meters used in the moored array were Aanderaa Model RCM-4's, equipped with pressure sensors. The pressure sensor accuracy is quoted as being better than 1% of the range. The sensor in the uppermost meter of the array had a range of 0-200 psi, with an accuracy equivalent to ± 4.5 ft of saline water. The sensors in the other two instruments had a range of 0-500 psi, with a correspondingly reduced accuracy. A further consideration is the resolution provided by one data bit in the data logger, which is equivalent to 0.5 ft of water. Thus, an uncertainty of one bit in each pressure reading could result in an error of ± 1 ft in determining depth differences. A value for the hysteresis error of the pressure sensors is not given but, for small changes in depth, it could result in a substantial percentage error in depth differences. The accuracy of directions obtained from the magnetic compass is given as $\pm 5^\circ$ by the manufacturer. The direction and pressure data are obtained as instantaneous values, whereas the speed is integrated over the sample period. The sampling interval used in the present instance was 2 minutes.

A spherical steel buoy with a diameter of approximately 3 ft and a weight in air of 322 lb was used as a subsurface float for the array. It was planned for installation at a height above bottom of about 520 ft, using $\frac{1}{4}$ -inch diameter 6x19 steel cable to connect it to an anchor clump of 3 railway wheels and an 80 lb Danforth anchor. The three current meters were to be positioned at 100 ft, 300 ft and 500 ft above bottom in quiescent water, i.e. a spacing of 200 ft between instruments. The actual separations, as obtained by measurement of the components involved and allowing for some cable stretch, were slightly different and are given in Table I. The current meters are actually installed in the cable by means of a spindle and gimbal arrangement, with the cable fastening to the ends of the spindle. The pressure sensor location is about 1 ft below the upper end of the spindle, whose total length is about 2.4 ft. This is reflected in the entries of the table.

Sensor Data

The data records obtained from the test mooring were carefully examined to obtain a good sample set for subsequent processing. Unfortunately, the instrument in the middle position had an intermittent malfunction which narrowed the choice of samples considerably. The chosen data set is presented in Table II. There is good correspondence of the velocities. The directions are slightly different at the bottom sensor, but not enough to be of much consequence. For subsequent use in the mathematical mooring model, the mean of 10 samples is used. This is an aid in smoothing out irregularities in the data arising from the previously mentioned difference in sampling technique between speed and pressure or direction, or from nonuniformities in the velocity profile between measurement stations. It should also be pointed out that, while oceanographic variables are normally reported in the metric system as in Table II, they will here be converted to engineering units (ft-lb-sec) for use in the mooring model. These units are used in the model because of the present utility of the force unit in connection with mooring systems (as anyone who tries to purchase a cable with a breaking strength of X newtons will soon find out). Table III presents some pertinent data thus converted.

TABLE I. Mooring Component Dimensions

<u>Component</u>	<u>Length (ft)</u>	<u>Distance between Major Components (ft)</u>
Anchor clump	2.0	
Unstretched cable	96.5	
Cable extension	0.1	
Swivel & shackles	1.0	
Lower spindle end (LSE) to bottom pressure sensor	1.4	
		101.0
Bottom pressure sensor to upper spindle end (USE)	1.0	
Unstretched cable	198.7	
Cable extension	0.3	
LSE to middle pressure sensor	1.4	
		201.4
Middle pressure sensor to USE	1.0	
Swivel & shackles	1.0	
Unstretched cable	199.0	
Cable extension	0.3	
LSE to top pressure sensor	1.4	
		202.7
Top pressure sensor to USE	1.0	
Swivel & shackles	1.0	
Cable	21.3	
		23.3

TABLE II. Data Obtained From Current Meter Sensors

Record No.	Instrument No.								
	2199			2326			2194		
	Pressure (m)*	Direction (°T)	Speed (cm/sec)	Pressure (m)*	Direction (°T)	Speed (cm/sec)	Pressure (m)*	Direction (°T)	Speed (cm/sec)
251	75.7	153	151	138.2	159	158	194.9	140	154
252	76.0	153	151	138.6	159	139	194.9	139	139
253	75.7	153	146	138.6	153	146	194.9	137	144
254	75.1	152	144	138.6	154	140	194.9	135	151
255	74.7	153	146	137.9	160	139	194.9	134	141
256	74.7	158	141	137.9	162	139	194.9	138	146
257	74.8	159	146	137.9	164	139	194.9	140	140
258	74.5	157	144	137.9	162	137	194.9	141	143
259	74.7	160	140	137.9	157	151	194.9	142	153
260	75.7	158	141	138.6	155	175	194.9	141	153
Mean Value	75.2	155.6	145.0	138.2	158.5	146.3	194.9	138.7	146.4
Rest Position	66.3			129.9			192.4		

Mean value of all speed samples = 146 cm/sec

Mean value of all direction samples = 151°T

* Pressure unit is meters of fresh water

TABLE III. Sensor Data Converted To Ft-Lb-Sec System

	Instrument No.		
	2199	2326	2194
Mean Depth (ft)*	240.9	442.8	624.4
Rest Position (ft)*	212.4	416.2	616.4
Change in depth (ft)	28.5	26.6	8.0

Mean speed = 4.8 ft/sec

Mean direction = 151°T

* Depth is obtained from the pressure reading and includes the effect due to the water column being saline (specific gravity = 1.024).

The Mooring Model

Mathematical simulation of the mooring system is accomplished by writing the appropriate static force balance equations for the buoy, the cable and the instruments, and solving them simultaneously using a numerical integration procedure. Boundary conditions are established by the buoy at the upper end of the cable and the integration proceeds from there, in discrete steps, to the anchor end of the cable. Here, the anchor and the bottom must coincide (within a specified limit) or an iteration is necessary. Because of the step-wise integration, the cable consists of an integral number of segment lengths and instruments can only be inserted between segments. As a result, the model dimensions must be altered slightly from those of the real system it is intended to simulate. The effect of this is shown in Table IV for the present case. The next requirement is one of setting out the remaining model input parameters with reasonable accuracy, as presented in Table V.

A value for the drag coefficient of the fairing is assumed and the model predictions obtained for the change in depth of the sensors under the influence of the given current. When this is done for two or three different values of drag coefficient, an interpolation can be made for that coefficient which corresponds to the measured depth excursions. Mention should be made of the fact that only the normal drag force is considered here, consisting principally of form drag, but including a small additive skin friction term. Longitudinal drag is neglected as an unnecessary complication (although provision for calculating it is included in the model). Thus, if the cable is at an angle to the flow, the drag is taken basically as the product of the square of the sine of the angle and the drag which would occur normal to the flow. So long as the angles involved are reasonably close to 90°, the error

due to the omission of frictional drag in the axial direction is small.

TABLE IV. Mooring Component Rest Position Distances (ft above bottom)

Component	Distance			
	Planned	Measured	Pressure*	Model
Bottom sensor	100	101.0	101.1	100
Middle sensor	300	302.4	301.3	300
Top sensor	500	505.1	505.1	506
Buoy	520	528.4	528.4	528

Model cable segment length = 2 ft

No. of segments = 264

* Derived from pressure sensor data assuming a water depth of 717.5 ft so that the top sensor position coincides with the measured value.

Fairing Drag Coefficient

Two model simulations were made, using C_{DF} values of 0.45 and 0.55.

These resulted in predicted depth excursions which bracketed the actual excursions of the upper two current meters. A linear interpolation was then made, indicating coincidence of the measured and predicted excursions at a value of $C_{DF} = 0.50$ for the upper instrument, $C_{DF} = 0.52$ for the middle instrument, and $C_{DF} = 0.28$ for the lower one. This latter value is suspect in light of the agreement in results for the top two meters. Also the bottom sensor underwent a relatively small excursion with a possibility of a relatively large hysteresis error. Much more confidence is placed in the result obtained from the top sensor, since it is the most accurate of the three used and it experienced the largest excursion in depth. Thus, the value used henceforth for the drag coefficient of the fairing (based on frontal area) is:

$$C_{DF} = 0.50$$

for sub-critical flow. The uncertainty in this value due to the data logger accuracy of ± 1 bit is only ± 0.02 . More uncertainty resides in the lack of complete knowledge of the velocity profile, but a number cannot readily be assigned to this.

TABLE V - Model Input Parameters

1. Velocity Profile:

Uniform, 4.8 ft/sec

2. Buoy:

Radius = 1.542 ft

Reynolds No. = 9.9×10^5 (super-critical)

$C_{DB} = 0.2$

Buoyancy = 984 lb (for specific weight of water = 64 lb/ft³)

Weight = 322 lb

Weight, including the weight in water of swivels and shackles = 356 lb.

3. Cable:

(a) Wire Rope:

Diameter = 0.021 ft

Reynolds No. = 6.7×10^3 (sub-critical)

$C_{DR} = 1.4$

Weight = 10.0 lb/100 ft

Buoyancy = 2.2 lb/100 ft

Unstretched length = 515.5 ft (excluding swivels and current meter spindles)

(b) Fathom Rigstream Fairing:

Width (frontal aspect) = 0.030 ft

Chord = 0.125 ft

Reynolds No. = 4.0×10^4 (based on chord)

$C_{DF} =$ To be determined

Weight = 10.2 lbs/100 ft

Buoyancy = 7.5 lbs/100 ft

Length = 478 ft

(c) Fairing - Wire Rope Combination:

Width = 0.030 ft

Weight = 20.2 lbs/100 ft

Buoyancy = 9.7 lbs/100 ft

4. Instruments (Aanderaa current meters):

Diameter = 0.42 ft

Reynolds number = 1.3×10^5 (sub-critical)

$C_{DI} = 1.1$

Weight = 54 lb

Buoyancy = 17 lb

Frontal area = 0.5 ft²

Instrument locations = 24, 228, 428 ft from buoy

At first glance, the estimated drag coefficient value seems high for a reasonably streamlined shape. However, it should be emphasized that the flow regime is sub-critical, i.e. the boundary layer has not yet become turbulent with a consequent rearward movement of the flow separation points. (Also, we have usually had much more exposure to examples of super-critical drag coefficients for streamlined bodies.) Hoerner (1958, p. 13-19) shows a fairing having a cross-section almost identical to that of the Rigstream fairing, except that the trailing edge is less blunt. He gives a sub-critical drag coefficient of 0.73 for that fairing, and a super-critical coefficient of 0.16. Almost always, the cable of any normal mooring system will experience only sub-critical flow; towed systems may be subjected to super-critical flow.

As a check on the validity of the estimate for C_{DF} , the derived value is used for a prediction of instrument excursion corresponding to another point in the empirical data set. At this point, the data is not constant over more than 2 or 3 samples, but it is smoothly varying so we can, with some confidence, use specific records for a spot check, dispensing with averages as used previously. For this case, the converted data is given in Table VI. The velocity profile is obviously not uniform but does appear to be almost linear. Therefore, a least-mean-squares fit was used to obtain coefficients for a profile of the form $V = a + bz$, where V is the velocity and z is the depth. The predicted instrument excursions are also shown in Table VI. It is seen that the uppermost two instruments were actually displaced downwards more than the distance predicted by the model, with the disagreement being of the order of 10%. The indication is either that the estimated drag coefficient for the fairing is too small or, more likely, that the velocity between instrument positions was higher than assumed.

TABLE VI. Data Pertaining to Check on C_{DF} Estimate

	Instrument No.		
	2199	2326	2194
Current Speed (ft/sec)	6.2	5.4	4.2
Current Direction (°T)	150	157	144
Recorded Instrument Depth (ft)	269.5	463.6	631.2
Rest Position (ft)	212.4	416.2	616.4
Actual change in depth (ft)	57.1	47.4	14.8
Predicted change in depth (ft)	51.3	43.2	19.6

Effect of Faired Cable

Now that an estimate of fairing drag has been obtained, the reduction effected in the magnitude of instrument excursions due to use of the fairing can be determined by having the mooring model simulate both faired and unfaired cables at various current speeds. Since the test mooring was typical of a normal data-gathering array, it will continue to be used as an example.

Table VII presents the results of several such simulations. An examination of this data indicates that a substantial reduction in vertical excursion depth is obtained by using the fairing, with the largest percentage reduction occurring at the lower velocities.

TABLE VII. Predicted Instrument Excursions at Several Current Speeds Using Faired and Unfaired Cable (All values are in feet).

Instrument Position	V = 4 ft/sec		V = 6 ft/sec		V = 8 ft/sec	
	Faired	Unfaired	Faired	Unfaired	Faired	Unfaired
Top	14	30	55	102	120	186
Middle	12	28	49	89	101	154
Bottom	6	14	24	41	45	64

Effect of Increased Buoyancy

It is instructive to examine the reduction in excursion depth which results from an increase in the buoyant force at the upper end of the cable. The most practical way of adding buoyancy is to do it in modules corresponding to the available buoys, i.e. install additional buoys in the system. In practice, this may require the use of a heavier anchor as well. If carried to extremes, a stronger (and thicker) cable would be necessary, leading to some additional drag, and this might well invoke the law of diminishing returns. For the present example, the provision of two identical buoys in the system does not require any increase in cable strength. The predicted excursions in such a case are given in Table VIII. The results there can be compared with the two situations presented in Table VII, where it will be seen that a much greater reduction in excursion depth is obtained through the addition of an extra buoy as compared to the addition of cable fairing. This is more clearly seen, perhaps, in Figure 2, where the data pertaining to the top instrument of the moored array is plotted for each of the three situations discussed above.

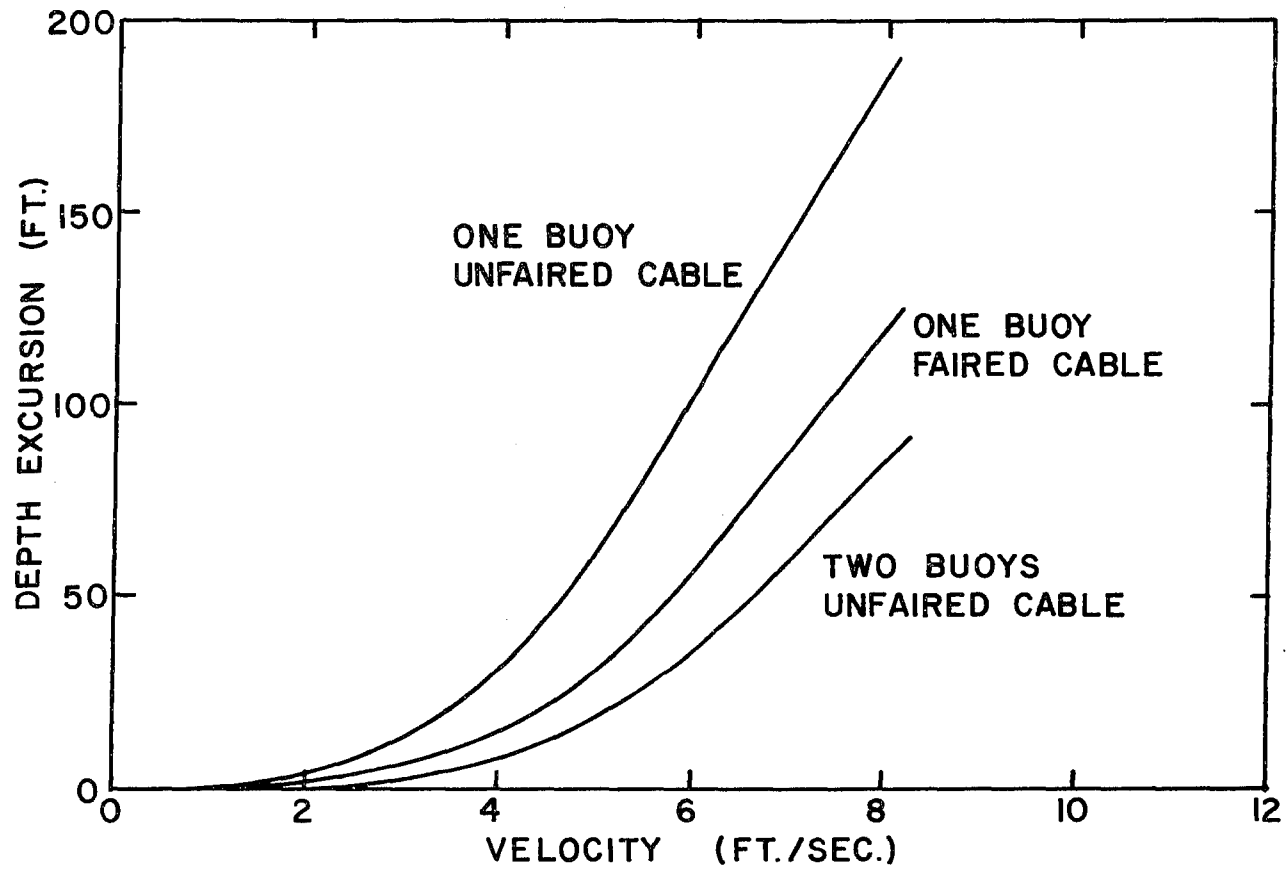


Figure 2. Vertical deflection from rest position for the top instrument in a moored array.

TABLE VIII. Predicted Instrument Excursions at Several Current Speeds Using Two Buoys and Unfaired Cable (All values are in feet).

Instrument Position	V = 4 ft/sec	V = 6 ft/sec	V = 8 ft/sec
Top	8	35	85
Middle	7	31	72
Bottom	3	14	32

Conclusion

The preceding considerations show that a cable fairing can be used to reduce cable drag and, thereby, the vertical excursions undergone by instruments on the cable when the current speed increases. However, a more effective way of reducing the excursions is to double the buoyant force at the upper end of the cable. In all likelihood, it will be easier to cope with an extra buoy during the installation of an array than it will be to handle a cable covered with plastic fairing. Some consideration must be given, though, to the increased anchor weight required by the use of an additional buoy, and to the possibility that a heavier cable might also be required if the extra buoyancy increases the cable load beyond the normal working range.

Another point, not yet discussed, concerns the "strumming" behaviour of a cable. Strumming, or vibration, results when vortices are shed from an object at a frequency close to the natural frequency of the object. This is apparently a common occurrence with wire rope and may result in a substantial increase in drag. Vortex shedding is inhibited by the use of a splitter plate or fairing, so this may well be a consideration in favour of the plastic fairing. There is an easier-to-use alternative here as well, in the form of the so-called "haired" fairing. This consists of a multitude of flexible plastic threads or ribbons fastened permanently to a cable in such a fashion as to trail downstream from the cable, acting as splitter plates to inhibit vortex shedding.

Acknowledgements

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