

AD-A058 745

NEVADA UNIV RENO ENGINEERING RESEARCH AND DEVELOPME--ETC F/6 13/10  
PERFORMANCE TESTS AND ANALYSES ON A 7 FOOT HYDROSPHERE MODEL.(U)  
JAN 77

UNCLASSIFIED

N00600-76-C-1815

NL

| OF |

AD  
A058745



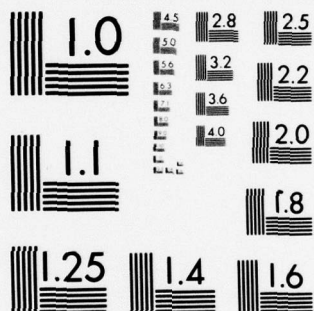
END

DATE

FILMED

11-78

DDC



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

AD A0 58745

DDC FILE COPY

N00600-76-C-1815

**DISTRIBUTION STATEMENT A**

Approved for public release  
Distribution Unlimited

① SC  
**LEVEL** *EF*

DDC  
RECEIVED  
SEP 15 1978  
A -

78 07 26 067

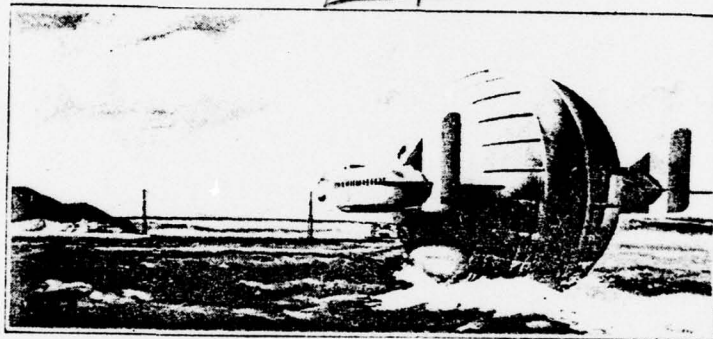
AD A0 587 45

DDC FILE COPY

⑥  
"PERFORMANCE TESTS AND  
ANALYSES ON A 7 FOOT  
HYDROSPHERE MODEL."

⑪  
14 Jan 1977

⑫ 52p.



①  
**LEVEL II**

DDC  
**RECEIVED**  
SEP 15 1978  
A

⑬  
N00600-76-C-1815

Prepared for:

Engineering Research and  
Development Center (ERDC)  
College of Engineering  
University of Nevada, Reno  
Reno, Nevada 89507

Prepared by:

Scientific Engineering Systems, Inc.  
55 North Edison Way  
P.O. Box 1171  
Reno, Nevada 89504  
(702)-322-7109

ORIGINAL CONTAINS COLOR PLATES: ALL DDC  
REPRODUCTIONS WILL BE IN BLACK AND WHITE

Sub  
Contract

410 846  
**78 07 26 067**

13



# TABLE OF CONTENTS

|                                                                                     | <u>Page</u> |
|-------------------------------------------------------------------------------------|-------------|
| I. BACKGROUND INFORMATION . . . . .                                                 | 1           |
| II. ACQUISITION, PROCESSING AND TABULATION OF THE<br>ADDITIONAL TEST DATA . . . . . | 5           |
| III. GRAPHICAL PRESENTATION OF THE DATA . . . . .                                   | 11          |
| IV. CONCLUSIONS AND RECOMMENDATIONS . . . . .                                       | 24          |
| V. APPENDICIES                                                                      |             |
| A. TABULATION OF THE DATA                                                           |             |
| B. FILM RECORD                                                                      |             |
| C. COMPUTER PROGRAM USED TO REDUCE THE DATA                                         |             |

|                                                           |                                     |
|-----------------------------------------------------------|-------------------------------------|
| ADDITIONAL TEST                                           |                                     |
| DATE SECTION                                              | <input checked="" type="checkbox"/> |
| FILE SECTION                                              | <input type="checkbox"/>            |
| <i>copy sheet</i><br><i>R-78-1268</i><br><i>John 1977</i> |                                     |
| <small>DATE OF SPECIAL</small>                            |                                     |
| <i>A</i>                                                  |                                     |

RE: Appendix A  
The pages that have the printing cut  
off are not important per Mr. D. Smith,  
DTNSRDC

## I. BACKGROUND INFORMATION

The Hydrosphere is a unique vehicle in that it is both a vehicle and a propulsion system in a single form; that is, the sphere is the vehicle and the rotation of the sphere provides the propulsion. Some years ago, this concept was proved by Dr. Alex Dandini, who is currently with the University of Nevada, Reno. Dr. Dandini designed, fabricated, and successfully operated a ten foot diameter sphere. This sphere had small air propellers on each side for directional control and used a gyroscope for lateral stability. Power for the sphere was provided by a 120 hp Studebaker engine driving six automobile wheels which ran on tracks on the shell's interior. The propelling torque was provided by the weight of the engine being forward of the center of buoyancy. It was noted that under static conditions the depth of the submergence was approximately 20% of the sphere's diameter. The exterior was circled by two parallel keel bands, and extending outward from each keel band were 24 propulsion vanes tapering in height from the height of the keel band to about one inch at a distance of three feet outward.

Dr. Dandini operated the Hydrosphere in various sea conditions in and around the San Francisco Bay Area. He reported speeds up to 34 mph and observed high propulsion efficiency (low slip), amphibious operation, and excellent stability. The Hydrosphere was destroyed in a fire before more advanced development could be undertaken. Many years then elapsed before the U.S. Navy became interested in unique concepts for rollercraft and propulsors which operate through air-water interfaces. A meeting was held at the Naval Ship Research and Development Center, Annapolis (NSRDC/A), March, 1973, wherein various new concepts were discussed. Among these was the Hydrosphere as presented by Mr. D.F. Smith (NSRDC/A). It was

decided that basic experiments should be conducted with the Hydrosphere concept to determine such factors as:

- Size and scaling effects in order to justify extrapolation of model results to full size systems.
- Vane spacing and configuration in order to optimize system performance.
- Characterize the Hydrosphere using the concept of "propulsion efficiency."

A study was conducted at the Desert Research Institute (DRI), University of Nevada System, during the period July 1, 1973 to June 30, 1974. The study involved the design, fabrication, and testing of a three foot diameter Hydrosphere model. Various tests were conducted by the DRI to determine the effects of various vane spacings and configurations, the amount of slip, and qualitative information concerning power, stability and smoothness of performance. Some useful data has resulted from these previous studies, namely, proof of concept, slip data as a function of sphere diameter, vane design information, and qualitative data in the form of movie film. It was concluded that a larger diameter sphere should be designed, fabricated, and tested to determine scaling effects as a function of diameter. A seven foot diameter sphere was chosen primarily due to the availability of a mold for fabrication of the sphere using fiberglass.

Scientific Engineering Systems, Inc. of Reno, Nevada was awarded a subcontract by the University of Nevada, Reno to provide engineering services for the management, design, fabrication, and testing phases of the seven foot Hydrosphere program. The actual cost of materials, sphere fabrication, machine shop work, and instrumentation was subcontracted on a direct cost basis. The university of Nevada provided special facilities, instrumentation, and limited support whenever possible.



The seven foot Hydrosphere was successfully designed, fabricated and subjected to initial testing. There have been several reports prepared and submitted to NSRDC/Annapolis during these past two years, namely:

Interim Report I - This report provided background information, theoretical discussions, preliminary design information including structural, power plant considerations, control systems, weight estimates, and experimental procedures.

Interim Report II - This report provided a detailed summary of the various design options considered, the selection of a design method, a design report including structural, control systems, propulsion vane design, engine components, and proposed data acquisition methods.

Interim Report III - This report provided a submission summarizing fabrication procedures, problems encountered, and techniques employed leading to the final assembly of the seven foot Hydrosphere.

Final Report - Part I - This report included a brief outline of each of the above noted Interim Reports, as well as detailed discussions covering the periods of testing. The initial data gathered was presented along with preliminary conclusions and recommendations.

Final Report - Part II - This report included a discussion about throttle control system changes that provided improved steady state performance. Additional testing was accomplished and the results presented in this report. A more detailed discussion of the theoretical aspects of dynamic similarity was presented with specific applications being made to the Hydrosphere concept. A review of 3 ft data was made and the results were also summarized in this report. Conclusions and recommendations for future work were included.

The University of Nevada along with Scientific Engineering Systems, Inc. have been able to complete a considerable amount of design and



fabrication activity and still carry out a significant amount of work in a fairly short time on a modest budget.

The Hydrosphere model was operated satisfactorily and in the opinion of an outside consultant, Dr. Allen Acosta, "...the data obtained are meaningful and represent real physical events for the operation of the Hydrosphere." The basic problem was that there was not sufficient funding available to gather the extensive data required to provide a technical base for the evaluation of the Hydrosphere propulsion concept.

A major justification for additional testing centered around the fact that the University of Nevada had developed an operating model of the Hydrosphere and the performance data taken on this model indicated significant potential for some naval applications. The data were not, however, sufficient to provide an explanation for a significant scattering of data points. An additional contract was let to the Engineering Research and Development Center (ERDC), University of Nevada, to develop and conduct a test program, utilizing the seven foot model for the purpose of generating supplemental data necessary to resolve this apparent disparity and to establish the feasibility of this concept for a variety of potential Navy operational applications.

A subcontract was let to Scientific Engineering Systems to aid the ERDC in developing, conducting and reporting on this additional test program. A suitable test plan was prepared and submitted to the Navy for approval. The basic approved test plan and subsequent field trials are described in the next sections of this report. Also included are conclusions and recommendations for future work.

## II. ACQUISITION, PROCESSING AND TABULATION OF THE ADDITIONAL TEST DATA

A number of test runs were made at two lakes near Reno, Nevada, i.e., Boca Reservoir and Lake Tahoe. The course was set up in each case parallel to the shoreline. The length of the course for the additional testing program was 150 feet. A 16 mm camera was used to record the test runs and a stopwatch was used to provide run times. A summary of the data gathered is shown in Appendix A. A record of the films taken is shown in Appendix B. Runs 1 through 30 represent the data previously reported in Final Report, Part II. The additional testing data were recorded using run numbers 31 through 205.

The data were gathered and categorized according to the following general experimental procedures: (See Appendix A)

### 1. Self propelled, free running mode

Data were gathered while operating the Hydrosphere in a self-propelled, free running mode over the 150' measured course. The data runs under this category are 31-91 and 120-162 (inclusive).

### 2. Self propelled and towing mode (Figure 1)

Data were gathered while operating the Hydrosphere in a self propelled and towing mode over the 150' measured course. The data runs under this category are 92-119 (inclusive).

### 3. Locked sphere and towing mode

The Hydrosphere was "locked" so that it would not rotate. The chase boat provided a tow force and pulled the Hydrosphere over the 150' measured course. The data runs under this category are 163-174 (inclusive).

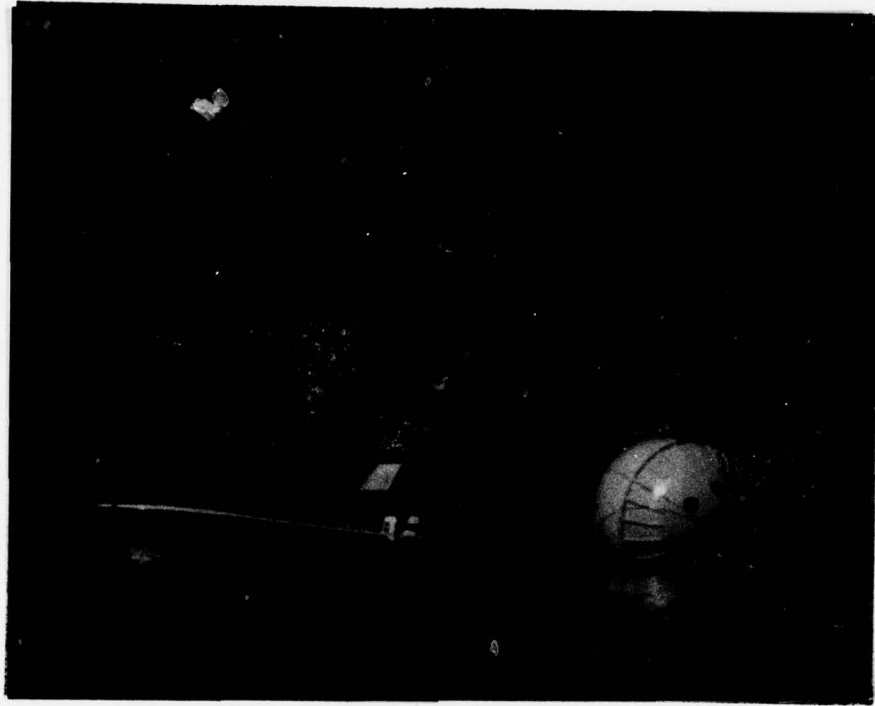


Figure (1) - Photograph showing the Hydrosphere  
towing setup.

4. Free rolling sphere and towing mode

The Hydrosphere was allowed to roll freely by removal of the drive chains. The chase boat provided a tow force and pulled the rolling Hydrosphere over the 150' measured course. The data runs under this category are 175-181 (inclusive).

5. Reverse free rolling and towing mode

The Hydrosphere was allowed to roll freely by removal of the drive chains. The Hydrosphere was pulled "backwards" in order to determine whether or not there would be a noticeable difference due to vane effects. The data runs under this category are 182-186 (inclusive).

6. Underwater films

The Hydrosphere was operated in several self propelled, free running and towing modes while underwater films were taken. The data runs under this category are 187-205 (inclusive).

A special underwater camera system, Figure 2, was fabricated in order to accomplish the underwater filming. A diver was placed in approximately 15-20 ft of water directly under the Hydrosphere test course. Excellent films resulted due primarily to the excellent clarity of the water in Lake Tahoe. The films are quite useful for studying the sphere-water interface under dynamic conditions.



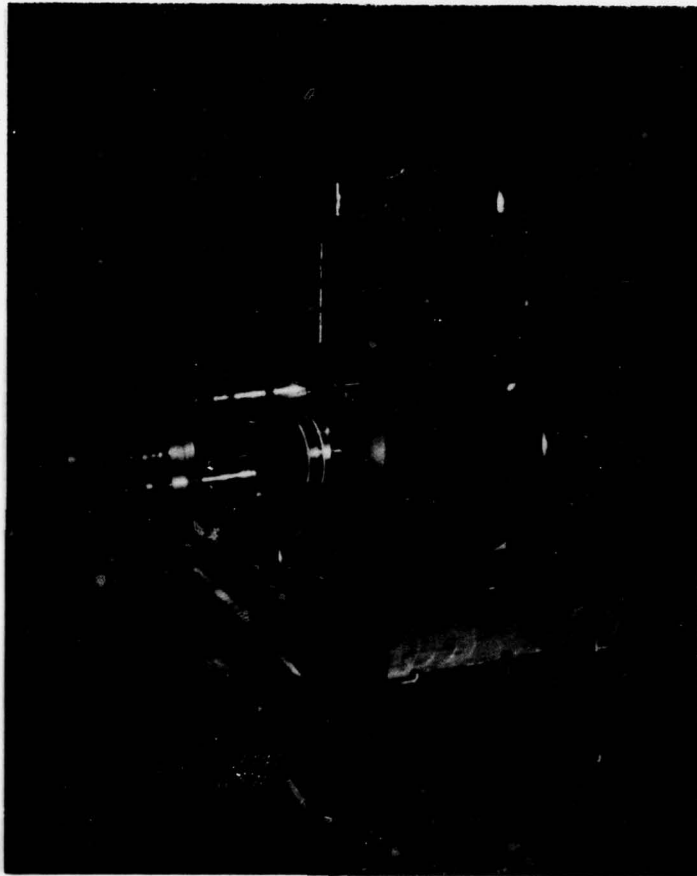


Figure (2) - Underwater camera used for  
filming of the Hydrosphere  
at Lake Tahoe.

A computer program was written to aid in processing the data obtained from the many data runs. This program is included as Appendix C. The general program inputs and outputs are described below:

Program inputs

RUN = Run number  
REV = Number of revolutions over the 150' course  
TIME = Run time over the 150' course (sec)  
THETA = Torque angle of the engine system referenced to equilibrium (degrees)  
FTOWR = Towing force by the chase boat (lbf)  
THETAR = Towing angle of the tow line (degrees)

Program calculations and outputs

The various equations used to process the data have been discussed in detail in Final Report, Part II. A brief summary of these equations and the corresponding program outputs are described below:

- OMEGA =  $\frac{\text{\# of revolutions over the 150' course}}{\text{run time over the 150' course}}$
- SLIP =  $(1 - \frac{R_i}{R_a}) 100 (\%)$

where,

$$\begin{aligned} R_i &= \text{ideal number of revolutions over the} \\ &\quad \text{150' course, i.e., zero slip} \\ &= \frac{150}{\pi D} = \frac{150}{\pi(7)} = 6.8 \end{aligned}$$

and,

$$R_a = \text{actual measured number of revolutions over the 150' course}$$

- VCLFPS = Centerline velocity =  $\frac{150'}{\text{TIME}}$  (ft/sec)

- SPHHP = Power developed by the Hydrosphere  
=  $7.48 * \text{OMEGA} * \sin(\text{THETA})$
- TOWHP = Towing power applied to the Hydrosphere by the boat (lbf)  
=  $\frac{150 * \text{FTOWR} * \cos(\text{THETAR})}{550 * \text{TIME}}$  (hp)
- TOTHP = Total horsepower applied by the Hydrosphere and the tow boat  
= SPHHP + TOWHP
- CD = Effective drag coefficient  
=  $\frac{120 * \text{TOTHP}}{(\text{VCLFPS})^3}$
- FR = Froude number  
=  $\frac{\text{VCLFPS}}{(\text{gD})^{1/2}} = \frac{\text{VCLFPS}}{15.01}$

Also an "effective" drag-lift ratio,  $\eta_t$ , was calculated where

$$\eta_t = \frac{550P}{WV}$$

and,

P = total power applied to the Hydrosphere (hp)

W = total weight of the Hydrosphere (lbs)

V = center line velocity (ft/sec)

The results of these calculations are shown tabulated in Appendix A. The next section of this report will present the various graphical representations that were felt to be best descriptive of the Hydrosphere model performance. Appropriate comments are made concerning each of the data plots.

### III. GRAPHICAL PRESENTATION OF THE DATA

A plot was made of the "effective" drag coefficient  $C_D$  as a function of Froude number  $F_r$  for the Hydrosphere under "locked" sphere and "free rolling" sphere conditions without self propulsion. These points are represented as runs 163-174 (inclusive) for the "locked" sphere and runs 175-181 (inclusive) for the "free rolling" sphere. These data points are shown plotted in Figure 3. These runs were all taken at the same time using the same experimental procedures and equipment, etc.; however, it can be seen that the "free rolling" points appear to be well behaved, while on the other hand, the "locked sphere" points exhibit a more "erratic" behavior. The reason for this is that each of the runs was taken in an opposite direction, so that only every other run is in the same direction. Since there was a light wind blowing at the time, this data would indicate that the rolling sphere performance is much less affected by wind than the locked sphere. It can be seen that in each run the free rolling sphere drag is significantly lower than that for the locked sphere case. The major reason for this is the fact that the rolling sphere is able to pass the bow wave under and around itself thus reducing the effective drag. The data also indicates that above a certain Froude number there is little or no difference between this free rolling and locked sphere operation. This very sharp increase in drag coefficient can also be observed when one considers the relationship between drag - lift ratio and Froude number.

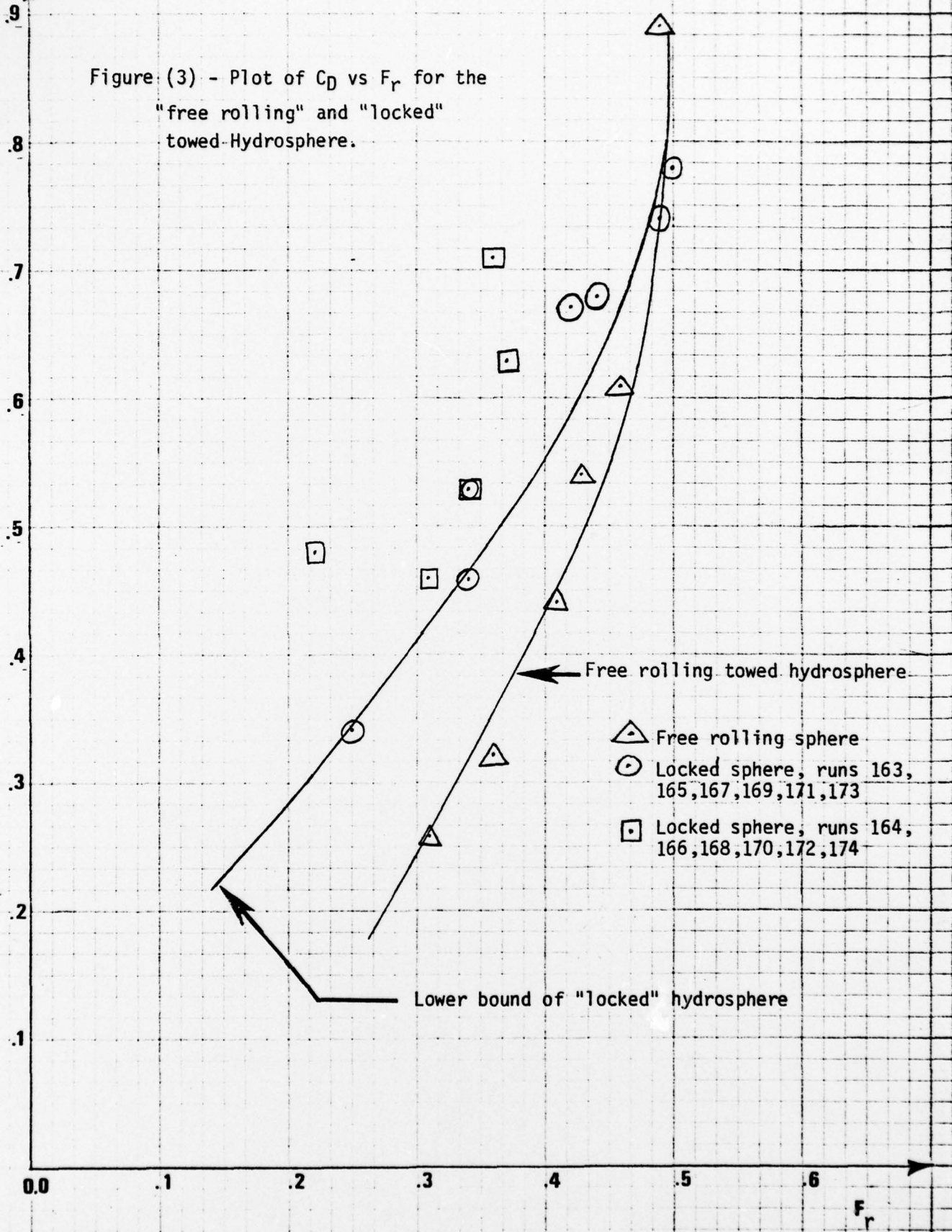
It must be noted that  $C_D$  is truly only an "effective" drag coefficient since the data analysis considered here assumes a constant submerged cross sectional area only, i.e.,

$$C_D = \frac{1100 P_g}{\rho A_s V^3}$$



Figure (3) - Plot of  $C_D$  vs  $F_r$  for the "free rolling" and "locked" towed Hydrosphere.

$C_D$



$$C_D = \frac{120 P}{V^3}$$

$$F_r = \frac{V}{\sqrt{lg}}$$

$F_r$

where,

$$A_s \approx 0.8D^2 F^{3/2} [\sqrt{1-F} + 0.67] \text{ (the submerged cross sectional area, ft}^2\text{)}$$

D = the diameter (ft)

F = fractional part of diameter submerged

P = power (hp)

g = gravitational constant

e = density of the fluid (lbs/ft<sup>3</sup>)

V = centerline velocity (ft/sec)

The locked sphere tends to "sit" more firmly down in the water as the towing force is increased. If it were possible to measure this change in submergence the drag coefficient would be calculated to be somewhat lower than that shown. The free rolling sphere does exhibit an excellent steady state behavior with lower drag.

It should be remembered that when flow occurs past a flat surface parallel to it, the fluid exerts a drag force on the surface as a direct result of viscous action. The resultant frictional force in the downstream direction is usually known as the skin friction drag, and the factors on which its magnitude depends are well covered in the literature. In the case of the Hydrosphere, however, relative flow occurs past a surface which is not parallel to the flow and also the surface is allowed to rotate. There are then additional drag forces resulting from pressure differences over the submerged surface area. One must consider, therefore, not only the skin friction drag due to the forces tangential to the surface but also the pressure or form drag forces that are normal to the surface.

In almost all cases in which flow takes place around a solid body of Reynolds numbers greater than about one hundred, the boundary layer separates from the surface towards the rear of the

body. Downstream of the separation position the flow is greatly disturbed by large scale eddies, and this region of eddying motion is usually known as the wake. As a result of the energy dissipated by the highly turbulent motion in the wake the pressure there is reduced and the pressure drag on the body is thus increased. The magnitude of the pressure drag usually depends very much on the size of the wake and this in turn, depends on the position of separation. The locked sphere is not a streamlined body and hence the flow is separated over much of the surface, thus increasing dramatically the pressure drag. The rolling sphere, on the other hand, maintains an attached flow pattern thus providing a reduced wake and a lesser amount of pressure drag. The data plotted in Figure 3 supports this concept.

The flow pattern in the wake of the Hydrosphere depends on the Reynolds Number of the flow. It is useful, therefore, to consider a plot of Reynolds Number versus the effective drag for the Hydrosphere. It is well documented in the literature that the drag coefficient for a completely submerged sphere exhibits reduced drag when the boundary layer becomes turbulent. This reduction is somewhat more gradual for a sphere than that for a streamlined body because of the smaller contribution made by the pressure drag to the total drag of the streamlined body. A plot of the Reynolds Number,  $R_e$  versus the effective drag coefficient,  $C_D$  is shown in Figure 4. This data is for the locked sphere and towing mode (runs 163-174). The data indicates that a critical Reynolds Number of approximately  $0.8 \times 10^6$  exists where the boundary layer becomes turbulent. There does not appear to be a region where  $C_D$  becomes independent of  $R_e$  at least over the limited ranges of  $R_e$  that were measured. It was felt that underwater photography would aid in gaining an understanding about the flow patterns around the Hydrosphere.



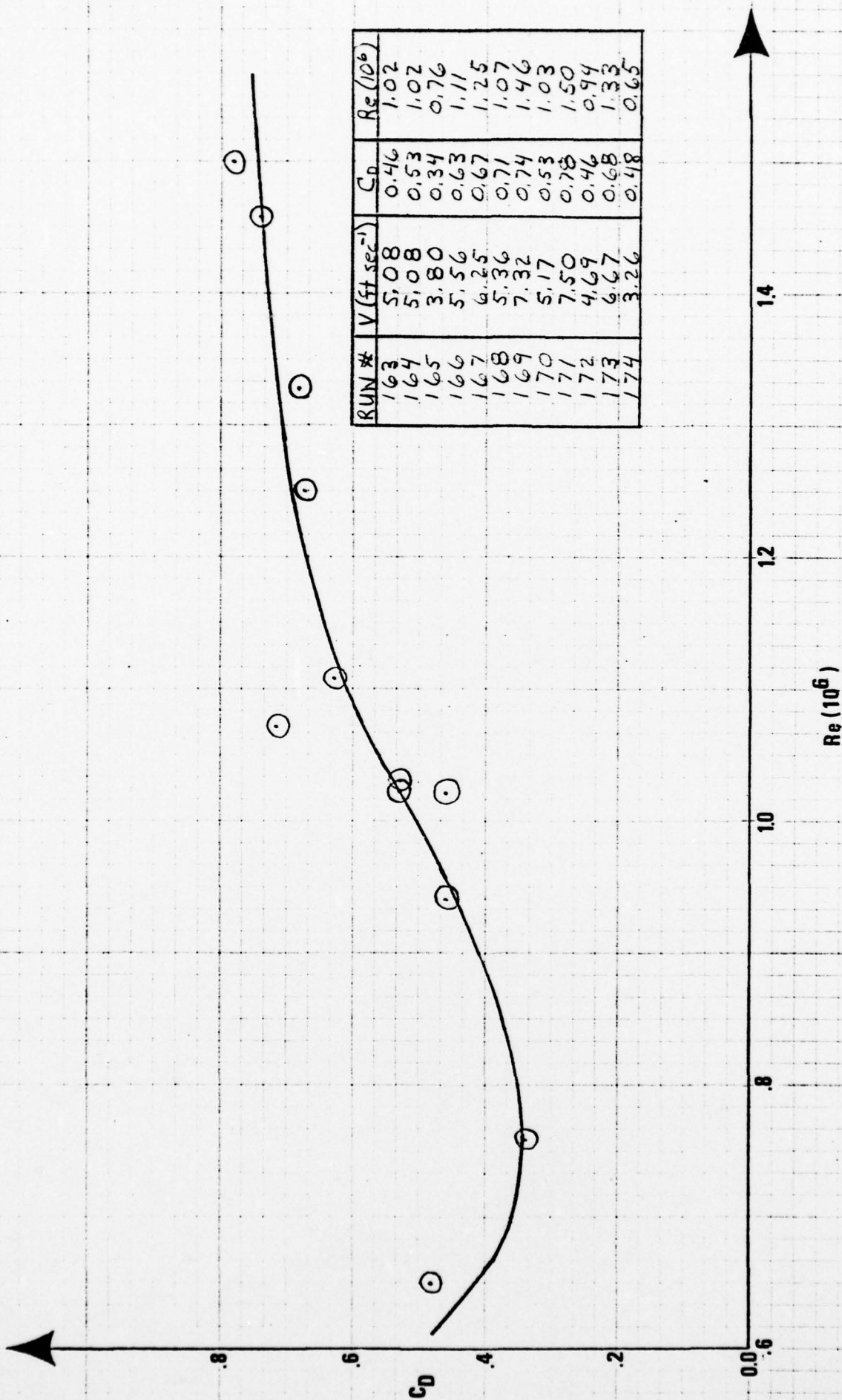


Figure (4) - Plot of  $C_D$  vs Reynolds number for locked rotor



An underwater camera box shown in Figure 2 was constructed of  $\frac{1}{2}$ " thick plexiglass for the 16 mm Bell & Howell movie camera. This box has an optical glass face which accommodates all three lenses of the turret. A crank on the side allows the camera to be rewound while underwater. The standard shutter release is activated by a spring loaded button.

For underwater photography the lenses were set to focus nearer than in air because of the change in index of refraction in going from water to air. Filming speed was 2X and 4X the normally used 16 frames per second. This was done in order to better resolve the flow characteristics. The lens' apertures were adjusted to account for this and for the slightly reduced light intensity underwater.

Underwater movies of the operation of the Hydrosphere were taken at Lake Tahoe which has extremely clear water. All camera work was done by a scuba diver in about twenty feet of water. The diver surfaced between runs in order to coordinate his function with the Hydrosphere crew.

Two 100 foot rolls of color film were made of the Hydrosphere operating self powered and towed/powered with a range of speeds over the 150 foot course.

The developed films have been reviewed for general qualitative information about the flows around the sphere. Air bubbles, generated at the front of the sphere, are carried with the water and act as flow tracers. Figure 5 shows bubbles in the areas of the vanes and between the keel bands. These bubbles typically flow to the points of least pressure within about  $20^\circ$  of sphere revolution after entering the water, and stay attached until they are carried out of the water at the rear of the sphere. The bubbles in the keel band area slowly migrate in the direction of the fluid flow in some cases. The most interesting results, however, show total separation of flow from the keel bands and vanes in some cases. An example of this is shown in Figure 6 where ribbons of bubbles can be seen leaving

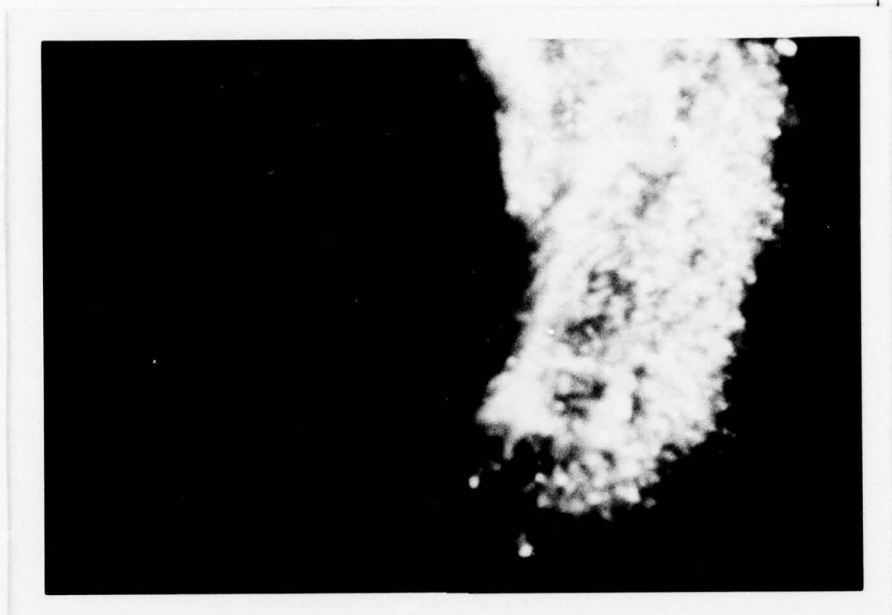


Figure (5) - Underwater photograph showing air bubbles in the area of the vanes and the keel band.



Figure (6) - Underwater photograph showing ribbons of bubbles leaving the sphere surface near the keel bands.

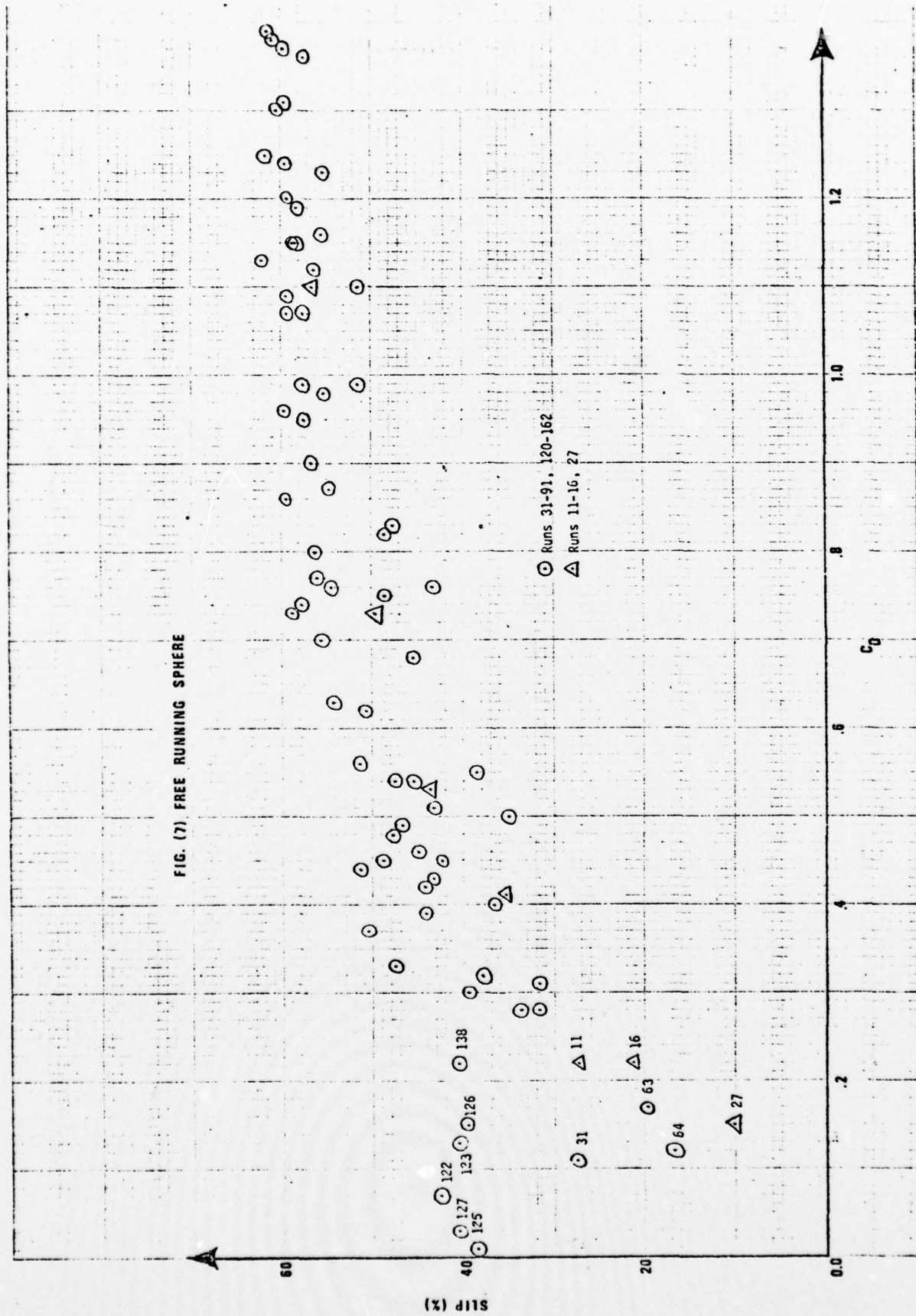
the sphere from the keel bands. This was not observed for the center section of the sphere surface.

In some cases the exhaust from the tow boat left many small bubbles well distributed through the water, which improved flow observation.

These movies were a satisfactory first attempt at underwater work and demonstrate that significant information of this type can be derived in an effective manner. It should be noted that these still photos were rephotographed from the projected movie film and have lost some detail in the processing. The actual movie films are far more graphic and easier to study.

Another plot of interest is a comparison of the drag coefficient  $C_D$  and slip,  $S$ . A plot of runs for the Hydrosphere operating in a self propelled, free running mode is shown in Figure 7 (runs 11-16, 27, 31-91 and 120-162, inclusive). There is a definite interesting relationship between the effective drag coefficient,  $C_D$  and slip. The drag is very sensitive to slip and increases very rapidly for slippage above approximately 40%. More important is the very definite "dual mode" characteristic observed in Figure 7. The Hydrosphere can operate very efficiently even at a higher slip, however a corresponding price is paid in the center line velocity. This fact was confirmed by observing the Hydrosphere's applied power and recording the slip on film over the 150 ft course. The data was also supported by observing the changes in the wave generation characteristics for these runs. The Hydrosphere can develop a mode wherein the drag is greatly reduced and yet the center line velocity is increased. This is clearly shown in runs 11, 16, 31, 27, 63 and 64. During the first analysis it appeared that there was a smooth relationship between the slip and  $C_D$ ; however, as the data were analyzed it became apparent that a dual mode definitely exists. Experimental error would not account for this

FIG. (7) FREE RUNNING SPHERE





phenomenon since the slip measurements are recorded on film and hence are easily and accurately determined; and also the power measurements are verified by observing from the film the magnitudes of the wave generative characteristics. For example, runs 123, 31, and 64 did exhibit approximately the same wave generating characteristics; however, the slip varied from 40% down to 10%. There was also a corresponding increase in the centerline velocity from 4.23 ft/sec for run 123 to 6.45 ft/sec for run 27.

This data supports the theory that boundary layer control may be the significant factor for Hydrosphere performance. It is not completely understood just how one maintains the low slip, higher velocity mode; however, it does merit further study. It is interesting to note that the most efficient runs occurred when the Hydrosphere was operated at an angular velocity of

$$.31 \leq \omega \leq .39 \text{ (rev/sec)}$$

A tabulation of these runs is shown in Table I.

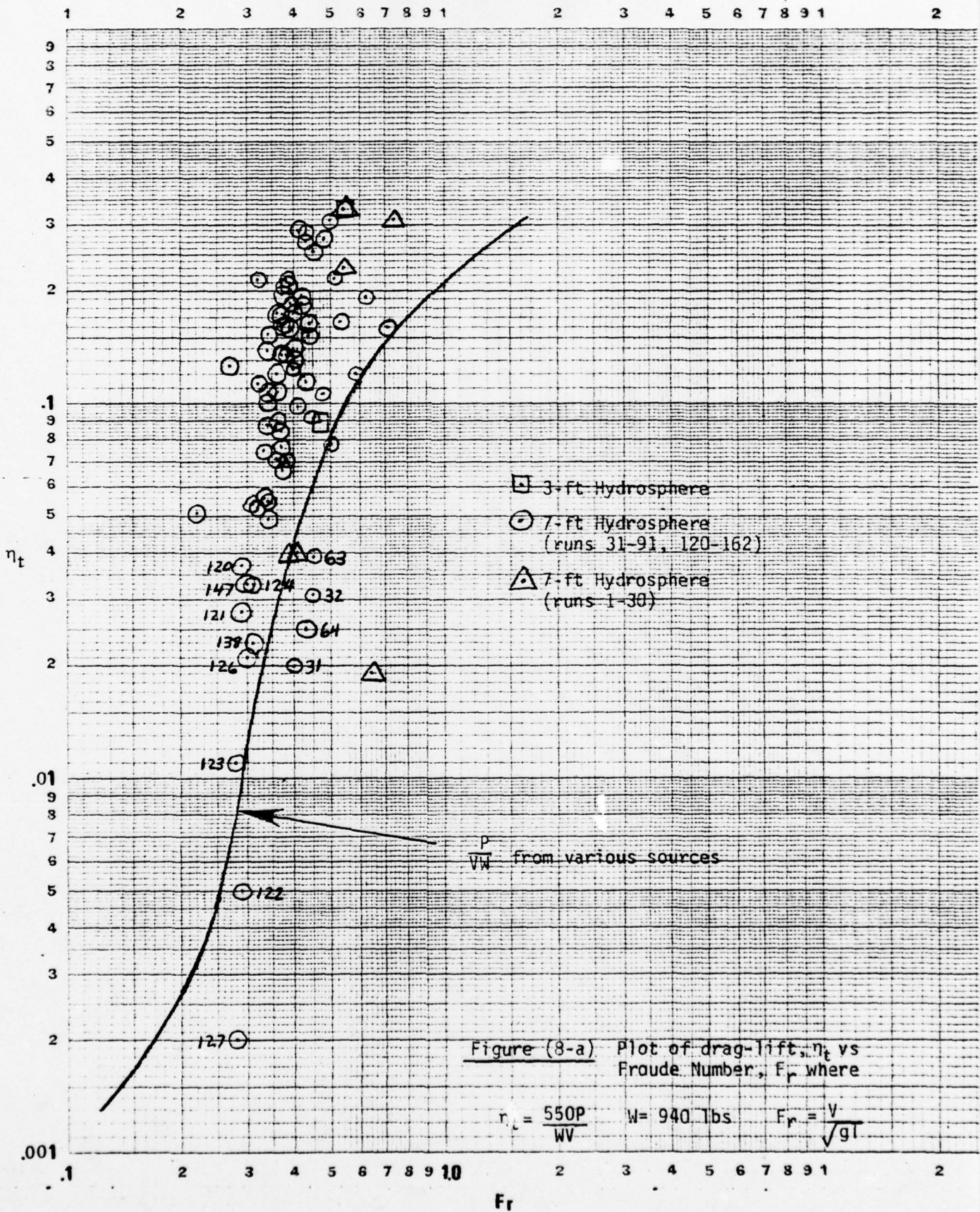
There is another set of curves that can help to compare the Hydrosphere to other types of water craft, that is, a plot of the drag-lift coefficient,  $\eta$ , versus the Froude Number,  $F_r$ . These plots, Figures (8a, 8b) cover the data gathered in the field running self-propelled mode (runs 1-30, 31-91, and 120-162) and the towing plus self-propelled modes (runs 17-22, and 92-119). The question of data scatter has been resolved as can be seen in Figure 8. The Hydrosphere does actually exhibit a wide range of operating characteristics when one compares  $\eta_t$  with  $F_r$ . In fact it appears doubtful that the Hydrosphere can be adequately classified using only this type of classical comparison for the watercraft. It does suggest, however, that the Hydrosphere concept can be utilized by special design for a wide range of applications and operating conditions.

| Run # | $\omega$ (rev/sec) | $C_D$ |
|-------|--------------------|-------|
| 11    | .36                | .22   |
| 16    | .34                | .22   |
| 27    | .32                | .15   |
| 31    | .38                | .11   |
| 63    | .39                | .17   |
| 64    | .36                | .12   |
| 122   | .34                | .07   |
| 123   | .32                | .13   |
| 125   | .31                | .01   |
| 126   | .34                | .15   |
| 127   | .32                | .03   |
| 138   | .35                | .22   |

Table I

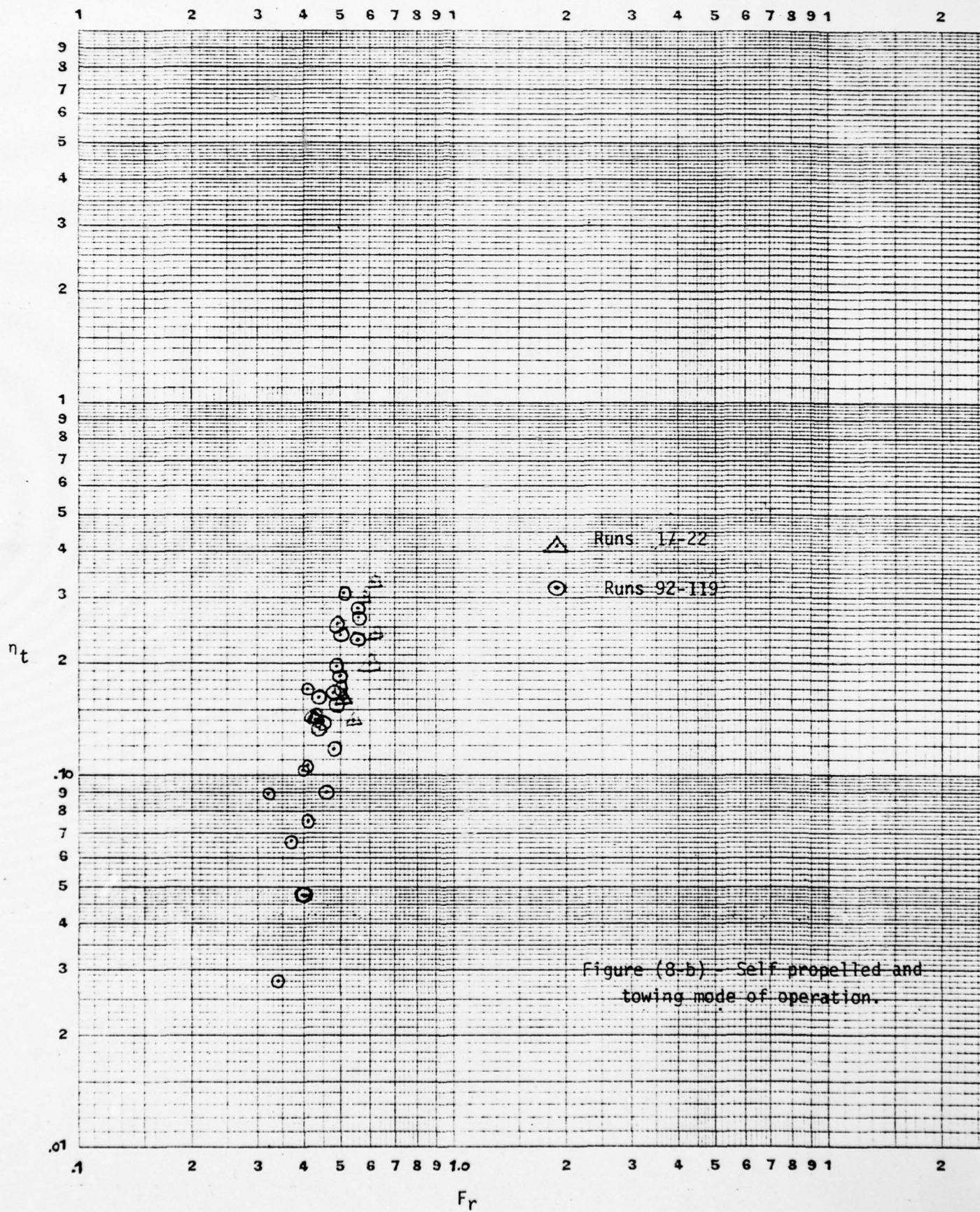
Tabulation of runs showing drag values,  
 $C_D$  below 0.23.

Free Running Sphere





# Towed Sphere





#### IV. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The Hydrosphere concept has been evaluated in detail and attempts made to quantify performance parameters. Extensive experimental data have been gathered and analyzed in an effort to describe and predict Hydrosphere performance characteristics. This new propulsion concept exhibits very complex flow characteristics, especially when compared to the more conventional watercraft. The work accomplished to date does, however, allow several conclusions to be reached.

- (a) The Hydrosphere concept produces a stable operating system.
- (b) Excellent lift-drag ratios can be obtained even at significant slip; however, when speed is of concern additional consideration must be given to the slip parameter.
- (c) The Hydrosphere exhibits definite "multi-mode" characteristics. This means that the craft can be operated in a low slip and correspondingly higher velocity mode, that is quite different from that of a conventional planing watercraft.
- (d) The Hydrosphere can be operated over a wide range of velocity and drag-lift ratios. The concept provides a number of interesting alternatives for proposing new types of multi terrain vehicles.
- (e) It is not understood at this time what operating parameters are the most critical to operating the Hydrosphere in the highly efficient low slip mode.
- (f) The rolling sphere was less susceptible to wind loading than was the "locked" sphere. Also the rolling sphere developed less total drag than the locked sphere.
- (g) The Hydrosphere is basically a boundary control type watercraft. It has been shown that there are definite modes wherein highly

efficient low slip operation can be achieved. The effects of towing were not very great in that little was gained by applying significant towing power to the sphere. It is felt that this is because of the experimental difficulty in towing the Hydrosphere with the proper degree of forward slip, which may be necessary to achieve the low drag mode.

- (h) The 7' Hydrosphere "optimum" mode occurred in all cases when the angular velocity,  $\omega$ , was between  $.32 \leq \omega \leq .39$ .
- (i) There is sufficient data favorable to the Hydrosphere concept to justify further research.

There are still several important questions to be answered before one can understand and characterize the Hydrosphere concept. The basic questions are:

- How to model and scale Hydrospheres since it is still not clear what methods or parameters can be used for scaling performance to larger spheres. The general wave generating characteristics appear to be similar when one observes the wave generating performance of the 3', 7' and 10' Hydrospheres; however, the effect of loading has not been determined. There is sufficient evidence to warrant further study into the Hydrosphere concept.

The next step in the Hydrosphere program should be a special set of tests designed to evaluate Hydrosphere performance under various loading conditions. This was not possible to accomplish within the present experimental project because the 7 ft Hydrosphere model was already operating at a 17% submergence level and it was not possible to lighten the model. It should be possible, however, to operate and gather performance data on a body of water having a greater density. This has the same effect as less load, the case of greatest interest.

For example, performance runs on the Great Salt Lake in Utah could provide a suitable set of data to evaluate Hydrosphere performance under controlled loading conditions.

Such a set of data could also provide a basis for determining whether or not loading is a significant factor to having the Hydrosphere operate in its higher velocity-lower slip mode. It is felt that these runs could be accomplished rapidly for less than \$8,500. The Hydrosphere model and support equipment (with personnel) could be moved to Salt Lake for a week or ten day period of testing.

The Hydrosphere concept should be of interest to the Navy based on the already demonstrated performance characteristics. For example, it is possible with the present data to consider the Hydrosphere as a low velocity, efficient watercraft capable of moving cargo over swamp areas and inland waterways. Once the cargo has been delivered the craft could then achieve a higher velocity for the return trip to the cargo staging area. This concept, for example, could provide the Navy with a watercraft capable of transporting standard containers over multi terrain conditions. It is also felt that the variable loading tests described above could greatly aid in helping to determine and predict Hydrosphere performance especially since multi mode performance has been experimentally observed.

# APPENDIX A

This Appendix includes the entire set of data for the extended Hydrosphere project. Runs 11 through 30 were presented and discussed in the Final Report Part II, dated October 20, 1975. The new data were gathered in six (6) separate days of testing at Boca Reservoir and Lake Tahoe, Nevada.

| Run Numbers<br>(inclusive) | Date     | Location   | Notes                                                        |
|----------------------------|----------|------------|--------------------------------------------------------------|
| 31-38                      | 9/7/76   | Boca       | Self propelled, free running                                 |
| 39-71                      | 9/21/76  | Boca       | Self propelled, free running                                 |
| 72-91                      | 9/28/76  | Boca       | Self propelled, free running                                 |
| 92-119                     | 10/19/76 | Lake Tahoe | Self propelled and towed                                     |
| 120-162                    | 10/29/76 | Lake Tahoe | Self propelled, free running                                 |
| 163-174                    | 10/29/76 | Lake Tahoe | Tow locked sphere                                            |
| 175-181                    | 10/29/76 | Lake Tahoe | Tow free rolling                                             |
| 182-186                    | 10/29/76 | Lake Tahoe | Tow reverse free rolling                                     |
| 187-205                    | 10/30/76 | Lake Tahoe | Underwater film, runs 202-205<br>were self propelled, towing |

| Run Numbers<br>(inclusive) | Date    | Location | Notes                        |
|----------------------------|---------|----------|------------------------------|
| 11-16, 27                  | 9/23/75 | Boca     | Self propelled, free running |
| 17-22, 26                  | 9/23/75 | Boca     | Self propelled and towed     |
| 23-25                      | 9/23/75 | Boca     | Tow locked sphere            |
| 28-30                      | 9/23/75 | Boca     | Tow free rolling             |



Data taken Sept. 23, 1975

THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDG

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta$ | ROPE $\phi$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | Fr  | C <sub>0</sub> | n   |
|-------|---------|------------|--------------------|--------|---------------|------------|----------|-------------|-------------------|--------|-----------|----------|-----|----------------|-----|
| 11    | 6.2     | 17.0       | .36                | 27.4   | 5.88          | 4.0        | 8.0      | —           | 0                 | 0      | .37       | .37      | .39 | .22            | .04 |
| 12    | 9.0     | 12.4       | .73                | 50.0   | 8.06          | 5.5        | 36.4     | —           | 0                 | 0      | 3.2       | 3.2      | .54 | .73            | .23 |
| 13    | 7.0     | 10.3       | .68                | 35.7   | 9.71          | 6.6        | 38.0     | —           | 0                 | 0      | 3.1       | 3.1      | .65 | .41            | .19 |
| 14    | 10.5    | 12.5       | .84                | 57.1   | 8.00          | 5.5        | 45.6     | —           | 0                 | 0      | 4.5       | 4.5      | .53 | 1.1            | .33 |
| 15    | 8.0     | 9.0        | .89                | 43.8   | 11.11         | 7.6        | 63.0     | —           | 0                 | 0      | 5.9       | 5.9      | .74 | .53            | .31 |
| 16    | 5.7     | 16.6       | .34                | 21.1   | 6.02          | 4.1        | 8.9      | —           | 0                 | 0      | .39       | .39      | .40 | .22            | .04 |
| 17    | 7.0     | 13.0       | .54                | 35.7   | 7.69          | 5.2        | 17.3     | 0           | 63                | .88    | 1.2       | 2.1      | .51 | .55            | .16 |
| 18    | 8.4     | 11.0       | .76                | 46.4   | 9.09          | 6.2        | 37.0     | 0           | 106               | 1.75   | 3.4       | 5.2      | .61 | .83            | .33 |
| 19    | 3.8     | 11.1       | .34                | -15.6  | 9.00          | 6.1        | 3.9      | 0           | 174               | 2.85   | .17       | 3.0      | .60 | .49            | .20 |
| 20    | 6.3     | 10.8       | .58                | 28.6   | 9.26          | 6.3        | 30.5     | 0           | 138               | 2.32   | 2.2       | 4.5      | .62 | .67            | .28 |
| 21    | 8.7     | 11.5       | .76                | 48.3   | 8.70          | 6.9        | 33.1     | 0           | 91                | 1.44   | 3.1       | 4.5      | .58 | .82            | .30 |
| 22    | 5.0     | 12.4       | .40                | 10.0   | 8.06          | 5.5        | small    | 0           | 129               | 1.89   | small     | 1.89     | .54 | .43            | .14 |
| 23    | 0.0     | 22.5       | 0                  | —      | 4.44          | 3.0        | —        | 0           | 54                | .44    | —         | .44      | .30 | .60            | .06 |

[illegible]

THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDC

THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDG

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta^\circ$ | ROPE $\times$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | Fr  | C <sub>D</sub> | $\eta_t$ |
|-------|---------|------------|--------------------|--------|---------------|------------|----------------|---------------|-------------------|--------|-----------|----------|-----|----------------|----------|
| 31    | 9.4     | 25.0       | .38                | 27.43  | 6.0           | 4.09       | 4.0            | —             | —                 | 0      | .20       | .20      | .40 | 0.11           | .020     |
| 32    | 17.0    | 22.0       | .77                | 59.87  | 6.82          | 4.65       | 38.9           | —             | —                 | 0      | 3.63      | 3.63     | .45 | 1.37           | .311     |
| 33    | 10.8    | 22.0       | .49                | 36.84  | 6.82          | 4.65       | 16.9           | —             | —                 | 0      | 1.07      | 1.07     | .45 | .40            | .092     |
| 34    | 10.3    | 20.0       | .52                | 33.77  | 7.50          | 5.11       | 15.0           | —             | —                 | 0      | 1.00      | 1.00     | .50 | .28            | .078     |
| 35    | 12.0    | 21.0       | .57                | 43.16  | 7.14          | 4.87       | 17.9           | —             | —                 | 0      | 1.31      | 1.31     | .48 | .43            | .107     |
| 36    | 11.8    | 16.0       | .74                | 42.19  | 9.38          | 6.39       | 34.0           | —             | —                 | 0      | 3.08      | 3.08     | .62 | .45            | .192     |
| 37    | 14.0    | 21.0       | .67                | 51.28  | 7.14          | 4.87       | —              | —             | —                 | 0      | —         | —        | .48 | —              | —        |
| 38    | 8.0     | 28.5       | .28                | 14.73  | 5.26          | 3.59       | —              | —             | —                 | 0      | —         | —        | .35 | —              | —        |
| 39    | 6.5     | 19.0       | .34                | -4.94  | 7.89          | 5.38       | —              | —             | —                 | 0      | —         | —        | .53 | —              | —        |
| 40    | 12.0    | 23.0       | .52                | 43.16  | 6.52          | 4.45       | —              | —             | —                 | 0      | —         | —        | .43 | —              | —        |
| 41    | 9.5     | 22.0       | .43                | 28.20  | 6.82          | 4.65       | —              | —             | —                 | 0      | —         | —        | .45 | —              | —        |
| 42    | 11.0    | 26.0       | .42                | 37.99  | 5.77          | 3.93       | —              | —             | —                 | 0      | —         | —        | .38 | —              | —        |
| 43    | 9.0     | 21.0       | .43                | 24.21  | 7.14          | 4.87       | —              | —             | —                 | 0      | —         | —        | .48 | —              | —        |



THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDG

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta^\circ$ | ROPE $\lambda$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | Fr  | C <sub>0</sub> | n <sub>t</sub> |
|-------|---------|------------|--------------------|--------|---------------|------------|----------------|----------------|-------------------|--------|-----------|----------|-----|----------------|----------------|
| 44    | 10.5    | 23.5       | .45                | 35.04  | 6.38          | 4.35       | —              | —              | —                 | 0      | —         | —        | .43 | —              | —              |
| 45    | 9.5     | 16.0       | .59                | 28.20  | 9.38          | 6.39       | —              | —              | —                 | 0      | —         | —        | .62 | —              | —              |
| 46    | 12.5    | 23.0       | .54                | 45.43  | 6.52          | 4.45       | —              | —              | —                 | 0      | —         | —        | .43 | —              | —              |
| 47    | 12.0    | 22.0       | .55                | 43.16  | 6.82          | 4.65       | —              | —              | —                 | 0      | —         | —        | .45 | —              | —              |
| 48    | 10.5    | 19.0       | .55                | 35.04  | 7.89          | 5.38       | —              | —              | —                 | 0      | —         | —        | .53 | —              | —              |
| 49    | 13.5    | 21.5       | .63                | 49.47  | 6.98          | 4.76       | —              | —              | —                 | 0      | —         | —        | .46 | —              | —              |
| 50    | 11.5    | 19.0       | .61                | 40.68  | 7.89          | 5.38       | —              | —              | —                 | 0      | —         | —        | .53 | —              | —              |
| 51    | 13.5    | 21.5       | .63                | 49.47  | 6.98          | 4.76       | —              | —              | —                 | 0      | —         | —        | .46 | —              | —              |
| 52    | 11.5    | 18.5       | .62                | 40.68  | 8.11          | 5.53       | —              | —              | —                 | 0      | —         | —        | .54 | —              | —              |
| 53    | 12.0    | 18.5       | .65                | 43.16  | 8.11          | 5.53       | —              | —              | —                 | 0      | —         | —        | .54 | —              | —              |
| 54    | 10.5    | 15.0       | .70                | 35.04  | 10.00         | 6.82       | —              | —              | —                 | 0      | —         | —        | .67 | —              | —              |
| 55    | 14.0    | 21.0       | .67                | 51.28  | 7.14          | 4.87       | —              | —              | —                 | 0      | —         | —        | .48 | —              | —              |
| 56    | 12.5    | 18.0       | .69                | 45.43  | 8.33          | 5.68       | —              | —              | —                 | 0      | —         | —        | .56 | —              | —              |



THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDG

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta^\circ$ | ROPE $\frac{1}{4}$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | Fr  | C <sub>0</sub> | N <sub>e</sub> |
|-------|---------|------------|--------------------|--------|---------------|------------|----------------|--------------------|-------------------|--------|-----------|----------|-----|----------------|----------------|
| 57    | 15.5    | 20.5       | .76                | 55.99  | 7.32          | 4.99       | —              | —                  | —                 | 0      | —         | —        | .49 | —              | —              |
| 58    | 14.0    | 18.0       | .78                | 51.28  | 8.33          | 5.68       | —              | —                  | —                 | 0      | —         | —        | .56 | —              | —              |
| 59    | 14.5    | 19.5       | .74                | 52.96  | 7.69          | 5.24       | —              | —                  | —                 | 0      | —         | —        | .51 | —              | —              |
| 60    | 12.0    | 18.5       | .65                | 43.16  | 8.11          | 5.53       | —              | —                  | —                 | 0      | —         | —        | .54 | —              | —              |
| 61    | 13.0    | 18.5       | .70                | 47.53  | 8.11          | 5.53       | —              | —                  | —                 | 0      | —         | —        | .54 | —              | —              |
| 62    | 10.0    | 17.0       | .59                | 31.79  | 8.82          | 6.62       | 23.5           | —                  | —                 | 0      | 1.76      | 1.76     | .59 | 0.31           | 0.12           |
| 63    | 8.5     | 22.0       | .39                | 19.75  | 6.82          | 4.65       | 8.9            | —                  | —                 | 0      | .45       | .45      | .45 | .17            | .039           |
| 64    | 8.2     | 23.0       | .36                | 16.81  | 6.52          | 4.45       | 6.0            | —                  | —                 | 0      | .28       | .28      | .43 | .12            | .025           |
| 65    | 12.0    | 22.5       | .53                | 43.16  | 6.67          | 4.55       | 27.9           | —                  | —                 | 0      | 1.87      | 1.87     | .44 | .76            | .164           |
| 66    | 12.5    | 23.0       | .54                | 45.43  | 6.52          | 4.45       | 18.0           | —                  | —                 | 0      | 1.26      | 1.26     | .43 | .54            | .113           |
| 67    | 11.1    | 19.0       | .58                | 38.55  | 7.89          | 5.38       | 30.9           | —                  | —                 | 0      | 2.24      | 2.24     | .53 | .55            | .166           |
| 68    | 15.6    | 22.0       | .71                | 56.27  | 6.82          | 4.65       | 34.0           | —                  | —                 | 0      | 2.97      | 2.97     | .45 | 1.12           | .255           |
| 69    | 13.3    | 19.5       | .68                | 48.71  | 7.69          | 5.24       | 33.9           | —                  | —                 | 0      | 2.85      | 2.85     | .51 | .75            | .217           |

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. ( $\frac{ft}{sec}$ ) | Vel. (mph) | $\theta^\circ$ | ROPE $\phi$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | Fr  | C <sub>0</sub> | n    |
|-------|---------|------------|--------------------|--------|---------------------------|------------|----------------|-------------|-------------------|--------|-----------|----------|-----|----------------|------|
| 70    | 15.6    | 21.0       | .74                | 56.27  | 7.14                      | 4.87       | 37.0           | —           | —                 | 0      | 3.34      | 3.34     | .48 | 1.10           | .274 |
| 71    | 10.0    | 14.0       | .71                | 31.79  | 10.71                     | 7.31       | 32.4           | —           | —                 | 0      | 2.85      | 2.85     | .71 | .28            | .160 |
| 72    | 14.0    | 26.0       | .54                | 51.28  | 5.77                      | 3.93       | 10.0           | —           | —                 | 0      | .70       | .70      | .38 | .44            | .07  |
| 73    | 12.2    | 29.0       | .42                | 44.09  | 5.17                      | 3.53       | 8.9            | —           | —                 | 0      | .49       | .49      | .34 | .42            | .05  |
| 74    | 16.6    | 22.5       | .74                | 58.91  | 6.67                      | 4.55       | 19.0           | —           | —                 | 0      | 1.80      | 1.80     | .44 | .73            | .158 |
| 75    | 15.4    | 25.0       | .62                | 55.71  | 6.00                      | 4.09       | 15.9           | —           | —                 | 0      | 1.26      | 1.26     | .40 | .70            | .123 |
| 76    | 18.0    | 20.0       | .90                | 62.10  | 7.50                      | 5.11       | 36.0           | —           | —                 | 0      | 3.96      | 3.96     | .50 | 1.13           | .309 |
| 77    | 17.7    | 23.0       | .77                | 61.46  | 6.52                      | 4.45       | 33.9           | —           | —                 | 0      | 3.21      | 3.21     | .43 | 1.39           | .288 |
| 78    | 18.2    | 24.5       | .74                | 62.52  | 6.12                      | 4.17       | 33.0           | —           | —                 | 0      | 3.03      | 3.03     | .41 | 1.58           | .290 |
| 79    | 17.5    | 23.5       | .74                | 61.02  | 6.38                      | 4.35       | 32.7           | —           | —                 | 0      | 2.99      | 2.99     | .43 | 1.38           | .270 |
| 80    | 12.5    | 29.0       | .43                | 45.43  | 5.17                      | 3.53       | 14.0           | —           | —                 | 0      | .78       | .78      | .34 | .68            | .088 |
| 81    | 12.0    | 27.0       | .44                | 43.16  | 5.56                      | 3.79       | 12.9           | —           | —                 | 0      | .73       | .73      | .37 | .51            | .077 |
| 82    | 13.3    | 27.0       | .49                | 48.71  | 5.56                      | 3.79       | 10.0           | —           | —                 | 0      | .64       | .64      | .37 | .45            | .067 |

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta^\circ$ | ROPE $\phi$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | Fr  | C <sub>0</sub> | $\eta_c$ |
|-------|---------|------------|--------------------|--------|---------------|------------|----------------|-------------|-------------------|--------|-----------|----------|-----|----------------|----------|
| 83    | 13.8    | 27.5       | .50                | 50.57  | 5.45          | 3.72       | 12.9           | —           | —                 | 0      | .84       | .84      | .36 | .62            | .090     |
| 84    | 12.8    | 27.5       | .47                | 46.71  | 5.45          | 3.72       | 11.0           | —           | —                 | 0      | .66       | .66      | .36 | .49            | .071     |
| 85    | 15.0    | 24.0       | .63                | 54.52  | 6.25          | 4.26       | 25.9           | —           | —                 | 0      | 2.06      | 2.06     | .42 | 1.01           | .193     |
| 86    | 16.2    | 25.0       | .65                | 57.89  | 6.00          | 4.09       | 16.0           | —           | —                 | 0      | 1.34      | 1.34     | .40 | .74            | .131     |
| 87    | 16.0    | 25.0       | .64                | 57.37  | 6.00          | 4.09       | 21.9           | —           | —                 | 0      | 1.79      | 1.79     | .40 | .99            | .175     |
| 88    | 15.6    | 25.0       | .62                | 56.27  | 6.00          | 4.09       | 18.0           | —           | —                 | 0      | 1.44      | 1.44     | .40 | .80            | .140     |
| 89    | 15.2    | 24.0       | .63                | 55.12  | 6.25          | 4.26       | 24.9           | —           | —                 | 0      | 1.99      | 1.99     | .42 | .98            | .186     |
| 90    | 17.0    | 26.0       | .65                | 59.87  | 5.77          | 3.93       | 25.6           | —           | —                 | 0      | 2.10      | 2.10     | .38 | 1.31           | .213     |
| 91    | 16.0    | 24.5       | .65                | 57.37  | 6.12          | 4.17       | —              | —           | —                 | 0      | —         | —        | .41 | —              | —        |
| 92    | 4.6     | 29.0       | .16                | -48.29 | 5.17          | 3.53       | 2.1            | 27.5        | 25                | .21    | .04       | .25      | .34 | .22            | .028     |
| 93    | 4.5     | 25.0       | .18                | -51.58 | 6.00          | 4.09       | small          | 27.0        | 50                | .49    | 0         | .49      | .40 | .27            | .048     |
| 94    | 8.6     | 21.5       | .40                | 20.68  | 6.98          | 4.76       | 4.9            | 27.5        | 72                | .81    | .26       | 1.07     | .46 | .38            | .090     |
| 95    | 4.5     | 31.0       | .15                | -51.58 | 4.84          | 3.30       | 2.0            | 27.3        | 90                | .70    | .04       | .74      | .32 | .79            | .089     |



THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDG

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta^\circ$ | ROPE $\phi$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | Fr  | C <sub>D</sub> | $n_z$ |
|-------|---------|------------|--------------------|--------|---------------|------------|----------------|-------------|-------------------|--------|-----------|----------|-----|----------------|-------|
| 96    | 10.4    | 21.0       | .50                | 34.41  | 7.14          | 4.87       | 17.9           | 26.3        | 26                | .30    | 1.14      | 1.44     | .48 | .47            | .118  |
| 97    | 12.9    | 24.0       | .54                | 47.12  | 6.25          | 4.26       | 3.9            | 29.0        | 125               | 1.24   | .27       | 1.52     | .42 | .75            | .142  |
| 98    | 11.7    | 19.5       | .60                | 41.70  | 7.69          | 5.24       | 22.9           | 29.5        | 190               | 2.31   | 1.75      | 4.06     | .51 | 1.07           | .309  |
| 99    | 9.6     | 18.0       | .53                | 28.94  | 8.33          | 5.68       | 15.9           | 22.5        | 208               | 2.91   | 1.09      | 4.00     | .56 | .83            | .281  |
| 100   | 7.7     | 18.0       | .43                | 11.41  | 8.33          | 5.68       | 8.9            | 22.0        | 198               | 2.78   | .50       | 3.28     | .56 | .68            | .231  |
| 101   | 9.0     | 18.5       | .49                | 24.21  | 8.11          | 5.53       | -              | -           | 210               | 0      | -         | -        | .54 | -              | -     |
| 102   | 11.4    | 18.0       | .63                | 40.16  | 8.33          | 5.68       | 27.9           | 21.5        | 110               | 1.55   | 2.22      | 3.77     | .56 | .78            | .265  |
| 103   | 8.6     | 20.5       | .42                | 20.68  | 7.32          | 4.19       | 9.9            | 24.4        | 115               | 1.39   | .54       | 1.93     | .49 | .59            | .154  |
| 104   | 9.4     | 20.0       | .47                | 27.43  | 7.50          | 5.11       | 12.9           | 26.0        | 115               | 1.41   | .78       | 2.19     | .50 | .62            | .171  |
| 105   | 8.6     | 21.0       | .41                | 20.68  | 7.14          | 4.87       | 11.9           | 25.0        | 120               | 1.41   | .63       | 2.04     | .48 | .67            | .167  |
| 106   | 8.8     | 20.0       | .44                | 22.49  | 7.50          | 5.11       | 13.9           | 24.0        | 126               | 1.57   | .79       | 2.36     | .50 | .67            | .184  |
| 107   | 12.8    | 20.0       | .64                | 46.71  | 7.50          | 5.11       | 23.9           | 25.5        | 90                | 1.11   | 1.94      | 3.05     | .50 | .87            | .238  |
| 108   | 13.9    | 20.5       | .68                | 50.93  | 7.32          | 4.99       | 23.9           | 25.0        | 93                | 1.12   | 2.05      | 3.18     | .49 | .97            | .254  |



THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDG

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta^\circ$ | ROPE $\phi$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | Fr  | C <sub>0</sub> | N <sub>z</sub> |
|-------|---------|------------|--------------------|--------|---------------|------------|----------------|-------------|-------------------|--------|-----------|----------|-----|----------------|----------------|
| 109   | 12.5    | 20.5       | .61                | 45.43  | 7.32          | 4.99       | 20.9           | 22.3        | 67                | .82    | 1.63      | 2.45     | .49 | .75            | .196           |
| 110   | 12.5    | 22.0       | .57                | 45.43  | 6.82          | 4.65       | 15.9           | 26.0        | 40                | .45    | 1.16      | 1.61     | .45 | .61            | .138           |
| 111   | 12.5    | 22.5       | .56                | 45.43  | 6.67          | 4.55       | 18.9           | 25.8        | 45                | .49    | 1.35      | 1.84     | .44 | .74            | .161           |
| 112   | 12.2    | 22.5       | .54                | 44.09  | 6.67          | 4.55       | 17.9           | 28.0        | 26                | .28    | 1.25      | 1.52     | .44 | .62            | .133           |
| 113   | 13.5    | 23.5       | .57                | 49.47  | 6.38          | 4.35       | 16.9           | 27.5        | 28                | .29    | 1.25      | 1.54     | .43 | .71            | .141           |
| 114   | 13.1    | 23.5       | .56                | 47.93  | 6.38          | 4.35       | 18.9           | 27.0        | 20                | .21    | 1.35      | 1.56     | .43 | .72            | .143           |
| 115   | 14.5    | 24.5       | .59                | 52.96  | 6.12          | 4.17       | 20.9           | 28.0        | 20                | .20    | 1.58      | 1.78     | .41 | .93            | .170           |
| 116   | 12.7    | 24.5       | .52                | 46.29  | 6.12          | 4.17       | 12.9           | 28.5        | 25                | .24    | .87       | 1.11     | .41 | .58            | .106           |
| 117   | 11.8    | 24.5       | .48                | 42.19  | 6.12          | 4.17       | 11.9           | 28.0        | 4                 | .04    | .74       | .78      | .41 | .41            | .075           |
| 118   | 12.0    | 27.0       | .44                | 43.16  | 5.56          | 3.79       | 9.9            | 29.0        | 8                 | .07    | .57       | .64      | .37 | .45            | .067           |
| 119   | 11.0    | 25.0       | .44                | 37.99  | 6.00          | 4.09       | 8.9            | 23.0        | 55                | .55    | .51       | 1.06     | .40 | .59            | .103           |
| 120   | 12.2    | 34.0       | .36                | 44.09  | 4.41          | 3.01       | 6.0            | —           | —                 | 0      | .28       | .28      | .29 | .39            | .037           |
| 121   | 11.3    | 34.0       | .33                | 39.63  | 4.41          | 3.01       | 4.9            | —           | —                 | 0      | .21       | .21      | .29 | .30            | .028           |

THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDC

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta$ | ROPE $\Delta$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | $F_r$ | $C_D$ | $n_z$ |
|-------|---------|------------|--------------------|--------|---------------|------------|----------|---------------|-------------------|--------|-----------|----------|-------|-------|-------|
| 122   | 11.9    | 35.0       | .34                | 42.68  | 4.29          | 2.92       | 1.0      | —             | —                 | 0      | .04       | .04      | .29   | .07   | .005  |
| 123   | 11.5    | 35.5       | .32                | 40.68  | 4.23          | 2.88       | 1.9      | —             | —                 | 0      | .08       | .08      | .28   | .13   | .011  |
| 124   | 11.0    | 32.5       | .34                | 37.99  | 4.62          | 3.15       | 6.0      | —             | —                 | 0      | .26       | .26      | .31   | .32   | .033  |
| 125   | 11.1    | 36.0       | .31                | 38.55  | 4.17          | 2.84       | 0.1      | —             | —                 | 0      | .004      | .004     | .28   | .01   | .0006 |
| 126   | 11.3    | 33.5       | .34                | 39.63  | 4.48          | 3.05       | 2.5      | —             | —                 | 0      | .11       | .11      | .30   | .15   | .021  |
| 127   | 11.5    | 35.5       | .32                | 40.68  | 4.23          | 2.88       | 0.4      | —             | —                 | 0      | .017      | .017     | .28   | .03   | .002  |
| 128   | 13.3    | 29.0       | .46                | 48.71  | 5.17          | 3.53       | 16.0     | —             | —                 | 0      | .95       | .95      | .34   | .82   | .108  |
| 129   | 13.8    | 29.0       | .48                | 50.57  | 5.17          | 3.53       | 6.9      | —             | —                 | 0      | .43       | .43      | .34   | .37   | .049  |
| 130   | 17.2    | 27.0       | .64                | 60.34  | 5.56          | 3.79       | 23.0     | —             | —                 | 0      | 1.86      | 1.86     | .37   | 1.30  | .196  |
| 131   | 15.0    | 28.0       | .54                | 54.52  | 5.36          | 3.65       | 13.9     | —             | —                 | 0      | .97       | .97      | .36   | .76   | .106  |
| 132   | 14.0    | 27.0       | .52                | 51.28  | 5.56          | 3.79       | 12.0     | —             | —                 | 0      | .81       | .81      | .37   | .56   | .085  |
| 133   | 16.7    | 27.5       | .61                | 59.15  | 5.45          | 3.72       | 20.9     | —             | —                 | 0      | 1.62      | 1.62     | .36   | 1.20  | .174  |
| 134   | 16.1    | 27.0       | .60                | 57.63  | 5.56          | 3.79       | 20.0     | —             | —                 | 0      | 1.53      | 1.53     | .37   | 1.07  | .161  |

THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDG

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta$ | ROPE $\frac{1}{4}$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | Fr  | C <sub>0</sub> | n    |
|-------|---------|------------|--------------------|--------|---------------|------------|----------|--------------------|-------------------|--------|-----------|----------|-----|----------------|------|
| 135   | 15.5    | 29.0       | .53                | 55.99  | 5.17          | 3.53       | 12.9     | —                  | —                 | 0      | .89       | .89      | .34 | .77            | .101 |
| 136   | 15.1    | 26.5       | .57                | 54.83  | 5.46          | 3.86       | 18.0     | —                  | —                 | 0      | 1.32      | 1.32     | .38 | .87            | .136 |
| 137   | 15.3    | 29.0       | .53                | 55.42  | 5.17          | 3.53       | 19.9     | —                  | —                 | 0      | 1.34      | 1.34     | .34 | 1.16           | .152 |
| 138   | 11.5    | 32.5       | .35                | 40.68  | 4.62          | 3.15       | 4.0      | —                  | —                 | 0      | .83       | .83      | .31 | .22            | .02  |
| 139   | 17.0    | 37.5       | .45                | 59.87  | 4.00          | 2.73       | 14.9     | —                  | —                 | 0      | .87       | .87      | .27 | 1.63           | .12  |
| 140   | 13.0    | 27.5       | .47                | 47.53  | 5.45          | 3.72       | 18.5     | —                  | —                 | 0      | 1.12      | 1.12     | .36 | .83            | .126 |
| 141   | 15.2    | 28.0       | .54                | 55.12  | 5.36          | 3.65       | 22.9     | —                  | —                 | 0      | 1.58      | 1.58     | .36 | 1.23           | .172 |
| 142   | 15.8    | 27.0       | .59                | 56.83  | 5.56          | 3.79       | 17.0     | —                  | —                 | 0      | 1.28      | 1.28     | .37 | .90            | .135 |
| 143   | 16.6    | 27.0       | .61                | 58.91  | 5.56          | 3.79       | 20.9     | —                  | —                 | 0      | 1.64      | 1.64     | .37 | 1.15           | .173 |
| 144   | 16.9    | 25.5       | .66                | 59.64  | 5.88          | 4.01       | 25.0     | —                  | —                 | 0      | 2.10      | 2.10     | .39 | 1.24           | .209 |
| 145   | 14.1    | 31.0       | .45                | 51.62  | 4.84          | 3.30       | 15.9     | —                  | —                 | 0      | .93       | .93      | .32 | .99            | .112 |
| 146   | 12.4    | 30.0       | .41                | 44.99  | 5.00          | 3.41       | 9.0      | —                  | —                 | 0      | .48       | .48      | .33 | .46            | .056 |
| 147   | 13.0    | 33.5       | .39                | 47.53  | 4.48          | 3.05       | 4.9      | —                  | —                 | 0      | .25       | .25      | .30 | .33            | .033 |



THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDG

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta$ | ROPE $\phi$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | Fr  | C <sub>D</sub> | N <sub>x</sub> |
|-------|---------|------------|--------------------|--------|---------------|------------|----------|-------------|-------------------|--------|-----------|----------|-----|----------------|----------------|
| 148   | 10.5    | 32.0       | .33                | 35.04  | 4.69          | 3.20       | 10.0     | —           | —                 | 0      | .43       | .43      | .31 | .50            | .054           |
| 149   | 13.1    | 31.5       | .42                | 47.93  | 4.76          | 3.25       | 7.9      | —           | —                 | 0      | .43       | .43      | .32 | .48            | .053           |
| 150   | 16.8    | 26.5       | .63                | 59.40  | 5.66          | 3.86       | 20.0     | —           | —                 | 0      | 1.62      | 1.62     | .38 | 1.07           | .167           |
| 151   | 17.0    | 46.5       | .37                | 59.87  | 3.30          | 2.25       | 5.9      | —           | —                 | 0      | .29       | .29      | .22 | .96            | .051           |
| 152   | 18.7    | 31.5       | .59                | 63.52  | 4.76          | 3.25       | 23.0     | —           | —                 | 0      | 1.74      | 1.74     | .32 | 1.93           | .214           |
| 153   | 14.9    | 30.5       | .49                | 54.22  | 4.92          | 3.35       | 9.9      | —           | —                 | 0      | .63       | .63      | .33 | .63            | .075           |
| 154   | 17.8    | 25.5       | .70                | 61.68  | 5.88          | 4.01       | 24.0     | —           | —                 | 0      | 2.12      | 2.12     | .39 | 1.25           | .211           |
| 155   | 16.8    | 26.5       | .63                | 59.40  | 5.66          | 3.86       | 15.9     | —           | —                 | 0      | 1.30      | 1.30     | .38 | .86            | .134           |
| 156   | 16.8    | 25.5       | .66                | 59.40  | 5.88          | 4.01       | 22.0     | —           | —                 | 0      | 1.85      | 1.85     | .39 | 1.09           | .184           |
| 157   | 16.4    | 26.0       | .63                | 58.41  | 5.77          | 3.93       | 22.9     | —           | —                 | 0      | 1.84      | 1.84     | .38 | 1.15           | .187           |
| 158   | 16.3    | 25.5       | .64                | 58.15  | 5.88          | 4.01       | 25.0     | —           | —                 | 0      | 2.02      | 2.02     | .39 | 1.19           | .201           |
| 159   | 16.0    | 27.0       | .59                | 57.37  | 5.56          | 3.79       | 25.9     | —           | —                 | 0      | 1.94      | 1.94     | .37 | 1.36           | .204           |
| 160   | 16.0    | 25.5       | .63                | 57.37  | 5.88          | 4.01       | 20.0     | —           | —                 | 0      | 1.61      | 1.61     | .39 | .95            | .160           |

THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDG

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta$ | ROPE $\phi$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | F <sub>r</sub> | C <sub>0</sub> | N    |
|-------|---------|------------|--------------------|--------|---------------|------------|----------|-------------|-------------------|--------|-----------|----------|----------------|----------------|------|
| 161   | 14.0    | 29.5       | .47                | 51.28  | 5.08          | 3.47       | 19.9     | —           | —                 | 0      | 1.21      | 1.21     | .34            | 1.10           | .139 |
| 162   | 13.0    | 24.5       | .53                | 47.53  | 6.12          | 4.17       | 15.0     | —           | —                 | 0      | 1.03      | 1.03     | .41            | .54            | .098 |
| 163   | 0       | 29.5       | 0                  | —      | 5.08          | 3.47       | —        | 26          | 60                | .50    | 0         | .50      | .34            | .46            | .058 |
| 164   | 0       | 29.5       | 0                  | —      | 5.08          | 3.47       | —        | 26          | 70                | .58    | 0         | .58      | .34            | .53            | .067 |
| 165   | 0       | 39.5       | 0                  | —      | 3.80          | 2.59       | —        | 26          | 25                | .16    | 0         | .16      | .25            | .34            | .025 |
| 166   | 0       | 27.0       | 0                  | —      | 5.56          | 3.79       | —        | 26          | 99                | .90    | 0         | .90      | .37            | .63            | .095 |
| 167   | 0       | 24.0       | 0                  | —      | 6.25          | 4.26       | —        | 26          | 133               | 1.36   | 0         | 1.36     | .42            | .67            | .127 |
| 168   | 0       | 28.0       | 0                  | —      | 5.36          | 3.65       | —        | 26          | 104               | .91    | 0         | .91      | .36            | .71            | .099 |
| 169   | 0       | 20.5       | 0                  | —      | 7.32          | 4.99       | —        | 26          | 203               | 2.43   | 0         | 2.43     | .49            | .74            | .194 |
| 170   | 0       | 29.0       | 0                  | —      | 5.17          | 3.53       | —        | 26          | 72                | .61    | 0         | .61      | .34            | .53            | .067 |
| 171   | 0       | 20.0       | 0                  | —      | 7.50          | 5.11       | —        | 26          | 225               | 2.76   | 0         | 2.76     | .50            | .78            | .215 |
| 172   | 0       | 32.0       | 0                  | —      | 4.69          | 3.20       | —        | 26          | 52                | .40    | 0         | .40      | .31            | .46            | .050 |
| 173   | 0       | 22.5       | 0                  | —      | 6.67          | 4.55       | —        | 26          | 153               | 1.67   | 0         | 1.67     | .44            | .68            | .146 |

\* NOT RECORDED

THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDQ

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec) | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta^\circ$ | ROPE $\frac{1}{4}$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | Fr  | C <sub>0</sub> | n    |
|-------|---------|------------|--------------------|--------|---------------|------------|----------------|--------------------|-------------------|--------|-----------|----------|-----|----------------|------|
| 174   | 0       | 46.0       | 0                  | —      | 3.26          | 2.22       | —              | 26                 | 26                | .14    | 0         | .14      | .22 | .48            | .025 |
| 175   | *       | 21.5       | —                  | —      | 6.98          | 4.76       | —              | 26                 | 152               | 1.73   | 0         | 1.73     | .46 | .61            | .145 |
| 176   | *       | 27.5       | —                  | —      | 5.45          | 3.72       | —              | 26                 | 50                | .45    | 0         | .45      | .36 | .33            | .048 |
| 177   | 10      | 20.5       | .49                | 31.78  | 7.32          | 4.99       | —              | 26                 | 242               | 2.89   | 0         | 2.89     | .49 | .89            | .231 |
| 178   | *       | 24.0       | —                  | —      | 6.25          | 4.26       | —              | 26                 | 150               | 1.53   | 0         | 1.53     | .42 | .75            | .143 |
| 179   | 8       | 23.0       | .35                | 14.75  | 6.52          | 4.45       | —              | 26                 | 118               | 1.26   | 0         | 1.26     | .43 | .54            | .113 |
| 180   | *       | 32.5       | —                  | —      | 4.62          | 3.15       | —              | 26                 | 28                | .21    | 0         | .21      | .31 | .26            | .027 |
| 181   | *       | 24.5       | —                  | —      | 6.12          | 4.17       | —              | 26                 | 85                | .85    | 0         | .85      | .41 | .44            | .081 |
| 182   | *       | 30.0       | —                  | —      | 5.00          | 3.41       | —              | 26                 | 42                | .34    | 0         | .34      | .33 | .33            | .040 |
| 183   | 8       | 21.0       | .38                | 14.75  | 7.14          | 4.87       | —              | 26                 | 208               | 2.43   | 0         | 2.43     | .48 | .80            | .199 |
| 184   | 8       | 25.0       | .32                | 14.75  | 6.00          | 4.09       | —              | 26                 | 108               | 1.06   | 0         | 1.06     | .40 | .59            | .103 |
| 185   | 7       | 22.5       | .31                | 2.57   | 6.67          | 4.55       | —              | 26                 | 160               | 1.74   | 0         | 1.74     | .44 | .71            | .153 |
| 186   | 7       | 31.0       | .23                | 2.57   | 4.84          | 3.30       | —              | 26                 | 30                | .24    | 0         | .24      | .32 | .25            | .029 |



THIS PAGE IS BEST QUALITY PRACTICABLE  
FROM COPY FURNISHED TO DDG

| RUN # | NO. REV | TIME (sec) | $\omega$ (rev/sec)    | % SLIP | Vel. (ft/sec) | Vel. (mph) | $\theta^\circ$ | ROPE $\frac{1}{4}$ | ROPE FORCE (lbs.) | TOW HP | SPHERE HP | TOTAL HP | Fr  | C <sub>0</sub> | N <sub>t</sub> |
|-------|---------|------------|-----------------------|--------|---------------|------------|----------------|--------------------|-------------------|--------|-----------|----------|-----|----------------|----------------|
| 187   | 10.0    | 42.0       | .24                   | 31.79  | 3.57          | 2.44       | —              | —                  | —                 | 0      | —         | —        | .24 | —              | —              |
| 188   |         | RUN        | ABORTED DUE TO ENGINE |        |               |            |                | SHUT               | DOWN              |        |           |          |     |                |                |
| 189   | 10.5    | 42.0       | .25                   | 35.04  | 3.57          | 2.44       | —              | —                  | —                 | 0      | —         | —        | .24 | —              | —              |
| 190   | 12.0    | 31.5       | .38                   | 43.16  | 4.76          | 3.25       | —              | —                  | —                 | 0      | —         | —        | .32 | —              | —              |
| 191   | 12.0    | 31.0       | .39                   | 43.16  | 4.84          | 3.30       | —              | —                  | —                 | 0      | —         | —        | .32 | —              | —              |
| 192   | 12.0    | 29.5       | .41                   | 43.16  | 5.08          | 3.47       | —              | —                  | —                 | 0      | —         | —        | .34 | —              | —              |
| 193   | 12.5    | 29.5       | .42                   | 45.43  | 5.08          | 3.47       | —              | —                  | —                 | 0      | —         | —        | .34 | —              | —              |
| 194   | 12.5    | 28.0       | .45                   | 45.43  | 5.36          | 3.65       | —              | —                  | —                 | 0      | —         | —        | .36 | —              | —              |
| 195   | 12.5    | 29.5       | .42                   | 45.43  | 5.08          | 3.47       | —              | —                  | —                 | 0      | —         | —        | .34 | —              | —              |
| 196   | 12.0    | 27.5       | .44                   | 43.16  | 5.45          | 3.72       | —              | —                  | —                 | 0      | —         | —        | .36 | —              | —              |
| 197   | 13.0    | 30.0       | .43                   | 47.53  | 5.00          | 3.41       | —              | —                  | —                 | 0      | —         | —        | .33 | —              | —              |
| 198   | 11.0    | 31.0       | .35                   | 37.99  | 4.84          | 3.30       | —              | —                  | —                 | 0      | —         | —        | .32 | —              | —              |
| 199   | 11.0    | 29.5       | .37                   | 37.99  | 5.08          | 3.47       | —              | —                  | —                 | 0      | —         | —        | .34 | —              | —              |



APPENDIX B

Film Record



Film Record

| Run # | Film Footage | Run # | Film Footage |
|-------|--------------|-------|--------------|
| 31    | 0-17         | 74    | 27-40        |
| 32    | 17-36        | 75    | 40-53        |
| 33    | 36-53        | 76    | 53-64        |
| 34    | 53-72        | 77    | 64-75        |
| 35    | 72-86        | 78    | 75-87        |
| 36    | 86-105       | 79    | 87-96        |
| 37    | none         | 80    | none         |
| 38    | none         | 81    | 5-8          |
| 39    | on boat      | 82    | 8-19         |
| 40    | on boat      | 83    | 19-30        |
| :     | :            | 84    | 30-41        |
| 61    | on boat      | 85    | 41-49        |
| 62    | 5-7          | 86    | 49-59        |
| 63    | 7-12         | 87    | 59-73        |
| 64    | 12-23        | 88    | 73-82        |
| 65    | 23-33        | 89    | 82-91        |
| 66    | 33-43        | 90    | 92-104       |
| 67    | 43-52        | 91    | none         |
| 68    | 52-63        | 92    | 4-15         |
| 69    | 63-73        | 93    | 15-23        |
| 70    | 73-83        | 94    | 23-34        |
| 71    | 83-90        | 95    | 34-48        |
| 72    | 5-12         | 96    | 48-58        |
| 73    | 12-27        | 97    | 58-70        |

| Run # | Film Footage | Run # | Film Footage |
|-------|--------------|-------|--------------|
| 98    | 70-81        | 124   | 154-168      |
| 99    | 81-90        | 125   | 0-20         |
| 100   | 90 -         | 126   | 20-38        |
| 101   | none         | 127   | 38-55        |
| 102   | 0-13         | 128   | 55-69        |
| 103   | 13-24        | 129   | 69-84        |
| 104   | 24-36        | 130   | 84-100       |
| 105   | 36-49        | 131   | 103-120      |
| 106   | 52-63        | 132   | 0-15         |
| 107   | 63-73        | 133   | 15-29        |
| 108   | 73-84        | 134   | 29-43        |
| 109   | 84-95        | 135   | 43-57        |
| 110   | 95-107       | 136   | 57-71        |
| 111   | 0-8          | 137   | 71-85        |
| 112   | 8-20         | 138   | 85-101       |
| 113   | 20-32        | 139   | 101-120      |
| 114   | 32-43        | 140   | 0-14         |
| 115   | 43-55        | 141   | 14-27        |
| 116   | 55-66        | 142   | 27-40        |
| 117   | 69-79        | 143   | 40-53        |
| 118   | 79-88        | 144   | 53-66        |
| 119   | 0-13         | 145   | 66-81        |
| 120   | 83-101       | 146   | 81-95        |
| 121   | 101-118      | 147   | 95-110       |
| 122   | 118-136      | 148   | 0-16         |
| 123   | 136-154      | 149   | 16-31        |

| Run # | Film Footage |
|-------|--------------|
| 150   | 31-44        |
| 151   | 44-63        |
| 152   | 63-78        |
| 153   | 78-92        |
| 154   | 92-105       |
| 155   | 0-14         |
| 156   | 14-28        |
| 157   | 28-41        |
| 158   | 41-54        |
| 159   | 54-67        |
| 160   | 67-80        |
| 161   | 80-94        |
| 162   | 96-108       |
| 163   | none         |
| 164   | none         |
| 165   | none         |
| .     | .            |
| 186   | none         |
| 187   | underwater   |
| 188   | underwater   |
| .     | .            |
| 205   | underwater   |



APPENDIX C

Computer Program Used to Reduce the  
Hydrosphere Data.

COURSE LENGTH

? 150.0

ENTER NUMBER OF RUNS TO BE COMPUTED

? 1

ENTER RUN, REV, TIME, THETA, FTOWR, THETAR

? 92, 4.6, 29, 2.1, 25, 27.5

| RUN  | OMEGA | SLIP   | FPS  | MPH  | HPS | TWHP | THP | FR  | CD  |
|------|-------|--------|------|------|-----|------|-----|-----|-----|
| 92   | .16   | -48.29 | 5.17 | 3.53 | .04 | .21  | .25 | .34 | .22 |
| STOP |       |        |      |      |     |      |     |     |     |

SRU 1.302 UNTS.

RUN COMPLETE.

LNH

```
00100  PROGRAM ROVER (INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT)
00110  DIMENSION RUN(50), REV(50), TIME(50), THETA(50), FTOW(50),
00120+  OMEGA(50), VCLFPS(50), VCLMPH(50), SPHHP(50), TOWHP(50),
00130+  TOTH(50), SLIP(50), CD(50), FR(50)
00135  DIMENSION THETAR(50), FTOWR(50)
00140  PI=355./113.
00150  INTEGER RUN
00160  WRITE (6,1)
00170  1 FORMAT (*COURSE LENGTH*)
00180  READ, COURSE
00190  WRITE(6,2)
00200  2 FORMAT (*ENTER NUMBER OF RUNS TO BE COMPUTED*)
00210  READ, N
00220  WRITE (6,3)
00230  3 FORMAT (*ENTER RUN, REV, TIME, THETA, FTOWR, THETAR*)
00240  DO 10 I=1,N
00250  10 READ, RUN(I), REV(I), TIME(I), THETA(I), FTOWR(I), THETAR(I)
00260  WRITE (6,5)
00270  5 FORMAT (//)
00280  WRITE (6,6)
00290  6 FORMAT(* RUN OMEGA SLIP FPS MPH HPS TWHP*,
00300+  3X,*THP FR CD*)
00310  DO 20 J=1,N
00320  RIDEAL=COURSE/21.99
00330  OMEGA(J)=REV(J)/TIME(J)
00340  VCLFPS(J)=COURSE/TIME(J)
00350  VCLMPH(J)=VCLFPS(J)/(88./60.)
00360  SPHHP(J)=7.48*OMEGA(J)*(SIN(PI*THETA(J)/180.))
00365  FTOW(J)=FTOWR(J)*COS(PI*THETAR(J)/180.)
00370  TOWHP(J)=(COURSE*FTOW(J))/(550.*TIME(J))
00380  TOTH(J)=SPHHP(J)+TOWHP(J)
00390  SLIP(J)=(1-(RIDEAL/REV(J)))*100
00400  CD(J)=(120*TOTH(J))/(VCLFPS(J)**3.)
00410  FR(J)=VCLFPS(J)/15.01
00420  WRITE (6,4) RUN(J), OMEGA(J), SLIP(J), VCLFPS(J), VCLMPH(J),
00430+  SPHHP(J), TOWHP(J), TOTH(J), FR(J), CD(J)
00440  4 FORMAT (/,2X,I3,9F7.2)
00450  20 CONTINUE
00460  STOP
00470  END
READY.
BYE
```

BH42E13 LOG OFF 16.49.49.

BH42E13 SRU 5.430 UNTS.