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DESCRIPTION OF A WATER TANK AND OF INITIAL LOW REYNOLDS NUMBER FLOW AND BUOYANT FREE MODEL TESTS

COLLEGE OF ENGINEERING

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Description Of A Water Tank And Of Initial Low Reynolds Number Flow And Buoyant Free Model Tests

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FOREWORD

This report was prepared by the College of Engineering, University of Florida, Gainesville, Florida 32601, under Contract No. F08635-70-C-0065 with the Air Force Armament Laboratory, Eglin Air Force Base, Florida. Dr. George B. Findley (DLMA) was program manager for the Armament Laboratory. This effort was conducted during the period from October 1971 to April 1973.

This technical report has been reviewed and is approved.

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ABSTRACT

A water tank has been designed and constructed at the University of Florida for the purpose of visualizing low Reynolds number flows. Static or drain-down test conditions may be used, the former for observation of the free movement of positively or negatively buoyant models. The tank is four feet by four feet in horizontal dimensions, and its square test section is six feet high; it is constructed entirely of Plexiglas and therefore is corrosion free. The maximum unit Reynolds number in the drain-down mode is 10^4 per inch. Photographs of flow about the Basic Finner model from preliminary tests are included. Buoyant sphere trajectories were observed in preliminary trials to be planar or spiral depending upon Reynolds number.

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LIST OF FIGURES

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SECTION I

INTRODUCTION

1. Purpose of Facility

The facility is designed to permit visual or photographic observation from almost any angle. With the introduction of colored fluid filaments, the electrolytic generation of hydrogen bubbles, or in the presence of very small air bubbles or fine particles, the visualization of the incompressible flow about models of technical interest is readily achieved. Since unit Reynolds numbers are limited to the range 800 to 10^4 per inch, studies of flow about forward portions of bodies where separation is not influential may be conducted. Thus, the forward aspects of an entire aircraft, including fuselage, wings, engines and external stores, may be tested. For configurations having sharp corners or cutoff bases which fix separation independently of Reynolds number the observations should be realistic.

Both still and moving pictures may be taken from several angles simultaneously.

2. Design Features

The tank has a 4- x 4- x 6-foot rectangular configuration set upright upon an inverted pyramid (Figure 1).

The test section of the tank is constructed of one-inch-thick Plexiglas glued together with methyl methacrylate, a two-part clear acrylic non-yellowing adhesive, so as to permit maximum optical access to the flow in proximity to the model and to avoid corrosion. All piping, valves, controls, straighteners, and meters in water contact in the system are constructed either of aluminum, stainless-steel, fiberglass, or are polyethylene or epoxy-coated to prevent corrosion. An external steel angle-iron cradle adds structural support to the Plexiglas tank which sustains a substantial hydrostatic pressure.

The glued construction was chosen to avoid sealing problems which would arise if bolted joints and seams were used. The glue and glued-fillet joints required annealing <u>in situ</u> one at a time at 160°F for 24 hours. A temporary electrically heated oven was constructed over the entire tank for this purpose.

At the bottom of the tank a pyramidal convergent section slopes at 30° to the vertical and terminates in a flanged 6-inch opening. There are two accesses to the tank interior: the opening at the top of the tank and the double access window located on one side. The

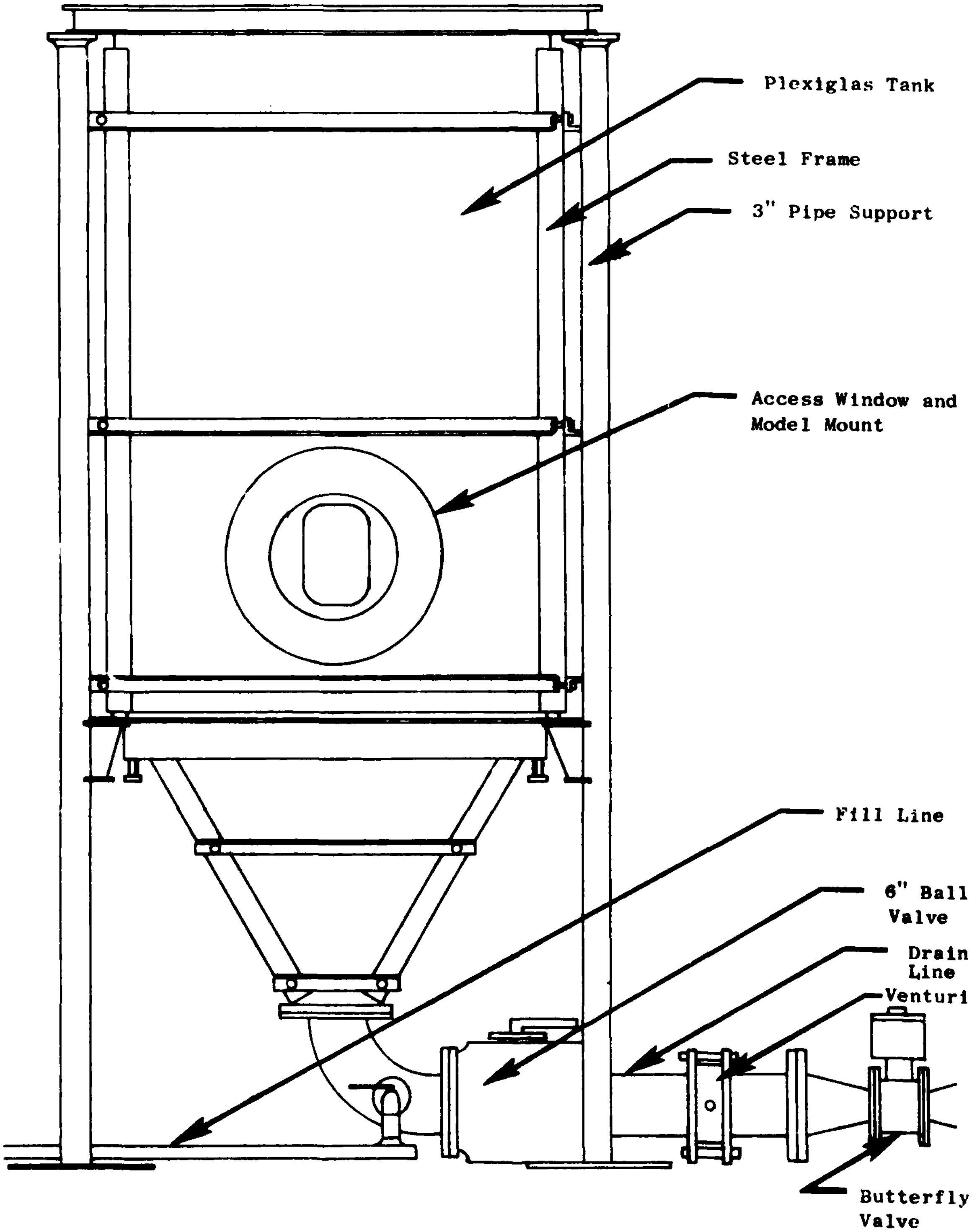

Figure 1. 4 x 4 Feet Vertical Flow Water Tank for Flow Visualization

double access window consists of a 7-1/2-inch x 10-inch rectangular window centered within a 16-inch circular window. Both windows open into the tank and are sealed against O-rings by pressure clamps and the hydrostatic pressure. The rectangular window can be removed by opening it into the tank, rotating it 90°, turning it edgewise, and then withdrawing it from the tank. The circular window can be removed only through the open top of the water tank.

Models may be mounted directly upon the rectangular window or upon a sting attached to the rectangular window. A full 360° rotation of the model is accomplished by rotating the 16-inch circular window to any desired angle.

The angle iron support structure rests upon four vertical 3-inch pipes. Angle irons with cork gaskets are used at all corners of the Plexiglas tank for support. In addition, the walls of the tank are supported along their spans by stringers of angle iron. These stringers keep the wall deflection and stress from becoming excessive while causing only a minimum of visual blockage. The positions of the three stringers around the test section were selected to keep the stress safety factor above 1.5 and to equalize the maximum stress occurring in the Plexiglas panels between the stringers. The weight of the water is supported by the inverted pyramidal cradle. Stresses in the Plexiglas in this convergent section are not critical since the unsupported spans in this section are relatively small.

3. Operation in Drain-down Mode

Operation of the water tank in the drain-down configuration is quite simple. The tank is filled with tap water through a 1-1/2-inch fill line which enters the tank through a fitting located in the first elbow of the drain line above the 6-inch ball valve. A water purification system is being contemplated for the fill line as the tap water has a green cast and some solid particle content. Approximately 30 minutes are required to fill the tank to its 900-gallon capacity. An alarm buzzes when the tank is nearly full. The desired test section velocity is selected by adjusting the 4-inch control valve to a setting between 0.7 inch/second and 1/3 inch/second. At the desired time the 6-inch ball valve is fully opened, and the water drains from the tank at a constant speed despite the fact that the hydrostatic head is steadily decreasing. Initially there are approximately 4 feet of water above the model so testing can be conducted for approximately 45 seconds. Roughly two hours after filling the tank the turbulence due to filling has subsided to the point where another run can be made. Turbulence damping devices could easily be added to shorten this waiting period.

SECTION II

FLOW VISUALIZATION

1. Colored Streak Lines

To date, all flow visualization tests in this facility have used dye filaments as the observed element. Food coloring was tried initially, but tended to coagulate quickly and was not easily visible when injected in the stream. Next analine dyes were tried with some success, using the brighter colors. The addition of milk to the dye increases the brightness of the filament. Alcohol can be used to adjust the specific gravity of the mixture, but care must be exercised not to allow concentrated alcohol to contact the Plexiglas as this can cause crazing. Fluorescein-sodium biological stain diluted to 1 gram/liter of water has been the most successful dye used in this facility to date. This dye is a very bright green under moderate lighting conditions. Examples of photographs of such fluorescein filaments are included as Figures 2 and 3.

The dye can be injected through holes in the model or from a comb of tubes upstream of the model. Both methods have advantages and disadvantages. It has been found that a pressurized dye system and metering orifices work best to control the rate of dye injection. The dye should be injected at the same speed and in the same direction as the local flow in order to minimize disturbances.

Lighting the model with a plane of light admitted through a slitted curtain improves the pictures by making the model and dye filaments bright with respect to the background. The elimination of stray light from the tank is also important in attaining good photographic quality.

2. Hydrogen Bubble Generation

Hydrogen bubble visualization is available, but photographs have not been obtained here. This method uses 1-mil platinum wire as an electrode in the water to generate hydrogen bubbles by electrolysis along the length of the wire. The bubbles are then swept downstream into the region of interest. The electrode current can be turned on and off at short intervals of known duration to yield local velocity data in the flows photographed.

3. Air Bubble Observation

If detergent is added to the water as the tank is being filled, very small air bubbles are formed and entrained throughout the test medium. When illuminated in a thin plane and photographed with a time exposure, these air bubbles produce photographic streaks which are close to traces of streamlines. This method of visualization has proved to have qualitative value (Werlé 1973), but this technique has not yet been used here.

SECTION III

FREE MODEL TRAJECTORIES

1. Buoyancy Propulsion

Small models having either positive or negative buoyancy can be released and observed in free flight in the static tank. If the motion is stable, it can be held at one level by introducing a counterflow of water. As an aid to stabilizing the location of the model in this case, the test section dimensions can be so shaped as to trap the model within the test section bounds by means of the dynamic pressure distribution. For downward water flow a relatively small test section area at the upper end and a relatively large test section area at the lower end would trap a positively buoyant model of stable flight dynamic characteristics. This tank can be modified very easily to suit this purpose by installing tapered Plexiglas corner fillets through the open tank top.

2. Sphere Tests

A series of positively buoyant sphere tests have been conducted in the static tank. The principal result of interest to date is that two distinct modes of oscillating trajectory have been observed. The oscillation either lies in a single plane or describes a spiral. Another way to describe this is that the plane of oscillation is either fixed or rotating about the axis of the trajectory. Again these trajectories may be called two-dimensional and three-dimensional or spiral, respectively.

The two-dimensional trajectory oscillation has been found to occur at Reynolds numbers above 500, and the spiral trajectory occurs at Reynolds numbers below 300.

The flow about these rising spheres has not yet been visualized or photographed. It is not known, for example, whether a sphere which is in spiral flight is rotating about its body axis. Such motion would be comparable to the case of roll lc in sometimes observed in coasting finned-rocket flights.

This behavior of a free body in a static fluid has a close relationship to that of oscillating flow about a fixed body such as a sphere or cylinder which experiences periodic vortex shedding characterized by the Strouhal number. (The Strouhal number equals nD/V, where n is the vortex shedding frequency, D is the body diameter, and V is the remote fluid velocity.) (See Figure 2.)

SECTION IV

BASIC FINNER TESTS

1. Lee-side Separation

A valuable contribution to the study of separation on the lee-side of inclined pointed bodies of revolution would be the visualization of such separation while also obtaining quantitative force and moment data. First results of the visualization technique wherein colored filaments introduced upstream encounter the model are illustrated by the typical photograph shown in Figure 3.

2. Comparison of Dye Injection Sites

Colored filaments of dye may be injected into the water flow through small tubes. Such a tube may be fitted inside of the model and end in a flush orifice at the model surface, or much the same result can be obtained in a separate flow region by attaching the tubing tangentially to the exterior surface of the model. Alternatively the tube may be aligned with the oncoming stream and the colored filament allowed to encounter the model as a visible streamline. The choice of site depends, of course, upon the flow configuration and what region of it is to be made visible. The duration of the test must be sufficiently long to permit the dye to move throughout the region to be visualized. This condition is met in the drain-down mode of operation but not with time to spare. It would be nice to have time to adjust dye supply line pressures so as to emit the dye without disturbing the flow. It would also be good to have time to move the emission tube to determine the best site for optimal visualization.

SECTION V

TURBULENCE EFFECTS

1. Reynolds Number Simulation

It would, of course, be desirable to operate the test at cross-flow Reynolds numbers exceeding the critical so that transition to turbulence could have its effect. In the cross-flow Reynolds number range attainable in the present water tank, transition does not occur. However, separation does occur as illustrated, and its overall effect upon the flow is similar to separation at supercritical Reynolds number. The separation zone is larger at the low Reynolds numbers available in this facility than it would be if the critical value could be exceeded because laminar boundary layers can overcome only a small pressure rise after passing the minimum pressure point. Failing to do so, the boundary layer separates.

Some consideration may be given to means of simulating higher Reynolds numbers. For example, surface roughening may induce early transition and effectively lower the critical Reynolds number. It is found that for the Basic Finner at an angle of attach of 30° a model diameter of almost 30 inches would be required and a roughness height of 0.3 inch. This corresponds to Faye and Warsap's measurement of $Re_{crit} = 3 \times 10^4$ for k/d = 0.02 (Reference 2, Figure 21.15).

Another alternative is to introduce turbulence into the free stream. Reductions from 3×10^5 to 1×10^3 have been reported for critical Reynolds numbers of spheres (References 2, 3, and 4). Reducing the critical cross-flow Reynolds number to the required value of 1,150 for a 1-inch-diameter Basic Finner model at $\alpha = 30°$ for observation in the present facility would require a free-stream turbulence level of about 0.15. The introduction of such intense turbulence in the test medium would seriously disrupt and disperse the injected dye filaments used for flow visualization.

The conclusion is the only laminar separation phenomena may be expected to be observed visually in the present facility. Much can, of course, be learned in such experiments without transition to turbulence. With strong free-stream turbulence, measurements may possibly be made in the supercritical Reynolds number domain.

2. Spin-Stabilized Body Tests

In the case of an inclined body of revolution, spin will tend on one side to delay laminar separation, a proximate cause of boundary layer transition and, on the other, to hasten it.

A configuration like the Basic Finner would be unlikely to attain high rotational velocities about its longitudinal axis. However, it should be noted that the critical cross-flow Reynolds number might be reduced as a result of spin. Evidence for this possibility is indirect, having been reported for spheres spinning about the axis aligned with the flow direction (Reference 2, Figure 11.10). For example, for $R\omega/\nu = 1.8$ the drag dropped abruptly by 75 per cent at $Re = 2 \times 10^5$ for the non-spinning sphere.

Again, it has been predicted by Truckenbrodt and confirmed by Parr that the transition point moves forward with increasing rotation rate of a sphere-cylinder with axis aligned with the flow (Reference 2, Figure 22.19). For $VR/\nu = 3 \times 10^5$, $R\omega/V = 4$ placed transition less than one radius aft of the sphere-cylinder juncture whereas without spin it had been at least three radii aft.

3. Interaction of Body with Gusts

Another class of experiments which may be conducted in the water tank may be described as dispersion experiments. In these either the individual trajectory or statistical average of many trajectories may be observed and measured. This would be done in either of two ways:
(1) measure dynamic response of model to flow acceleration, or
(2) measure space-time history of models scaled to the turbulence as they fall either singly or in groups. The Basic Finner configuration is amenable to tests performed in the former way.

SECTION VI

ADVANTAGES OF CONTINUOUS FLOW

1. Sting Mounted Models

The obvious advantage of continuous flow is that running times are extended indefinitely. Transient phenomena due to starting the flow have an opportunity to die out, and those due to the approach of the free surface do not occur. If interest centers on the steady state, little testing time is actually available in a drain-down tank of modest height and reservoir volume because much of the available time must be devoted to establishing the flow. Less well anticipated was the early observation in the present facility that the streamlines become unsteady as the free surface approaches from above and well in advance of its arrival.

With continuous flow, presuming a sufficiently low turbulence level in the free stream, flows may be observed at length and in detail. Hydrogen bubble generation will be the cleanest technique of visualization, but also coloring matter may be injected economically, allowing for periodic replacement of the water supply or for continuous scavenging of the discolored portion.

2. Free Models

The free-fall of a body having a specific gravity slightly greater than unity can be arrested by upflow of the test medium. The test section velocity can be made to vary slightly with streamwise position to bring about the balance of model weight by model draw within a single plane of cross-section. Completely free model behavior can be observed at length in such a situation as long as it remains stable.

Figure 2. Wake of a Cylinder

Figure 3. Basic Finner at $\alpha = 30°$

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13. ABSTRACT

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