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Abstract

This paper discusses the design and development of a new experimental system designed to produce a variety of steady and unsteady flows. Accelerating, decelerating and oscillating flows over lifting surfaces are primary examples of the unsteady flow configurations that can be generated. Also this report presents details of preliminary tests performed to determine the performance of this system. These include quantitative and qualitative testing on two-dimensional and three-dimensional flow configurations.

1. Introduction

Wind tunnel testing is an essential tool in aerospace engineering as well as in performing basic scientific research. The recent developments in Computational Fluid Dynamics (CFD) and the use of this technology in engineering and in research require a verification source and a reference guide to economize computational efforts. The wind tunnel is a primary tool that can provide such needs. Most wind tunnels are designed as open-circuit or closed circuit tunnels where the freestream flows are steady [1]. Very often the modification of these tunnels to produce unsteady flow proves to be difficult and costly.

Recenty, a research program on unsteady flow testing was initiated at the Depertment of Mechanical and Aerospace Engineering and Engineering Mechanics at UMR. There a new subsonic wind tunnel has been designed and developed. The tunnel has been designed primarily to conduct basic research on unsteady flow configurations were the flow and/or test model motion is time dependant. The main focus of these research efforts is exploring possibilities of utilizing unsteady flow effects that could have significant consequences on enhancing aerodynamic performance of lifting bodies [2].

This paper presents part of these efforts and focuses on the development of a new experimental system designed for conducting aerodynamic testing on unsteady flows.

2. System Design and Capabilities

To develop an experimental system that can be utilized for steady and unsteady flow testing, a test section and movable cart were designed and constructed. One of the design requirements of the system was to incorporate it into an 18" X 18" subsonic wind tunnel. The cart was designed so it could be maneuvered inside the tunnel test section to generate accelerating and decelerating motions.

As shown in Figure 1, the test section is supported on a support frame which was constructed from wood and consists of four levels. The two lower levels were built into the system for use as shelves to accommodate data acquisition equipment and needed hardware.

An 18" X 18" X 96" plexiglass test section was constructed and mounted on the support frame. Clear 1/2" plexiglass was selected to allow for flow visualization experiments to be performed from both sides and the top. Each plexiglass wall is supported by 2" angle aluminum, which was screwed to the glass and bolted to the deck of the main frame.

To generate unsteady flows, a movable cart and test model carrier were also developed. As can be seen in Figure 1 (b), the cart rides on rails that span the length of the support frame on the third level. The cart was constructed from 1/2" aluminum and travels outside of the test section in between the third level and the deck. Two aluminum angles were mounted to the platform to be used as rails which guide the cart.

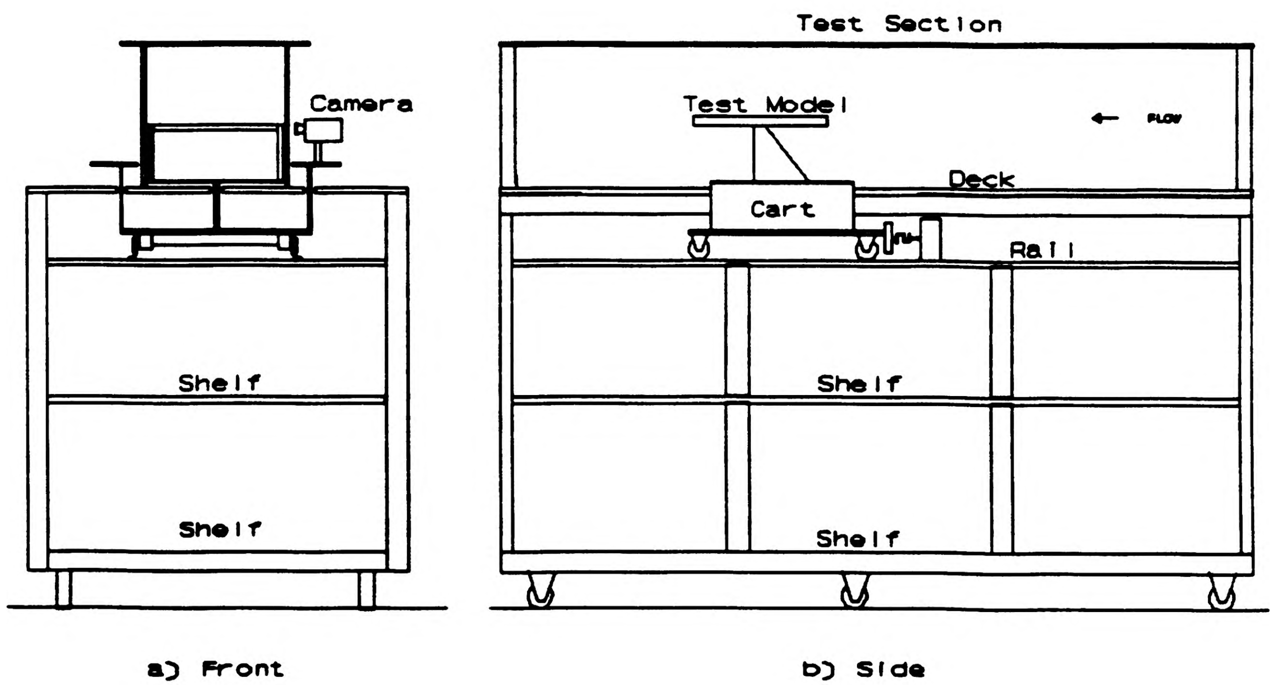

Figure 1 Front and Side Views of the Experimental System

A slot was left in the deck so that a test model carrier could be installed and maneuvered inside the test section. For steady flow testing, this slot is covered with linoleum to prevent air leakage into the test section. The carrier is constructed of 1/4" aluminum and mounted on a vertical plate on the cart. In addition to the test model carrier, the cart also carries two aluminum plates where a movie camera can be mounted outside the test section for flow visualization purposes. The various components of the cart-carrier set up are shown in Figure 2.

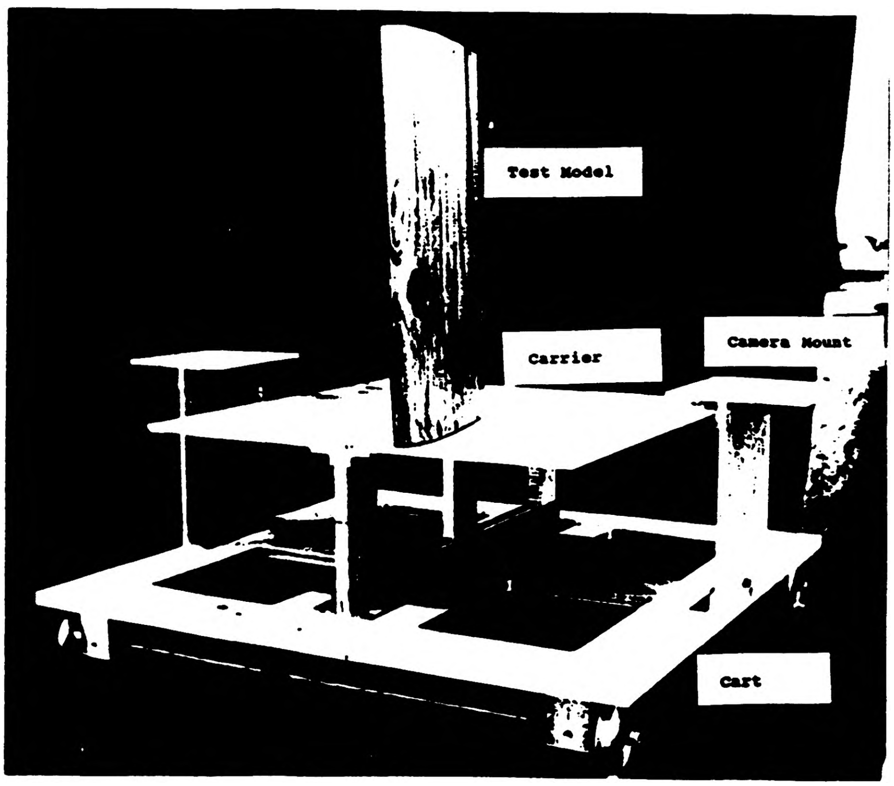

Figure 2 Photograph of the Cart-Carrier Set Up

For quantitative testing such as drag measurements, a load cell can be mounted between a fixed block and the cart. This load cell is rated for 100 lbs and accurate to 1/100 lbs.

As mentioned earlier, the experimental system can be employed to generate a wide range of accelerating and decelerating motions. A spring set up is employed to produce rapid accelerations. In this arrangement the cart is attached to a set of springs at a distance of 4 ft from the mounting block by nylon string, shown in Figure 3. The distance allows for enough space in front of the cart to produce the required acceleration.

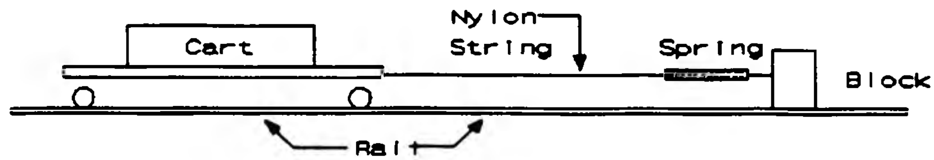

Figure 3 Experimental Set Up for Cart Acceleration

As can be seen in Figure 4, by using a large spring stiffness such as k1, a nearly impulsive motion can be generated. With decreasing spring stiffness, such as k2 or k3, and/or decreasing the initial spring deflection a wide range of acceleration rates can be obtained.

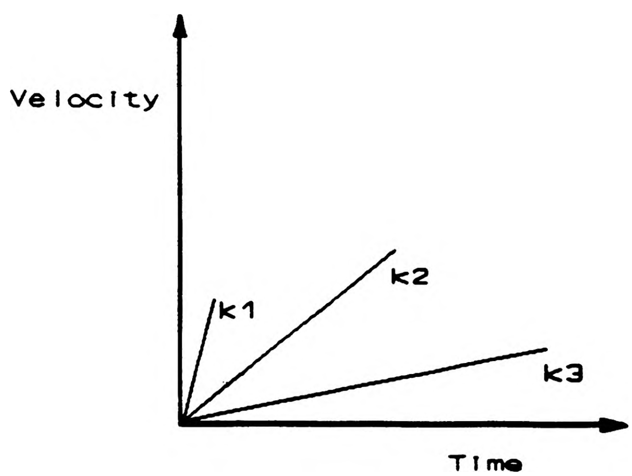

Figure 4 Examples of Acceleration Rates Using Springs

Once construction of the experimental system was completed, the flow quality within the tunnel was investigated. This was done by performing measurements of the velocity profile. Four stations were selected, starting at distance of 13" from the front of the test section and equally spaced through a distance of 68". The velocity profiles were measured at each station with a pitot-static tube traversed through a small opening in the top of the test section. The data from these measurements resulted in a reasonable representation of the boundary layer thickness over the tunnel ceiling. The boundary layer thickness was plotted vs.

the distance along the test section at a velocity of 44 ft/sec. As can be seen in Figure 5, the boundary layer thickness increased from 1 1/4" at a distance of 9", to 2 1/2" at a distance of 90". This is a reasonable value for this test section at this velocity.

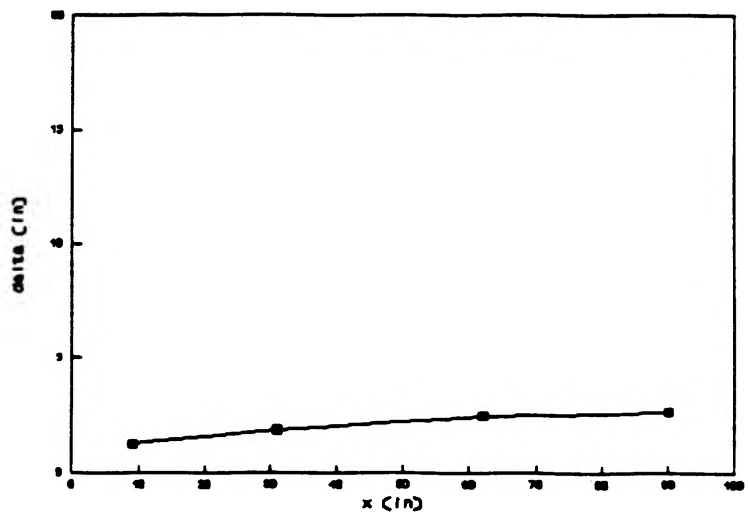

Figure 5 Boundary Layer Thickness Along Tunnel Ceiling at 44 ft/sec

3. Experiments in Steady Flow: A Quantitative Example

In addition to the unsteady testing capabilities, the system can be employed for steady flow testing. As an example, the set up shown in Figure 6 is utilized to measure the drag on a test model. The model was mounted on the carrier vertically with an angle of attack adjustment mechanism. The drag on the wing was sensed by a load cell and transmitted to a load cell digital meter. The test section flow velocity was measured by a pitot-static tube and a pressure transducer.

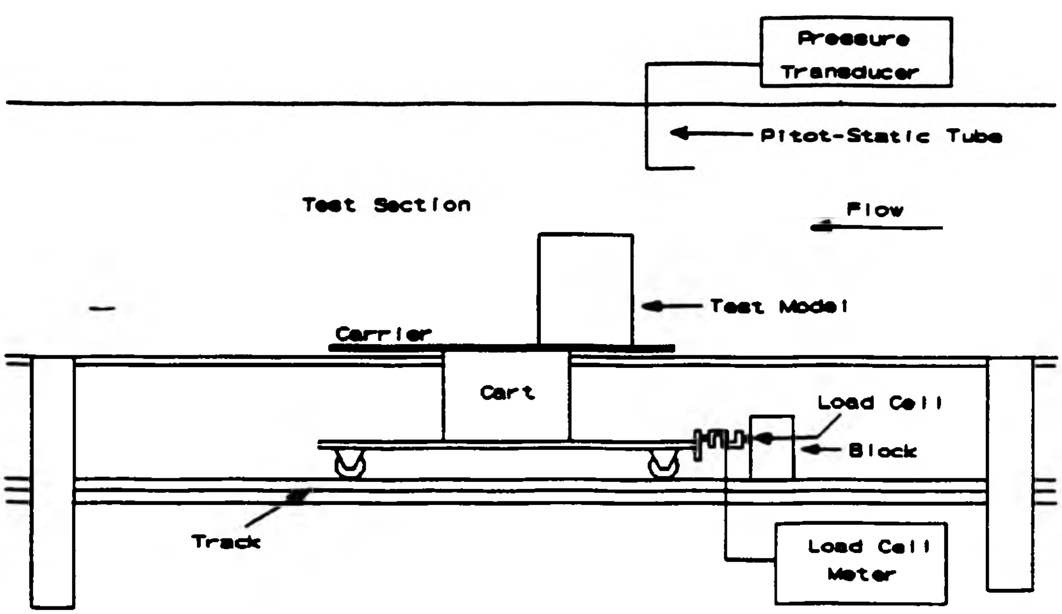

Figure 6 Drag Measurement Set Up

Figure 7 shows an example of the wing drag coefficient as a function of angle of attack. A 6" X 17" flat plate model was subjected to a flow velocity of 40.8 ft/sec. As expected the graph shows a sharp increase in drag coefficient at an angle of attack of 20 degrees.

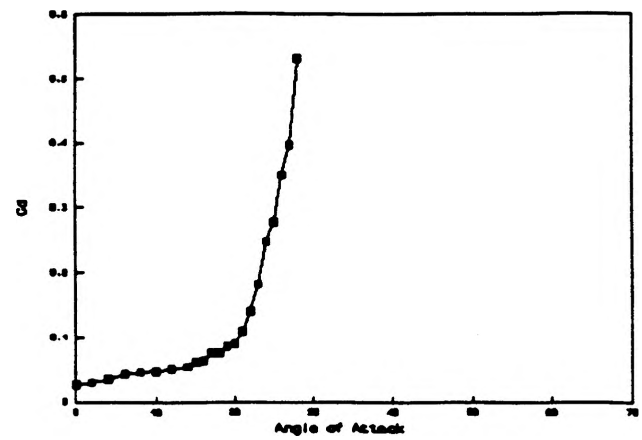

Figure 7 Example of Drag Coefficient vs. Angle of Attack for a Flat Plate Wing Model

4. Experiments in Unsteady Flow: A Qualitative Example

To present an example of the unsteady flow testing capabilities of the system, a few flow visualization experiments on accelerating flow starting from rest were performed. The vertical model was again mounted on the cart with the spring system described above. Prior to releasing the cart, liquid titanium tetrachloride ($TiCl_4$) was injected directly to the surface of the wing [3]. This liquid reacts with the moisture in the airflow and produces dense white smoke, which was photographed by a Bolex movie camara at a rate of 64 frames per second.

Figure 8 is an illustration which shows a typical vortex development near the wing tip. This development consists of a wing tip vortex and a leading edge vortex which converge at the upper right corner of the test model.

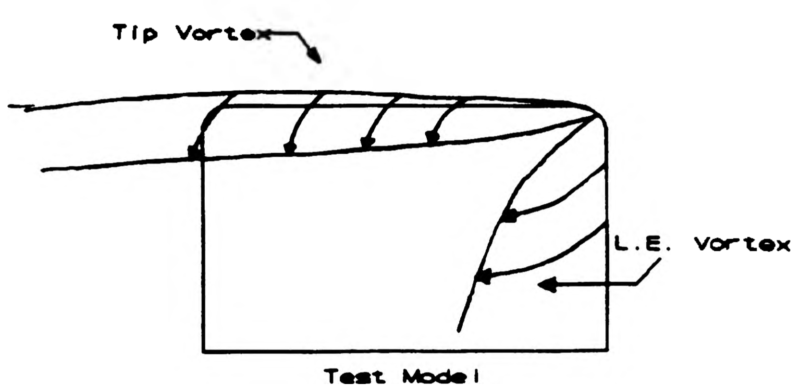

Figure 8 A Sketch of a Typical Wing Tip Vortex System

Figure 9 shows an example of a photographic sequence that visualizes the wing tip and leading edge vorticies over a flat plate model with an initial acceleration rate of 10 ft/sec^2. In this sequence, the flow is from right to left and the time increment is 1/32 seconds.

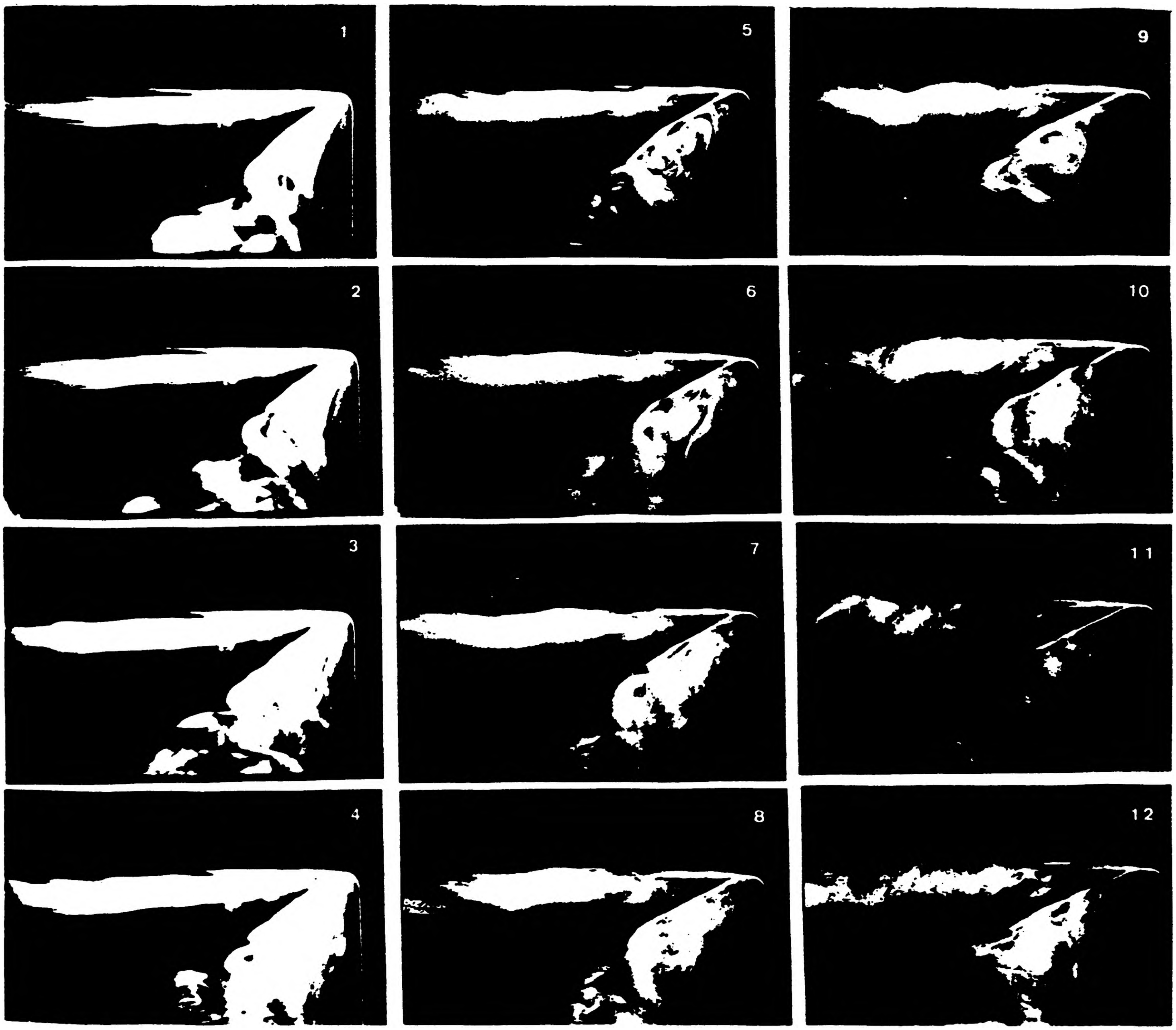

Figure 9 Photographic Sequence Visualizes Vortex Developments Near a Rectangular Wing Tip in Accelerating Flow

The initial acceleration for this experiment was determined by photographing a scale behind the model. The velocity of the cart can be determined by finding the distance the cart traveled per frame and knowing the frame rate of the movie camara. The acceleration can then be found by finding the differences in velocity for a series of frames. Figure 10 is a sample of a series for an initial acceleration of 10 ft/sec^2.

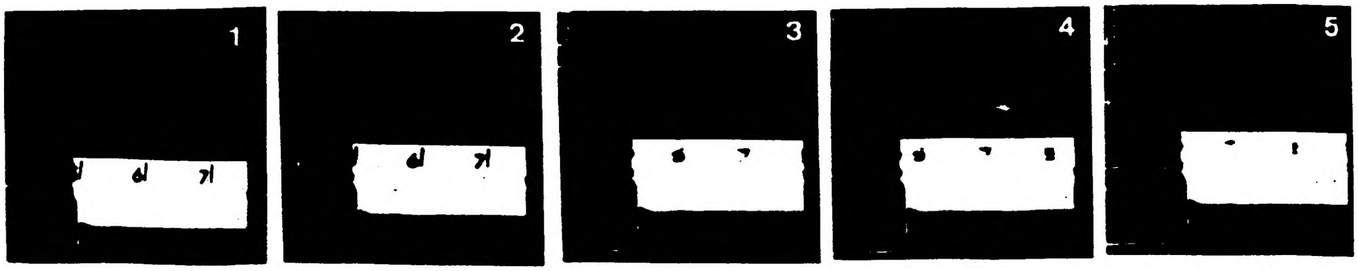

Figure 10 Photographic Sequence of a Scale Used for Determining Acceleration Rates

5. Concluding Remarks

This paper reports the development of an exprimental system incorporated into an 18" X 18" subsonic wind tunnel to add unsteady flow testing capabilities. This system can be employed for aerodynamic testing on accelerating flow, decelerating flow, and oscillating flow over lifting surfaces. This system is being utilized for quantitative and qualitative experiments on a variety of unsteady configurations. The main focus of these experiments is exploration into the possibilities of utilizing unsteady flow effects that could have significant consequences on enhancing aerodynamic performance of lifting surfaces.

Acknowledgements

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