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PROGRESS REPORT NO. 5

RESEARCH DESIGN PROBLEMS RELATING TO FACILITIES FOR SIMULATING THE AERODYNAMIC EFFECTS OF ATMOSPHERIC GUSTS ON AIRCRAFT COMPONENTS

October 26, 1953—April 26, 1954

By

A. M. Kuethe

J. D. Schetzer

L. C. Garby

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SUMMARY

A vortex generator device for simulating atmospheric gusts in a wind tunnel has been tested and is found to be suitable for producing large gust gradients of the "rough air" type. The gusts are adequately repeatable and instrumentation for measuring their effect on wing lift has been developed.

Conclusions regarding the feasibility of gust generating devices are drawn and recommendations are made to continue development of the vortex generator and moving bump type systems.

Specifications on large-scale models of the two gust generating facilities are included in this Progress Report.

I VORTEX GENERATOR

In this period, experimental work was carried out on the vortex type of gust generator. A description of the mechanical operation has been given in Progress Reports #2 and #4. The generator is mounted at the entrance of a test section, which has its side walls extended outward approximately 13 inches beyond the inlet jet, see Figure 1-a. The expansion of the side walls gives the stream freedom to deflect when the flippers are operated. In effect, the test section operates as a semi-open jet.

To identify positions in the test section, the following rectangular coordinate system is used, see Figure 1-b. The origin of the coordinate system is located on the floor of the tunnel, midway between the two side walls, and 5-3/4 inches downstream of the hinge line of the flippers. The scale unit along all axes is in inches. The coordinate axes are denoted as follows:

x axis--extends along the flow direction; positive sense is downstream.

y axis--lies in the horizontal plane and is normal to the wind direction; positive sense follows from the right-hand rule.

z axis--extends in the vertical direction; positive sense is upward.

TEST SECTION SURVEY (STEADY FLOW)

Velocity and turbulence surveys were made in the tunnel with the flippers both in and out. In Figure 2a is shown the velocity distribution along the tunnel center line with flippers installed. This survey was made by means of a total head probe, and the result is similar in character to that obtained in an open jet.

The turbulence level of the tunnel was measured at a number of longitudinal stations. In Figure 2b is shown the turbulence level across the tunnel at stations $x = 10$ and $x = 30$. From this data, it can be seen that the turbulence level increases rapidly as one moves downstream. With the flippers installed there is a strong wake measured behind each of the flippers.

The turbulence level at stations x = 10 and y = 0 is about 0.2% of the free stream velocity.

TEST SECTION SURVEY (GUST GENERATOR OPERATING)

The deflection history of the flippers is shown in Figure 3. The technique used to measure the deflection is described in Progress Report #4. It may be noted that the rotational rate of the flipper is greater in the advancing portion of the cycle than in the return portion of the cycle. However, it follows a roughly sinusoidal pattern.

To detect the angle of flow change, X type hot wire probes are used. With this system, the change of flow direction in the plane of the inclined wires is measured as the difference in potential between the two wires. This potential difference is then fed to the D.C. input of an oscilloscope.

The wires are located in the xy plane, are inclined at approximately 45 degrees to the flow and are located about 2 mm. apart in the vertical direction. Tungsten wire of 0.0002 inches in diameter, that have an active length of approximately 4 mm., are used. Generally, wires are selected whose resistances match within 3%. For these tests an overheating ratio of 0.5 is used. The heating current for the wires is furnished by means of 24-volt aircraft batteries, one battery being used for each wire. This provides a convenient and stable power source.

Calibration of the x probes is carried out by setting the tunnel at a given speed and setting the wires at a series of flow angles in the stream. The deflection of the oscilloscope beam is photographed and data reduced from this unit. There is some fluctuation of flow direction over a rather long period. Therefore, to get a representative calibration curve, a camera exposure of five seconds is used for each angle setting of flow.

To survey the tunnel, two X type hot wire probes are used. One probe is fixed in location and serves as a monitor, while the other probe is used to survey the test section. A Thiele-Wright hot wire anemometer unit is used to operate the test probe, while a Bureau of Standards type of anemometer as reported in NACA-ACR-5K27, is used for the monitor control.

In operation of the system, both the monitor and test probe are recorded simultaneously on a dual beam scope. Both beams of the scope use a common sweep and have the same time base. In addition to the recording of the two probe traces, a timing pulse is placed on the scope in order to provide a time count. To do this, the z axis of the monitor probe is modulated by a 100 c.p.s. signal from a sine wave generator, and this signal trace is then photographed on the same picture as the hot wire traces.

In surveying the tunnel with the X probe, the monitor probe is kept at a fixed location in order to provide a means of comparison between runs. The location of the monitor probe is:

$$x = 8.5, \quad y = -2.5, \quad z = 6.$$

The probe was displaced in the y direction in order to keep it out of the wake of flipper #4. (See Figure 1a)

A series of tests were then made to determine the flow characteristics with the flipper acting in order to obtain the best location for the installation of the lifting surface, which is used to measure the effectiveness of the gust generator device.

The general areas covered by each survey are given in the table following.

In series 1, tests were made with all flippers operating. Test (a) is a survey along the x axis of the tunnel at $y = -1.5$ and $z = 13$. In Figure 4 are shown hot wire oscillograms of this test. The lower trace in each oscillogram is that of the test probe, while the upper trace is the monitor response. The horizontal dashed line is the time trace; the time between corresponding point is 0.01 seconds. In Figure 5 is shown the flow angle versus time plot for the survey along the x axis.

With all the flippers installed a strong wake effect is observed for surveys along the y axis or along the x axis at sufficient distance downstream of the flippers. A wake-free flow of two chords lengths in the y direction is adequate for testing the lifting surface. To provide this, various flippers were removed from the gust-generator mechanism and surveys made of the resulting flow pattern. These tests are represented by Series 2, 3, and 4 in the following table. From these tests, a gust generator configuration having flippers number 3 and 4 removed was selected and the leading edge of the lifting surface placed at $x = 10$, and $y = -2.5$.

BALANCE SYSTEM (STATIC OPERATION)

The mechanical operation of the balance system is described in Progress Report #4. Since the balance will be used to measure transient forces, it is important that it follow the applied force accurately. To check this, a step force is applied to the balance and the output observed on the oscilloscope. This step force is applied

OUTLINE OF THE "X PROBE" SURVEY OF THE TEST SECTION

Series	Test	Direction Axis of Traverse	Range of Traverse	Units in Each Step	Fixed Ordinates			Configuration of Flippers	Time Pulse Frequency CPS	Wind Speed fps
					x	y	z			
1	a	x	10 to 70	10		-1.5	13	All in	100	35.5
	b	y	-7 to +7	1	30.5		13	All in	100	35.5
2	a	x	10 to 60	10		0	13	#4 flipper out	100	35.5
	b	y	-6 to +6	1	30.5		13		100	35.5
	c	y	-5 to +5	1	10.0		13		100	30.8
3	a	x	10 to 60	10		-1.5	13	#3, #4 & #5 flippers out	100	35.5
	b	y	-6 to +6	1	30.5		13		100	35.5
4	a	y	-7 to +7	1	10.0		13	#3 & #4 flippers out	100	30.8
	b	z	+5 to +14	1	6.5	-2.5			100	30.8
5	a	y	-5 to +5	1	10.0		13	#4 flippers in only	100	29.5
	b	y	-7 to +7	1	30.5		13		100	29.5

by suspending a weight on a thread which is attached to the free end of the lifting surface. This applies a force in the lift direction. In operation, the balance system is placed under load by means of the thread, the oscilloscope sweep is started, and the thread is then cut. The response to this step force is recorded by photographing the oscilloscope face.

The response of the balance system to a step force indicated three modes of oscillation and that some of the modes were under-damped. Various damping techniques were tried. However, the most satisfactory arrangement was found to be the use of electrical filtering. An electrical filter having a 40 c.p.s. cutoff point and a 18 d.b. per octave falloff was used. This filter was constructed from a differential amplifier type of computor.

With the low pass filter installed, the balance response to a step function input is shown in Figure 6a for the condition of no air-flow. In Figure 6b is shown the step response of the airfoil when the tunnel is being operated at approximately 60 feet per second. In both Figures, a 50-cycle time pulse is placed on the oscillograms; the time between corresponding points on the time trace is 0.02 seconds. For both cases, the rise time is 0.0087 seconds. There does not appear to be much additional damping due to the operation of the wind tunnel.

STATIC FORCE CALIBRATION OF LIFTING SURFACE

In Figure 7a is shown the lifting surface installation. The position of the airfoil is:

$$\left.\begin{aligned} x &= 10 \\ y &= -2.5 \end{aligned}\right) \text{ leading edge}$$

Airfoil--NACA 0018
Chord--6 inches
Lift sensitive span section = 12 inches
Distance from floor to bottom of lift sensitive span = 4.5 inches
Distance from floor to top of lift sensitive span = 16.5 inches.

As described in Progress Report #4, the airfoil acts as a cantilever beam with the restraint and displacement measuring mechanisms located in the section nearest the floor of the tunnel. The upper section merely serves as an end piece in order to keep the flow as nearly two-dimensional as possible.

In Figure 7b is shown the calibrating mechanism of the balance system. In operation of this unit, a bracket is attached to the airfoil such that positive or negative lift loads may be applied by a bell crank mechanism. By applying these forces at a number of points along the span of the airfoil, the true lift response can be obtained. In Figure 7c is shown a typical balance calibration curve. The mean of the absolute error of the balance is 0.0077 pounds for the range being tested.

LIFT CURVE SLOPE OF LIFTING SURFACE

The lift curve slope of the surface was obtained by setting the airfoil at a series of angles of attack and recording the lift force. Actually the normal force is measured, but for relatively small angles this is considered the same as the lift force. In Figure 8 is shown the lift curve of the surface. The slope of this curve is 0.92% of 2π; thus the lifting surface is very close to a two-dimensional wing.

DYNAMIC LIFT MEASUREMENTS

Data is recorded by photographing the oscilloscope face, and the scope is triggered by the action of the flippers as in the previous case. Three pieces of information are recorded by the oscilloscope; the dynamic lift, response of the hot wire monitor, and a time base signal. Circuitry for the balance system has been referred to on preceding pages, and the circuit used for the hot wire unit is exactly the same as that used previously. The time base is obtained by z modulating the hot wire trace. This is done by taking a special sweep across the scope previous to recording the lift and hot wire data.

The positions of the lifting surface and hot wire probe in the test section are given below:

	Airfoil (leading edge)	X Hot Wire Probe
x	10	7.5
y	-2.5	-2.5
z		5.0

Tests were made at wind speeds of 15, 30 and 60 feet per second. Shown in Figure 9 are the oscillograms for the above tunnel speed conditions. In Figures 10a, 10b and 10c are shown the reduced data for these tunnel speeds.

In Figure 10a are shown 6 runs at a tunnel speed of 59.7 feet per second. The variations in lift measurements follow the variations in flow as shown by the monitor wire.

The hot wire probe is located 2-1/2 inches ahead of the leading edge of airfoil. Velocity measurements made at this station indicate that the same velocity occurs there as occurs at the reference pitot tube point for the tunnel. Thus, for a tunnel velocity of 59.7, 0.00350 seconds are required for the flow pattern to travel from the probe to the leading edge of the lifting surface. Similarly, it requires 0.0119 seconds for the pattern to travel from the probe to the trailing edge of the lifting surface. Referring to 10a, it can be observed that zero angle of attack as measured by the probe, and zero lift as measured by the balance are separated by an interval of approximately .025 seconds. Thus, there is a time delay of 0.013 to 0.021 seconds, which may be attributed to unsteady aerodynamics and balance response. Therefore, of this, not more than .004 seconds can be assigned to balance lag.

Further analysis of the data is in progress.

II CONCLUSIONS ON THE FLIPPER TYPE GUST GENERATING DEVICE

The flipper device described in this Progress Report is capable of producing large local angle of attack changes in less than a half chord of travel. Therefore, it is suited to simulating "rough air" type gustiness. The instrumentation required to measure the rapid responses involved must have considerably better dynamic characteristics than that required for the bump device. The instrumentation problem, however, does not appear to be critical. No way has been devised to take direct measurements of the lift under steady conditions that can be compared with dynamic measurements for the purpose of isolating the non-steady effect. This is no drawback as far as measuring dynamic response is concerned, but it makes development of analytical methods difficult.

The repeatability of the unsteady flow generated by the flipper appears to be satisfactory.

III CONCLUSIONS ON THE BUMP TYPE GUST GENERATING DEVICE

A detailed description of the moving bump device for generating non-stationary aerodynamic effects is contained in Progress Report No. 3. Small model tests indicate that a repeatable non-stationary flow can be produced that will change the average angle of attack of a wing by 6 degrees in two chords of wing travel. By suitable design the angle of attack change can be increased to 10 degrees in two chords of travel. Preliminary tests indicated that instrumentation can be developed that will adequately measure the non-steady effect associated with rates of change of angle of attack of this magnitude.

The moving bump device for producing gust gradients of the magnitude indicated above is believed to be particularly useful because direct measurement of dynamic and quasi steady lift under identical conditions may be made. This facilitates comparison with theory, and the development of analytical methods for predicting loads produced by gusts.

IV RECOMMENDATIONS

Of the various devices considered for generating unsteady flow in a wind tunnel, the moving bump and the flipper have shown greatest promise. Small scale models and associated instrumentation have been constructed, and sufficient test data has been obtained to prove the feasibility of both devices.

Because the two devices simulate gust gradients of different magnitudes as explained in the preceding paragraphs, it is recommended that development of both mechanisms be continued. The appropriate next step is the construction of larger scale models so that data in the proper Reynolds number range may be obtained. Development of instrumentation, and exploratory tests to determine the utility of these types of gust generating facilities should be continued.

V SPECIFICATIONS FOR GUST SIMULATION MODEL

A sketch of the Model Gust Simulation Generator, as provided for under Contract No. 33(616)-316, is shown in Figure 11. The model would be constructed on University of Michigan property, (referring to Figure 12), the cost of station 5 through 13 and of the building housing the test section to be borne by the University, while the cost of that portion from station 13 through the working section to station 5 is chargeable to the contract.

Configuration and Performance

A sketch of the Gust Simulation Model is shown in Figure 11. This model will be coupled with a fan and return passage to form a single return passage type tunnel. Important items in the configuration and performance are listed below:

A. Basic Dimensions

Test Section:

Width--7 ft.
Height--5 ft.
Length--25 ft.

Settling Chamber:

Contraction Ratio--15

Width--26 ft.
Height--20 ft.
Length--20 ft.

Number of screens in settling chamber--5

First Diffuser:

Equivalent Cone Angle

Section 2-3--3^o
Section 3-4--5^o

Area Ratio: Test Section Area/Area at Station 4 = 0.224
Length of Diffuser--44 ft.

B. Aerodynamic Performance in Test Section

Speed range--zero to 230 f.p.s. at a test section density of one atmosphere.
Maximum Reynolds No.--1.5×10^6 per ft. for a density of one atmosphere in the test section.
Free Stream Turbulence Level--0.01%.
Power required--280 H.P. will be required at V = 230 and a density of one atmosphere.

C. Gust Simulation Device

A gust generator of the "moving bump" type will be built and installed in the test section. The design of this bump will follow that described in Progress Reports #2 and #3.

Provision will be made in the design so that other generating devices such as the Vortex Generator Types, Progress Reports #3 and #4, can be easily installed.

In Figure 13b is shown a sketch of the test section with the "moving bump" installed in it. Figure 13c shows how the test section could be altered to accommodate the Vortex Generator.

D. Design Details

1. Test Section:

The basic frame of the test section will be made of structural steel, while all walls will be lined with plywood. See Figures 13a and 13b for details. The design of this section will be such that it will be possible to easily make alterations to the test section. Furthermore, the diffuser section 2-3, see Figure 12, will be built in such a manner that it may be replaced easily.

2. Design Loads:

Steel shell type of construction will be used from Station 2 through to Station 5. From Station 13 through to Station 1, the structure will be of steel beam construction with a plywood liner to form the aerodynamic surface.

The steel shell and structural steel framework with the exception of Section 12-13 will be capable of withstanding an outward acting pressure load of one atmosphere or an inward acting pressure of 1/2 an atmosphere. The test section will be designed to carry a load of 200 pounds per sq. ft.

3. Settling Chamber and Nozzle Section:

The basic frame of the settling chamber and nozzle section will be made of a steel beam structure capable of carrying a one atmosphere pressure load. Plywood panels will be used to form the inner surface, and to carry and distribute the airloads into the steel structure.

Five screens will be installed in the settling chamber. Each screen will be mounted in its own steel frame and provisions will be made to easily add or relocate the position of the screens in the settling chamber. One screen will be installed in the rapid expansion section to prevent flow separation along the walls.

The nozzle section will be 25 ft. long. Formation of the nozzle contour will be accomplished by bending plywood panels to the desired contour. Carved wooden ribs will be used to transfer the loads from the plywood into the basic steel structure.

SPECIFICATIONS OF THE RETURN CIRCUIT FOR THE GUST SIMULATION MODEL

The return circuit, from Station 5 through to Station 13, will be furnished by the University and will have the following specifications:

A. <u>Basic Dimensions</u>

The basic dimensions are given in Figure 12, and a sketch of the entire system is shown in Figure 11.

B. <u>Design Details</u>

1. Structure and Loads:

The structure from Station 5 through to Station 13 will be made of steel plate. Design loads for the structure from Station 5 through 12 will be for an outward acting load of one atmosphere and an inward acting load of 1/2 an atmosphere. Section 12-13 will be designed for an outward acting load of 300 lbs. per sq. ft.

All turning vanes will be formed to a radius from flat plate stock, and will have tapered leading and trailing edges.

2. The Power Plant and Fan:

The air speed will be controlled by changing the rotational speed of the fan. This fan will be of a single-stage type

VI INFLUENCE OF TUNNEL WALLS

Reduction of test data obtained in the gust facility to information applicable to wings in free flight must take into consideration interference effects due to the tunnel walls. Since these corrections cannot be known accurately, their magnitude should be small.

The tunnel wall corrections depend not only on the relative sizes of model and tunnel, but also on the type of flow pattern involved. The correction for a flat plate at an angle of attack (constant normal distribution of velocity) is not the same as that for a cambered airfoil. Similarly, in the unsteady flow case, the correction for an airfoil oscillating in pitch is not the same as the correction for an airfoil oscillating in plunge. For an unsteady flow, the correction for an airfoil with an arbitrary distribution of normal velocity depends upon the arbitrary distribution. This complicates the problem of assessing the tunnel wall interference.

Representative papers that treat the two-dimensional oscillating airfoil between parallel walls are those of Reissner(1) and Timman(2). Reissner uses the classical method of images to represent the airfoil and its wake between walls and solves the resulting integral equation by an approximate method. Timman gives an exact solution to the same problem by conformal mapping. It does not appear feasible at this time to adopt the numerical results of Reissner for the oscillating airfoil to the arbitrary unsteady flow case.

The approach used here is to isolate what is believed to be the primary effect of the tunnel walls and to set a maximum value on the influence of this effect on lift lag under typical testing conditions. The airfoil and its wake are placed between parallel walls. The usual assumptions of thin airfoil theory are made. In order to make the tunnel walls streamlines of the flow, the airfoil and its wake are reflected in the tunnel walls to infinity in both directions.

The lift lag is determined in part by the wake and in part by the apparent mass effect which is independent of the wake. Considering the wake lift only, two effects are observed:

(1) Because the airfoil is between walls, its quasi steady lift as a function of time will be modified. This affects the

distribution of vorticity in the wake and, therefore, the wake lift.

(2) The image system of the wake will induce a flow at the airfoil and the resulting lift must be counted as part of the wake lift.

These two effects interact on one another and an exact solution of the problem must consider the two simultaneously. However, it is believed that the primary effect of the walls can be obtained by considering the effects separately and adding them.

Computations following the procedure outlined above are in progress.

(1) Reissner, E., Wind Tunnel Corrections for the Two-Dimensional Theory of Oscillating Airfoils, Cornell Aeronautical Lab., Inc., Buffalo, N.Y. Report No. SB-318-8-3.

(2) Timman, R., The Aerodynamic Forces on an Oscillating Aerofoil Between Two Parallel Walls, Applied Science Research, Vol. 43, pp. 31-57.

VII WORK PLANNED FOR NEXT PERIOD

1. Small scale experimentation with the moving bump device will be continued in order to explore the limits of the utility of this type of gust generating facility in aircraft testing.

2. Development of the associated instrumentation will be continued.

3. Theoretical considerations on wall interference effects will be continued.

4. Bids on the construction of the higher Reynolds number model will be accepted and the detail specifications will be completed.

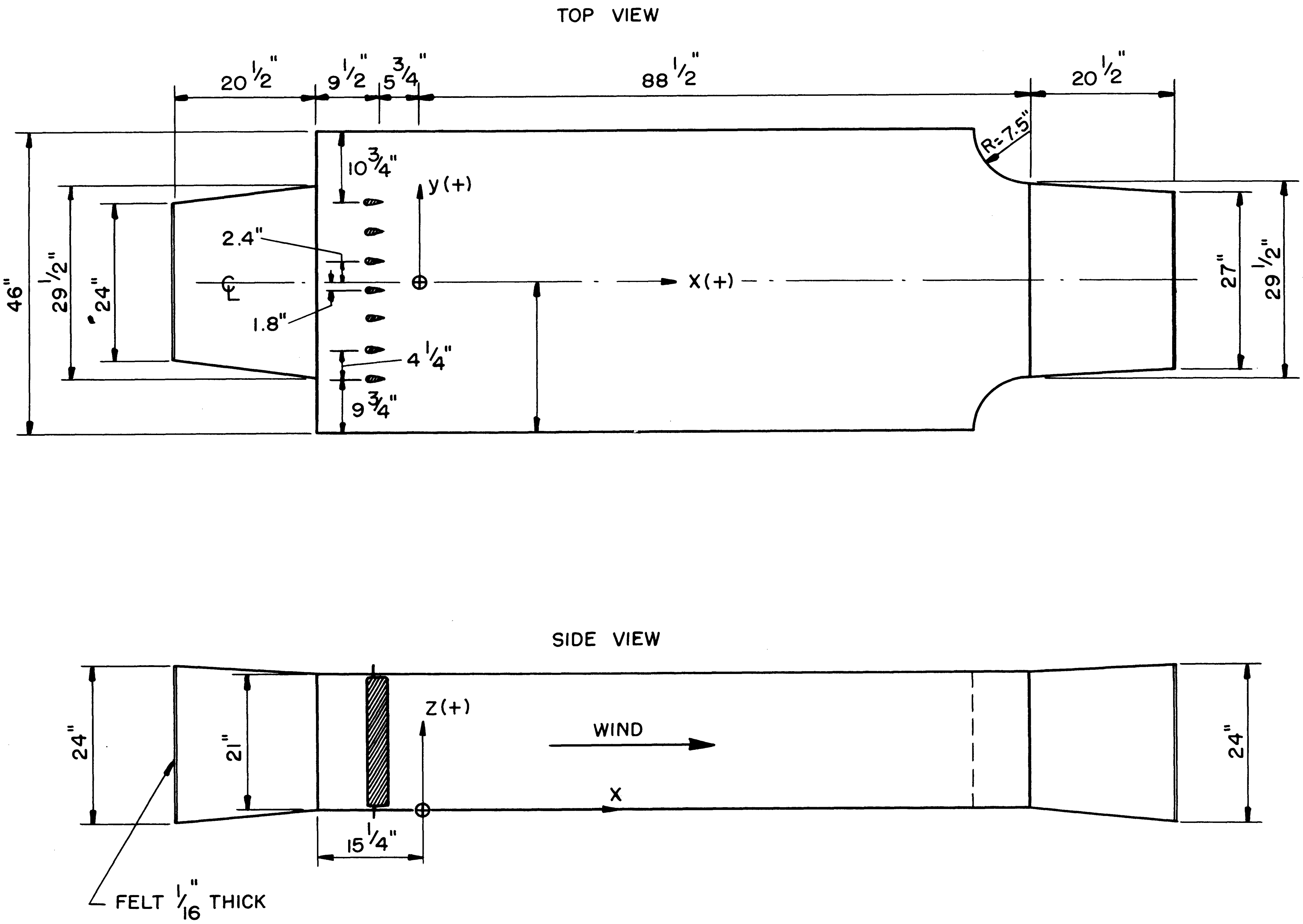


Fig. 1a. Sketch of Vortex Generator Installation.

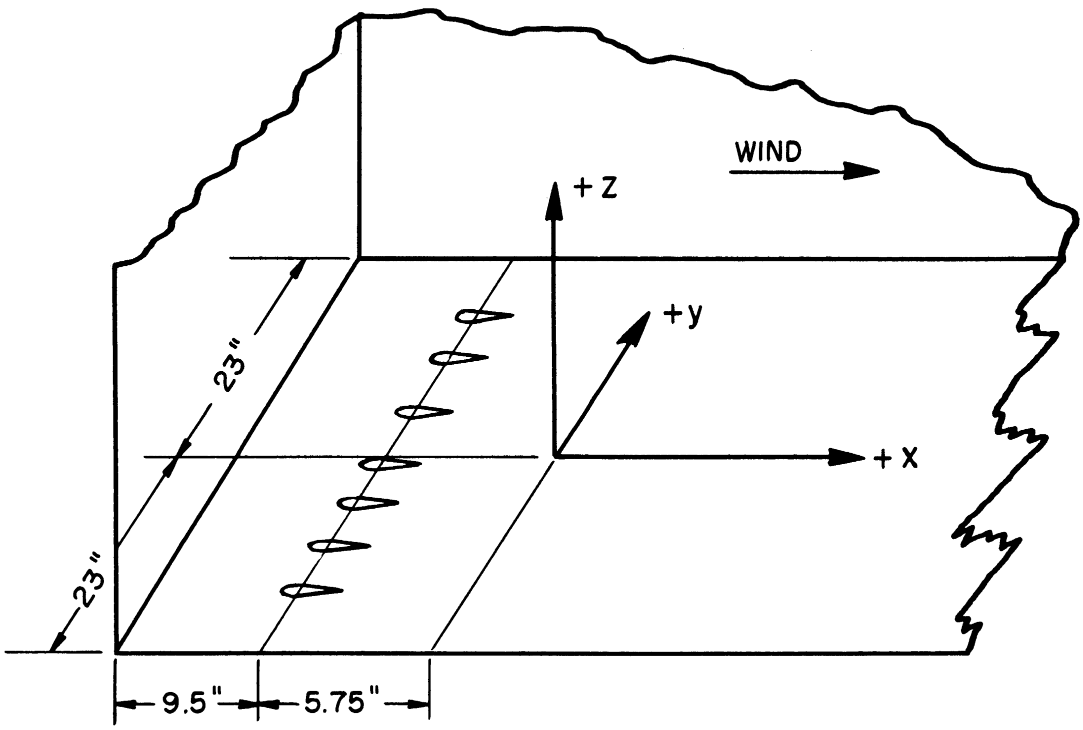


Fig. 1b. Coordinate System Used to Locate All Points in the Test Section.

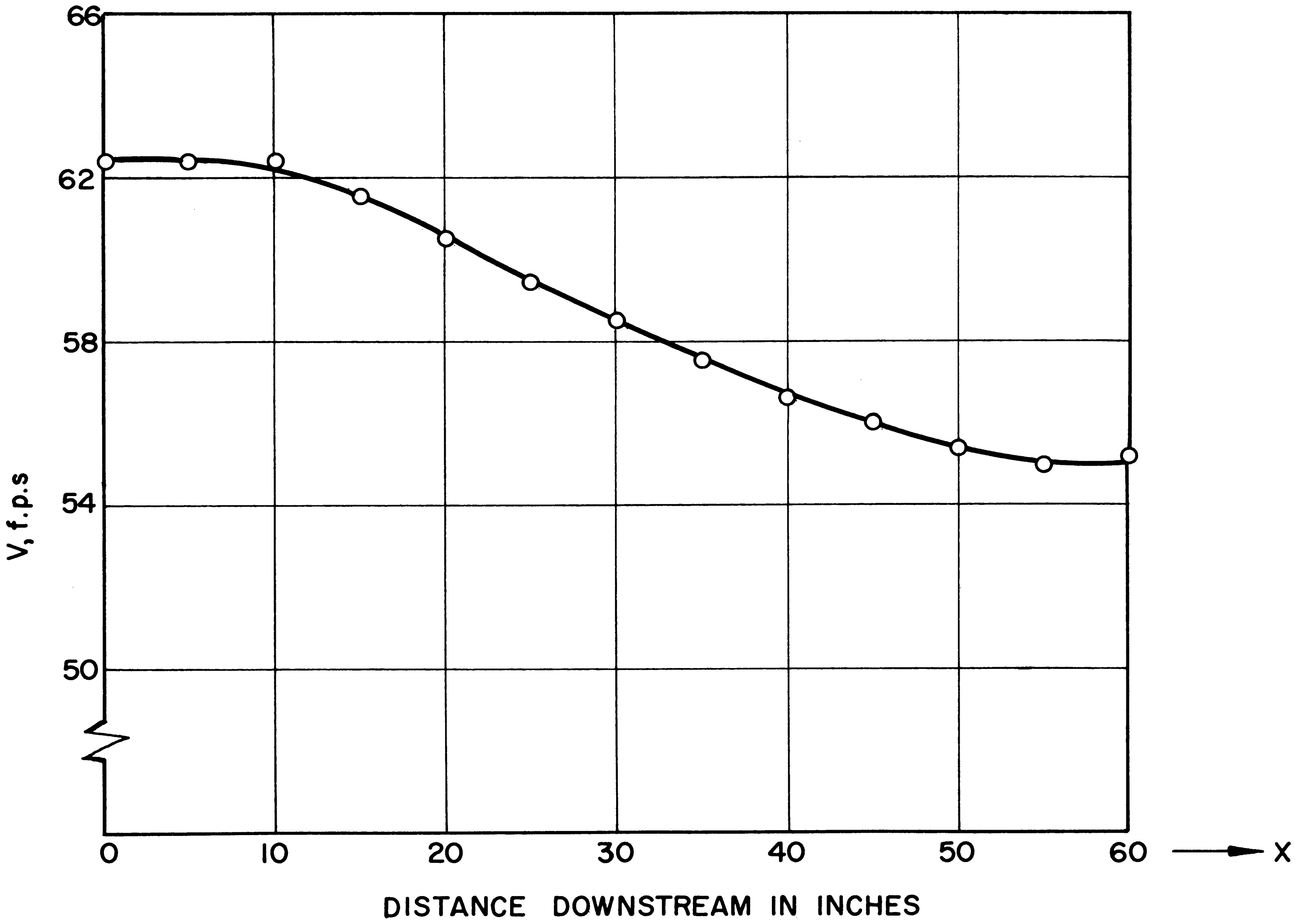


Fig. 2a. Velocity Distribution Along x axis with y = 0 & z = 10.5. Measurements Made with Total Head Probe.

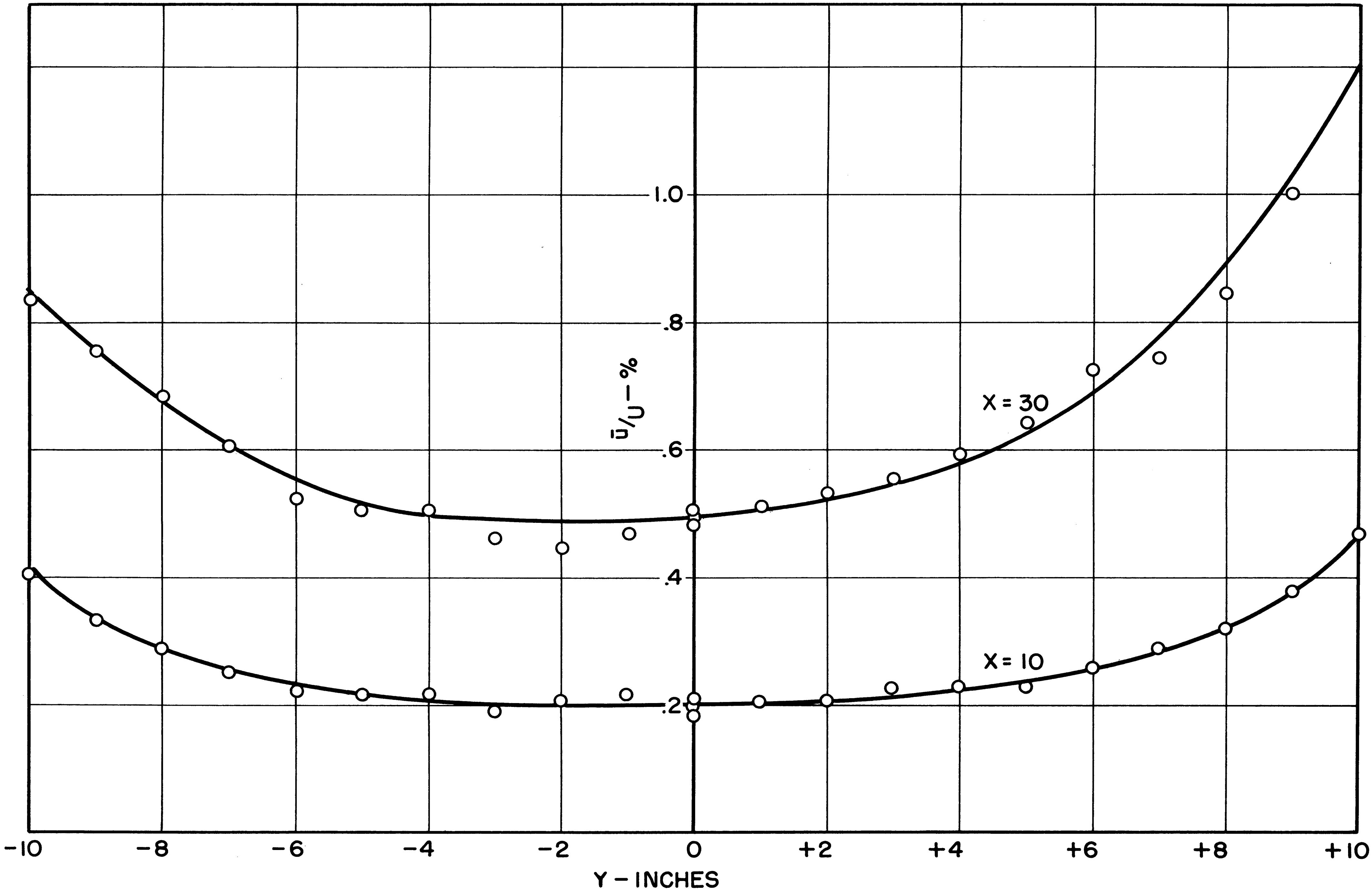


Fig. 2b. Turbulence Distribution Across Tunnel at x = 10 & x = 30 with z = 11. All Flippers Removed.

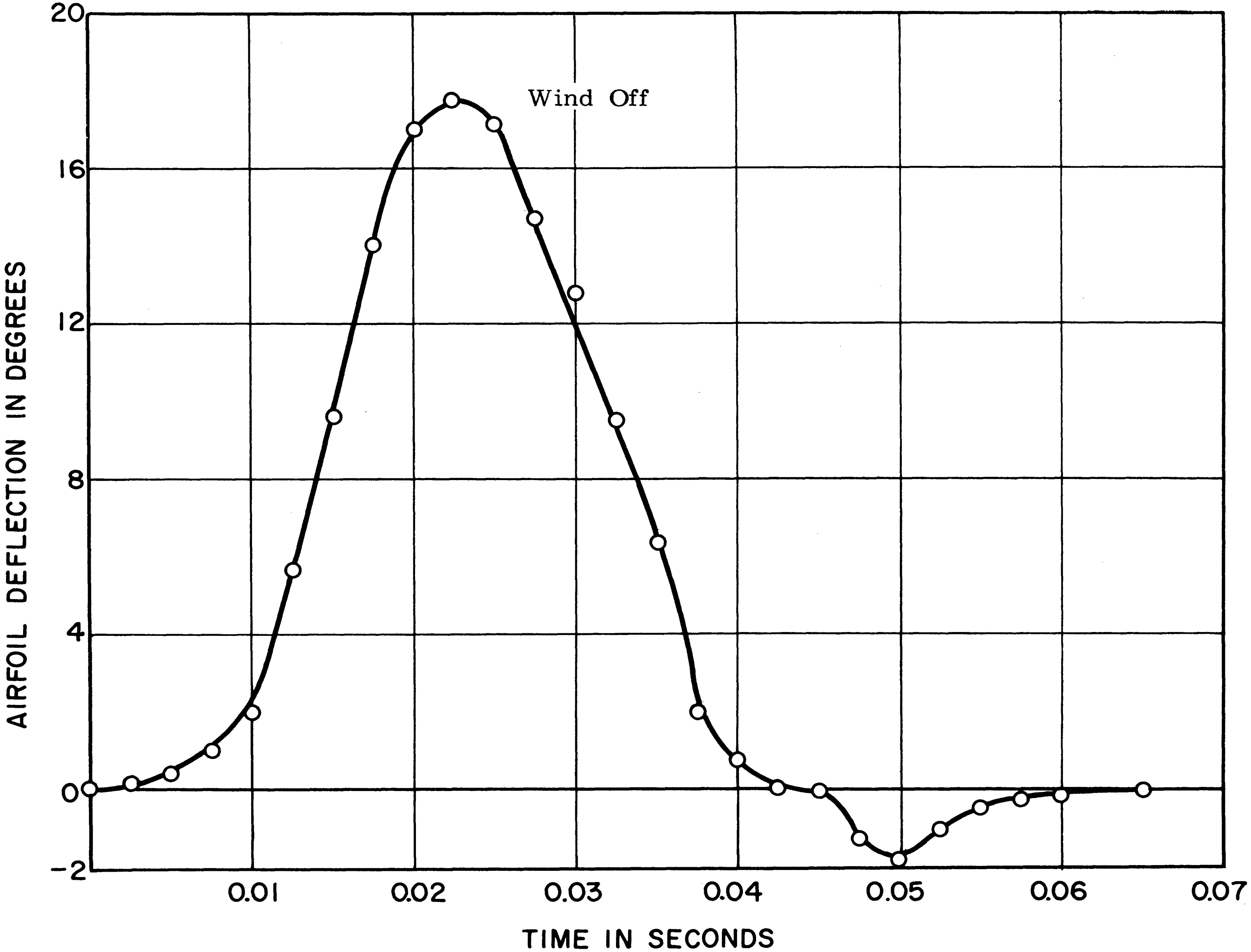
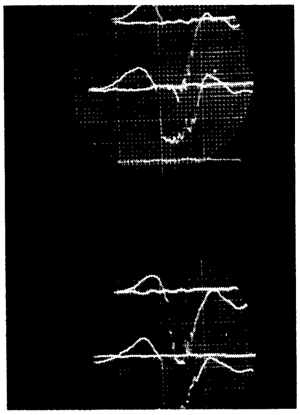


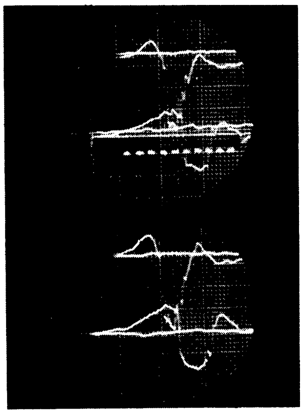
Fig. 3. Deflection History of Vortex Generator Flippers.

Fig. 4. Hot Wire Oscillograms of (v) Velocity Component Along x Tunnel Axis. All Flippers Installed.

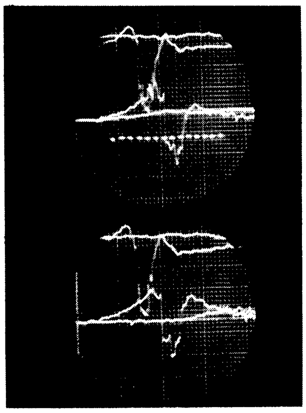
Series 1, test a
Wind Speed = 35.5 f.p.s.
y = -1.5, z = 13



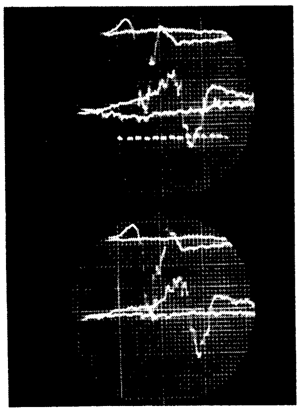
x = 10



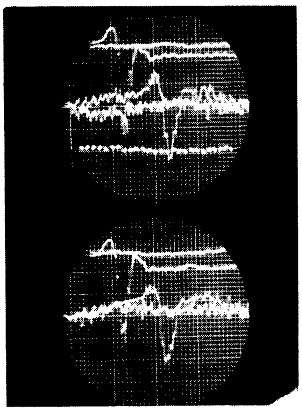
x = 20



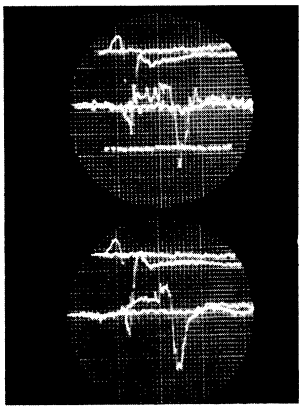
x = 30



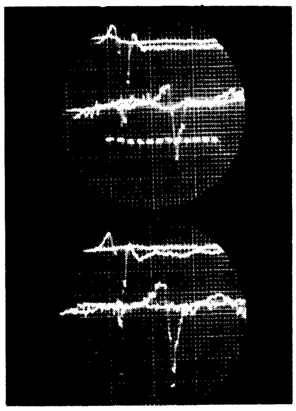
x = 40



x = 50



x = 60



x = 70

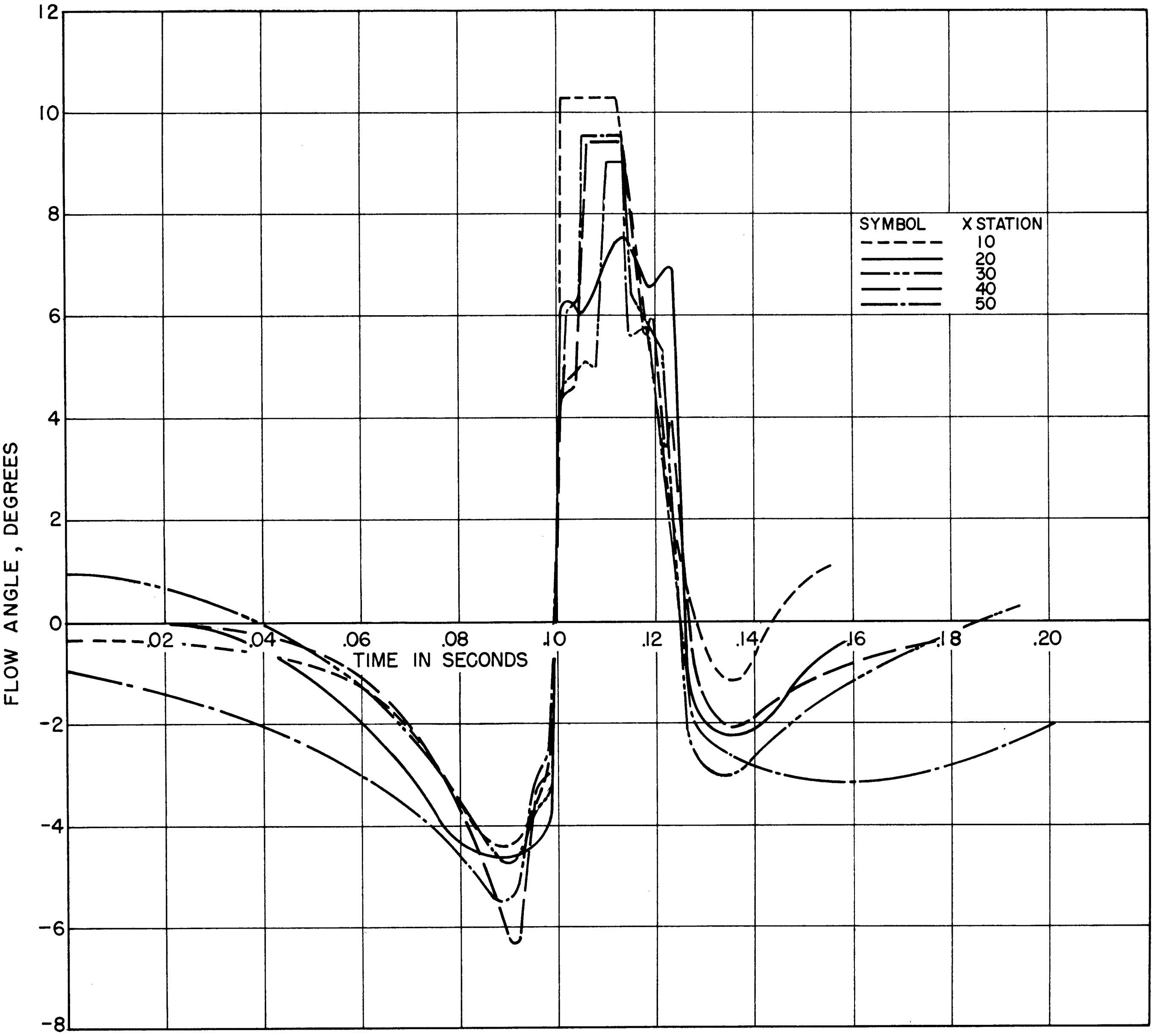


Fig. 5. Measured Flow Deflection vs Time at Stations Along the x Axis.

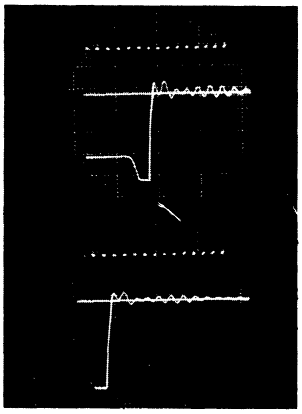
$x = 10, 20, 30, 40, \& 50$

$y = -1.5$

$z = 13$

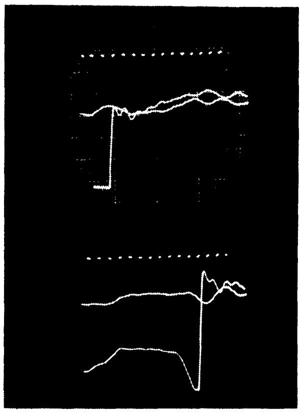
Wind Speed = 35.5 f.p.s.

Fig. a



Tunnel Off
50 c.p.s. time signal

Fig. b



Tunnel On
v = 59.5 f.p.s.

Low pass filter, 40 c.p.s. cutoff with an 18 d.b. per octave falloff used in both cases.

Fig. 6a & 6b. Response of Balance System to a Step Input.

Fig. 7a & 7b. Photographs of Lifting Surface Installation in Tunnel and Calibrating Mechanism.

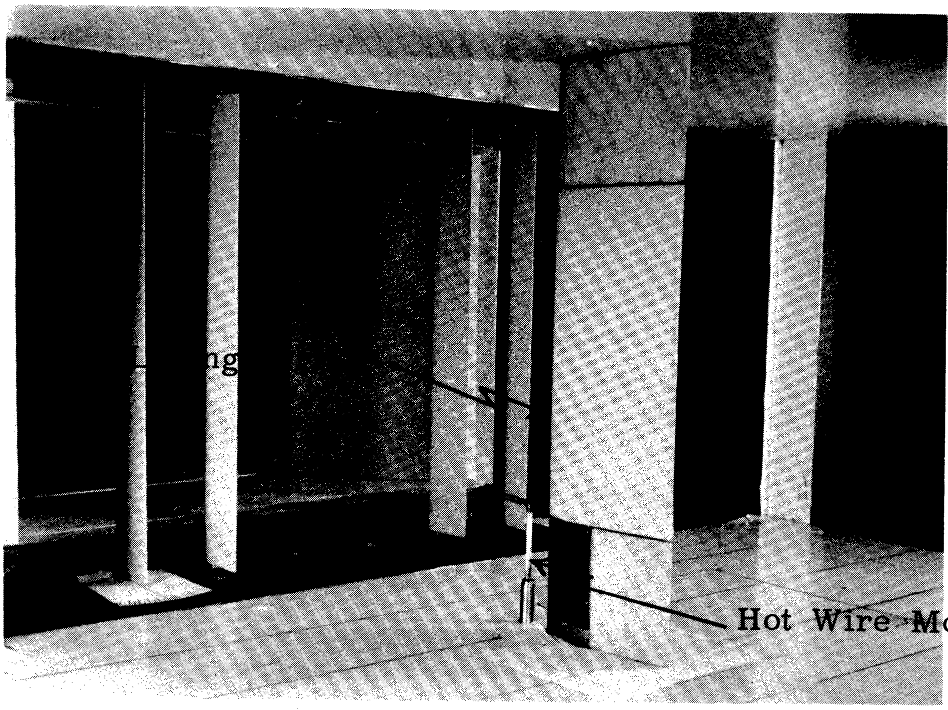


Fig. 7a. Photograph of the Lifting Surface Installation Along with the Monitor Probe.

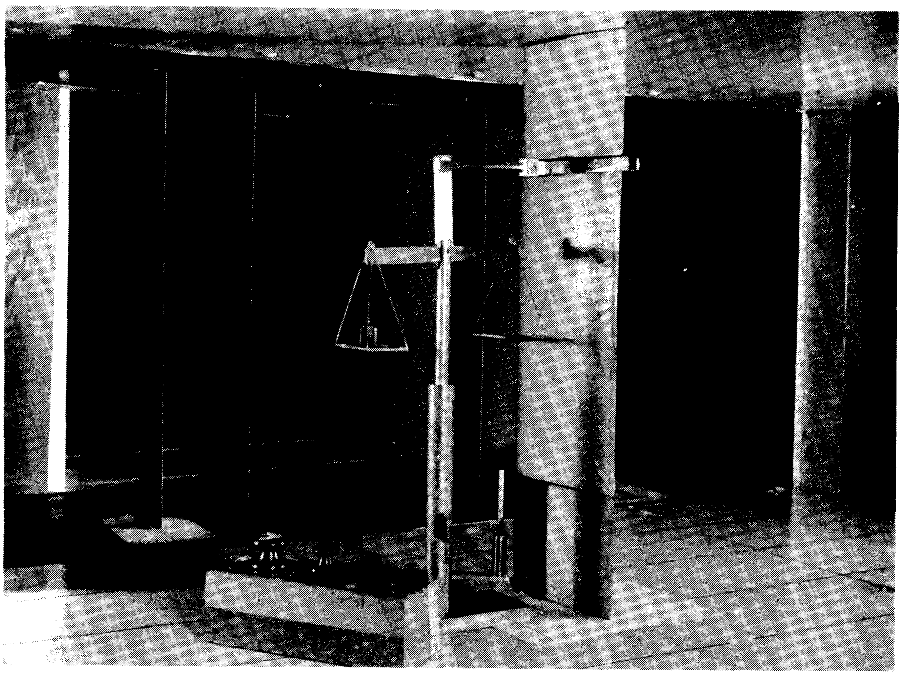


Fig. 7b. Photograph of the Mechanism Used to Static Calibrate the Balance System.

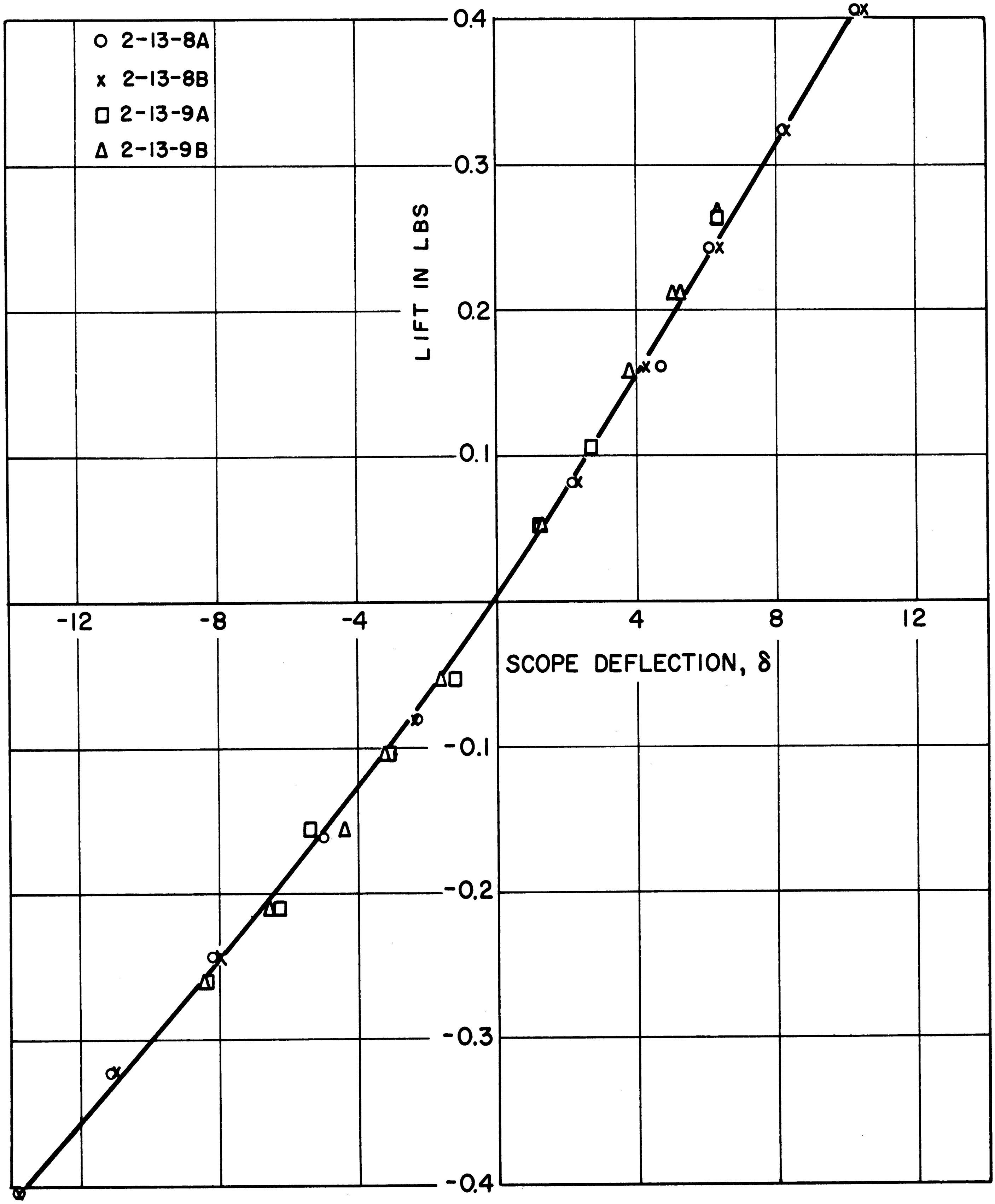


Fig. 7c. Static Lift Force Calibration Curve of Lifting Surface.

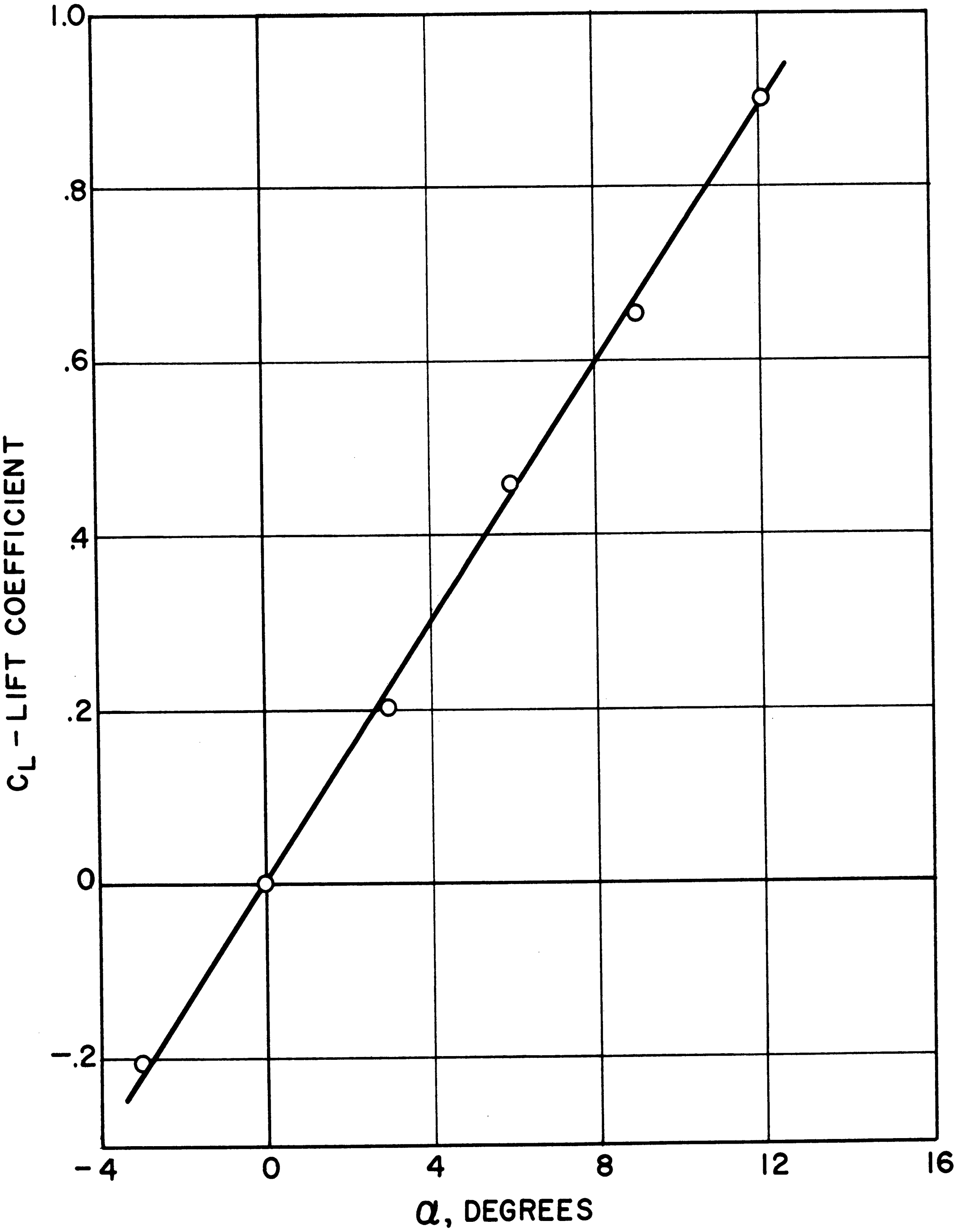
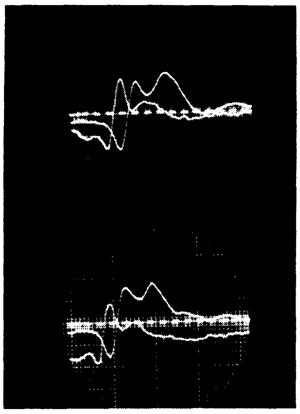
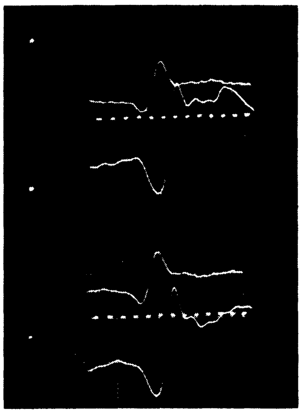


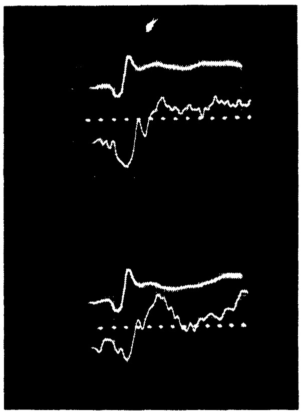
Fig. 8. Measured Static Lift Coefficient vs Angle of Attack for the Lifting Surface.



Tunnel Speed = 59.7 f. p. s.
Dashed line is a 50 c. p. s. time pulse.
Monitor probe trace is first trace to cross time pulse line in both pictures.
Lifting surface trace is second trace to cross time pulse line in both pictures.



Tunnel Speed = 30 f. p. s.
Dashed line is a 50 c. p. s. time pulse.
Monitor probe is upper trace in both pictures.
Lifting surface response is lower curve in both pictures.



Tunnel Speed = 15 f. p. s.
Dashed line is a 50 c. p. s. time pulse.
Monitor probe is upper curve in both pictures.
Lifting surface response is lower curve in both pictures.

Fig. 9. Oscillograms of the Lifting Surface and Monitor Probe Respond to the Vortex Generator.

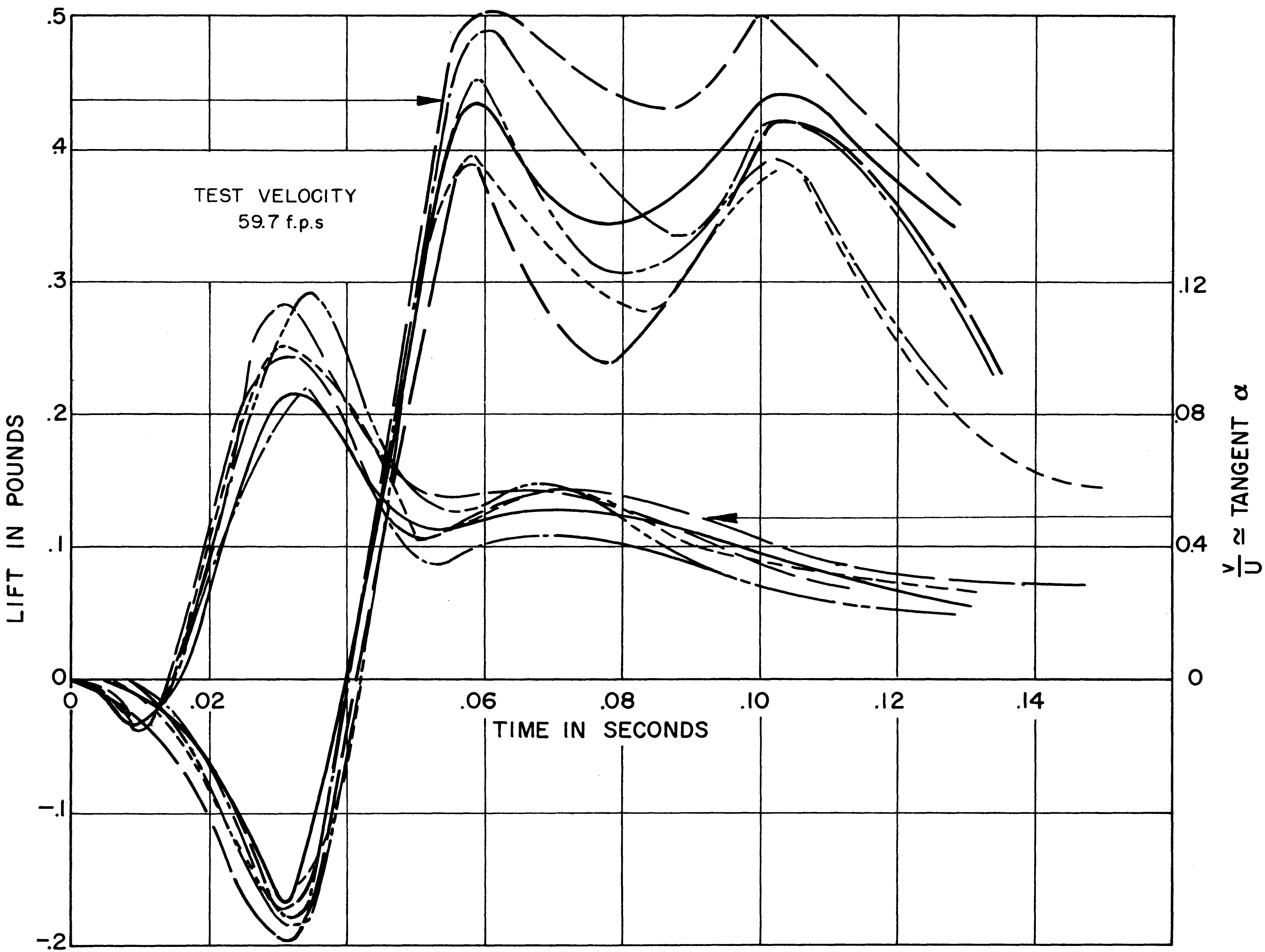


Fig. 10a. Response of Lifting Surface and Monitor Probe to Vortex Generator.

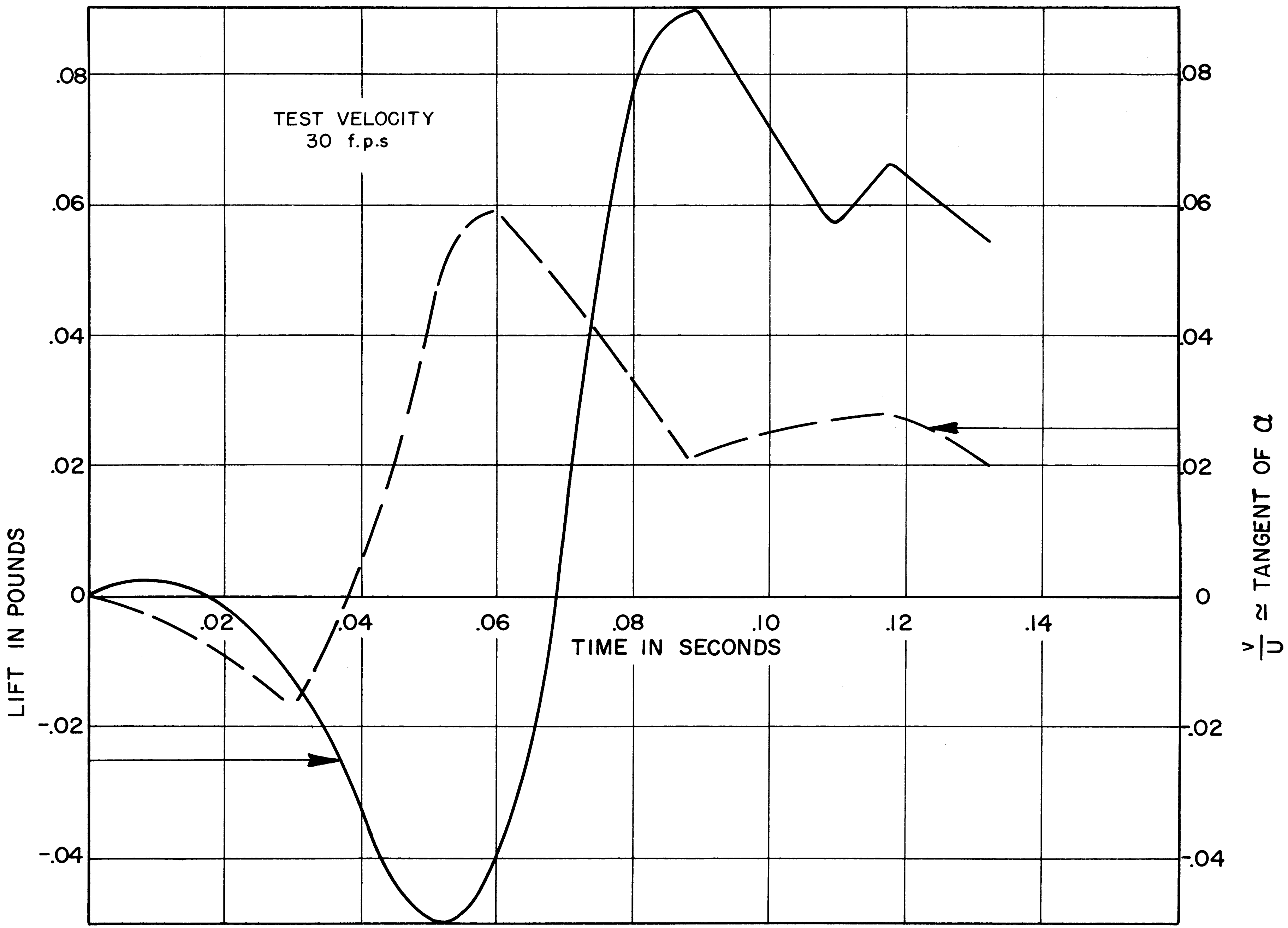


Fig. 10b. Response of Lifting Surface and Monitor Probe to Vortex Generator.

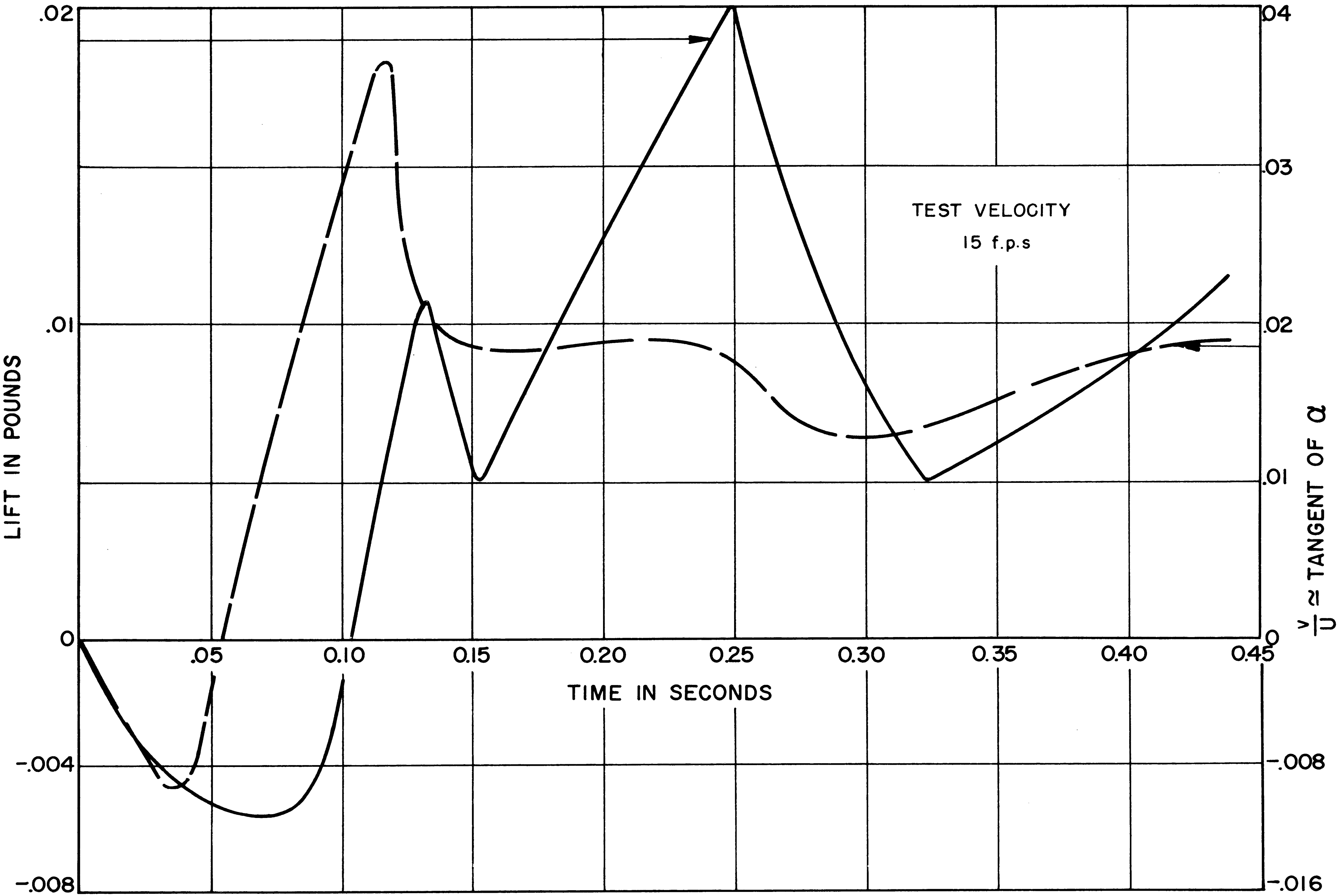


Fig. 10c. Response of Lifting Surface and Monitor Probe to Vortex Generator.

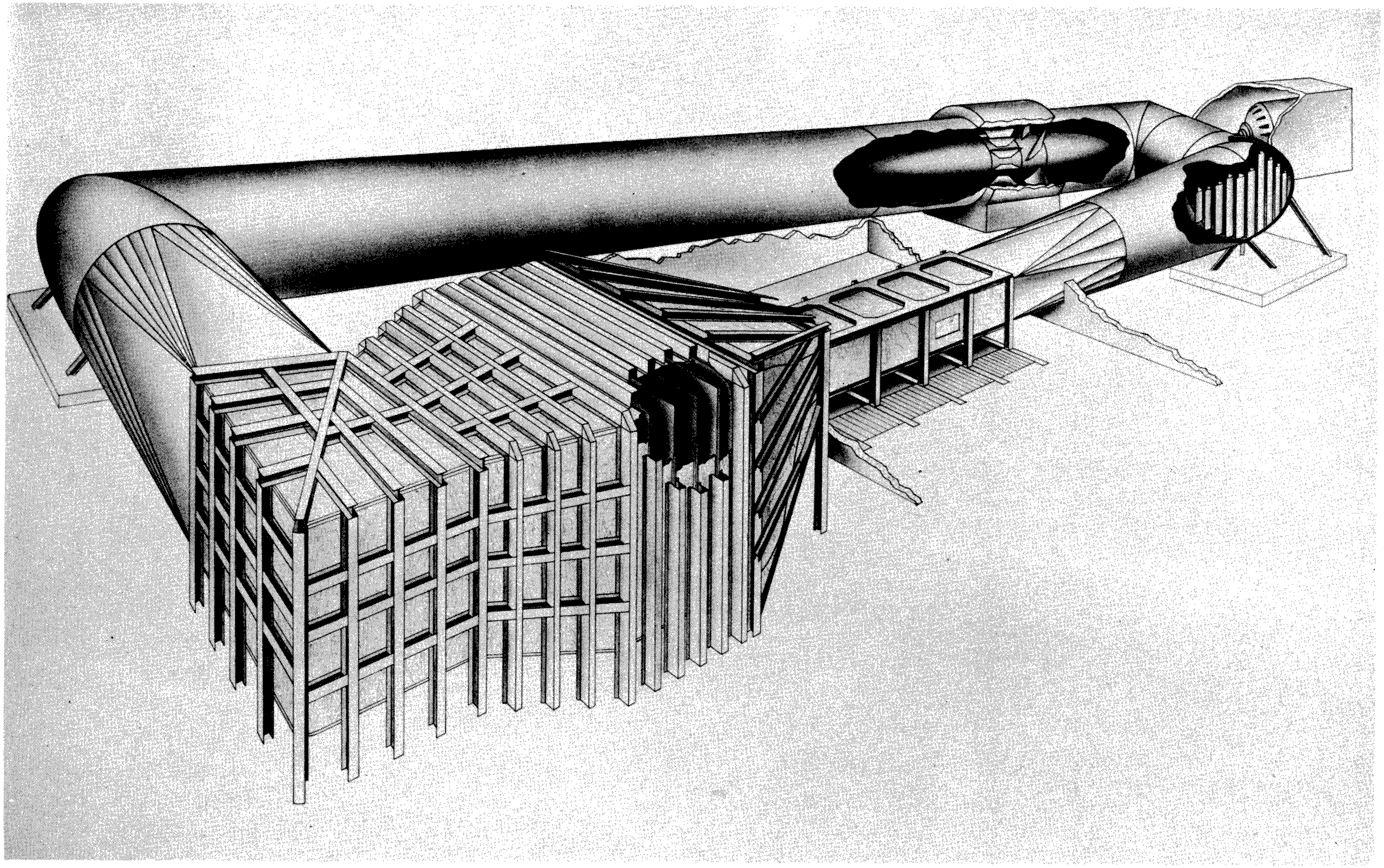
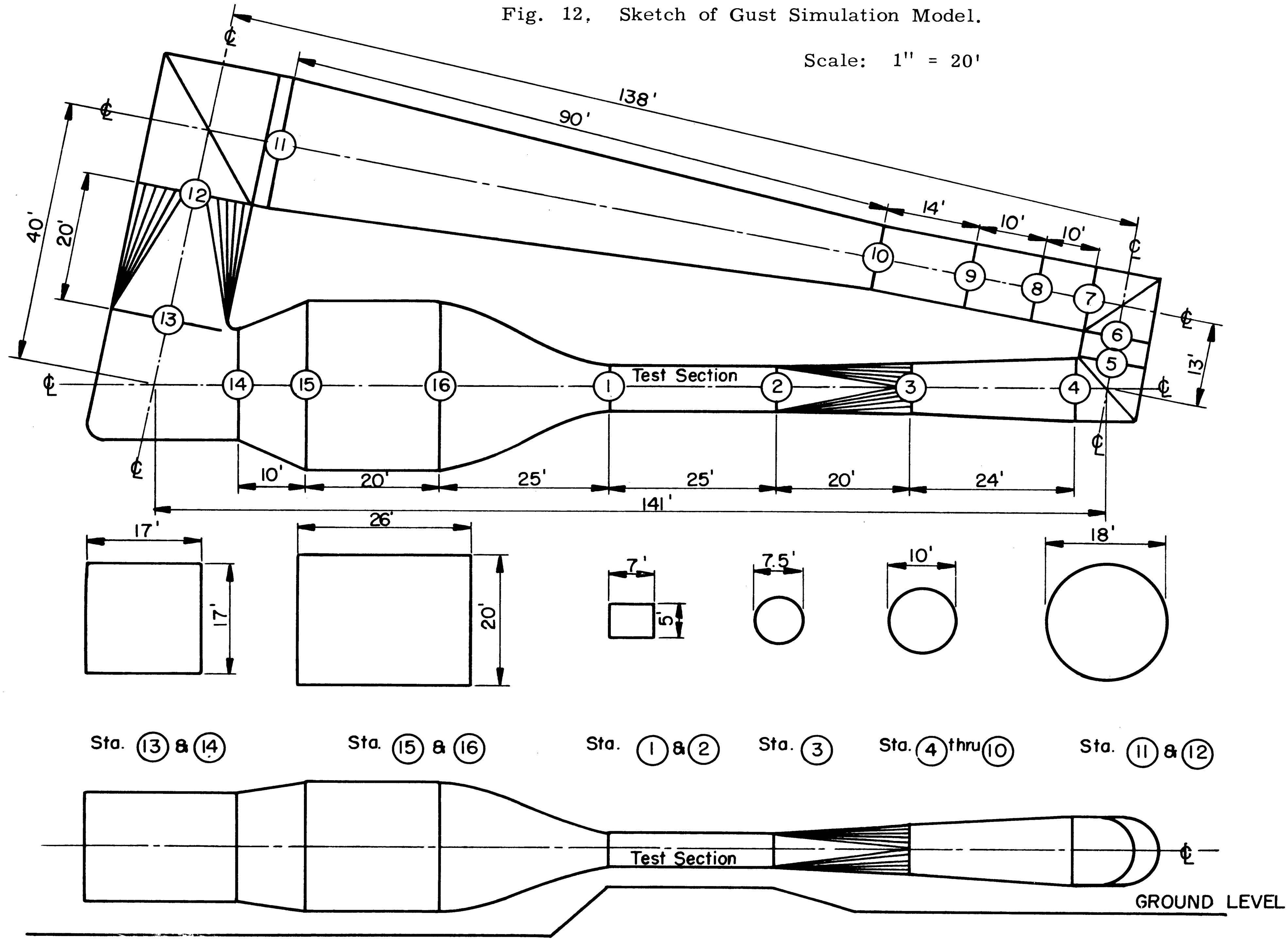


Fig. 11. Sketch of Gust Generator Model.

Fig. 12, Sketch of Gust Simulation Model.

Scale: 1'' = 20'



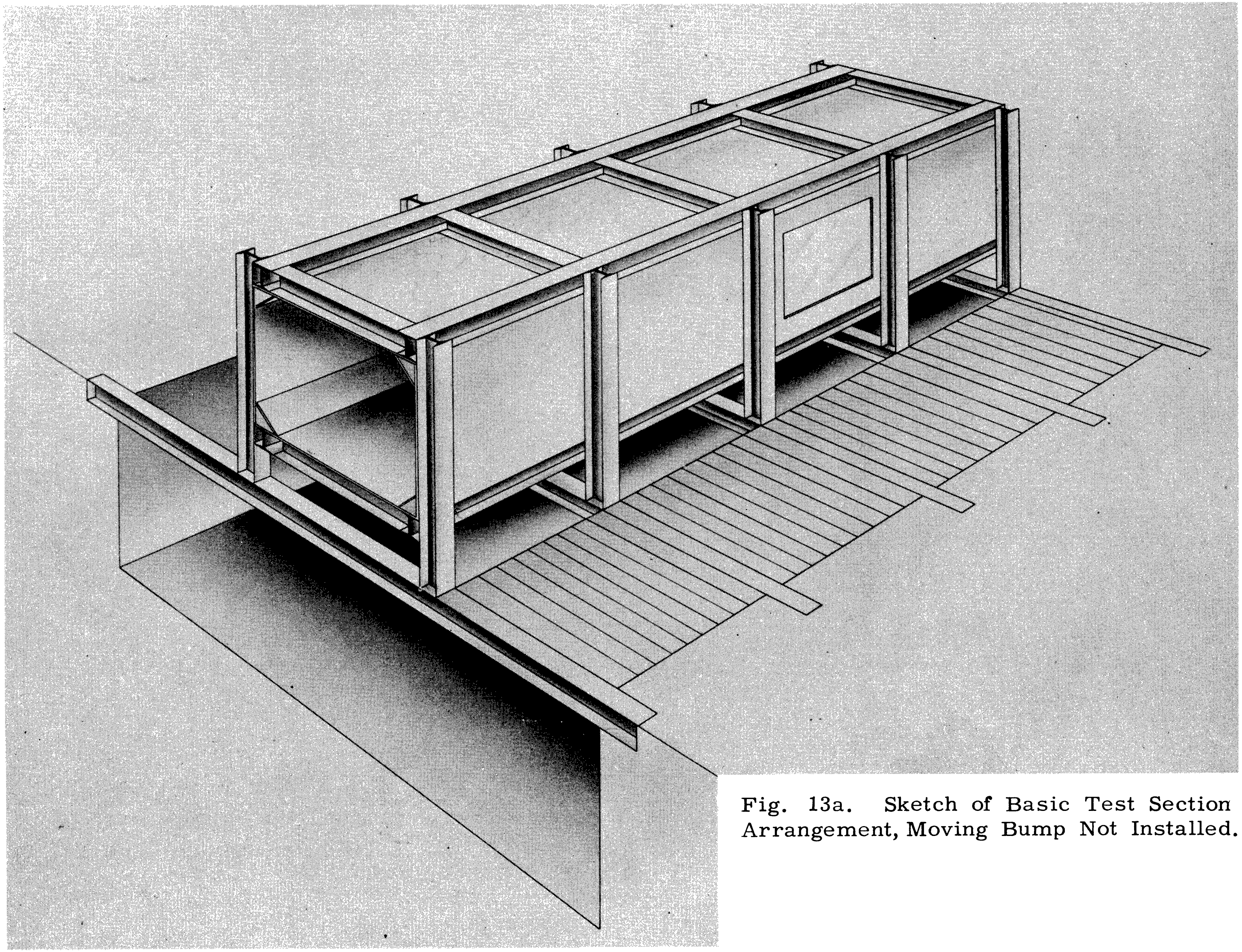


Fig. 13a. Sketch of Basic Test Section Arrangement, Moving Bump Not Installed.

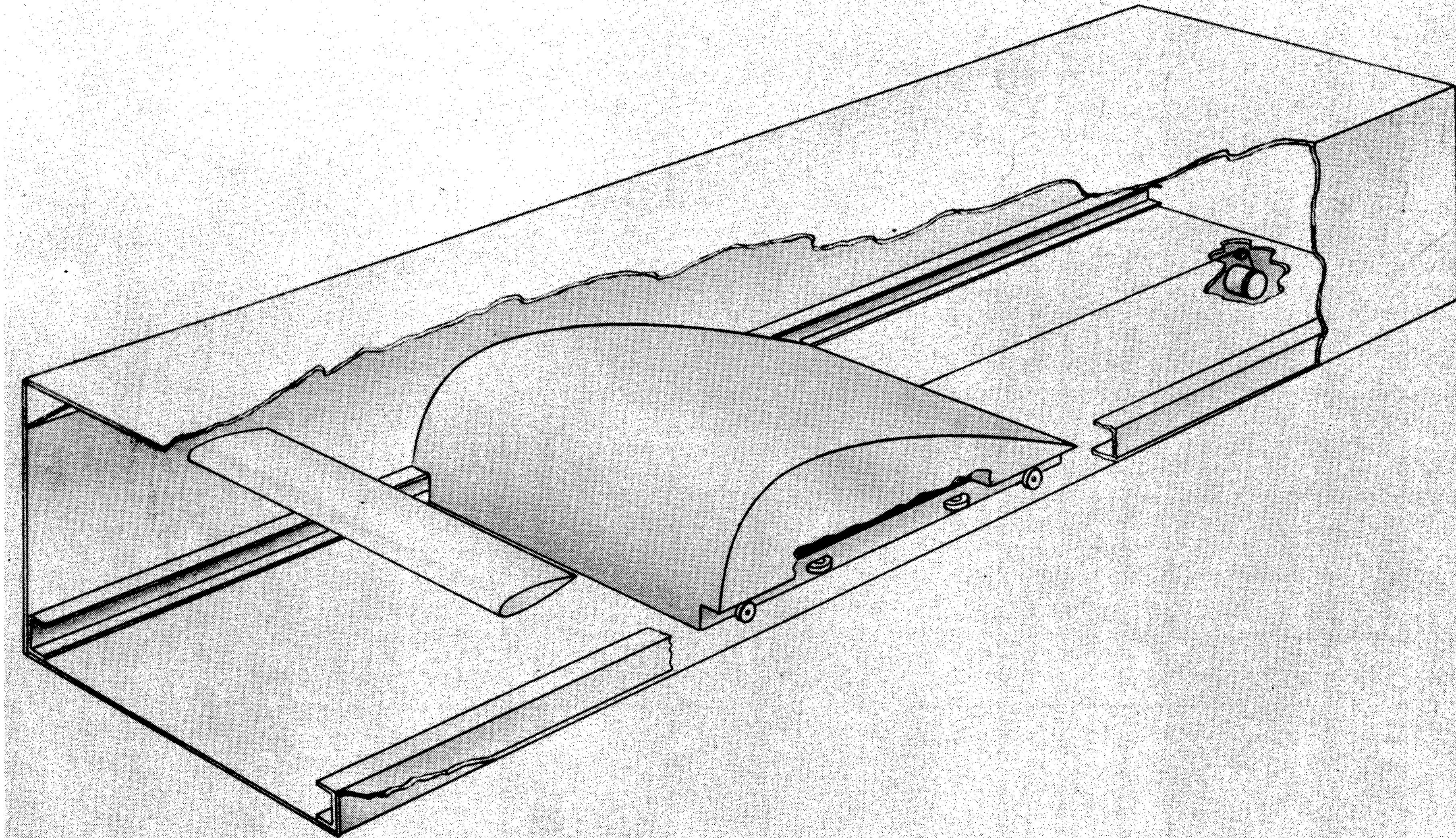


Fig. 13b. Sketch Showing Moving Bump Installed in Test Section.

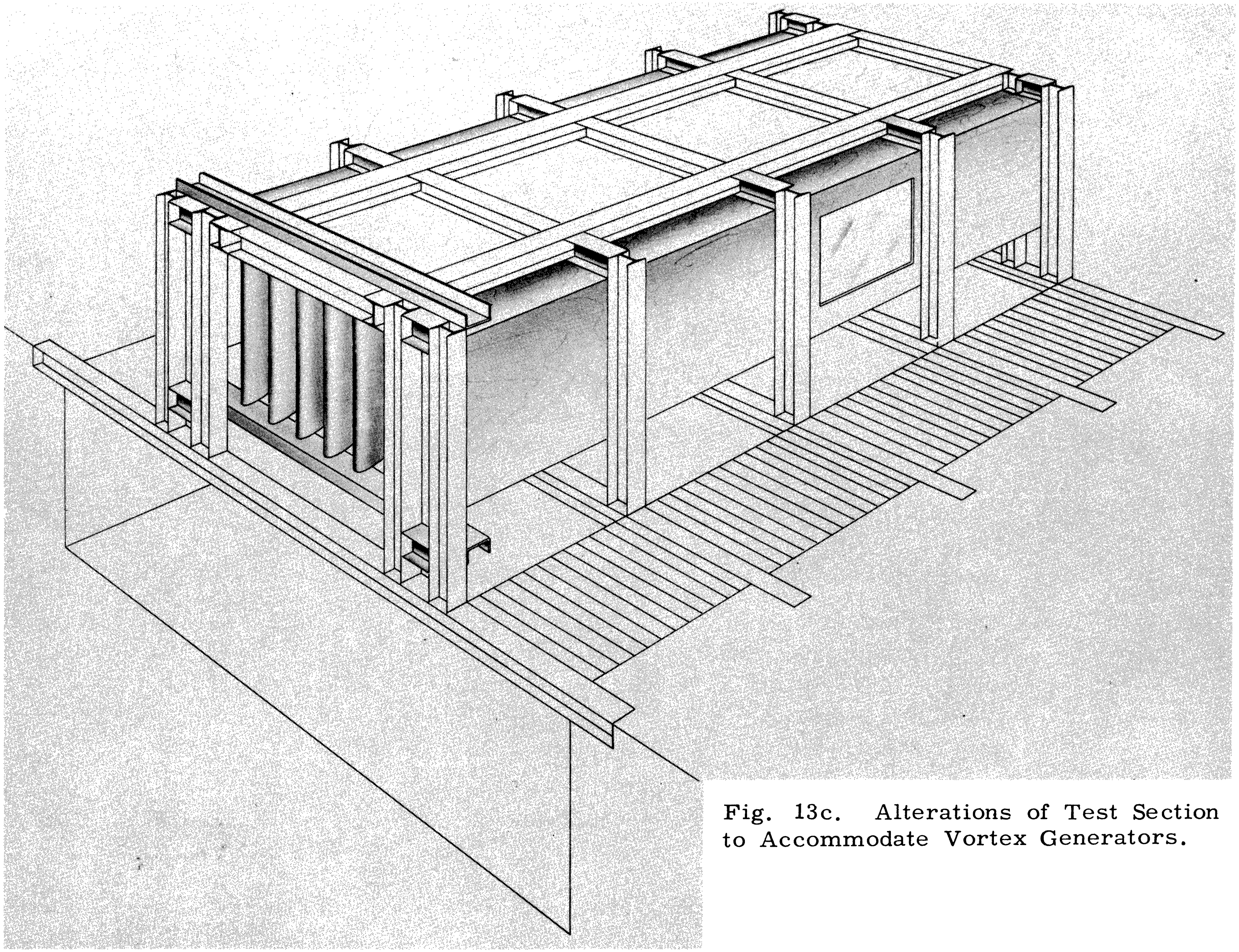


Fig. 13c. Alterations of Test Section to Accommodate Vortex Generators.