April 22, 1958 M. MENARD 2,831,505

VARIABLE SECTION NOZZLE NECK

Filed May 6, 1956 4 Sheets-Sheet 1

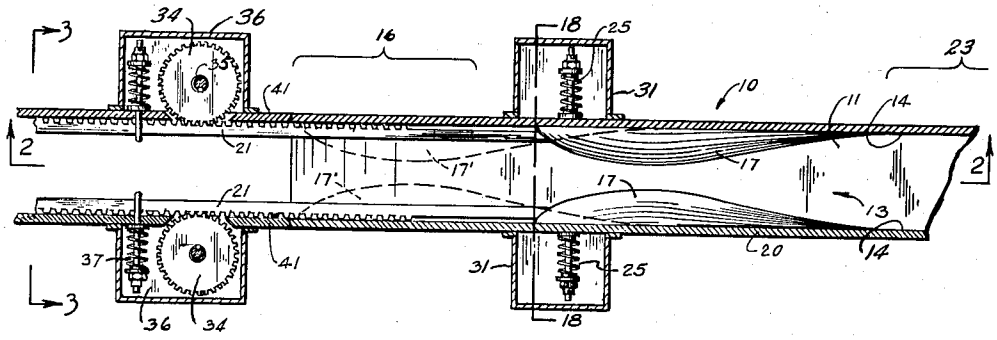


FIG. 1

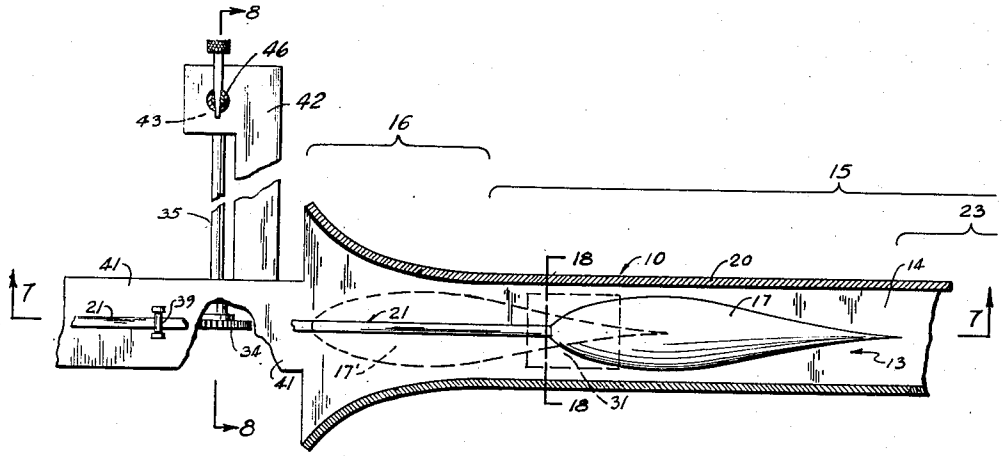


FIG. 2

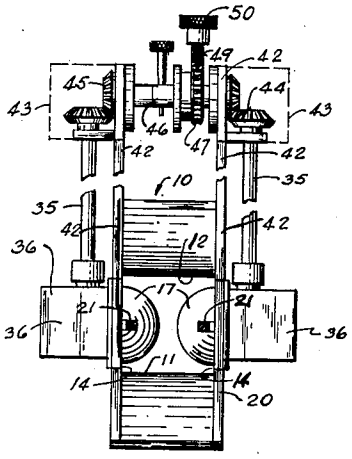


FIG. 3

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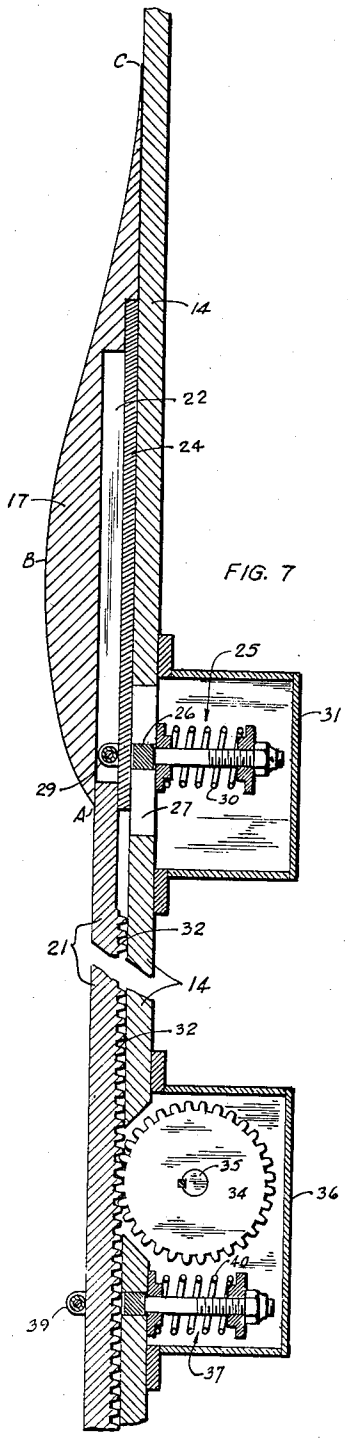


FIG. 7

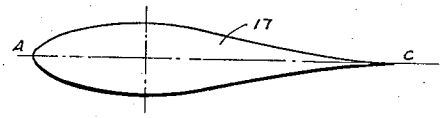


FIG. 4

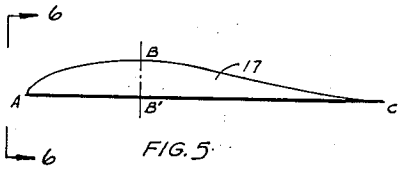


FIG. 5

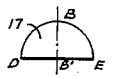


FIG. 6

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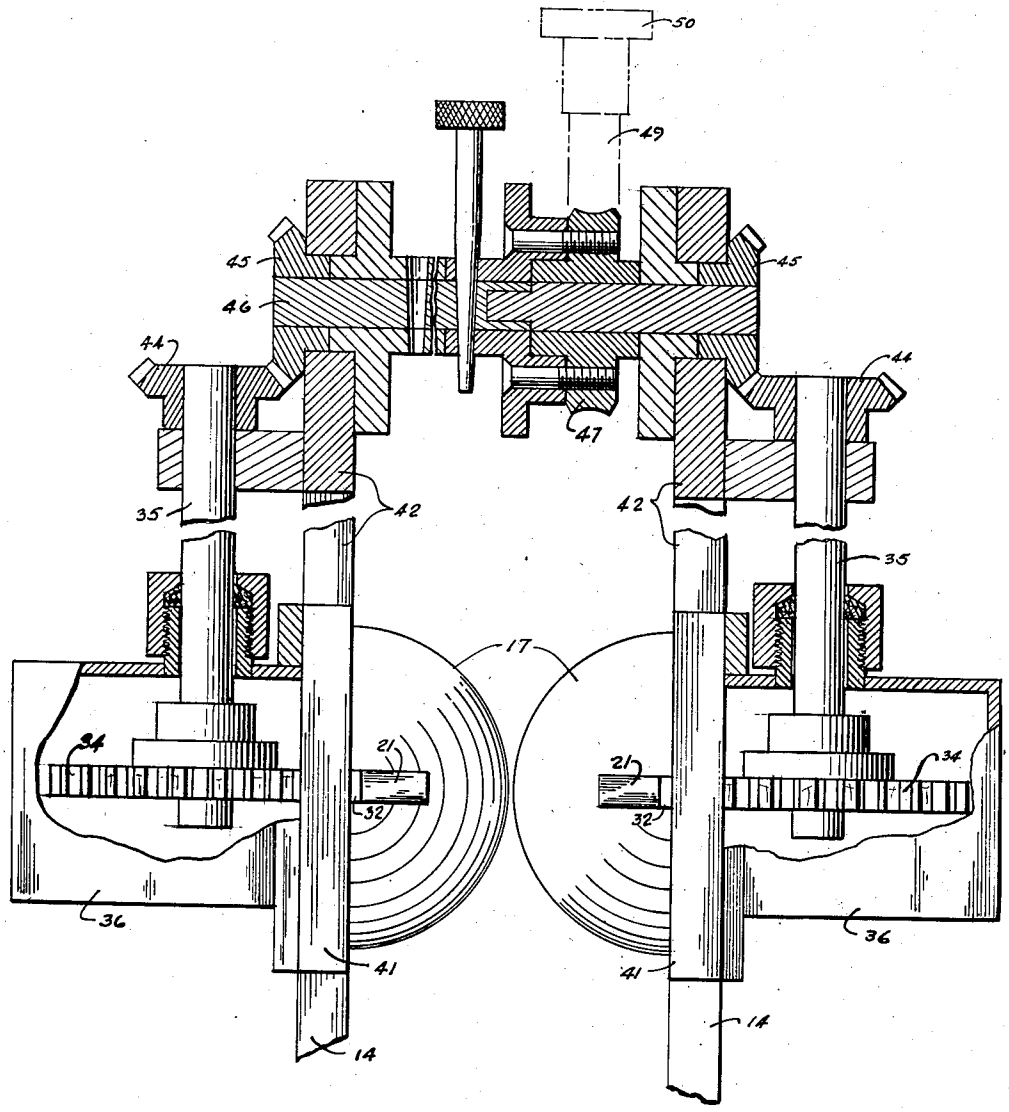


FIG. 8

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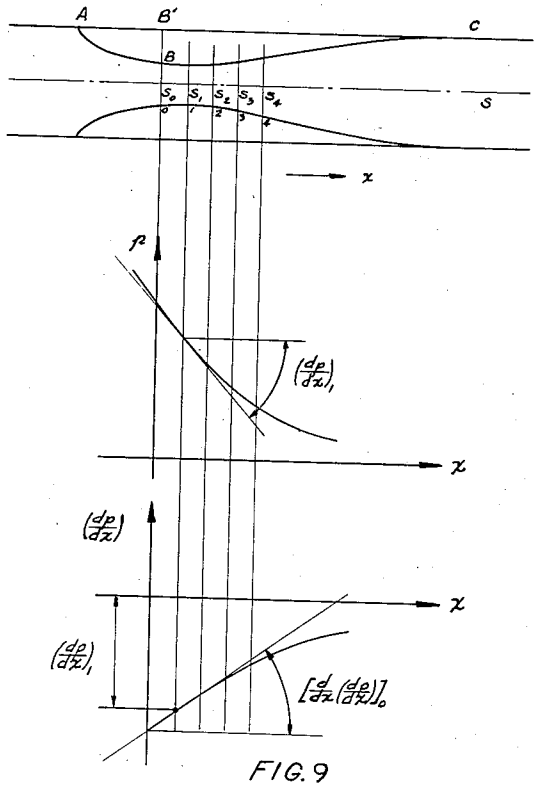


FIG. 9

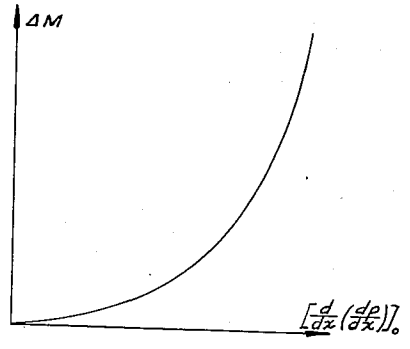


FIG. 10

United States Patent Office 2,831,505
Patented Apr. 22, 1958

2,831,505

VARIABLE SECTION NOZZLE NECK

Maurice Menard, Saint-Cyr, France, assignor of one-half to Conservatoire National des Arts et Metiers, Paris, France

Application March 6, 1956, Serial No. 569,792

Claims priority, application France June 29, 1951

6 Claims. (Cl. 138—45)

This invention relates to a wind tunnel for testing devices such as models at high air speeds. The invention particularly relates to a wind tunnel in which the cross-sectional area of the inlet end of the tunnel may readily be changed, whereby the speed of the air in the passage may be varied. The wind tunnel of the invention is particularly adapted for producing streams of air travelling in the range from subsonic to a substantial number of times the speed of sound.

This application is a continuation-in-part of application Serial No. 272,162, filed February 18, 1952, now abandoned.

Prior variable air-speed wind tunnels of the type wherein the effective area of the tunnel passage may be changed have been relatively unsatisfactory both as to construction and operation. Some prior tunnels of this type employ replaceable fixed entrance ends or nozzles. To change the effective cross-sectional area of the entrance end of the tunnel the nozzle must be changed, an operation which usually requires several hours. This not only adds considerably to the labor cost of the testing operation, but also, in effect, wastes valuable time in which the test equipment is idle. Further, this type of wind tunnel precludes changing the effective cross-sectional area of the tunnel while it is in operation, but also does not allow a smooth change in such area, since the different replacement nozzles must of necessity differ appreciably from each other.

Other prior valuable air-speed wind tunnels have employed flexible deformable walls forming the throat of the tunnel, the walls being deformed as by jacks working from the outside of the tunnel. Such flexible throats are very expensive to make. Further, the contour of the throat is difficult to control and reproduce, and in many instances, in certain adjusted deformed positions, the contour of the throat is far from ideal.

The wind tunnel of the present invention is of simple, rugged construction, easily made and operated. The construction of the tunnel is such that a marked change in the effective cross-sectional area of the entering end of the tunnel may be made, even under operating conditions, by one person in a very short time. The change in cross-sectional area of the entering end of the tunnel of the invention is continuous, and thus may be varied in infinitely small steps. This the behavior of a device such as a model may readily be investigated fully in all portions of a range of air speeds from subsonic to well above the speed of sound.

The wind tunnel of the invention is shown in a preferred embodiment in the accompanying drawings forming part of the specification.

In the drawings

Fig. 1 is a fragmentary view in longitudinal axial section through the entrance or throat end of the tunnel, the zone of the adjustable flow-controlling members or bosses, and a portion of the testing section of the tunnel, the sectioning plane lying normal to the first, parallel walls of the tunnel.

Fig. 2 is a view similar to Fig. 1 but with the sectioning plane displaced 90° about the longitudinal axis of the tunnel from the sectioning plane of Fig. 1, the section of Fig. 2 being taken along line **2—2** of Fig. 1.

Fig. 3 is an end elevation of the wind tunnel from the throat or entering end thereof, the view being taken from line **3—3** of Fig. 1.

Fig. 4 is a plan of an air-flow-controlling boss of the wind tunnel of the invention.

Fig. 5 is a side elevation of such boss.

Fig. 6 is an end elevation of the boss of Figs. 4 and 5, the view being taken from line **6—6** of Fig. 5.

Fig. 7 is an enlarged view in section of a portion of the wind tunnel wall at the location of an air-flow-controlling boss, and of parts of the mechanism for adjusting the boss longitudinally of the tunnel, certain of the parts being shown in elevation, the section being taken generally along the line **7—7** of Fig. 2.

Fig. 8 is an enlarged view in section of parts of the mechanism for adjusting the boss, the mechanism being broken away in portions thereof to save space in illustration, the section being taken generally along the line **8—8** of Fig. 2, certain of the parts being shown in elevation.

Fig. 9 is a schematic view of the portion of the wind tunnel at the air-flow controlling bosses, and related graphs showing variation in the rate of flow of air in the tunnel at various zones of the bosses.

Fig. 10 is a graph plotting ΔM, the magnitude of the oscillation M of the Mach number on the axis of the throat of the tunnel, against the rate of change of the pressure of the air with respect to distance measured along the axis of the tunnel.

Referring now to Figs. 1, 2, and 3, it will be seen that the illustrated preferred embodiment of the wind tunnel, generally designated **10**, is of rectangular cross-section, and has a first pair of opposite parallel plane walls **14**, shown vertical in Fig. 3, and a second pair of opposite walls **11** and **12**, shown as the bottom and top walls, respectively, in Fig. 3. Walls **11**, **12**, and **14** define a longitudinally extending passage **13** through the tunnel. The walls **11** and **12** are mirror images of each other. From generally the line **18—18** rearwardly (toward the right in Figs. 1 and 2) the walls **11** and **12** are shown as being plane and parallel. If desired, such portions of walls **11** and **12** may diverge slightly in a rearward direction. In any event, in such portion walls **11** and **12** may be said to be at least generally parallel. The forward portion **16** of walls **11** and **12**, to the left of line **18—18** in Figs. 1 and 2, constitutes a flared throat; portions **16** of walls **11** and **12** merge smoothly with the rearward plane portions thereof.

The wind tunnel of the invention is provided with means whereby the effective cross-sectional area of the throat may be adjusted, whereeby the speed of travel of the air stream through the tunnel passage may be selectively varied. The tunnel shown is provided with two similar bosses **17**, oppositely disposed on sidewalls **14** so as to define a constricted zone between them. The bosses **17** are adjustable longitudinally of the tunnel between the position indicated in the dotted outlines **17'** in Figs. 1 and 2, in which they lie largely forwardly of the line **18—18**, to the one shown in solid outline in such figures, in which they lie wholly to the rear of line **18—18**. It will be apparent that when any portion of the bosses **17** lies forwardly of line **18—18** any adjustment of the bosses longituinally of the wind tunnel from such position alters the effective cross-sectional area of the throat of the tunnel, forward adjustment of the bosses decreasing such area, and thus the rate of flow of air through the throat and thus the tunnel, and rearward adjustment of the bosses increasing such area and rate of air flow. Bosses **17**, in all their

adjusted positions, are located forwardly of the testing section 23 of the tunnel.

The bosses 17 are rigid similar bodies which are mirror images of each other and, as shown, are similarly positioned on the walls 14 of the tunnel symmetrically as regards the longitudinal center lines of their respective walls 14. The configuration of the bosses will be more apparent from a consideration of Figs. 4, 5, and 6. Each boss is somewhat narrower than the distance between opposite walls 11 and 12. Each boss has a flat outer face, shown in Fig. 5 as lying on the plane AB'C. The boss is symmetrical with respect to the longitudinal plane through points AC and lying normal to the plane ADCE Fig. 4. The inner surface of the boss is convex, the curve AB (Fig. 5) preferably being a quarter of an ellipse with a half minor axis BB' and a half major axis AB'. The curve DBE (Fig. 6) is shown as a half circle, although it may be made as half an ellipse, if desired. The curve BC (Fig. 5) is a smooth long reverse curve, the boss tapering to a pointed feather edge at C. The effect of such curvatures of various portions of the inner face of the boss is to make such face smoothly streamline. In a preferred construction, the ratio

$$\frac{AB'}{BB'}=4$$

and the ratio BB'/DE is a function of the maximum Mach number at which the tunnel is to operate. The bosses 17 are mounted with their plane outer faces against the inner surface of the respective wall 14 of the tunnel. The bosses are adjusted by being slid along walls 14 between the solid line position to that shown at 17'. Preferably the bosses are interconnected so as to be adjusted simultaneously by operation of one adjusting means, which is shown more clearly in Figs. 7 and 8.

As shown in these figures, mounted centrally of each wall 14 of the tunnel is a longitudinally rectangular rod-like member 21 which slides along the inner surface of the wall. The forward, leading edge of boss 17 is preferably connected to the inner trailing edge of member 21 as by being welded thereto. Connected to the rear end of member 21 and aligned therewith is a thinner rectangular rod-like member 24 which also slides along the inner face of wall 14. The two ends of member 24 are attached to boss 17 at a recess in the outer flat face of the boss. Inwardly of member 24 boss 17 is longitudinally slotted at 22 to provide space for a hold-down yoke 29, which retains members 21, 24, and boss 17 forcibly in contact with the inner face of wall 14. Yoke 29 forms the head of an elongated stem 26 of a hold-down member 25 which projects through longitudinal slot 27 in wall 14. Member 25 includes a coil compression spring 30 acting, in effect, between wall 14 and the outer end of the stem of member 25. Each hold-down member is enclosed in a protective container 31.

Positioned forwardly of the mouth of the tunnel on each side thereof, and supported on central extensions 41 of walls 14 thereof, are further protective enclosures 36 containing mechanism for longitudinally adjusting each member 21 and with it the respective boss 17. In each enclosure there is a pinion 34, keyed to shaft 35, the pinion meshing with a rack gear 32 on the outer face of member 21. Enclosure 36 also contains the main part of a hold-down bracket 37, the inner end of which is formed as a yoke projecting through a slot in wall 14 and overlies member 21 to hold it strongly in engagement with the wall 14. A coil compression spring 40 acts between wall 14 and the outer end of the hold-down member.

As shown in Fig. 8, shafts 35 may be drivingly connected so that the two bosses 17 may be adjusted simultaneously in the same direction and to the same extent by a single adjusting means. Connected to supports 41 are transversely extending (vertical in Figs. 2 and 3) parallel members 42 which serve to support closures 43 and members journalling the upper ends of shafts 35. Between closures 43 there extends a transverse shaft 46 which carries on its outer ends bevel gears 45 meshing with bevel gears 44 on the upper ends of shafts 35, as shown in Fig. 8. Mounted on shaft 46 is a worm gear 47 which meshes with a worm (not shown) on shaft 49 journalled in a fixed support (not illustrated). Turning of shaft 49 by hand knob 50 will thus cause equal travel of bosses 17 in the same direction longitudinally of the tunnel. A disconnectable coupling, as shown, may be interposed in shaft 46 between worm gear 47 and the left-hand pinion 45 to allow initial identical positioning of the two bosses 17.

As has been pointed out above, the wind tunnel of the invention is capable of use to produce a high speed air stream which is adjustable as to speed in a range from subsonic to at least several times the sonic speed. Adjustment of the speed of air travel through the testing section of the tunnel at subsonic speeds is effected by suitable adjustment of the exhaust blower for the tunnel. When the tunnel is operated with the air stream travelling through the testing section thereof at the speed of sound or above, the speed of air travel through such section is determined by the ratio S/S_c (see Fig. 9), wherein S is the cross-section of the testing section, and S_c is the cross-section of the narrowest zone of the tunnel. Under such conditions the speed of flow of the air increases as the section increases (in the zone S_c—C), and becomes constant in the testing section 23.

In operating the wind tunnel of the invention, the bosses 17 are first moved to the furthest upstream position (17') in the convergent mouth of the tunnel. Upon starting the blower, the tunnel then operates like a customary subsonic wind tunnel. When the blower has accelerated sufficiently for the air to reach the speed of sound in the testing section, the bosses are progressively moved downstream from position 17' toward position 17 (Figs. 1 and 2), thus progressively decreasing the area of air flow and increasing the Mach number in the testing section. The maximum Mach number is obtained when the bosses are in the full line position there shown. Adjustment of the bosses between positions 17' and 17 is continuous, and may be made with the tunnel in operation. Such adjustment is easily effected, a typical tunnel made in accordance with the invention being customarily adjusted to vary the Mach number between 0.6 and 1.8 in three minutes. With such embodiment of the tunnel the Mach number can be continuously adjusted up to 3, although this is not the highest Mach number obtainable by use of the invention.

In wind tunnels a substantial uniformity of speed of air flow in the testing section is necessary for accuracy of test results. The more nearly uniform the air speed, the more accurate the results. It has been found that the wind tunnel of the invention, employing bosses 17 of the disclosed configuration, shows a variation of Mach number in the testing section of $\Delta M/_m=\pm 0.002$.

In the schematic view of Fig. 9 the minimum cross-section of the throat of the wind tunnel is designated S_c, and the cross-section of the testing section of the tunnel is designated S. An isentropic expansion occurs from S_c to S. By applying Bernoulli's and the "continuity" equation for flow of elastic fluid, the required value of Mach number M determines S/S_c. Since the bosses 17 are of predetermined shape, the ratio S/S_c gives the ratio BB'/DE, where BB' and DE are two of the above discussed dimensions of each boss 17.

The aerodynamic quality required of the wind tunnel determines the value of the ratio $BB'/B'C$ (Figs. 4, 5, and 6) through the use of an experimental curve, shown in Fig. 10, which was determined by numerous tests.

In Fig. 9 the bosses are shown cut by several transverse planes numbered 0, 1, 2, 3, 4. . . . In the zone of plane 1 the area of air flow S_1 determines the ratio S_1/S_c. This ratio in turn determines the speed of travel

of air at plane 1 according to Bernoulli's and the continuity equations. The air pressure at each of planes 1, 2, 3, 4, . . . can therefore be determined.

The curve I (upper curve of Fig. 9) indicates the pressure of the air in the tunnel as a function of the positions 1, 2, 3, 4. . . . At the points 1, 2, 3, 4 . . . the slope of the curve I is measured as follows:

$$\left(\frac{dp}{dx1}\right)$$

Slope of curve I at 1

$$\left(\frac{dp}{dx2}\right)$$

Slope of curve I at 2

$$\left(\frac{dp}{dx3}\right)$$

Slope of curve I at 3

$$\left(\frac{dp}{dx4}\right)$$

Slope of curve I at 4

A theoretical curve II (lower curve of Fig. 9) indicates the evolution of dp/dx as a function of the abscissa. At the point 0 the curve II shows a slope of

$$\left[\frac{d}{dx}\left(\frac{dp}{dx}\right)\right]_0$$

By reference to the experimental curve of Fig. 10 the magnitude of variation or oscillation ΔM of the Mach number on the longitudinal axis of the wind tunnel may be read.

Although for purposes of illustration I have shown and described a preferred embodiment of a variable speed wind tunnel in accordance with the invention, it will be understood that such embodiment is illustrative only, since the invention is capable of considerable variation as to details. The invention is, therefore, to be defined by the scope of the claims appended hereto.

What I claim and desired to secure by Letters Patent is:

1. A wind tunnel comprising a rectangular sectioned duct having a passage therethrough and having an inlet and an outlet end and a testing section between such ends, said duct having two first opposite plane and parallel walls, the other two second opposite walls being initially convergent at the inlet end and then at least generally parallel, at least one rigid boss located in the duct adjacent the inlet end thereof said boss having a plane outer face engaging a first inner wall of the duct and a streamlined inner face forming a portion of the wall of the passage, and means for displacing the boss longitudinally of the duct toward and away from the inlet end thereof from a furthest outwardly adjusted position in which at least the forward end of the boss lies within the inlet end of the duct to a furthest inwardly adjusted position in which the boss lies retracted into the duct beyond the convergent portions of the second walls of the wind tunnel, so as to vary the cross-sectional area of the inlet end of the wind tunnel.

2. A wind tunnel as claimed in claim 1, in which the boss is narrower than the width of the first walls and lies substantially centrally of one first wall.

3. A wind tunnel as claimed in claim 2, in which the boss is symmetrical about its longitudinal mid-plane normal to the first walls of the tunnel, and the inner face of the boss is smoothly convex.

4. A wind tunnel comprising a rectangular sectioned duct having a passage therethrough and having an inlet and an outlet end and a testing section between such ends, said duct having two first opposite plane and parallel walls, the other two second opposite walls being initially convergent at the inlet end and then at least generally parallel, two similar confronting oppositely disposed rigid bosses located in the duct adjacent the inlet end thereof, said bosses each having a plane outer face engaging a first inner wall of the duct and a streamlined convex inner face forming a portion of the wall of the passage, and means for simultaneously and similarly displacing the bosses longitudinally of the duct toward and away from the inlet end thereof from a furthest outwardly adjusted position in which at least the forward ends of the bosses lie within the inlet end of the duct to a furthest inwardly adjusted position in which the bosses lie retracted into the duct beyond the convergent portions of the second walls of the wind tunnel, so as to vary the cross-sectional area of the inlet end of the wind tunnel.

5. A wind tunnel as claimed in claim 4, in which the bosses are narrower than the width of the first walls and lie substantially centrally of their respective first walls.

6. A wind tunnel as claimed in claim 5, in which the bosses are symmetrical about their common longitudinal mid-plane normal to the first walls of the tunnel, and the inner face of each boss is smoothly convex.

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