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LIFT SENSING AND MEASURING SYSTEM

Filed April 14, 1964

FIG. 1

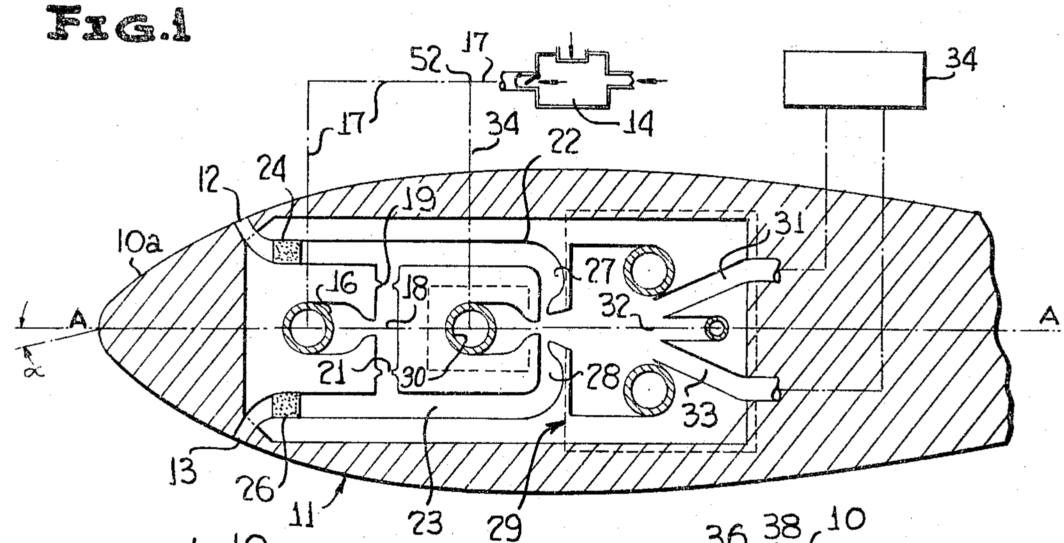
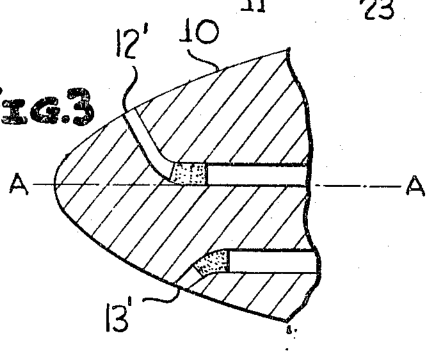


FIG. 3



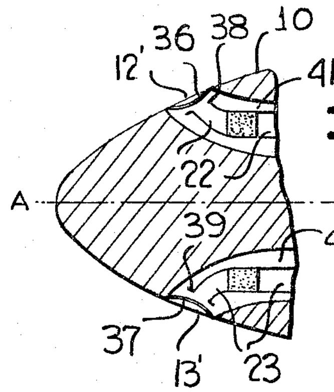


FIG. 4

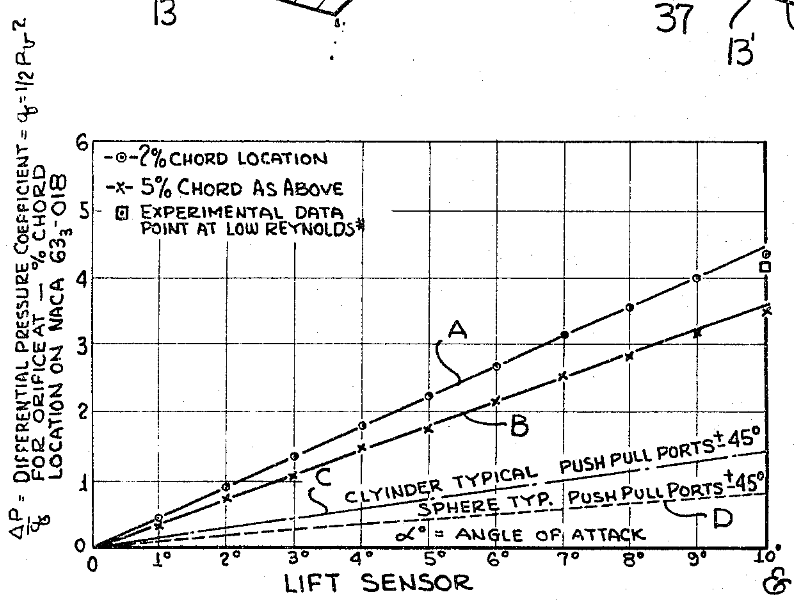


FIG. 2

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LIFT SENSING AND MEASURING SYSTEM

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The present invention relates to lift sensors and, more particularly, to a lift sensor having a high speed of response and high gain.

It is an object of the present invention to provide a lift sensor including an air foil having sensing ports located above and below the centerline of the foil and a range of locations between two percent and twenty percent of the chord of the foil and employing a pure fluid amplifier directly in the sensor to increase the signal response of the system.

It is another object of the present invention to provide a lift sensor employing an air foil having ports disposed above and below the centerline of the foil and a range of locations between two percent and twenty percent of the chord length, wherein sensing is effected by varying the apparent impedance to outflow of fluid through the ports as a result of variations of pressure of the ambient fluid at the ports with angle of attack of the foil.

It is yet another object of the present invention to employ a fluid power amplifier in a foil utilized as a lift sensor and to apply differential pressure signals provided by the sensor directly to the power amplifier so as to increase the pressure and rate of flow of fluid provided by the sensor so as to reduce the integrating effect of long tubes connecting the sensor to the utilization instruments and to increase speed of response as a result of increased rate of flow of fluid in the system.

It is another object of the present invention to provide a lift sensing mechanism employing an air foil having differential pressure ports located above and below the centerline of the foil which foil is selected such that a relatively linear response is provided between the angle of attack and differential pressure sensed at the ports.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of several specific embodiments thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a view in elevation of the lift sensor of the present invention;

FIGURE 2 is a graph illustrating performance characteristics of the foil of FIGURE 1;

FIGURE 3 illustrates a modification of the port arrangement of the sensor of FIGURE 1; and

FIGURE 4 is a further modification of the port arrangement of the sensor of FIGURE 1.

Referring now specifically to FIGURE 1 of the accompanying drawings, there is illustrated a foil **10** having incorporated therein a lift sensor generally designated by the reference numeral **11**. The lift sensor **11** comprises a pair of ports **12** and **13** located above and below, respectively, the chord line A—A of the foil **10**. As previously indicated, it is desired that fluid exit through the ports **12** and **13** rather than be permitted to ingress therethrough. The reason for this is that, by causing the fluid to exit through the ports, dirt and other foreign material cannot enter the apparatus and, in consequence, cannot alter its operating characteristics or, in the extreme, render the system inoperative. Preventing induction of dirt is important not only in the case of an air system but is of considerable importance in sensing lift in a hydrofoil system where the sensor is, of necessity, under water.

Fluid which is caused to egress through the ports **12** and **13** is derived from a source of pressure **14** which is piped to a nozzle **16** through pipes **17**. Fluid received by the nozzle **16** is directed into a cross passage **18** and through metering orifices **19** and **21** to further passages **22** and **23**, respectively. The passages **22** and **23** communicate with ports **12** and **13** through fluid impedances **24** and **26**, respectively. The fluid impedances or resistors **24** and **26** limit in a predetermined manner the flow of fluid from the passages **22** and **23** and establish a bias level or minimum pressure for the pressure therein for the case where ports **12** and **13** are exposed to their minimum external pressures. The other ends of the passages **22** and **23** are also partially restricted, so as to expedite the maintenance of the desired pressure therein, by means of nozzles **27** and **28** of a pure fluid amplifier **29** to be described in detail subsequently.

As a result of the restriction of all ends of the tubes **22** and **23**, a predetermined pressure may be established in the passages **22** and **23** which can be varied in the present system only by varying the external pressure at the ports **12** and **13**. For instance, if the foil **10** is stationary and there is substantially no external dynamic pressure at the ports **12** and **13**, a predetermined flow rate from these ports is established by the external static pressure and predetermined and equal pressures are established in passages **22** and **23**. However, if the foil is caused to move through the fluid, the external pressure at the ports **12** and **13** is changed, resulting in a change of flow from the ports and therefore, a change of pressure in the passages **22** and **23**. As the angle of attack of the foil is varied, the external pressures at the ports **12** and **13** vary differentially so that the flow of fluid from one of the ports is different from flow from the other of the ports. In consequence, the pressures existing in input passages **22** and **23** are different and, as will be described in detail subsequently, the difference in pressures is a function of the lift of the system.

Referring now to fluid amplifier **29**, the amplifier includes a power nozzle **30** for issuing a stream of fluid towards a plurality of output channels **31**, **32** and **33**. The fluid under pressure is supplied to the nozzle **30** from the source **14** via the tubes or pipes **17** and a further tube **34**. The fluid issued by nozzle **30** is proportioned between the output passages **31**, **32** and **33** as determined by the differential pressure existing between the tubes **22** and **23**. If there is no differential in pressure across the stream, the majority of the fluid flows to the tube **32** from which it may be returned to the source **14** or be dumped into the ambient fluid. A small but equal quantity of the fluid enters the passages **31** and **33** and is directed to a utilization device **34**. The utilization device may be an auto-pilot, a lift indicator or any instrument which may utilize the lift information.

Upon the development of different pressures in the passages **22** and **23**, the quantities of fluid issued by the nozzles **27** and **28** vary and the direction of the stream issued by the nozzle **30** is changed. For instance, if a positive angle of attack is increased which, short of stall, will produce an increase in lift, the pressure in the passage **23** rises above that in passage **22**, the stream issued by the nozzle **30** is deflected upwardly, as viewed in FIGURE 1, and a greater proportion of the fluid enters the outlet passage **31** than enters the outlet passage **33**. This condition is sensed by the utilization device as an indication of an increase in lift.

The apparatus measures lift rather than just angle of attack since the difference of external back pressure at the ports **12** and **13** is a function not only of the angle of attack but also of the free-stream dynamic pressure. Since the free-stream dynamic pressure is (for the subsonic case) a function of the square of the velocity of the foil relative to the fluid medium, the differential pressure in the ports **22** and **23** becomes a function of both velocity and angle of attack which are the two dominant features determining the lift of the foil.

The ports **12** and **13**, although illustrated as a single round hole, may constitute a series if small holes, elongated slots, or any other arrangement which is compatible with foil response and low integration effect.

The difficulty encountered in many lift or angle-of-attack sensors is the slow response of the system and the integration of the fluid signals due, respectively, to low rates of fluid flow through the sensing mechanisms and the averaging of signal due to the averaging effects of the passages connecting the lift sensor to the utilization mechanism. The present invention overcomes these difficulties to a great extent by the inclusion of the fast-response, pure fluid amplifier **29** directly in the foil **10.** If the amplifier **29** is a power amplifier which therefore increases both the pressure and flow rate relative to the pressures and flow rates developed by the sensing mechanism **11**, the speed of response of the overall system is increased and the integrating effects of the conduits connecting the device to the utilization mechanism are greatly decreased. More particularly, by increasing the pressure and flow rate, the fluid signal reaches its destination more rapidly and increased speed of response is achieved. The reasons for the reduction in integrating effects is not quite so obvious. The conduits connecting the output passages **31** and **33** of the amplifier to the utilization means **34** are relatively long in most instances and store a large amount of fluid. Because of the storage of the fluid, these devices exhibit a certain impedance to fluid flow; that is, fluid resistance, fluid inertance and fluid capacitance resist a change in the flow conditions therein. Potential and kinetic energy are stored in the conduits. When the fluid signal level changes, the stored energy level changes to a new value. In establishing this new condition, energy must be supplied by the signal source or discharged to the system load. An integrating effect results. The integrating effect may be materially reduced and the speed of response of the system enhanced by increasing the ratio of rate of supply of signal energy to desired change of stored energy level. The power amplifier **29** is designed, in any given system, to provide the desired ratio of signal energy to the desired change of stored energy and thus, reduce the integrating effect that is normally encountered in these systems.

The selection of the particular airfoil to be employed and the location of the ports **12** and **13** are important considerations in providing a suitable sensor. It has been found that the closer the ports are maintained to the front of the foil; that is, the smaller the chord percent location of the ports, the greater the sensitivity of the apparatus. On the other hand, the greater the percent of chord at which the ports are located, the greater is the range of angles of attack over which the device remains linear.

Referring now specifically to FIGURE 2 of the accompanying drawings, $\Delta P/q$ versus angle of attack is plotted for the sensor of the present invention for two different port locations and compared with two prior-art types of angle-of-attack sensors. These curves are plotted without taking into account the gain provided by the amplifier **29**. Curves A and B of FIGURE 2 are for airfoil Type NACA63_3–018. The curve A is for two percent chord location while curve B is for a five percent chord location on the same type airfoil.

It will be noted that, at two percent chord, the sensitivity of foil is quite great and at 9° angle of attack, $\Delta P/q$ is 4.0. The gain is substantially linear through 9° but starts to fall off rather rapidly as 10° is approached. Curve B indicates the gain of the system with the ports at the five percent chord location. It will be noted that the rate of fall-off of the gain above an angle of attack of 9° is smaller than is the case with the ports at the two percent chord location. However, the gain of this arrangement is less than for the two percent chord location. Thus, depending upon the variation in angle of attack over which the apparatus must be operable, the sensing ports or apertures are located nearer or farther away from the leading edge of the device; that is, at lesser and greater chord locations. It has been found that suitable locations of the ports lie between two percent and twenty percent of the chord of the foil. Above approximately twenty percent, the gain of the sensor is relatively low and the response becomes non-linear over the operating range of interest.

For purposes of comparison, curves C and D have been added which are for cylindrical and spherical angle of attack sensing devices, respectively, with the ports located at ±45° of the zero angle of attack stagnation point. It will be noted that the sensitivity of the foil-type sensor of the present invention is considerably greater than that of the more conventional prior art types even without the additional gain provided by amplifier **29**.

Foil-type sensors have been suggested in the past but, in all of these, the ports in the foil open into relatively large chambers or passages which introduce very slow response and severe integrating effects into the system. In the present invention, the system is such that the speed of response is greatly increased over the aforesaid chamber types and the integrating effect is greatly reduced relative to those which are connected to utilization apparatus by long channels or tubes.

It is not essential, in accordance with the present invention, that the ports **12** and **13** be located at precisely the same percentge of chord. More particularly, and reference is made to FIGURE 3, the ports **12** and **13**, which are designated as **12'** and **13'** in FIGURE 3, may be located at different distances from the centerline A of the foil where specific characteristics are to be achieved. It may be that a zero pressure differential cannot readily be obtained with a particular foil arrangement in specific enviroment due to initial location or placement; or it may be that zero pressure differences may not be desired as an initial condition. By employing asymmetrically located ports, a null signal under a specific preselected lift condition may be insured or conversely, a specific signal at zero angle of attack may be obtained.

Another port arrangement which may be employed in the present invention is illustrated in FIGURE 4. In this arrangement, the ports provided in the foil have inserted therein flexible diaphragms **36** and **37**. The passages **22** and **23** terminate just short of the flexible diaphragms **36** and **37** in annular discs **38** and **39**, respectively. Flow tubes **41** and **42** surround passages **22** and **23** and are sealed to the interior of the leading edge of the foil so as to encompass the diaphragms **36** and **37**. The annular discs **38** and **39** extend close to the inner walls of the tubes **41** and **42**, respectively, and define a region between the discs and the diaphragms. This region is maintained at a pressure that varies as a function of the flexure position of the diaphragms relative to the discs. The bleed of fluid around the edges of the discs into tubes **41** and **42** permits the pressure to respond to variations in position of the diaphragms. The tubes **41** and **42** may be returned to a desired pressure at some level below the minimum gaging pressure of the system. It is to be understood, of course, that the degree of the deflection of the diaphragm **36** or **37** is a function of both the internal pressure between the disc and diaphragm internal surface and of the external pressure presented at the diaphragm external surface. This external pressure is in turn a function of the angle of attack and velocity of the foil relative to the ambient medium. In effect, the deflection of diaphragms **36** and **37** control the bleed from the tubes **22** and **23**, thus varying the pressure in the tubes and, in consequence, the differential in pressure supplied to the amplifier **29**.

The foil employed herein is illustrated as being symmetrical. The present invention may employ cambered airfoils with good results. The effect of camber is merely to reduce the incidence at which a given lift coefficient is produced and has little effect upon the overall lift characteristics, such as change of lift with change of angle of attack or change of shape of the lift versus angle-of-attack curve. The asymmetrical location of the ports, as suggested in FIGURE 3, may be employed with a cambered foil to obtain a particular zero-lift-versus-angle-of-attack characteristic for the sensor.

While we have described and illustrated several specific embodiments of our invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

What we claim is:

1. A system for monitoring lift forces acting on a foil wherein all elements forming the system remain stationary during operation thereof comprising a body movable relative to a fluid medium and receiving forces of lift during movement thereof, said body including a leading surface and a leading edge located at the midpoint of said leading surface, first and second pressure sensing ports formed in said leading surface positioned between two percent and twenty percent of the chord length of said member, first and second fluid receiving passages, one end of each passage communicating with a different one of said pressure sensing ports, means for supplying fluid under generally constant pressure to each of said passages intermediate the lengths thereof, fluid resistances located adjacent both ends of said passages for restricting flow therethrough, and means actuated by fluid issuing from said other ends of said passages for determining the differential in pressure between said passages.

2. The combination according to claim 1 wherein said means for supplying fluid supplies fluid at a pressure greater than the anticipated maximum total pressure at said ports.

3. A system as claimed in claim 1 wherein said ports are asymmetrically positioned relative to said leading surface.

4. The system as claimed in claim 1 wherein one of said ports is positioned a distance five percent of the chord length of said body downstream of said leading edge, the other port being positioned a distance ten percent of the chord length of said body downstream of said leading edge.

5. A system for sensing and measuring lift comprising an airfoil, a pure fluid amplifier of the beam-deflection type located in said airfoil, said amplifier including a power nozzle for issuing a power stream, first and second control nozzles and output means for receiving the power stream issuing from said power nozzle, first and second fluid-conveying passages, a fluid resistance formed adjacent one end of each of said passages, a pair of ports formed in the leading edge of the airfoil above and below

the chord line, said one end of each of said passages communicating with a different one of said ports, the other end of each passage connected to said control nozzles of said amplifier for supplying fluid pressure signals thereto, means for supplying fluid to each of said fluid-conveying passages intermediate the ends thereof and fluid-resistance means positioned upstream of said passages and downstream of said means for supplying pressure for maintaining a predetermined constant pressure supply to said passages.

6. The system as claimed in claim 5 wherein said means for supplying fluid to said fluid-conveying passages is coupled to said power nozzle of said pure fluid amplifier so as to supply power stream fluid thereto.

7. The combination according to claim 5 further comprising flexible, fluid-tight diaphragms covering said ports, said one of said passages each terminating adjacent a different one of said diaphragms.

8. The combination according to claim 5 wherein said airfoil is a symmetrical foil and said ports are located at the two percent chord.

9. A system for sensing lift forces on a foil comprising a foil, a pair of ports formed in said foil adjacent the leading edge of and above the below, respectively, the chord line of said foil, a pure fluid amplifier having a power nozzle, a pair of control nozzles and at least two fluid output passages for receiving fluid from said power nozzle, and means connecting said control nozzles to receive fluid signals which vary as a function of the differential in fluid pressure across said ports in said foil.

10. The combination according to claim 9 wherein said fluid amplifier is a power amplifier whereby signal integration is reduced.

11. The combination according to claim 9 wherein said fluid amplifier is located internally of said foil.

12. The combination according to claim 9 further comprising flexible, fluid-tight diaphragms covering said ports.

13. The combination according to claim 12 wherein each of said means connecting said control nozzles to receive fluid signals terminates adjacent a different one of said diaphragms.

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