FLIGHT RESEARCH

INSTRUMENTATION

Richard B. Skoog or
Burnett L. Gadeberg

Here at the Flight Research Section you will hear talks on recent tail-load research and compressibility problems encountered in flight. Before these talks are presented, however, I would like to explain briefly the why and how of the instruments used in the flight research of this Laboratory so that you will be able to follow the succeeding talks more readily.

Through the years, the development of suitable instruments by the NACA has kept pace fairly well with the development of modern aircraft until at the present time it is possible to measure almost everything the engineer wishes to know about the behaviour of an airplane in flight. Quantities such as positions of the various control surfaces, forces exerted on the controls by the pilot, sideslip angle, and air pressures can all be measured with good accuracy. Other quantities indicative of the motion, response, or loading of the airplane can also be measured with equal ease.

The instruments used by this Laboratory for flight research were originally conceived at the Langley Laboratory and were designed and built by the NACA specifically for use in recording rapidly changing flight conditions. It was highly important,

therefore, that the instruments have instant response characteristics so that the quantities being measured could be followed accurately as variations occurred. In order to do this, the absolute minimum of moving parts combined with negligible weight for these parts was seen to be necessary as the primary requirement. To meet this requirement the Committee instruments employ a simple optical system wherein a moving beam of light traces its path on a screen, thereby entirely eliminating many moving parts. The instruments we have are sensitive -- yet rugged -- and are as compact as possible because of the limited space available for installation in many airplanes.

Records are taken in all NACA recording flight instruments on ordinary photographic film. To illustrate how the records are obtained and also something of the nature of the records, let me describe briefly the inner workings of two typical instruments. We have here a schematic diagram (fig. 6(b)) of the NACA recording accelerometer. The instrument consists essentially of a light, a lens mounted on the end of a cantilever beam, and the film screen. If an acceleration or abrupt movement is applied to the instrument at right angles to the beam, the beam will deflect, thereby causing the light ray to be deflected by the lens. You can see then that the position of the light spot on the screen is determined by the acceleration existing. In order that continuous records can be obtained as the

acceleration is varied in flight, the film screen is reeled through the instrument in the same manner as in a motion picture camera. Since the instrument does not have a shutter as in a camera, however, the resulting record appears as a continuous line on the moving film rather than as a series of dots. Conventional processing of the film is required, of course, before the record is usable.

A similar diagram for the NACA pressure recorder showing the more usual way of deflecting the light beam is shown on the next chart (fig. 6 (c)). In this instrument, as in most of our instruments, a movable mirror is used instead of a movable lens. The operating element of the unit pictured here -- known as a pressure cell -- is the flexible diaphragm, movement of which causes the mirror to rotate about its pivot. Pressures are transmitted to the cell from the pressure points being studied on an airplane by means of tubing. The pressure being measured is fed into one of the taps on the cell while a constant reference pressure is applied to the other tap. Movement of the diaphragm under pressure then causes the light spot to move on the film as before.

We have here two of the actual instruments used in our flight tests so that you can get a better idea of the instruments themselves. The smaller one is the recording accelerometer I have described to you. Film is loaded into this drum which is detachable for ease in servicing the instrument between flights.

There are two electrical plugs here on the base of the instrument. One of these drives a motor which pulls the film through the instrument. The other is connected to an electric timer which synchronizes this instrument with all others similarly connected. The other instrument is known as a multiple manometer and is capable of measuring 30 pressures at once. The shiny capsules you see are pressure cells of the type I have described. There are an equal number of these cells on the other side of the instrument. By combining many cells into a single instrument in this way, the flight equivalent of the more bulky wind tunnel liquid manometer bank has been realized.

In the nose compartment of the Lockheed P-80 on your left (fig. 6 (d)), you can see several NACA instruments as they appear installed forflight research work. Unfortunately lack of time prevents your closer examination of the installation here; however, at lunch you will have an opportunity to inspect a similar installation in another P-80 if you should care to do so. There is also a display of newly developed instruments which you may find interesting.

In these few minutes we have tried to show you how we obtain research data in flight. The next talk by Mr. White (or Sadoff) will show you how measurements of air pressures on the tail surfaces of an airplane were utilized to provide valuable design information in regard to tail loads.

TAIL LOADS

Maurice D. White
or Melvin Sadoff

The design of high-performance airplanes places a heavy responsibility with the structural designer. He must make the airplane just strong enough to do its job. If he makes it too strong, then he has added unnecessary weight; if he doesn't make it strong enough, accidents occur and his company's reputation suffers.

It is important, therefore, that the designer know, precisely, the conditions of flight that he must design for, and how to design for these conditions accurately.

The NACA has given considerable attention to this problem, and I am going to describe briefly the latest contributions of the Flight Research Section in the field of tail loads. The problem consists of three major points:

First, to define the motions of the airplane that may result in breaking loads on the tail

Second, having determined these motions, to predict the magnitude of the resulting loads, and

Third, knowing the total loads, to predict their distribution over the tail.

To provide more data to solve these problems, an extensive series of tests was conducted on a typical pursuit airplane, a model of which you see here (fig. 6 (a)). This airplane,

equipped with instruments for measuring pressures over the tail surfaces, was maneuvered close to the point of structural failure.

Now let us consider first the horizontal tail. In this chart (fig. 6 (e)), the horizontal-tail loads for turning or pull-up maneuvers are shown as a function of Mach number for the test airplane. At low speeds, the loads are limited by wing stall. At high speeds, they are limited by the physical limitations of the pilot.

The predicted design loads are shown by the dotted lines and the experimental loads by full lines. At low speeds, the trends of the curves show reasonably good agreement. At speeds where compressibility effects become important, the actual loads begin to vary in a manner which current methods of computation cannot predict, and which if extended to higher speeds might lead to failure of the tail. These trends are serious -- very serious -- and indicate that compressibility effects introduce pressing problems in connection with loads in addition to the stability problems that are discussed by other speakers.

The pull-up push-down maneuver was also investigated. This maneuver simulates an abrupt correction by the pilot when the design load is about to be exceeded in a pull-up. While the loads resulting from this maneuver are higher than those for steady acceleration, the design specifications appear to account for the loads adequately.

The distributions of air loads over the horizontal tail are shown on these templates on the model (fig. 6 (f)). The blue outlines correspond to the pressure distributions in symmetrical flight or flight with zero sideslip. The red outlines represent the pressure distribution in sideslips. As you can see the loads in sideslips are higher on the leading side of the tail and lower on the trailing side of the tail. These effects are important from two considerations. First, in rolling pull-out maneuvers where large sideslip angles and high accelerations are obtained simultaneously, the increased load due to sideslip adds to the high load due to high acceleration. Second, the fuselage twist resulting from horizontal tail loads reinforces that due to vertical tail loads.

For the vertical tail the limiting conditions for which the tail should be designed were formerly specified rather arbitrarily. The need for more rational specifications was recognized and an investigation was made of several maneuvers in which it was thought the tail might fail. One of these is the rolling pull-out maneuver used in recovering from dive-bombing runs and in abrupt rolls out of a turn. Since the sideslip angles obtained in rolling pull-outs result from aileron operation, increased aileron effectiveness on modern airplanes has recently made the rolling pull-out maneuver important. The analysis of flight test data for this maneuver led to the development of a method for predicting maximum sideslip angle obtainable in rolling

pull-outs. The next chart (fig. 6 (g)) shows a comparison of the predicted sideslip angles with those obtained in flight. Data falling on this line would indicate perfect agreement of flight and theory. Each line represents a different airplane. The agreement shown for these airplanes is good considering the preliminary nature of the work. Once the sideslip angles are known, the determination of the actual loads is quite straightforward.

The fishtail maneuver deserves consideration in vertical tail design because of the high loads which occur in it. In this maneuver, directional oscillations of the airplane are reinforced by oscillating the rudder in synchronism with the airplane. At certain frequencies large sideslip angles are obtained with relatively little effort. This maneuver was investigated in flight and methods are being developed for predicting maximum tail loads in fishtailing maneuvers. This work is still in progress and correlation between theory and flight data to date is very encouraging.

The next chart (fig. 6 (h)) summarizes graphically the results of the investigations just described. As a convenient reference there is shown along the sides of the chart an airfoil at an angle of attack with a trailing edge flap set at three different positions corresponding to critical flight conditions. The load distribution for each configuration is shown in red. If we consider these sketches as those of a horizontal tail, the

corresponding manouvers are listed here. If we consider the sketches as those of a vertical tail, these are the corresponding manouvers.

You will recall that we previously classified our problem in terms of three objectives. One, to predict the motions of the airplane in the manouver; two, to predict the loads resulting from those motions; and three, to predict the distribution of the loads. Now we can see at a glance the scope of the investigations we have discussed and the results we have obtained. The boxes marked in red indicate where new methods or data have been contributed. The boxes marked in black indicate where a check of existing methods or data was made. For the horizontal tail new contributions have been made toward predicting the loads and their distribution in pull-ups, sideslips, and high-speed dives. For the vertical tail where definite gaps formerly existed in the knowledge of what airplane motions to consider for design, the analyses of the rolling pull-out and fishtail maneuvers has provided adequate data for present-day speeds.

Although there are items in all the boxes on this chart (fig. 6 (h)), it should not be inferred that all the data necessary to design the tail most efficiently are now known. There still remain many additional problems to be solved. These are, and will be, the subject of further NACA research.

Mr. Belsley (or Rathert) will now discuss results obtained in a dive at high Mach numbers.

HIGH-SPEED DIVE

Steven H. Belsley or
George A. Rathert, Jr.

Today you are inspecting a considerable array of laboratory research equipment dedicated to the solution of the problems to be encountered at the extremely high flight speeds of the immediate future. Many of these problems were first discovered during flight tests wherein the airplanes of today were dived to almost terminal velocity in order to obtain speeds approaching the level flight speeds of tomorrow.

To give you a clearer understanding of this well, but often inaccurately, publicized type of flight testing we shall review an exploratory dive conducted by Mr. Lawrence Clousing in this experimental Lockheed P-80 Shooting Star (fig. 6 (i)). As you can see, the nose compartment of the airplane (fig. 6 (d)) is completely equipped with the type of recording instruments discussed previously.

To help follow the progress of this dive assume that we are in the cockpit and will experience the same sensations and reactions as the pilot. The quantities we shall be most aware of during this dive are shown on this chart (fig. 6 (j)) plotted as a function of time. Here we see the elevator stick force, the normal acceleration or load factor, and the Mach number. We shall feel the normal acceleration as a force tending either to lift us

up against our safety belts or jam us down in our seats. We can keep track of the magnitude of this force by an instrument in the cockpit which indicates a number called the load factor. When the instrument reads + 8 g's we are being held in our seats by a force eight times our own weight. This quantity is of the utmost importance to us for two reasons: first, it indicates the magnitude of the over-all load to which we are subjecting the airplane, and second, it will indicate whether we are in level flight (a reading of + 1 g), a pull-out (a reading of greater than + 1 g), or a dive (a reading of less than + 1 g).

The dive we are reviewing is entered from an altitude of 35,000 feet. With full power applied, the airplane is gradually nosed down until a dive angle of approximately 40° is reached. We start our records at a Mach number of 0.79. The first indication we have in this dive of the effects of compressibility is a high-frequency, low-amplitude oscillation of the ailerons known as "buzz." At the same time we encounter a slight buffet which makes the whole airplane feel rough and seems to be increasing in severity as our speed increases. Since both of these phenomena have been encountered several times previously without danger, the dive is continued.

Our speed increases rapidly to 0.83 Mach number where we begin to encounter a much more serious effect of compressibility. Up to this time we have been pushing harder and harder on the stick in

order to keep the airplane in the dive and maintain a steady dive angle. Now, however, this trend abruptly reverses and we feel the required push force dropping off to the point where we are actually having to pull on the stick to prevent the dive from becoming steeper. What has happened is that at our present speeds the air loads are redistributing themselves in such a manner that the airplane now has a strong diving tendency of its own.

In order to effect a recovery from this dive we shall have to pull back on the stick and use the elevators to give the airplane a lift force greater than its own weight, in other words, a load factor greater than + 1 g. Since there is a limit to the amount of pull force which we can exert we can readily appreciate our danger; if we have to pull very hard to overcome this growing diving tendency we may not have an ample margin of pull force left to effect a recovery. Our predicament is illustrated on this chart (fig. 6 (k)). This curve shows us the amount of load factor we can obtain at any given Mach number by exerting an assumed constant pull force, for example 40 pounds. The curves for any other stick force will be similar in shape.

Notice that at the Mach number where the diving tendency set in, the load factor we can obtain starts to drop sharply, that at some higher Mach number the curve apparently would drop below + 1 g and enter the red dive area. What directly interests us, the effect on our dive path, is shown by these two curves (fig. 6 (l)). At a Mach

number of 0.8 our maximum pull force would have given us a safe pull-out. At the higher Mach number which we are now rapidly approaching, it is possible that we could not obtain a positive load factor and would be in an ever steepening dive.

Having no desire to find ourselves in such a predicament, we continue to haul back on the stick and begin our recovery. As our load factor begins to climb safely we run into more trouble. The severity of the buffeting increases quite rapidly and the aileron buzz turns into a very violent oscillation with a greatly enlarged angular movement.

Despite these two very disturbing phenomena we have to continue the pull-out and as we reach 3 g's we pass our peak Mach number of 0.866. Our speed is now falling off quite rapidly. As we would expect, however, the diving tendency which caused us so much concern is relieved very abruptly and the airplane suddenly pitches up toward a new danger; a full stall at extremely high speed, which might involve catastrophic structural loads. Even though we are prepared and react instantly, pushing a full 70 pounds forward on the stick in less than half a second, the load factor soars to a peak of 7½ g's. At this point the buffeting of the entire airplane is extremely violent and the wings deflect upward a considerable amount. This point represents a high-speed stall condition which for exceptional speed and severity is unique in flight-research experience. Our recovery from this stall is very abrupt, involving an acceleration change of 9 g in half a second, quite a severe jolt.

After a few minor longitudinal oscillations our recovery is fully effected. As we look out over the left wing we will notice a large wrinkle in the trailing edge of the aileron illustrating the tremendous forces involved in the aileron flutter.

Looking back over our experiences in this dive we can see immediately that we have encountered three problems that must be solved before the speeds we have reached will be safe and practical. These problems; the diving tendency, transonic aileron flutter, and high-speed buffeting are now under study at the suitable facilities of the NACA. During your inspection of this Laboratory you will hear reports on the development of dive-recovery flaps and studies of buffeting and transonic flutter. Each of these problems was first encountered in flight; the dive we have just reviewed representing the highest limit to which piloted flight research has been carried by the NACA. The methods and techniques developed to solve these problems are now being incorporated in your designs for tomorrow and will be proof-tested at the level-flight speeds which we could reach only by diving the Shooting Star. Those airplanes will then be ready for us to dive in their turn.

(a) General view.

Figure 6.- Flight research exhibit.

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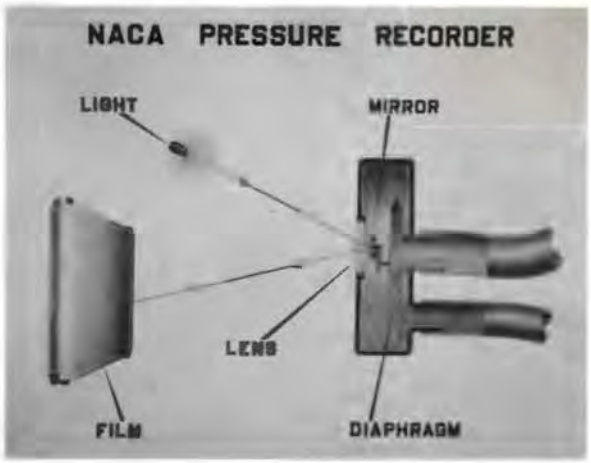
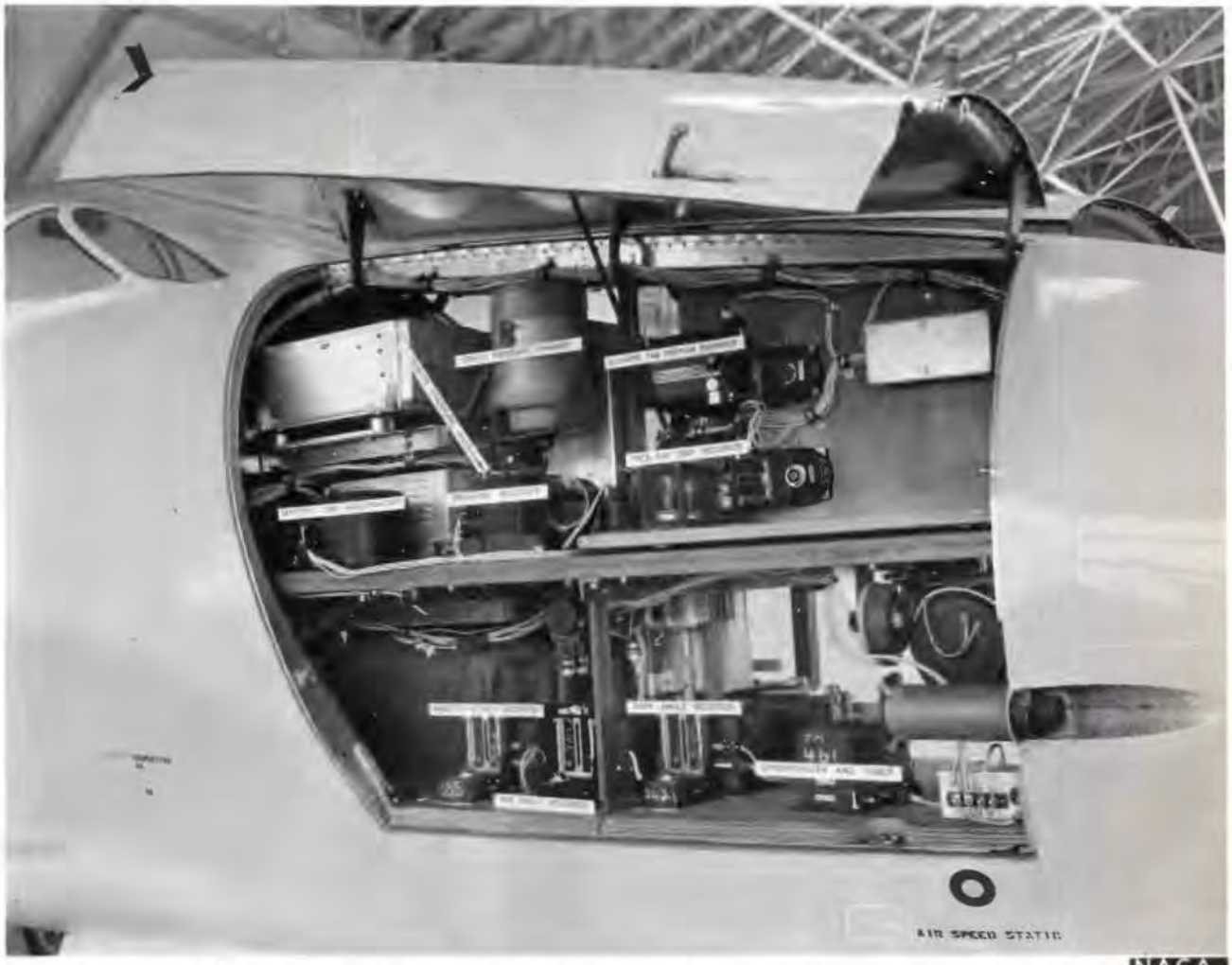
(b) First chart.



(c) Second chart.



(d) Instruments installed in Lockheed P-80 Shooting Star. NACA A-10278 7-22-46

Figure 6.- Continued.

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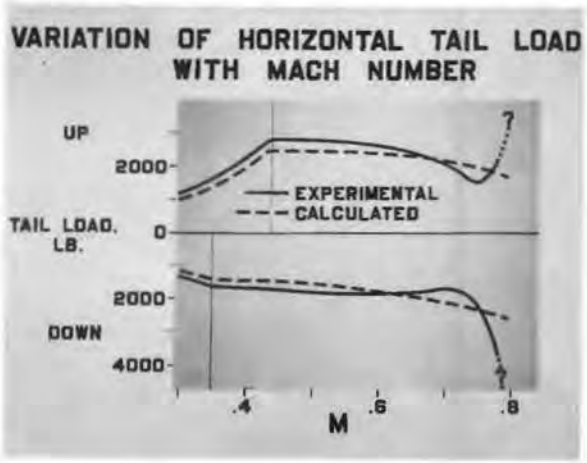
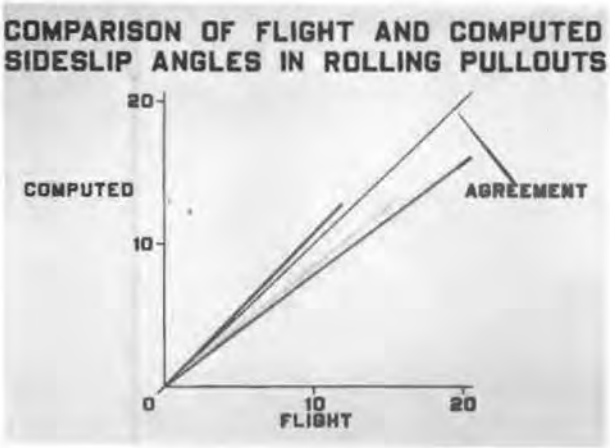


(e) Third chart.

(f) Tail load distribution.



(g) Fourth chart.

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Figure 6.- Continued.

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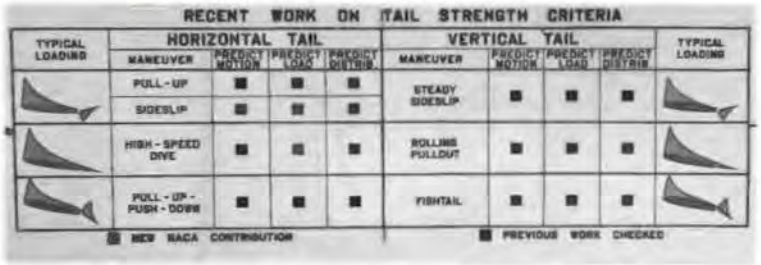
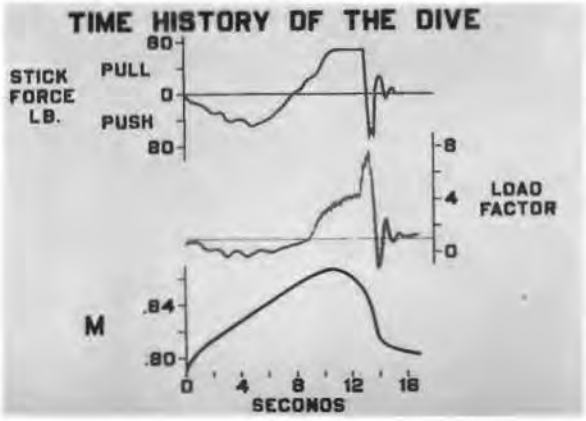
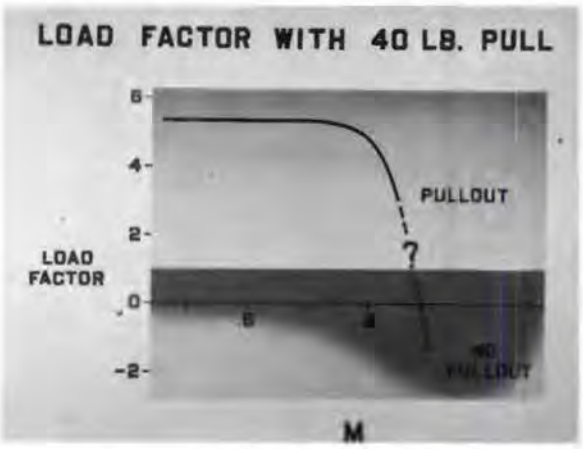


(h) Fifth chart.

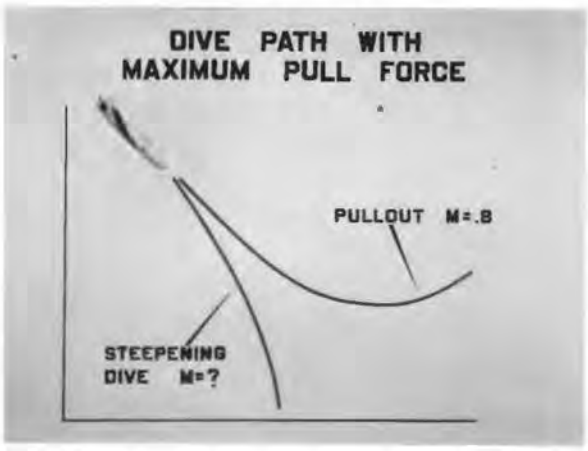
(i) Sixth chart.



(j) Seventh chart.



(k) Eighth chart.



(l) Ninth chart.

Figure 6.- Concluded.

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