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REPORTS AND MEMORANDA

Investigations of the Behaviour of Aircraft When Making a Forced Landing on Water (Ditching)

BY

A. G. SMITH, C. H. E. WARREN and D. F. WRIGHT

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CONTENTS

3. **Main Results**—*continued*

LIST OF ILLUSTRATIONS

Investigations of the Behaviour of Aircraft when making a Forced Landing on Water (Ditching)

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COMMUNICATED BY THE PRINCIPAL DIRECTOR OF SCIENTIFIC RESEARCH (AIR),
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March, 1952

Summary.—This investigation reviews the work done up to 1948 on the behaviour of aircraft when making a forced landing on water. It is confined in detail to the tests made on hydrodynamic and structural performance in the Free Launching Tank at the Royal Aircraft Establishment and the Controlled Launching Tank at the Marine Aircraft Experimental Establishment, and includes an analysis of the air-sea rescue questionnaires sent in by air crews who have experienced actual ditchings. Reference is also made to parallel work in the U.S.A. and Germany. The work done is primarily concerned with the contributions made to the Air-Sea Rescue Organisation in the 1939–45 war period and the determination of the ditching characteristics and requirements for post-war civil and military aircraft.

The work is analysed in terms of the techniques of testing used and the results obtained for:

(*a*) the best approach and touchdown techniques

(*b*) the hydrodynamic design and structural strength requirements to permit the aircraft to float for sufficient time to allow the occupants to escape to their dinghies.

It is now possible to understand broadly what features give good ditching characteristics and also the best procedure to be adopted by the crew and/or passengers to increase their chances of survival. More quantitative test techniques with better equipment are being developed to improve this understanding and to enable rational design ditching requirements to be formed. Work is required particularly on the effect of waves, the impact forces and pressure distribution on rationalised fuselage shapes and the optimum structural design to absorb the energy of impact by local failure without producing too severe a leakage.

It is clear that design for ditching must be restricted to the cases of a good approach and good behaviour on the water, and that the best and simplest ditching positions must be available for aircraft occupants, *e.g.*, aft-facing seats, otherwise the expenditure in weight may be prohibitive. The results given in this investigation show that these pre-requisites can be quite simply achieved.

1. **Historical Survey.**—1.1. **Introduction.**—During the war period 1939–45, many landplanes had to make a forced alighting on the sea (a ‘ ditching ’). The reasons for these ditchings were many and varied—shortage of fuel, engine failure, damage to the aircraft due to enemy action, bad weather, injury to the pilot, etc. In addition, many of these ditchings had to be made at night. An imaginary account of such a ditching is given in Appendix I, from which some idea of the problems involved may be obtained.

When ditching, the aircraft's crew and passengers may have to contend with high forward decelerations, rapid flooding because of extensive local structural damage on the bottom, possible loss of the nose or tail of the fuselage, and a final nose down floating attitude. The flotation

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time is likely to be only a few minutes or, in good circumstances, a quarter of an hour for escape from a multi-engined aircraft, whilst only seconds may be available for a fighter. In bad cases there may also be severe instability and diving. The complete loss of the aircraft in ditching is inevitable, but in order to save the lives of as many aircrew as possible, an Air-Sea Rescue organisation was built up. The problems were attacked in four ways:

(i) the ditching behaviour of aircraft was investigated with the object of finding the best way to bring a landplane to rest on the water, and also of obtaining information on the loads, damage and leakage likely to occur

(ii) the organising of a 'ditching drill' including the allocation for each aircraft of suitable 'ditching stations', so that the passengers and crew would be trained to conduct themselves in the best manner for their own survival

(iii) the provision of rubber dinghies in the aircraft and emergency equipment in the dinghies, so as to provide for the protection of the survivors until their rescue

(iv) the provision of sea and air rescue craft (motor boats, seaplanes, airborne lifeboats, Lindholme dinghies, etc., and means of communication) for the eventual rescue of the survivors.

Considerable advances were made towards a solution of all these problems, but, in practice, for an aircrew to have a chance of survival, a satisfactory solution to each problem had to be found for each aircraft. Typical examples of this are provided by the cases of the *Hudson*, a twin-engined bomber of about 18,000 lb all-up weight and the *Fortress*, a four-engined bomber of about 55,000 lb all-up weight.

In the case of the *Hudson*, nearly fifty aircraft in succession were lost without trace in the first year of the war. Tests were initiated on a dynamic* model[1], and they revealed that a structural collapse of the bomb-aimer's window in the nose, and of the bomb doors under the fuselage, produced a vicious nose-in with high deceleration, especially when the strong Fowler flaps were also down. Accordingly, the bomb-aimer's window and the bomb doors were strengthened, and the pilots were instructed to change their handling technique and to ditch with flaps up. Subsequently, substantial improvement was obtained.

Similar model tests on the *Fortress*[9], however, showed that this aircraft should have comparatively good ditching characteristics despite an abnormally high casualty rate found full-scale. Because model tests had already given reliable information in the past, and there was no reason to disbelieve the results in this instance, attention was directed towards improving the ditching drill and equipment for this aircraft. The improvement led to the subsequent record rescue of 118 out of the 121 *Fortress* aircrew who ditched on one day's operations.

This investigation deals only with the researches on both civil and military aircraft made towards a solution of the first problem mentioned above, 'Investigation of the ditching behaviour of aircraft'. Research in this direction is possibly the most fundamental in that it should lead to an understanding of what features give an aircraft good or bad ditching characteristics from the handling, hydrodynamic and structural aspects. A good design from these standpoints makes the solutions of the other problems (ii) to (iv) above, considerably easier. Reference to the work done on these problems will only be made in so far as it directly affects the ditching behaviour.

1.2. **Investigations Made Before the 1939–45 War.**—Until the war (1939), very little was done to investigate the ditching behaviour of aircraft. The Royal Navy had attempted to obtain some information on military types by catapulting aircraft (*Swordfish, Skua*) into the sea, and also by intentionally ditching aircraft (*Osprey, Nimrod*). Such tests, although of a very *ad hoc* nature, nevertheless yielded useful qualitative information on the ditching behaviour and the damage likely to occur.

Other information on how a landplane behaves on water had been obtained before the war from dynamic model tests made on three aircraft[48, 49, 50] in the Seaplane Towing Tank at the R.A.E., Farnborough. In these tests the same technique was adopted as was used for seaplanes, *i.e.*, towing the models at various steady speeds through the water and observing the hydrodynamic behaviour. No attempt was made to represent the strength of the parts of the aircraft's structure that would probably fail under water loads, and no attempt was made to represent the alighting impact, which subsequent tests have shown to have a direct bearing on the ditching behaviour.

The general information obtained was, therefore, of limited usefulness. But some of the detailed conclusions have been borne out by later tests, such as,

(*a*) that propellers, even when clamped in coarse pitch, cause little diving tendency,

(*b*) that a bluff streamlined nose will cause diving if it is forced in the water, owing to the associated negative pressures near the nose of a streamlined body.

The shortcomings of towed model tests were fully realised, and one of the recommendations made was that ditching investigations should be made by catapulting free-flight models on to the water—a recommendation that was adopted early in the war to investigate, in the first instance, the ditching characteristics of the *Hudson*, *Spitfire*, *Hurricane* and *Fulmar*[1].

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* A dynamic model in this instance is one which is to scale with respect to size, mass and mass distribution, and with the strength of pertinent portions of the model also to scale.

1.3. **Investigations Made During and Immediately Following the 1939–45 War.**—Early in 1941, free launching model tests were started in an outdoor tank at the R.A.E., Farnborough (Figs. 1 and 2). In these tests, scale dynamic models (Fig. 5) were catapulted on to the water and the alightings were observed and photographed with a high-speed Vinten camera. These tests proved to be of much more value than the tests made before the war in the Seaplane Towing Tank, owing to the complete freedom of the model once it had left the catapult, and because the failing strength of parts of the structure thought to be important were represented (Fig. 6). It was possible to explore the ditching behaviour of an aircraft over a wide range of touch-down conditions, and information was obtained both on the best method of handling the aircraft[66] before impact and on the hydrodynamic and structural design features[66] that make the aircraft good or bad ditchers. To obtain information on the behaviour of aircraft when ditching in waves[11], etc., the catapult was taken to the National Physical Laboratory, Teddington, and tests were made in the Froude Tank, which has a wave-maker.

In parallel with the free launching model tests at the R.A.E., Farnborough, as much information as possible was obtained from operational ditchings as they occurred by the initiation of ditching questionnaires (Appendix I), collection of eye-witness accounts and the examination of the ditched aircraft where possible (Fig. 19). Pilots and eye-witnesses were asked to describe as accurately as possible the type of approach and alighting that was made, giving the aircraft speed, attitude, flap setting, and also the state of the sea and wind, etc. A typical, but fictitious, example is given in Appendix I. From the accumulated information obtained, recommendations were made as to the best handling technique to be adopted for each aircraft. From the examination of the salvaged aircraft, and from the crew's description of the ditchings, information was obtained on the structural weaknesses in the aircraft. Weak parts of the structure were strengthened where possible, and if strengthening was impracticable, ditching stations were so allocated as to render the failure less serious.

Early in the war a few aircraft were dropped on to the sea from cranes (Fig. 20). From an examination of the aircraft after dropping information was obtained on the damage likely to occur, and recommendations were made for strengthening the structure where necessary. Information was also obtained on the time of flotation, and on the principal sources of entry of water[51 to 56]. The value of simple dropping and sinking tests, however, decreased when information from operational ditchings became abundant. However, there is a case for a few such full-scale dropping tests under controlled conditions on civil aircraft in peace time.

Towards the end of the war, an investigation was started into the pressure loads likely to be encountered on a fuselage bottom during a ditching. This investigation, which was made in the Hull Controlled Launching Tank[64] at the M.A.E.E., Helensburgh (Fig. 3) followed the lines of similar work which had already been made to obtain data for the stressing of seaplanes[74]. A large-scale partial model of the fuselage was dropped on to water under various impact conditions, and detailed measurements made of the pressure distribution over the fuselage bottom during the initial impact (Fig. 21). The main feature of these tests was that, because the model was restrained except for movements of heave and pitch, large scales, up to one-third of full-scale, could be used[57, 58].

1.4. **Investigations Made Abroad.**—In the United States, model tests were made in the National Advisory Committee for Aeronautics No. 2 Tank at Langley Field (Fig. 4). It was realised, however, that towing tests of the sort made at the R.A.E., Farnborough, before the war, were of limited value and accordingly the towing carriage was used merely as a means for accelerating the model up to flying speed. It was then dropped freely on to the water from varying heights. Such tests were possible in the N.A.C.A. Tank because of its greater width compared with the R.A.E. Seaplane Towing Tank, and also because the carriage was slung from overhead rails. Such tests, however, did not give such accurate control over the relevant alighting parameters, especially the angle of descent at touchdown, nor was observation of the behaviour as easy as in catapult tests on to a pond. There was, however, the very big advantage of still-air conditions in an enclosed building. Outdoor catapult tests (Fig. 4) were, therefore, initiated and they were conducted in a similar manner to those already developed at the R.A.E. In both sets of tests in the United States the strength of weak parts of the structure was represented in much the same manner as in this country.

In Germany, dynamic model tests were made in the Seaplane Model Testing Tank at Hamburg[45 to 47]. They were of a similar nature to the tests made in the N.A.C.A. No. 2 Tank at Langley Field. The tank carriage was used to accelerate the model up to flying speed, and the model was then dropped freely on to the water. The flight path could not be predetermined with any accuracy but the path of the model after release was recorded through a system of mirrors fixed to the tank sides and photographed by stereoscopic cine cameras. No structural weaknesses were represented but the pressures over underblisters, etc., were measured in separate towing tests for stressing purposes. Tests were made in waves. Some systematic tests were made on the *Junkers Ju* 88, on which the fuselage shape and other parameters were varied. The results were in general agreement with those obtained in this country.

In 1944, the N.A.C.A. made one full-scale test, on a *Liberator*[59, 60] to link model test results with full-scale (Figs. 16 and 17). Full instrumentation was fitted to the aircraft (pressure recorders, attitude recorders, etc.) but many of the pressure recorders were lost owing to the break-up of the aircraft and very little information was obtained. The general behaviour, however, was in good agreement with that predicted from model tests[4, 59, 60].

A further full-scale test has been made, using radio control but unfortunately the aircraft ditched nose-down, and no useful information was obtained. Little is known of the full-scale tests made in Germany, but it is believed that full-scale aircraft were launched into the sea by catapult, and possibly also towed, to investigate their structural and sinking characteristics.

Just after the war ended, the U.S. Army Air Force began to develop a radio-controlled flying model technique for investigating the ditching characteristics of their own military aircraft[65]. The models were to be ditched in the open air and the behaviour, principal loads and pressures automatically recorded, partly in the model and partly at a ground station. Structural weaknesses were not to be represented. The programme envisaged development of the technique, application to determine test ditching techniques on specific aircraft and full-scale correlation by radio-controlled full-scale tests using a *Fortress*.

2. **Survey of Testing Methods.**—2.1. **Free-Launching Model Tests.**—The fundamental requirement of free-launching model tests is that a model, dynamically similar to the full-scale aircraft, shall strike the water under conditions which are similar to those that can occur full-scale. Under such conditions, the motion of the model, after striking the water, and the disturbed water, will be dynamically similar to that of the full-scale aircraft[61], provided also that any structural damage is similar model and full-scale, and provided that the differences in Reynolds number and surface tension number are unimportant.

A catapult was selected as the means for launching the models on to water under various conditions, represented by three main parameters (Fig. 8) *viz.*,

(i) speed at touchdown

(ii) angle of descent at touchdown

(iii) attitude at touchdown.

Ideally the rate of pitching, etc., at touchdown should also be represented.

To simulate asymetric alightings, or alightings in a cross-wind, etc., angles of bank and sideslip should be represented.

In addition, it should be possible to represent the various sea conditions likely to occur full-scale. This means that the tank into which the models are launched should be fitted with wavemakers[62] capable of producing a controlled range of wave heights, lengths and possibly directions. The outdoor tank used at the R.A.E., Farnborough (Fig. 1) had no wavemakers and accordingly the only tests in waves were made in the Froude Tank at the N.P.L., Teddington[11].

At the end of the war, an R.A.E. specification was prepared for a new ditching tank and catapult, which was accepted by the Aeronautical Research Council. It was better equipped for research and development and the leading particulars are considered later in this report[62].

2.1.1. **Description of R.A.E. launching catapult.**—The catapult that was designed by Mr. W. D. Tye of the R.A.E. and proved very successful, is shown in Fig. 2. The essential requirement was simplicity. It consisted of a flight beam, which was hinged at its forward end to enable the angle of descent of the model to be varied. The lower flange of the flight beam formed a track, along which an underslung carriage was pulled by cord, which was connected to a variable drop weight through pulleys and a six-part tackle. Variation of the drop weight enabled the launching speed, and thus the speed of the model at touchdown, to be varied. The drop weight was arrested by falling on to a heap of wood chips, the most reliable and efficient shock absorber found for the loads that were being used at the time of writing. The model was slung beneath the carriage and was supported at a point aft and above its centre of gravity, so that during the acceleration the aft end of the model was subjected to an upload, which was taken up by a suitable fitting on the rear of the carriage. The model was placed in the carriage in such a manner that it was free to leave in a forward direction. Detents, which fell out during the acceleration, were used to hold the model in the carriage when launching at high angles of descent. The aft support for the model was adjustable, thus enabling the attitude of the model to be varied.

The method of launching consisted in winding up the drop weight to an appropriate height, with the carriage bearing against a trigger catch. When this trigger was released, the drop weight fell, accelerating the carriage and model down the track. The carriage was arrested at the same moment as the drop weight struck the wood chips by running into a combined bungee and friction brake system. The bungee not only retarded the carriage but subsequently returned it out of the friction brake. The model continued on its path at the required speed, and provided that it was correctly ' trimmed ' it struck the water at the preset angles of descent and attitude. Trimming tests were necessary before each test to find the elevator setting which trimmed the model on a straight course after leaving the catapult. These elevator settings were obtained by trial and error.

Bank and sideslip could be imparted to the model when required by means of a fitting which enabled it to be set asymmetrically on the carriage.

2.1.2. **Choice of model scale.**—The relation giving the launching speed in terms of the drop weight can be determined from elementary dynamical considerations. It is

$$U^2 = \frac{2\,WgNd}{W + N^2 w}$$

where U is the launching speed (ft/sec)

W drop weight (lb)

w weight to be accelerated (lb), (*i,e.*, weight of carriage + weight of model + an allowance for the inertia of the cord and pulleys)

N reduction ratio of the pulleys

d travel of the carriage (ft).

The friction in the system was small, and of the same order of magnitude as the favourable effect of the component of the gravitational force on the carriage down the inclined track. Both effects were neglected.

For the catapult as designed, the reduction ratio of the pulleys (N) was 6, the travel of the carriage (d) was 20 ft and the weight of the carriage, with the allowance for the inertia of the cord and pulleys was 10 lb. The length of track and maximum useful acceleration enabled models of, say, 20 lb in weight to be launched[62] at speeds of 56 ft/sec. Greater weights and speeds, *i.e.*, more on model scale, could be obtained if desired by lengthening the track, but often greater speeds were either too much for the length of tank available or the larger models had spans greater than 9 ft, which was the maximum to clear the catapult front supports.

The scale of the model is chosen so that the greatest drop weight, W, (740 lb) would launch the model at the highest touchdown speed required. Since the gravitational acceleration and also the air and water densities are the same model and full-scale, the fixing of the model scale ($1 : n$. say) automatically determined the ratios between model and full-scale of all other dimensional quantities. Typical ratios are as follows,

Forces and weights	$1 : n^3$
Moments of inertia	$1 : n^5$
Pressures	$1 : n$
Speeds	$1 : n^{1/2}$
Accelerations	$1 : 1$
Times	$1 : n^{1/2}$

2.1.3. **Construction of models.**—The models were made mainly of balsa wood, together with ply and pine, to the correct external shape, in accordance with R.A.E. seaplane towing tank practice. The spans generally varied between 4 and 9 ft depending on size, wing loading and aspect ratio. The wings were built up with solid balsa leading and trailing edges, connected by ribs which were covered with sheet balsa on the upper surface and by sheet ply, for strength on the water, on the lower surface. The fuselage was made from a solid block of balsa, hollowed out internally to give an average thickness of about half an inch. Tail surfaces, nacelles, etc. were usually of solid balsa, strengthened with hard wood or ply, and hollowed out internally if necessary (Fig. 7). The models were finished with several coats of shellac and clear varnish in order to make them waterproof. They were subject to very rough treatment in the ditching experiments, but generally stood up to this exceptionally well. Models were made in the R.A.E. model-making shop.

The assembled model was ballasted to the correct scale weight and centre of gravity position. The pitching moment of inertia usually came out about 50 per cent above the correct scale value. In the U.S.A., where larger models were used and the problem was simpler, care was taken to represent more nearly the correct scale pitching moment of inertia, but as it was thought in this country that the effect of a too-high value would not lead to too erroneous results, no attempt was made to reduce it further, as this could only have been achieved at the cost of weakening the model, and increasing the man-hours required for its design and construction.

Details which would not affect the ditching behaviour, such as cabin tops, engine exhausts, upper turrets, elevator horns, etc., were either simplified or omitted altogether.

2.1.4. **Scale effect on aerodynamic characteristics.**—One difficulty met in scale model tests is obtaining the correct aerodynamic characteristics of the wing and tail surfaces. Model tests are made at a Reynolds number of about 0·3 million, based on wing mean chord. At this Reynolds number the stalling incidence of most wing sections used on aircraft is often 6 deg to 8 deg less model-scale than the corresponding full-scale value. In addition the elevator effectiveness is much reduced. For this reason, when representing flight at a speed just above the full-scale stalling speed, the model wing is sometimes completely stalled. In order to see how serious this could be, a model was fitted with full-span leading-edge slats, which increased the stalling incidence up to the correct value. The model is always launched as close to the water as possible so as to prevent changes in angle of descent and attitude between leaving the carriage and striking the water.

To avoid wing dropping problems on models where there was a particularly adverse scale effect on maximum lift, the wing-tip sections of such models were made with increased camber and geometrical washout. The wing roots usually enter the water during a ditching, and were therefore made to the correct section.

A further difficulty encountered was trimming the model due to large losses of elevator efficiency. The best remedy was to increase the chord of the elevator. The use of flaps or slots often made it difficult to keep the nose down, especially when there was a large ground effect.

The N.A.C.A. fitted a universal thin metal leading-edge slat to all their models when the wings did not affect water performance and this was claimed to give full-scale lift correlation and have little effect on trim conditions.

2.1.5. **Representation of structural weaknesses.**—It was considered sufficiently representative of full-scale conditions to make models very much overstrength in most respects but the failure of certain details has such an important effect on the ditching behaviour of some aircraft that it was essential that they should be represented. Certain parts of the model were made to fail at loads equivalent to the ultimate strength of the corresponding parts of the full scale aircraft. For instance, when a model was tested to see whether the flaps could safely be lowered for ditching, the flaps themselves were made strong enough to remain undamaged by the water forces, but were attached to the wing by threads which snapped when the load on them corresponded to the ultimate strength of the full-scale gear. Fig. 5 shows one arrangement used to represent flap failures, and Fig. 6 shows that usually adopted to represent the collapse of bomb doors. Radiator attachments and tailplane attachments were similarly represented.

If, as a result of some test, experience, or examination of the full-scale aircraft, it was clear that a particular part of the structure was much too weak, the model was shaped to represent the probable condition of the aircraft after ditching. This provides a convenient way of estimating the deterioration in ditching behaviour resulting from the failure of small panels, such as lower parachute exits, bomb-aiming windows, nose-wheel doors, etc.

In the N.A.C.A. tests structural damage was represented, rather than structural weakness, and windmilling propellers were usually added because of their effect on deceleration and trim in certain critical conditions.

2.1.6. **Pressure measurements.**—Various methods were tried to find the pressure loads that occur in ditching on some particular part of the aircraft structure, but none were wholly successful.

Holes covered with thin waterproof paper of known strength were tried to represent the lower stress structure of a fuselage, and useful qualitative effects were found, but the method was not satisfactory because it was difficult to get waterproof paper that was sufficiently weak, and in particular that had equal strength in all directions and at the frame attachments.

Another scheme was to measure the deflection of a rubber diaphragm of half an inch diameter. The deflection was measured by placing a small knob covered with wet marking ink behind the diaphragm. During similar alightings the knob was adjusted with a fine screw until the probability of the diaphragm's touching the ink was $\frac{1}{2}$. The pressure corresponding to this average deflection was found by a static calibration. This method of test was very slow and tedious. In addition, the pressure gauge responded very rapidly because of lack of stiffness and thus recorded pressure peaks which were of too short a duration to be serious in practice.

A third method that was tried was to attach to a diaphragm a sharp striker which, when at rest, just touched a block of soft metal. The effect of the impact pressure caused the striker to dent the block, and the magnitude of the pressure was obtained from the diameter of the dent.

2.1.7. **Cine film analysis.**—The alightings were filmed from the side of the tank by a Vinten high-speed cine camera (Fig. 1). From the film a clearer idea of the behaviour was obtained than was possible visually. In addition, from an analysis of the film a history of the fore-and-aft deceleration, speed and attitude could be obtained (Figs. 14b and 15b). To assist in this a scale was painted on the near side wall of the tank, and a striped indicating post was fitted on the model where it was least likely to be obscured by spray. The distance-time records were differentiated twice, and the mean longitudinal deceleration over a time interval of about a tenth of a second (model-scale) could be obtained. Quite useful accuracy of attitude and speed could be obtained, unless events happened too suddenly, but acceleration results were probably only accurate to the nearest $\frac{1}{4}g$. A light self-contained automatically recording accelerometer is required for this work. The Americans used one successfully in their larger models.

2.2. **Full-Scale Dropping Tests.**—Extensive dropping and sinking tests were made on the *Hudson*[51 to 55], and to a less extent on the *Botha*[56], by the M.A.E.E. at Helensburgh. In these tests full-scale aircraft were used, but the engines and details such as control surfaces, wing tips, etc., were missing. The aircraft were, however, ballasted to have the correct distribution of weight.

The tests consisted of dropping the aircraft on to the water from a crane, and observing the behaviour, time of flotation, and source of leakage. The drops (Fig. 20) were usually made with the aircraft in a three-point attitude, from a height of about 2 ft 6 in.

Observers inside the aircraft noted the position of numerous leaks and the aircraft was then dropped on again with these leaks sealed with plates or rags, depending on the size of the hole. It was found on the *Hudson*, for example, that the time of flotation could be increased by these means from about one minute to five minutes. Such sealing, of course, was not always possible on existing service aircraft, but the attention of designers was drawn to the importance of eliminating small leaks in the landplanes which have to operate over the sea.

In addition to the sources of leakage, information was obtained on the damage to be expected. On the *Hudson*, for example, the bomb-aimer's window was found to collapse. Static pressure tests were then made and a window designed that would withstand 12 lb/sq in. statically. This window was then fitted to the aircraft, and it satisfactorily withstood a dropping test from 2 ft 6 in.

The vertical decelerations that occurred in droppings were measured with R.A.E. B-type accelerometers.

2.3. **Impact Pressure Measurements in a Controlled Launching Tank.**—To obtain a broad picture of the impact pressures that occur on a landplane fuselage during a ditching, tests [57, 58] were made in the Hull Launching Tank[64] at the M.A.E.E. (Fig. 3) and followed the lines of similar work[74] which had already been made to obtain data for the local stressing of seaplane bottoms. The Hull Launching Tank might more descriptively be called a ' controlled launching tank ', in contrast to the free launching tank considered in section 2.1. There the model was prefectly free once it had been launched, but in these tests the model was free only in pitch and heave, it being restrained in roll and yaw, etc.

The apparatus used at the M.A.E.E. (Fig. 3) consisted of a tank 140 ft long by 11 ft wide, by $3\frac{1}{2}$ ft deep, and had a track mounted over the tank. The track had inclined portions at each end. A launching carriage could be hauled up to any position on the longer inclined portion, and upon release, ran down under gravity towards the tank, attaining a maximum speed at the bottom of the incline. On reaching the tract level, the model, which was attached to the carriage on a parallel motion mechanism, was automatically released and swung down on to the water. Wing lift was represented by balance weights on the end of a beam. This weight could be varied to cover conditions from ' fly-on ' alightings to fully stalled alightings. A range of vertical velocity was obtained by varying the height through which the model dropped. The attitude of the model was mechanically controlled until immediately prior to impact, after which the model was free to pitch and heave.

The maximum speed of launching was 36 ft/sec. A time history of the horizontal velocity during the subsequent motion was obtained by a Cambridge-type chronograph. The vertical velocity was measured by obtaining a time record of the distance of the model above the water by means of a sensitive scratch recorder. The attitude was measured in a similar way.

The pressure-time records were obtained by deflection-meters, which depended for their operation upon the deflection, under water pressure, of a small diaphragm carrying a control spindle. The movement of the spindle was recorded on a D.V.L. type scratch recorder in which a diamond point scratched on a small slide of steel or glass which was driven at right-angles to the direction of motion of the spindle. Timing marks were made at quarter-second intervals by a second diamond operated by a solenoid actuated from an external timing clock.

All records of velocity, attitude and pressure were synchronised.

A similar piece of equipment to the M.A.E.E. Launching Tank, the N.A.C.A. Impact Basin, is used in America, but its use has been restricted so far to the investigation of seaplane bottom loads. The results have, however, proved valuable in understanding the general theory of impact and its application to the landplane case. The principles of operation are similar to those of the M.A.E.E. Launching Tank but the carriage is accelerated by a catapult and all measurements are made electronically.

The pressure and acceleration measurement techniques used at the M.A.E.E. are also being changed to electronic, both because of the difficulties of measuring loads which have very short build-up times with sufficient accuracy using mechanical methods of recording, and also to obtain more accurate time synchronisation.

2.4. **Radio-controlled Powered Model Technique.**—Little can be said of the practical details of the radio-controlled powered-model technique because of its very early stage of development at the time of writing. Earlier work in the parallel seaplane model testing problem on the use of radio control has, however, been described by the initiator, Ernest Stout, in a paper[65] in the Journal of Aeronautical Sciences. There, some success is claimed in obtaining controlled conditions of test and useful quantitative observations.

2.5. **Notes on the Merits of the Various Testing Methods.**—At this stage it is pertinent to draw a few conclusions as to the merits of the various testing methods that have been used in connection with investigations into the ditching behaviour of landplanes. The criterion of merit will be the extent of speed and economy with which the various testing methods help to answer the questions: ' How do aircraft behave hydrodynamically in ditching ? ' and ' How do they behave structurally ? '

2.5.1. **Hydrodynamic behaviour.**—Consider the first question first—' How do aircraft behave hydrodynamically in ditching ? ' What is required here is a knowledge of whether an aircraft will dive, bounce, or run smoothly under various alighting conditions, what decelerations occur and what is the final flotation condition. The experience with free catapult-launched models has shown that this method of testing is well suited to furnish quickly and economically just this sort of information, provided that structural weaknesses are represented. No elaborate apparatus is required and, as is usual with model tests, a great amount of work can be performed with few personnel.

The method gives maximum control with repeatability of test conditions and opportunity for accurate quantitative measurements. As used in open-air conditions during the war period there was a severe loss of time because of lack of control of wind and water conditions, especially under British weather conditions. To obtain the maximum information from this method of test it is therefore essential that the models be launched into an indoor tank equipped with a wave-maker and possible wind-maker, so that these can be controlled. Such a design has been recommended by the Aeronautical Research Council.

Limitations to the method are that (*a*) very little useful information is given on how long the aircraft will float at the end of a ditching, (*b*) the effect of use of elevator control just before impact cannot be represented on the fixed-trim models used. The first limitation applied to any model technique and is concerned also with the representation of structural weakness and leaks. It has, however, proved possible to obtain a good idea of the flotation angle and where water will flood in, and from full-scale tests and experience, of the time. The second difficulty may not be important since any final impact condition can be represented, there remaining only the possible dynamic effects of rotation in pitch, *e.g.*, flatten out with critical nose-up pitch. There is also the convenience of actually representing a pilot's actions for specific aircraft tests. If thought important remote radio elevator control could be incorporated for these purposes.

The complete radio-controlled model technique is thought to offer possibilities for reasonable control when proportionate control with rapid response is achieved. The important drawback to the method is the dependence on meteorological conditions, especially in Great Britain, and an elaborate organisation to obtain measurements. The models themselves would be expensive because of their size (say 16-ft. span) and, being filled with complicated equipment, they would also be very vulnerable under ditching conditions. Practical experience is against such complications when simpler methods are available.

Towed-model tests at constant speed are not suitable for investigating the overall hydrodynamic behaviour in ditching, owing to the lateral restraints on the model, the lack of the initial disturbance caused by the alighting impact, and the vast number of runs required. But controlled towing tests to investigate specific hydrodynamic flow conditions can be useful. The Americans have used their towing tank carriages as catapults, the model being released at the correct speed and attitude (Fig. 4) but the control of the touchdown conditions is not so accurate as in free launching catapult tests and, in any case, such tests are possible only in fairly wide towing tanks.

The use of full-scale tests for regular investigations into the hydrodynamic behaviour in ditching is impracticable because an aircraft is lost in each test, and a large organisation and complicated equipment are required, especially if personal hazard is avoided by ditching the aircraft by radio control. It would, however, be an advantage to afford the luxury of an occasional full-scale test in order to provide a complete model full-scale comparison, particularly from the structural damage viewpoint.

On the other hand, as much information as possible should be obtained from operational ditchings, by questionnaires (Appendix I) and collection of eye-witness reports, etc., as these provide valuable full-scale information and are a check on the model results.

2.5.2. **Structural behaviour.**—Consider the second question—' How do aircraft behave structurally in ditching ? '. What is required here is a knowledge of the loads that occur on the aircraft structure, and of the damage and leakage that result. The controlled launching tank technique as developed at the M.A.E.E. is suitable for the investigation of the impact pressures. The use of a large-scale partial model, that is always attached to the carriage, enables the pressures to be transmitted directly to recorders on the carriage, allows measurements to be made under controlled conditions that would be impossible on small-scale free-flight models. A controlled launching tank could be used for measuring the subsequent planing pressures too, but the existing tank at the M.A.E.E. is too short for making runs at steady speeds. Such tests could, however, be made on a towed model in a towing tank, although fairly large-scale models would be required. Full-scale ditching tests could be used to provide information on the pressures, but again such tests would have all the disadvantages mentioned above, section 2.5.1.

It would appear, however, that full-scale dropping tests from a crane could be employed to yield useful information on the impact pressures, and especially to correlate such pressures with the damage that results, and obtain some idea of the flotation qualities both damaged and undamaged. The method is economical compared with the full-scale ditching because only old ' hulks ' need be used.

Again very valuable information on the damage that occurs can be obtained from operational ditchings, together with a correlation between the damage and the hydrodynamic behaviour.

3. **Main Results.**—From the results of tests made on free launched models at the R.A.E., Farnborough, and from the experience of pilots who ditched successfully, it is possible to assess the qualitative effect of the various parameters that may be considered as primarily affecting ditching behaviour. These parameters are divided into (*a*) those defining the approach conditions and (*b*) those defining the effect of the water impact on the aircraft. The first are primarily those over which the pilot has control, *i.e.*,

(i) speed at touchdown
(ii) angle of descent at touchdown (rate of descent)
(iii) attitude to horizontal at touchdown
(iv) direction relative to wind, swell and waves
(v) bank and sideslip at touchdown
(vi) flap setting
(vii) engine power and propeller settings,

and of these the first four are the most important. Additionally the pilot can control the aircraft conditions, *i.e.*, position of the undercarriage, bomb doors, under-turret, etc. The second set of parameters are those over which the aircraft designer has control, *i.e.*, the shape and strength of the fuselage bottom, bomb doors, engine radiators, wing position, nacelle location, and so on.

The final ditching behaviour must depend on the integration of the hydrodynamic and structural characteristics of the aircraft, as influenced by these two sets of parameters. In model test work, it has been shown how the hydrodynamic and structural characteristics can be isolated from each other for analytical purposes and the full-scale combination of the two will obviously depend largely on the water impact forces and pressures experienced. Not very much is yet known of the quantitative nature of impact forces and pressures on fuselages, although a considerable research programme is in hand on the general problem of V-shaped surfaces both in Great Britain and U.S.A. and a limited one on rounded shapes in Great Britain. The pressure distribution is the least well investigated, the available information on V wedges being given in Refs. 74 and 75 and on a flat and rounded fuselage shape in Refs 57 and 58 (Fig. 21).

The forces and mean pressures on a wedge impinging on water are there shown to be roughly proportional to

$$V_{n0}^2 \cot \beta$$

where V_{n0} is the component relative velocity normal to the surface of the body at the first moment of impact

and β is the angle between the surface of the body and the surface of the water.

In the absence of waves this may be written as

$$V_0^2 \sin^2 (\tau + \gamma) \cot \beta$$

where V_0 is the total velocity at the first moment of impact,

τ is the angle of the surface of the body to the horizontal,

and γ is the angle of descent.

3.1. **Effect of Parameters Under the Pilot's Control.**—3.1.1. **Effect of flight speed.**—As might be expected, other parameters being equal, it is generally best to alight at as slow a speed as possible relative to the water. This is because the impact forces and pressures at touchdown are less at lower speeds and in addition longitudinal instability on the water can be dangerous if it develops at high speeds. The formula above shows that, for a given attitude and angle of descent, impact forces and pressures vary as the square of the speed, but a low speed must not be obtained at the expense of increasing the angle of descent or of unduly increasing the ditching attitude.

Speed can be reduced satisfactorily by use of flaps and engine power, but the effect of these parameters will be considered more fully in sections 3.1.6 and 3.1.7, as they otherwise effect ditching behaviour. Speed can be reduced also by jettisoning fuel, bombs and other equipment, but the advantage gained is small. The stalling speed varies as the square root of the weight, and a 10 per cent reduction in weight, although relatively large, only reduces forces by the same amount. In addition, the ditching may be made worse if it is not possible to close bomb doors or other openings before impact occurs.

3.1.2. **Effect of angle of descent.**—The angle of descent at touchdown is certainly the most important variable that the pilot has to control. At small values of the angle of descent, impact forces and pressures are proportional to the square of the angle of descent. Alightings at large angles of descent (5 deg and above) result in very high impact pressures[58] (*see* Figs. 21b, 21c and 21d) which, in turn, are liable to lead to diving or, at best, to serious structural failures and very small flotation time. With most aircraft the minimum gliding angle, engine off, is about 4 deg. To reduce the angle of descent at touchdown the pilot may either ' flatten out ', or use engine power to flatten the glide angle, or use a combination of both. Other aspects of this problem will be dealt with in section 3.1.3, but in so far as angle of descent is concerned, it does not matter how the angle is reduced, except that at night, or over a calm sea, pilots have found it most difficult, and sometimes impossible, to judge their height for flattening out. In such cases, where possible, a ' fly-on ' landing is recommended, *i.e.*, an alighting in which the aircraft is flown on from a slow shallow powered glide.

When available, ditching questionnaire returns showed that in these fly-on night landings, pilots found the use of the landing light very valuable for helping to judge height and rate of descent.

3.1.3. **Effect of attitude.**—The question of what is the best attitude for the aircraft to have at touchdown is by no means simple to answer. This is because there is no simple answer that applies to all aircraft. Clearly the attitude should be such that the alighting is as gentle as possible, both to keep the impact forces and pressures as small as possible and to keep their distribution such as will not cause changes of trim that might have serious consequences.

The rough formula that the forces are proportional to

$$V_0^2 \sin^2 (\tau + \gamma) \cot \beta$$

shows that the loads are reduced if the attitude of touchdown τ is reduced. However, the attitude cannot be reduced independently of the speed, the two being related by the relationship determining the lift. Using this relationship one can determine the theoretical optimum attitude for minimum impact loads and, in most cases, it appears that a tail-well-down attitude is best, although the indications are that, for landings on a smooth sea at a small angle of descent, an almost level attitude ($\tau \simeq 0$) may be better.

The first part of the fuselage to touch the water will be at zero attitude, but as the draft increases other parts of the fuselage will meet the water at increasing attitudes, the rate of increase depending on the longitudinal curvature. This effect is illustrated on the *Tudor* model results, a pressure wave developing that travels forward and aft, in most cases (Fig. 21c).

Of more importance than the initial impact loads is the subsequent behaviour of the aircraft. If conditions are unfavourable, the initial impact moments may cause sudden changes in trim which, in turn, may lead to heavier impact loads on other parts of the structure, or to porpoising. Clearly the moments will be greatest in tail-well-down alightings, and thus on some aircraft tail-well-down attitudes may lead to trouble (Fig. 11). Aircraft with very low tailplanes, and particularly those with wide rear fuselages necessary to accommodate a rear turret, such as the *Stirling*, are liable to have their tail thrown off on impact, especially when alighting in waves. This may lead to fuselage failure amidships, or to diving. On such aircraft a tail-partly-down attitude has usually been recommended.

Another sort of trouble is sometimes found on aircraft with curved upswept rear fuselages. Such shapes are subjected to high suctions over the rear fuselage after the initial impact. The rear fuselage is sucked down lifting the nose out of the water (Figs. 9, 11 and 16). Under these circumstances, the wing may stall and the fuselage may fail amidships in the subsequent impact. Eventually the aircraft will pitch forward on to its nose, which will probably collapse, and the aircraft will dive. On such aircraft (*Liberator*, *York*, *Ambassador*) a ' level ' attitude at touchdown has been found to be best.

To sum up, a tail-well-down attitude is usually best owing to the lower speed possible, but on aircraft which are liable to receive large impact pressures or suctions on the rear fuselage, an attitude between tail-well-down and level is best. If, however, engine power is available, an almost-level attitude can be obtained by the use of full flap and power.

3.1.4. **Effect of direction relative to wind, swell and waves.**—In a rough sea it is necessary to distinguish between ' waves ' and ' swell[77] '. Waves are undulations caused by the wind then blowing, and they travel in the same direction as the wind, and with approximately the same speed, except in the vicinity of land. Their size depends on wind strength, the length of water over which it is blowing, duration of wind and depth of the water. Swell is undulations that are not caused by the wind then blowing. It may be the undulations caused by a storm that has passed over that region, or which may have travelled to the region from a distant storm area. Clearly a swell may travel in any direction relative to the wind then blowing. Wind waves and swell commonly exist together and across each other, so that no clearly defined system is distinguishable, and one has what is called a ' confused sea '.

The best landing in waves will depend on whether it is best to reduce the ground speed as much as possible by landing into wind irrespective of the wave configuration, or to reduce the effect of the wave configuration to a minimum by landing parallel to the prevalent crests and troughs irrespective of the wind, when no impacts with waves will be incurred.

Alighting on a rising wave front affects the impact in two ways. Firstly the attitude of the aircraft relative to the local water surface is reduced, thereby moving the centre of impact forward and increasing the wetted area for a given draft. This increases the impact forces considerably, although it does not appreciably affect the impact pressures. Secondly the rate of descent of the aircraft relative to the water surface is increased. A rough indication of this increase is given by the formula

$$\sqrt{\left(\frac{\pi g}{2}\cdot\frac{H}{L}\cdot H\right)}\ \text{ft/sec},$$

where H, L are respectively the height and length of the wave in feet (crest to trough and crest to crest).

This formula gives 3 ft/sec for waves 6 ft high and 180 ft long, a fairly severe wave in coastal waters. In an alighting at an angle of descent of 1 deg the rate of descent is of the order of 3 ft/sec, so that impact on such a wave could quadruple the pressures in addition to the possible added effect of the greatly increased wetted area.

When there is a swell, it is best to alight along the crests, even though this may mean alighting across wind. The dangers of alighting with even considerable drift are much less than the risks of a head-on impact into the next crest of the swell, This conclusion is supported by some tests made on a seaplane (*Mariner*) in open-sea conditions by the U.S. Coastguards for Air-Sea-Rescue purposes. The tests showed conclusively that in swells it was by far the best to land parallel to the crests and troughs, provided that the cross-wind was not more than about 30 knots. This speed should obviously depend upon the size and design of the aircraft.

When there is no distinguishable swell or when there is a strong wind which would make a cross-wind landing dangerous, it is best to alight into wind, because the advantage to be gained from the slower ground speed usually offsets the disadvantage of a possible head-on impact with a wave crest. When landing across waves it is best to alight on the falling side or trough, if possible. Alighting on a crest is liable to trip the aircraft into the next oncoming wave crest, and alighting on an upslope will subject the aircraft to heavy impact loads.

In practice the difficulty is usually to distinguish and to judge the prevailing wind and wave systems, especially if there is a confused sea. In such cases the wind waves generally form a ' chop ' or short steep sea breaking forwards when the wind speed is above the order of 15 knots. In such seas it is usually best to alight, fully stalled, into wind.

3.1.5. **Effect of bank and sideslip.**—Normally an aircraft should be put down with the wings level and without sideslip. In a swell, when alighting with a crosswind along the crests of the swell, sufficient sideslip should be applied so that the aircraft does not sideslip relative to the water.

In a rough sea, too, when alighting with a certain amount of drift it is sometimes advantageous to dip the wing on the side away from which the aircraft is drifting. Dropping the other wing is extremely dangerous. In fact, on some small aircraft which ditch badly (*Mustang*, *Hurricane*) the only possible satisfactory method of ditching them that has been found from free launched model tests is to alight with a skid in a direction away from the dipped wing. The pilot must be prepared for the violent yaw as the wing tip strikes the sea, but the aircraft should not dive. It is believed to have been executed unintentionally, but successfully, by a full-scale aircraft.

Model tests in calm water show, rather surprisingly, that landplanes do not yaw and dip a wing when ditching, even with a low wing. This is confirmed by full-scale evidence. Model tests show that tailless layouts, however, are directionally unstable. Model behaviour in waves has still to be tested, but since the reason is undoubtedly the very high drag of the aft end of the fuselage, little deviation from the rule is expected.

3.1.6. **Effect of flap setting.**—There is considerable evidence to show that use of flap can have important advantages. On some aircraft the risk of diving is reduced by alighting as slowly as possible, and in almost all cases the structural failures caused by the impact loads on the fuselage can be reduced by reducing the speed. Although one might expect that flaps would pitch the aircraft on to its nose, this pitching tendency is limited by the strength of the flaps and the length of time that they remain intact before being carried away. In most cases, where the maximum permissible flying speed with flaps down is less than 150 knots E.A.S., the flap strength is such that failure occurs almost as soon as the flaps strike the sea, and the transient nose-down pitching moment has no adverse effect. The force required to tear off large-chord flaps running on tracks, such as the Gouge or Fowler types, however, is sometimes high, and may persist for some short, but sufficiently long time. Split and slotted flaps are usually much weaker by comparison. They are either shut or are torn away when they strike the sea, and do not cause any nose-down pitching moment.

On high-wing aircraft as much flap as desired may be used to reduce the speed, consistent with not increasing the angle of descent at touchdown. On mid- and low-wing aircraft split and slotted flaps may usually be lowered as much as desired, but flaps of the Gouge or Fowler type should not be lowered[1]. Consistent with these directions a pilot should choose that flap setting which will make his gliding angle a minimum, unless, of course, he has engine power available to flatten his glide path, or if he considered that he should be able to make a good flatten out before touchdown. This is more difficult over sea than over land, but pilots of naval aircraft can usually judge their flatten out over the sea fairly successfully.

3.1.7. **Effect of engine power and propeller settings.**—If available, engines should be used to reduce the speed and angle of descent, but asymmetric power should not be used to the extent that the aircraft cannot be turned against it right down to the stall.

The effects of the propeller setting on ditching behaviour is negligible. Models of single-, two- and four-engined aircraft have been ditched with the propellers locked in fine pitch to represent alightings with seized engines. In all cases, the behaviour was as nearly as could be observed the same as with the propellers removed. This conclusion had been reached before the war on towed models in the R.A.E. Seaplane Towing Tank. There is no operational evidence in conflict with it.

3.2. **Effect of Parameters Under the Designer's Control.**—The evidence that has been obtained from various sources during the war enables the effect on the ditching characteristics of various design features to be assessed. First, however, it is necessary to consider what are desirable characteristics. The alighting on water of a landplane differs from that of a seaplane in that it is an emergency measure, and has only to be made once. The loss of the aircraft is accepted as inevitable, but it is essential that the following requirements are met in order to ensure the escape, and eventual rescue, of the crew and passengers in the dinghies:

(*a*) no tendency to dive

(*b*) no major structural failure which will endanger life either in itself or by the resulting inrush of water

(*c*) no excessive deceleration (*i.e.*, the deceleration must be within the limits set by safety harness, etc.)

(*d*) sufficient time of flotation to enable the crew and passengers to escape

(*e*) properly placed ditching exits and provision for dinghy stowage.

The ability of the aircraft to satisfy these requirements depends upon the shape and layout of the fuselage and other relevant parts of the structure, and upon their structural strength. Provided that these requirements are met, a fair amount of minor damage, particularly of a local nature, can be tolerated and may, in fact, be desirable (*see* section 3.2.9).

The effects of the various design parameters are considered separately in this paragraph. Possible design cases for ditching are discussed in section 4.

3.2.1. **Effect of size and wing loading.**—There is no outstanding advantage attributable to size. Sufficiently strong large aircraft can negotiate waves of a given size more easily than small aircraft, as would be expected on grounds of dynamic similarity, but against this must be debited the fact that large aircraft are usually relatively weaker than small aircraft, both in local and main structure.

Of much more importance than the size is the wing loading. A high wing loading is a disadvantage from two points of view. In the first place it increases the alighting speed and this, in turn, increases the impact loads at touchdown. Unless a very good alighting is made, considerable structural damage may be expected, and in a bad alighting, the aircraft may disintegrate on impact (Fig. 19). Even should a good alighting be made, dangerous porpoising, which may lead to structural failures, or diving, or both, is more likely to develop at high alighting speeds, especially in a rough sea. The bad ditching behaviour of the *Mosquito* is attributed mainly to its high alighting speed and the reasonable safe ditching that can be made with a *Horsa* with the wheels jettisoned, is due mostly to the low alighting speed.

Secondly, a high wing loading means a small wing of small buoyancy. After an aircraft has come to rest on the water the wings and empty fuel tanks provide the main source of buoyancy so that the time of flotation is likely to be reduced.

3.2.2. **Effect of fuselage shape.**—(*a*) **Cross-sectional shape.**—Most fuselage cross-sectional shapes may be classed as either ' round bottomed ' or ' flat bottomed '.

From seaplane experience it has been shown that the impact loads at touchdown can be very much reduced by means of a vee or rounded bottom, and that the greater the angle of deadrise the less the impact pressure, the mean pressure and forces varying roughly as the cotangent of the angle. Where the fuselage bottom is flat, therefore, very high impact pressures with extensive local failures will occur. On round-bottom fuselages these high impact pressures will be localised on the centre-line and the load will decrease towards the sides. Tests made in the controlled launching tank at the M.A.E.E. in severe impact conditions on a model *York*[57] have shown that local impact pressures as high as 200 lb sq in. can be attained over a large area on flat-bottomed aircraft, although these pressures only last for about 0·02 second. The mean impact pressures of 50 lb/sq in. over periods of 0·2 second are sufficient to completely collapse all skin structure and some frames. On a model *Tudor*[58] which has a round-bottomed fuselage, the peak transient pressures in a similarly severe ditching were of the order of 120 lb/sq in. and were concentrated on the centre line (Fig. 21) and over a time interval of about 0·2 second the mean impact pressures were of the order of 30 lb/sq in.

Rounded sections have an obvious advantage but even with such sections rates of descent must be kept very small to avoid severe damage, *e.g.*, of the order of 3 ft/sec at a water incidence of 6 deg.

(*b*) **Side-view shape.**—Fuselages which are long and only moderately curved, such as those of the *Halifax*, *Viking* and *Brabazon* (Fig. 15) have good ditching characteristics provided that other features are not unfavourable. Fuselages with under-surfaces which are sharply curved forward and aft in side-view, like those of the *Hudson* and *Ambassador*, suffer from two disadvantages, (i) forward they do not provide as much resistance to the downward pitching moment caused by damage, etc., at impact as straight fuselages do, (ii) the aft fuselage in such cases is subject to considerable suction forces, especially in fast alightings. The latter case causes the tail to be sucked down, and the sudden nose-up change of trim may cause the aircraft to fly off the water. The subsequent impact is usually disastrous.

Fuselages with noses which are long compared with the height of the centre of gravity above the bottom of the aircraft; either straight like those of the *Lancaster* or *Stirling* (Fig. 13) or streamlined like that of the *Fortress*, are extremely resistant to diving, even with extensive local damage.

The streamlined noses of fighter types, such as are associated with liquid-cooled in-line engines, offer no resistance to diving once it has been caused by other means, but bluff noses, such as are found with radial air-cooled engines do offer considerable resistance. Even if the aircraft is pitched nose-down for some reason, the worst that can occur is that the nose digs in and the aircraft pulls up abruptly with a moderately high deceleration. Operational experience on the *Wildcat*, *Corsair* and other naval aircraft having air-cooled engines, has shown that this behaviour is not serious as long as the pilot is securely strapped in.

(*c*) **Plan-view shape.**—Indications are that deep, narrow sterns run through the water quite smoothly without tending to bury the nose. A pointed tail of nearly circular section, as on the *Mosquito*, is also fairly satisfactory, although the low tailplane which is usually associated with such a design is generally a disadvantage. Sterns which are wide in plan-view, such as those shaped to accommodate the rear turret of bombers, may be a disadvantage because even in small waves they are likely to be thrown off the water sufficiently viciously to cause the aircraft to dive. In addition, the impact pressures may be sufficiently great to break off the rear fuselage. There have been many cases of *Lancasters*, *Stirlings* and *Liberators* ' breaking their backs ' in operational ditchings, and these failures may be due in part to high impact pressures over the rear fuselage at touchdown, in addition to the ' scoop ' effect of the rear fuselage when the bomb doors fail.

3.2.3. **Effect of wing position.**—(*a*) **Wing height.**—A high wing does not touch the water until the aircraft is almost at rest and the fuselage full of water, and therefore only affects the ditching from the static buoyancy standpoint. The crew and passengers are in serious risk of being trapped under water. In addition, a high wing bears none of the impact pressures, and the fuselage of a high-wing aircraft is likely to be more extensively damaged.

A low wing helps in bearing the impact pressures and, in addition, owing to its buoyancy, it enables the aircraft to float, if only for a short time, with the main part of the fuselage above water, usually in a nose-down attitude of 20 or 30 deg. This is ideal from the flotation aspect because in reasonable conditions the crew can walk along the wing and into the dinghies without getting wet. This is very important because the chances of survival are much greater if survivors can be got into the dinghy dry. The *Anson* and *Fortress* are particularly good in this respect.

On the other hand a low wing may be a disadvantage until the aircraft has come to rest. If the wing is thick, it may produce a violent deceleration, particularly if there is little dihedral over the centre portion. A thin wing, at a low setting, is likely to cut through waves and cause the aircraft to dive. A low wing is therefore liable to be dangerous, especially if the aircraft starts to porpoise, or if an alighting is made in a rough sea.

In many respects a mid-wing, especially a low mid-wing, is the best arrangement for ditching. In this position the wing is high enough to escape the worst of the impact, so that its buoyancy is probably more reliable than that of a low wing. In addition, ditching stations and exits can still be located above wing level, so that escape from the aircraft can be as straightforward as from a low-wing aircraft.

(*b*) **Wing setting.**—A large setting is an advantage. It has been shown that the smaller the fuselage attitude at touchdown the smaller the impact pressures, other parameters being the same. Clearly a large wing setting enables low-attitude alightings to be made at low speeds. The outstanding ditching qualities of the *Whitley* are probably partly due to the unusually large wing setting of 8 deg to the fuselage datum, which makes it possible to ditch that aircraft with the tail only slightly down at a speed just above the stall.

After impact an aircraft tends to plane, and on low- and mid-wing aircraft the wing trailing edge acts in a similar manner to the step of a seaplane. In order to plane at a reasonable attitude a seaplane has to have its step situated a short distance only behind its centre of gravity. Clearly on a landplane the equivalent step is usually an appreciable distance aft of the centre of gravity, and the attainment of a reasonable planing attitude depends upon the suction forces over the rear fuselage tending to keep the nose up. Most aircraft, particularly low-wing fighters, adopt a reasonable planing attitude, but free launched model tests on the *Spitfire* have shown that diving can occur even when the radiators are removed and no damage represented.

3.2.4. **Effect of tailplane position.**—Free launched model tests have indicated that, after impact, most low- and mid-wing aircraft tend to adopt a ' two-step ' planing attitude with the trailing edge of the wing and tail as the effective steps. If, however, the suction forces on the rear fuselage are high, then the tailplane may be broken off, if it has not already failed at impact (Fig. 10).

Until they were extensively strengthened, the elevators were regularly torn off a model *Stirling*, and on a model of a *Viking* the whole tailplane was broken off. On the *York* and the *Vampire* it was shown that in some ditchings the loads would be sufficiently great to break off the tailplane of the full-scale aircraft (Figs. 10 and 11).

The load on the tail may be sufficient to break off the whole rear fuselage, as has been reported in many operational ditchings. Such a failure would cause a very nose-down flotation attitude. To avoid this, therefore, the tailplane should be sufficiently high to escape high impact and planing pressures, especially on aircraft with upswept rear fuselages.

3.2.5. **Effect of nacelles.**—The effect of nacelles on ditching behaviour has not been considered to be very important except to passenger safety on transport aircraft. Free launching tests on models having nacelles extending down to or below the bottom of the fuselage have shown that the nacelles increase the deceleration and cause the nose to plough heavily through the water (Fig. 14a and 14b). It is possible that low nacelles may relieve the fuselage of some of the impact pressures, but there is no conclusive evidence on this point.

A comparison of the effects of air-cooled radial and liquid-cooled in-line engines was made on a model of the *Beaufighter*. It was found that the radial nacelles were better in holding up the nose of the aircraft. This advantage is expected to appear full-scale because the cylinders of a radial engine support the cowl against complete collapse.

Free launched model tests on the *Meteor* show that jet engine nacelles tend to make the aircraft trim nose-up, especially if the nacelles extend for some distance behind the trailing edge. This is confirmed by full-scale evidence. The fuselage of the *Vampire* may be considered as a nacelle for the present purpose, and on a model of this aircraft, too, there was a very large nose-up change of trim after touchdown (Fig. 10).

3.2.6. **Effect of air intakes.**—Free launched model tests have been made on *Firebrand*[12], *Mosquito*,[10] *Welkin*[16], *Tempest I*[21] and *Vampire*[27], all of which have wing leading-edge entries, on the *Gloster* E1/44[29], which has wing-root entries, and on the *Meteor*[23, 24], with nacelle entries. It was found that the aircraft trimmed so that the entries were kept clear of the water until a very low speed had been reached, and thus the entries had no direct effect on the ditching behaviour. They may, however, hasten the flooding of the aircraft, and reduce the flotation time. It is considered that, provided a design has good ditching qualities in other respects, entries should not be a disadvantage.

3.2.7. **Effect of underslung radiators.**—In the case of small single-engine aircraft, the ditching characteristics can be profoundly affected by the size and position of underslung radiators. Clearly the drag forces on such a radiator when it enters the water will tend to nose the aircraft in. The diving characteristics of the *Hurricane*[1] and *Mustang*[18] (Fig. 12) are due mainly to the nosing-in moment produced when the amidships under-fuselage radiator strikes the sea. The *Defiant*, a slightly larger aeroplane with the same kind of radiator, seems to fare slightly better. This is possibly due to the greater resistance to diving afforded by its longer nose.

On the other hand, the *Fulmar*[1] and *Firefly*[8], which have nose radiators, ditch remarkably well. Tests on a *Hurricane*[1] model have shown that moving the normal under-fuselage radiator forward and changing it to a *Henley* nose radiator, which is of the same type as that on the *Fulmar* and *Firefly*, eliminated the diving entirely. In fact, a radiator of this kind can make the ditching behaviour even better than a similar aircraft with no radiator.

The *Tempest*[21] model was tested with a nose radiator in two fore-and-aft positions (*i.e.*, the normal position, and a shortened nose version), and also without a radiator. It was found that without the nose radiator the model behaved remarkably well, but that with the nose radiators the behaviour was critical. In certain types of alighting the model planed with the radiator clear of the water, but on occasions it dug in and caused the model to pull up abruptly in much the same manner as a fourth version of the *Tempest* that was tested having an air-cooled radial engine. This abrupt pull-up behaviour found in the model tests agrees with the full-scale behaviour reported on such types of aircraft. Operational ditchings on the *Tomahawk* and *Typhoon* suggest that they behave in a similar manner to the *Tempest.*

The difference in behaviour between the *Fulmar* and *Firefly*, on the one hand, and the *Tempest, Tomahawk* and *Typhoon* on the other, suggests that not only the position of the underslung radiator is important, but also its size. The *Tempest* radiator is much larger than that of the *Fulmar*, which is shallower and flat-bottomed. Model tests on the *Wyvern*[35], which has two radiators similarly placed to those of the *Spitfire,* but much shallower, have shown that the model does not always dive. The long nose of this aircraft is possibly sufficient to offset the diving moment due to the radiator in certain cases.

To sum up, underslung radiators can produce bad ditching behaviour. To be least dangerous, they should be small and situated well forward under the nose, and it is advisable that the aircraft with such radiators should have some features to offset the diving moment.

The underslung radiators on liquid-cooled in-line engine nacelles of multi-engined aircraft do not have much effect, apart from causing the aircraft to decelerate more abruptly. They are usually torn off.

3.2.8. **Effect of undercarriages.**—All available evidence shows that undercarriages are a serious disadvantage, and that retractable undercarriages should never be lowered when ditching.

The *Swordfish* regularly pitches when ditched, the tail rising to about 70 deg, and the occupants often being thrown straight out over the nose. Models of the *Hurricane*[1] and *Beaufighter*[7] somersaulted when tested with the wheels down, and the *Horsa*[19] model nosed in heavily when the undercarriage was not jettisoned. Operational experience on this glider confirmed this.

The *Liberator*[1] with its undercarriage down, on the other hand, has been ditched successfully both operationally and in the model free launching tank. This result is attributed to the fact that the *Liberator* undercarriage projects only a short distance below the bottom of the fuselage. The *Liberator* usually ditches badly unless alighted very slowly, and a slow alighting speed is essential for aircraft with fixed undercarriages.

Tests on a number of models with and without tail wheels show that it does not matter whether or not the tail wheel is retracted.

3.2.9. **Effect of bomb doors and other weaknesses of the under-fuselage structure.**—The largest and most vulnerable portions of military aircraft are the bomb doors of bombers. When they strike the sea they usually fail because they are very weak and let large quantities of water into the aircraft. If the aircraft has other good ditching features, such as the *Whitley* or the *Fortress*[9], a good alighting can still be made, and escape from the aircraft need not be too difficult. With the *Lancaster*[5] and *Halifax*[3] the deceleration is increased slightly, but the general behaviour remains the same. On the *Liberator*[4], however, the extra resistance of the collapsed bomb doors is sufficient to cause the aircraft to dive.

Following the collapse of the bomb doors, the bulkhead at the aft end of the bomb compartment can have an important effect on the ditching behaviour. If this bulkhead is strong its resistance will cause the aircraft to nose in and, on some aircraft, dive. This was found in free launched model tests on the *Windsor*[28], and also in N.A.C.A. model tests on the *Liberator*. If, however, this bulkhead collapses, there will be a considerable inrush of water into the rear fuselage, which may do considerable damage, although the diving tendency will be much reduced.

Various remedies have been tried to offset the effect of the collapse of the bomb doors. Strengthening the doors to a sufficient extent would usually be too expensive in weight. To avoid the worst effects of failure, it has been suggested that the doors be mounted on some sort of resilient support so that they recovered their shape after the initial impact. The flotation bag installation on the *Wellington* performed this function besides providing buoyancy when the aircraft had come to rest. Model tests on the *Liberator*, however, showed that the violence of diving could not be reduced unless the doors were so stiff that they did not deflect until the load reached about 7 lb/sq in., *i.e.*, the strength that rigid doors would need to resist failure.

A further idea was tried on a *Windsor*[28] model. An inverted ramp was fitted, which extended from the junction of the deck over the bomb compartment with the aft bulkhead, downwards at an angle of about 20 deg to the horizontal. It was intended to deflect the water that poured through the collapsed aft bulkhead out through the bottom of the fuselage further aft. The scheme was a failure because the loads on the ramp created a large nose-down pitching moment which caused the aircraft to dive violently.

The most satisfactory scheme that has so far been devised to offset the bad effects likely to be caused by the bomb door failures, is to continue the deck over the bomb compartment straight aft to meet the fuselage skin, the skin below this level being merely a fairing to the bomb compartment. This arrangement has been tried on the *Windsor* model and tests showed it to be satisfactory. It has also been found successful on later jet bomber designs.

It is not quite certain how much the ditching behaviour of an aircraft is affected by other local failures in the bottom—parachute escape hatches, camera hatches, nose windows, etc. It appears, however, that as regards the actual alighting behaviour, local failures in the rear part of an aircraft are not very serious, and that local failures in the forward parts are not important unless the safety margin of the aircraft is small owing to other factors. Local failures do, however, seriously affect the flotation qualities after the aircraft has come to rest, unless there is a fairly watertight compartment above the failures. On the other hand, the local failures form an effective shock-absorbing mechanism to protect the main structure and are desirable so long as excessive flooding of passenger compartments is avoided.

3.3. **Devices for Improving Ditching Behaviour.**—Free launched model tests have shown that a great many aircraft would ditch reasonably well if the structure could stand up to the impact loads without failing. This is particularly true of large aircraft, where under-fuselage failures, such as bomb door collapse, may lead eventually to diving, or to a complete fuselage or wing break-up. It is clearly best to put right the cause leading to the bad behaviour before considering the numerous secondary troubles which are caused by, for instance, the high deceleration experienced during nosing-in, such as failures of safety harness, seat mountings, and equipment fastenings. Such a policy was followed on the *Hudson*[1], which dived violently before the bomb doors and nose window were strengthened. This section will therefore be devoted to various devices that have been considered for improving ditching behaviour.

3.3.1. **Fitting of steps and chines.**—It was thought that the nose-up change of trim that occurs at touchdown when a *York*[22] ditches (Fig. 11), which is caused by the suctions over the rear fuselage, might be avoided by fitting either a ' step ', as on a seaplane, or ' chines ' to spoil the flow and so destroy the suctions. Free launched model tests were made to investigate these points.

The idea of a step was found to be impracticable. A flap was fitted flush with the bottom of fuselage, and it was arranged so that it could be deflected about the front hinge-line to form a step just behind the centre of gravity. Not only was the flap subjected to severe impact pressures, owing to the lack of deadrise, but in addition difficulty was found in designing a stable form, because all settings of the flap tested led to porpoising instability, and eventually to diving. This failure of stability is undoubtedly because the flap as used forms a ' hook ', or suddenly deflects downwards the water flow which is already following the fuselage lines. This instability has been found on seaplane designs with similarly ' hooked ' steps. A properly designed step could be effective.

The N.A.C.A. tested a similar flap on a *Liberator*[41] model, but in a more forward position. They found that such a flap prevented the Liberator from diving, but that it led to porpoising. It would in addition be subject to very severe loads.

No success was obtained in experiments on the *York* with chines, or spoilers, designed to spoil the flow over the rear fuselage. N.A.C.A. tests on the *Liberator* model, however, have shown that chines on the forward fuselage can reduce the diving tendency by destroying the suctions near the nose of a streamlined body.

3.3.2. **Radiator palliatives.**—It has been already stated that the risk of diving can be avoided in the design stage by having an underslung radiator as far forward as possible. In some cases where this was not possible various corrective means have been tried.

Towed-model tests at steady speeds had suggested that the fitting of a retractable flap in front of a radiator would prevent diving, but this was not confirmed in free launched model tests. Free launched model tests on a *Mustang*, in particular, showed that such a flap would be subject to severe impact pressure. In addition, on the *Mustang* the flap caused porpoising instability which led to diving.

Free launched model tests showed that by jettisoning the radiator before touchdown it would be possible to ditch the *Hurricane* without diving. Further experiments were made to find to what extent the attachments would have to be weakened to allow the radiator to be torn off when it struck the sea without causing diving. It was found that the strength of the attachments would need to be reduced to about a tenth of their normal value, a value less than the strength required to prevent failure in the air in a dive.

3.3.3. **Towing a water drogue or kite.**—A few attempts were made to hold down the tail of the *Hurricane* model by towing a water drogue or kite. Neither scheme was a success. The drogues towed well, but the drogue lines streamed so nearly horizontal that they produced little nose-up pitching moment if attached near the tail wheel. Extensive structural modifications would have been required to allow them to be trailed from the top of the fin. A kite, on the other hand, could be towed deeply enough to produce a good nose-up pitching moment, but it could not be made to work consistently. Also, the loads on the cable would be very severe.

The N.A.C.A. tried the idea of fitting a scoop under the rear fuselage of a *Liberator* model in order to hold down the tail. It did not prevent the *Liberator* from diving, and such a scheme in any case would put severe loads on the scoop and on the whole rear fuselage, which would probably be broken off.

3.3.4. **Use of hydrofoils and planing surfaces.**—Free launched model tests have been made on both a *Hurricane* and a *Seafire* with a hydrofoil fitted to the deck landing arrester hook. The idea was that such a hydrofoil, set at a negative incidence, would pull down the tail and prevent diving. By being on the arrester hook the hydrofoil was about four feet below the fuselage, and thus it was well into the water before the radiator struck the sea.

The hydrofoil fitted to the *Hurricane* model corresponded to a full-scale measurement of 7-in. chord and 20-in. span. The results were very encouraging. During the course of many alightings in smooth water and in waves corresponding to a height of $3\frac{1}{2}$ ft, there was only one case of diving, and that was due to stalling the model on to the water in a nose-down attitude.

The tests on the *Seafire* were disappointing, mainly because the hydrofoil was too small—the measurements corresponding to a full-scale chord of 3-in. and 20-in. span—and did not prevent the diving entirely. The hydrofoil had been designed to be completely retractable, and a larger foil would not have been a practicable proposition.

Alternatively, instead of using a downward-lifting tail hydrofoil, a nose-up pitching moment to prevent diving can be provided by an upward-lifting nose hydrofoil. Such a hydrofoil was tested on a *Liberator*[4] model to counteract the diving moment caused by the inrush of water into the collapsed bomb doors. A hydrofoil corresponding to full-scale measurements of 17½-in. chord and 70-in. span was fitted about 18 in. below the nose wheel hatch, at a fairly large angle of incidence (10 deg). The hydrofoil prevented diving of the model in smooth water, but sometimes failed to hold up the nose in alightings across large waves which threw the tail into the air. Alightings made with up to 30 deg of sideslip were as reliable as alightings without sideslip.

Of the various ditching aids tried on models, the hydrofoil schemes were by far the most satisfactory. Of the two positions, the nose hydrofoil scheme appeared the better because, whereas the diving moment tends to bring a tail hydrofoil out of the water, a nose hydrofoil can be designed to plane on the surface. Then if the diving moment becomes excessive, the hydrofoil is forced under the water, and the extra foiling lift then counteracts the extra diving moment.

The reliability of model tests on hydrofoils is suspect, however, owing to cavitation. Cavitation occurs when the pressure at any point in a liquid is reduced to the vapour pressure. Owing to the relations of dynamical similarity the suctions on a $1/n$ scale model will be $1/n$ of the corresponding full-scale suctions. The atmospheric pressure, however, is the same model- and full-scale, and therefore cavitation will be reached at a lower corresponding speed full-scale than model-scale. Most hydrofoil sections cavitate at about 30 to 40 knots, which is between model- and full-scale speeds. It is likely therefore that the model tests have given an unduly optimistic picture of the lifting possibilities of hydrofoils. On a *Seafire* a section was used which was known to cavitate at model speeds, and it was unsuccessful. This was attributed to the small size of hydrofoil tried, but a non-cavitating foil would, no doubt, have stood a better chance of preventing the diving. It would seem, therefore, that a nose hydrofoil designed for planing would be the best ditching aid, because in such a condition it would not be subject to cavitation difficulties, and would give greatly increased lift at lower speeds.

The use of planing surfaces serves the same basic purpose as hydrofoils. In practice a hydrofoil behaves like a planing surface once the top-surface flow has separated because of either cavitation or aeration, or when it has surfaced. There is a large reduction of lift but the planing forces are steady. Such surfaces could be used as primary lifting surfaces, as already put forward for seaplanes[69, 70], or as auxiliary forward or aft lifting devices as tested on the *Liberator*[4]. The instability which is often present with a hinged flap can be avoided by using a flap lowered below the fuselage. Considerably more work is being done on such devices since they can make it possible to avoid more intensive structural and shape modifications to the fuselage.

The main drawback to any lifting device is the load to which is will be subjected in a ditching. Providing the device and its supporting struts are strong enough to withstand the loads, the choice of location on an aircraft fuselage is limited to strong members and even then must not interfere with normal aircraft ancillaries such as undercarriage legs.

4. **Design Requirements for Ditching.**—Design requirements for ditching must depend on the conditions in which a landplane may be expected to make a satisfactory forced landing on water and the loads to be expected. Such requirements must clearly not be so great as to make the necessary structure weight excessive, yet they must suffice to ensure the final escape of the crew and passengers. Clearly military personnel can be expected to contend with much severer conditions than civilians, in that they can better withstand shocks, exposure to water and weather and can move quickly and in a disciplined manner out of sinking and damaged aircraft. In particular, the final requirement for civil and military transports is a flotation time of the minimum order of fifteen minutes, as against only a few minutes for small military fighter and bomber type aircraft.

Few quantitative requirements for aircraft are as yet laid down by Airworthiness authorities but the broad requirement of International Civil Aviation Organisations is that civil landplanes which are liable to be more than 90 minutes from land must be able to ditch in safety without causing undue injury to the passengers and crew, and should remain afloat long enough for them to escape from the aircraft. The present British Air Registration Board requirement, 1950, is that 'the design of the aeroplane is such that, as far as is practicable, its behaviour in a premeditated ditching will be unlikely to cause immediate injury to the passengers, or to make their escape impossible and the aeroplane would, after ditching, remain afloat for a period long enough to permit all the occupants to leave their normal stations and escape from the aeroplane'—British Civil Design Requirements: Ditching (Section D, Chapter 4.2).

The present military requirement, 1950, is that 'Landplanes should be so designed that, in the event of an emergency alighting on water, they will float for sufficient time to enable the dinghy to be launched and the occupants to embark in it'.

To achieve these requirements it follows that the aircraft should, in general,

(*a*) possess good hydrodynamic qualities, *i.e.*, it should be possible to alight on water without danger of diving-in or bouncing-off, and that decelerations should be small both normally and fore-and-aft

(*b*) be structurally strong enough to withstand both the impact pressure at touchdown and the subsequent planing pressures (*c*) float long enough and in such a position that crew and passengers can get into their dinghies dry. This requires also the provision of suitably placed escape hatches and air-sea rescue dinghies and equipment.

Finally, the passengers and crew should be positioned and secured so that they can withstand the impact decelerations.

A preliminary investigation made in Ref. 68 showed that it was only possible to consider the most favourable impact conditions and hydrodynamic behaviour without incurring an excessive penalty in extra structure weight. The design assumptions outlined below were estimated to cost the order of $\frac{1}{2}$ per cent of the all-up weight on a transport aircraft.

(i) The touchdown should be made on the equivalent of calm water (*e.g.*, along wave crests in long swells and neglecting the effect of choppy water and short seas) such that the rate of descent does not exceed about 3 feet per second and the fuselage datum attitude about 6 deg to the water surface

(ii) The aircraft should stick on the water and plane tail-down at about 6 deg attitude until the nose sinks in at about half touch-down speed.

(iii) The fuselage-bottom cross-section should be rounded or Vee-shaped so that the maximum deceleration at impact does not exceed 1*g* downwards or 2*g* forwards, and the maximum distributed pressures on the centre and aft fuselage do not exceed 20 lb/sq in. and on the forward fuselage 12 lb/sq in.

(iv) The fuselage bottom should suffer no more damage than dishing of the plating or slight bending of the frames. It is hoped that the same structure will be sufficiently elastic to absorb without failure the energy in the initial peak pressure due to water of the order of 100 lb/sq in.

(v) The wing is of a low to mid position relative to the fuselage so that the crew and passenger compartments are above the waterline at the end of the landing run

(vi) As far as possible, all passengers should be fully supported in aft-facing seats and all other personnel supported with full body and head harness, all seating to be capable of 20*g* acceleration on military and 6*g* on civil aircraft.

These may be considered as defining provisional design ditching cases and the separate factors determining these conditions are discussed in more detail below, together with suggestions for research to make available the necessary evidence to lay down more quantitative and rational cases.

4.1. **Approach and Landing.**—The provisional design requirement of 1-deg angle of descent, with not greater than 6-deg fuselage attitude, corresponds to a comparatively good landing for emergency conditions. It is, however, difficult to consider a much worse case, because of the limitations of landplane structural strength, without paying excessively in structure weight. Clearly a requirement for a stalled-on landing into waves would require a fully developed seaplane bottom—possibly adding the order of 3 per cent to the all-up weight. The optimum design of fuselage section and use of wing position will possibly make more severe cases admissible but more quantitative assessment requires more data on the order of impact forces and pressures to be expected. Some have been obtained on a representative body in the Hull Launching Tank at the M.A.E.E. There are, however, large-scale effects due to surface tension and cavitation, which lead to much more extensive water adhesion and higher suctions model-scale and which are very sensitive to curvature in the directions of fluid flow. These double curvature effects could be eliminated in the first instance by testing simple cylinders.

In practice it should be possible to land along long swells cross-wind, if the aerodynamic handling is up to required standards, but the effective reduction of severity, due to landing this way instead of into wind across waves, has yet to be established by model tests. In short seas, it will normally be best to land into wind—as shown in section 3.1.4. Landing along waves is probably only necessary when the wind speed is low.

4.2. **Hydrodynamic Shape.**—The severity of damage and its importance will also depend on the hydrodynamic behaviour and the structural design. There is no hope of a satisfactory ditching if the aircraft dives or porpoises badly. Even in the stable case there is a design condition for planing forces at about half the touchdown speed when the fuselage can attain an attitude of up to 20 deg nose-up. Ideally, aft fuselage lines should be such as to cause the landplane to stick to the water in a slightly tail-down attitude after touchdown (*see* Fig. 15a).

4.3. **Strength and Leakage.**—It is not required that the landplane shall not be damaged in ditching, but only that it leaks slowly enough for all personnel to escape. Even after a good landing an aircraft may sink too rapidly because of extensive leakages, lack of wing support, etc. Although there may be widespread damage to the local skin, hinges, frames, etc., this may contribute little to the rate of leakage. Let us first, however, review the data that exist on the loads to be expected.

4.3.1. **Impact forces and pressures.**—In the simple case of no rotation, no chine immersion, and wing lift equal to aircraft weight, the maximum acceleration for the impact on water of a seaplane hull shaped like a uniform wedge can be expressed very closely in the form[71, 72]

$$-A\left(\frac{K\varrho}{M}\right)^{1/3} V_{n\,0}^{2}$$

where $V_{n\,0}$ is the component of velocity normal to the keel at the first moment of impact

A is a factor uniquely determined by the ratio of the flight path angle to the keel attitude to the horizontal at the first moment of impact and is given approximately in Fig. 24, more accurately in Ref. 72

K is a function of the geometry of the hull and of the impact conditions, *i.e.*, hull deadrise angle, step shape and wave shape, etc., and is given approximately in Fig. 25, more accurately in Ref. 72

ϱ is the density of the fluid

and M is the mass of the seaplane.

The above form for the maximum acceleration at impact is considered the most rational yet produced, and the corresponding maximum impact force agrees well with controlled launching tank and full-scale seaplane results[72]. A corresponding expression for time of build-up is also in good agreement with controlled model launching tests on seaplane fore-bodies, but indicates a much faster time of build-up than is found in full-scale. From the ditching standpoint, however, the total impact force is not so important except in so far as it gives some indication of the likelihood of major failure of the nose or tail portion, for nose or tail impacts respectively. The more important stresses are those causing local failure and leading to severe flooding and rapid sinking.

Work in the M.A.E.E. controlled launching tank[75] and full-scale has shown that the peak pressure measurements can be expressed as

$$p_{\max} = 1 \cdot 3\ \tfrac{1}{2}\varrho V_{n\ 0}{}^2 \cot^2 \beta$$

for simple impact conditions where β is the angle between the surface of the body and the surface of the water. The measurements of these peaks is important because it has been found that only be starting from the peak as a datum can, for example, local plating and stringer cases be considered (Figs. 22 and 23). However, the mean pressure over the whole wetted area is probably of more interest to designers and is simply obtained from the total impact force divided by the total wetted surface. For a wedge this can be shown to be of the order of

$$p_{\text{mean}} = \tfrac{1}{2}\varrho V_{n\ 0}{}^2 \cot \beta$$

at a maximum deceleration. This formula is a useful guide, but for $\beta < 5$ deg the mean pressure is not likely to be very much greater than its value for 5 deg. It should be remembered that for a wedge the wetted surface is determined from the wetted draft, which is about a $\tfrac{1}{2}\pi$ times the draft relative to the undisturbed water surface (Fig. 22). The more useful case of the impact of a cylinder is only just being considered, although some planing force measurements are reported in Ref. 76.

4.3.2. **Planing forces and pressures.**—It is interesting to know the planing forces and pressures at a given draft, in order to assess the loads in the possible planing case following the initial impact. For the wedge[71]

$$\text{planing force} = 3Kh^2\varrho V_n{}^2 \sec \beta\ ,$$

where K is the factor previously given in section 4.3.1.

V_n is the component of velocity normal to the keel

and h is the draft measured normal to the keel at the step,

and the mean pressure is

$$p_{\text{mean}} = \varrho V_n{}^2 \cot \beta\ .$$

In the application of the above expressions to cases which occur in ditching, it is probably best at present to use these wedge formulae, and to assume a mean β of the order of 5 deg for flat-bottomed fuselages and 15 deg for circular and elliptical fuselages.

4.3.3. **Structural considerations.**—On the basis of the experimental results and full-scale experience and the data given in sections 4.3.1 and 4.3.2, the load conditions to be contemplated are:

(*a*) for the impact case, a maximum sustained local pressure of between 20 lb/sq in. for round-bottomed to 30 lb/sq in. for flat-bottomed fuselages, and a distributed load over a triangular surface with its base at zero pressure and apex at maximum pressure, the base being at a depth corresponding to the expected draft

(*b*) for the planing case, a sustained local pressure and distributed load of 12 lb/sq in. (this applies to nose compartments).

These pressures should be regarded as giving ultimate stressing conditions with a safety factor of unity.

With a fuselage of conventional skin and stringer construction considerable increase in depth of frames below floor level would be required on those portions supporting the wetted surface, in addition to local thickening of stringers and plating. To avoid leakage, particular attention would need to be given to the design of skin joints.

Tests on leakage properties could be met very simply by dropping aircraft from various heights on to water over a range of attitudes. A few tests on discarded aircraft embodying a range of structural features would soon give very valuable information. The development of pressurised fuselages will automatically improve leakage qualities.

The main structure should be proof against bending and shear loads with the aid of local stiffening only, but uploads near the fuselage nose may lead to failure at the wing root.

The major design problem on military aircraft, from the pitching standpoint, will generally be the bomb doors. It will be almost impossible to make these adequately strong and the design solution will probably be to allow them to collapse and to provide for an inner box strong enough to remain reasonably leakproof after the ditching. To prevent diving, it will also be necessary to ensure that the collapse of the bomb door does not expose any strong bulkheads. These problems will be particularly important on designs with high landing speeds.

4.4. **Safety of Crew and Passengers.**—The importance of providing correct ditching stations to alleviate the effect of forward decelerations, and the provision of sufficient emergency exits well clear of the inrushing water, was well proved by experience in the 1939–1945 war.

The high forward decelerations usually met in ditching are important in that, although not often high enough to cause structural damage, quite small amounts are sufficient to make crew and passenger safety difficult to achieve without adequate support. A few rough measurements have been made in recent years at the R.A.E. (Figs. 14 and 15) which show that there are two possible peaks in deceleration, one during the initial impact, and one when the nose drops on, when about half the forward speed is lost. But as yet there is no way of estimating their order, although the qualitative effect of the various design parameters is considered in section 3.2. The drag force causing deceleration is normally greatly augmented by suctions aft on convex surfaces, which greatly increase the draft.

On military transport aircraft, it is now a British requirement that seats with full harness, or suitable ditching stations, such that forward decelerations up of to 20*g* can be withstood, shall be provided for all who cannot be given aft-facing seats.

On civil aircraft there is no specific requirement as yet, but clearly the simple and safe procedure is to provide aft-facing seats for passengers, who may, of course, be in any state of physical fitness. It is very doubtful if the usual argument, that passengers would object on psychological grounds, has any weight. The contrary reaction would seem psychologically more sound.

When the aircraft has come to rest, aft-facing seats will greatly mitigate against danger and panic resulting from a probable severe momentary inrush of water in the event of a poor ditching.

In most ditchings the aircraft will come to rest in a very nose-down attitude, probably with the fuselage fully immersed up to the pilot's compartment. Very good roof exits are therefore mandatory forward, and in ditching all personnel should be stationed as far aft as possible. This requirement is the same as for forced landings. Aft emergency exits must be put in the roof and high in the sides of the fuselage to enable quick exit to be made. The number and area will depend upon the number of personnel normally carried.

4.5. **Equipment for Escape and Rescue.**—No details of equipment requirements are considered in this review, but, in principle, all personnel should be provided with individual life jackets with appropriate recognition and search aids and all aircraft should carry sufficient dinghies with full protective clothing and stores to support all the occupants. Individual dinghies are also obligatory on military aircraft but group use of dinghies is generally considered better for survival—mainly on psychological or mutual aid grounds.

In cold conditions, it is vital that all occupants be able to get quickly into the dinghies in a dry condition and into the right protective clothing. Regular inspections of safety equipment in the aircraft and regular ditching drills for the crews are also a necessary part of an efficient rescue service.

Finally, there must be provided an efficient air/sea search help and rescue service, whether this be by means of dropped stores, airborne lifeboat, marine craft, seaplane or helicopter.

5. **Conclusions.**—In order that a satisfactory ditching on a landplane shall be possible, four main technical requirements must be met.

(*a*) The pilot must be able to put the aircraft down on the sea as gently as possible, the flight path not exceeding the order of 1 or 2 deg and the main impact attitude of the fuselage datum with the water the order of 6 deg. He must make full allowance for wind and waves, in long swells preferably landing along the length of the waves and crosswind if necessary, unless the wind speed exceeds the order of one quarter the stalling speed.

(*b*) The aircraft must possess good hydrodynamic qualities. It should be possible to alight on the water without danger of diving in or bouncing off and the forward decelerations should be small. This can be done by paying particular attention to the fuselage shape aft relative to that forward, and to the effect of ancillaries such as the undercarriage, underslung radiators and other objects, and to fuselage-bottom failure.

(*c*) The aircraft must be structurally strong enough to withstand both the impact forces at touch-down and also the subsequent planing pressures. This requires that conditions (*a*) and (*b*) must be satisfied or the penalty in weight is severe, and the landplane would be better designed as a seaplane. The aim of design must be just to avoid major failure, *e.g.*, breakage of the fuselage back, but allow maximum distributed local failure in order to absorb the energy of impact, yet at the same time prevent serious flooding. A low-mid wing is an obvious reserve buoyancy chamber which is not damaged by the ditching. Some alleviation of bad design should be obtainable by simple and economical lifting devices, *e.g.*, foils or planing surfaces.

(*d*) The aircraft must float long enough and in such an attitude that occupants can get into the dinghies dry. This time primarily depends on the factors in (*a*) to (*c*) but also on detail design to prevent large leaks. It is most important that a flotation time of the minimum order of fifteen minutes is available for civil and military transports. The correct positioning of escape hatches and escape dinghies clear of the anticipated water level is obvious, and allowance must be made for the normally extreme nose-down attitude (order of 20 deg) of final flotation. A vital factor is the correct support of the aircraft occupants to survive the impact decelerations and possible flooding, and there is little doubt that the simplest and most economical solution is aft-facing seats for passengers.

A fifth vital requirement is the reduction to a minimum of the human error, which can completely negative the good ditching characteristics of an aircraft. This means that all aircrew must know in detail the ditching drill and use of their safety equipment, for each aircraft, and in addition be able to help passengers, if these have not had the opportunity.

It is investigations into these problems that have formed the subject of the ditching behaviour of landplanes, a subject about which, at the beginning of the war, very little was known. Considerable knowledge has been gained, but most of it obtained during the war has been of a qualitative nature, having been obtained from tests on specific designs, and by observations rather than by measurement. What is ideally required now to put the subject on a sound footing is a well-conceived, more systematic research programme of tests, designed to give quantitative results and to enable rational ditching design requirements to be formulated.

Free launching tests on dynamic models have been shown to give reliable and accurate information of the hydrodynamic behaviour of aircraft when ditched. With better methods of recording, such tests could be made to yeild accurate velocity, deceleration and attitude histories of each alighting. Controlled launching tests on partial models have yielded information on the pressures that occur at touchdown. Such tests, together with rationalised towed model tests to provide the steady planing forces and wetted surfaces, could be made to complete the information required, by determining the pressure distributions to link up with the hydrodynamic behaviour obtained from the free launched model tests.

The work that has been done over the period examined is encouraging in that it shows what are the important parameters and what, qualitatively, are their effects. It can now be said confidently that it is possible to design landplanes so that they can be expected to ditch reasonably well as an emergency operation at little expense in performance, given the minimum of rational forethought.

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APPENDIX I

A Hypothetical Ditching Return

This is an example of questions asked and typical answers given for a hypothetical ditching. The answers are taken from several war-time returns but all names and circumstances are fictitious. Several possibilities have been amalgamated to illustrate the range of incidents.

Particulars of Aircraft

Type : Halifax.
Mark : VI.
No. : AB.123.
Unit : 102 Squadron.
Group : 12.
Command : Bomber.
Flight commenced from : Frenport.
Date and time : 5.5.43, 2235 hrs.
Date and time of incident : 6.5.43, 0321 hrs.
Final Rescue—Date and time : 9.5.43, 1535 hrs.
Position : 65. W. of ditching.
Position : Off Danish coast.

Weather

Conditions of light : Dark.
Vis. : Poor.
Moon : Nil.
Cloud : 10/10 at 2,000 ft.
Temp. Sea : 40° F.
Air : 50° F.
Wind : 15 knots at sea level.
Height of Waves : 1 to 2 ft.
Swell, crest to crest : 80 ft.
Height and direction of swell : 2 ft with wind direction.
Any unusual or special conditions : Slight drizzle.

Particulars of Crew

Duty in Aircraft	Number	Name	Rank	Fate*
Pilot	123456	Smith, J.	F/Lt.	U
Navigator	654321	Jones, B.	P/O	IS
Wireless Operator	987654	Brown, W.	F/Sgt.	U
Flight Engineer	112233	Robinson, W.	W/O	I
Rear Gunner	332211	Green, J.	Sgt.	K (in action)
Mid Upper Gunner	998877	White, D.	Sgt.	U

* Use symbols :
M—Missing
K—Killed
U—Uninjured
B—Incinerated
D—Drowned
I—Injured and admitted S.S.Q. or hospital
IS—Injured and not admitted S.S.Q. or hospital.

Events Prior to Escape from Aircraft

Reason for emergency ? Engine failure due to enemy action.

Height and time at which emergency became probable ? 1,500 ft at 0313 hrs.

Was any equipment/bombload jettisoned ? 2 flares only.

Was any fuel jettisoned ? No.

What fuel was available immediately prior to ditching ? 550 gallons.

Were bomb doors open or shut ? Shut.

Were wheels up or down at time of ditching ? Up.

Was flotation gear inflated ? State height. No.

Was any special equipment carried under fuselage or wings (*i.e.*, drop tanks, blisters, turrets, etc.) ? H2S blister (radar).

Were engines used on approach ? Port inner and starboard outer only.
Degree of flaps on approach ? Nil.
Final approach speed ? 120 knots.
Speed on impact ? 80 knots.
Angle of final approach to wind ? At right-angles.
Angle of final approach to swell ? Parallel to crests.
Did aircraft drop on surface ? Yes, stalled on.
From what height ? 1 foot.
Did aircraft touch down into wind ? No.
Was aircraft flattened out from glide ? Flattened out after power assisted glide.
What was attitude of aircraft on first impact ? Tail down.
On final impact ? Not known.
Did aircraft slew ? No.
If so, why ?—
State damage caused by ditching. Nose broke and fuselage broke aft of M/U turret.
Position of main entry of water. Nose.
Depth of water in aircraft: Knee deep.
Period aircraft floated. 3 min front, ½ min tail.
Attitude afloat. Front portion nose-down.
Aircraft sank nose/tail first.—

	Pilot	M/U	Nav.	W/Op.	F Eng.
What escape hatch did you jettison before alighting ?	—	Both M/U exits	Pilots exit	—	—
Did they function correctly ?	—	Yes	Yes	—	—
Was normal ditching station adopted before impact ?	Yes	Yes	Yes	Yes	No
If not, what position did you adopt ?	—	—	—	—	Standing against forward bulkhead
Were you strapped in ?	Yes	No	No	No	No
Did impact cause damage to safety equipment, seat or crash station ?	No	No	No	No	No
Were you displaced by second or subsequent impact ? State violence and direction of displacement.	No	No	Yes. Heavy deceleration forward	No	Yes. Violent car braking forward
Were you injured by impact ?	No	No	Yes	No	Yes
By which part of aircraft ? Cause and injury.	—	—	Not known. Cut face	—	Not known. Broken wrist
Were you injured before impact ?	No	No	No	No	No
Describe briefly nature of injuries.	—	—	—	—	—
Did seats, harness or bolts break on impact ?	No	No	No	No	No
Did inrush or water impede exit ?	No	No	No	No	No

Narrative

When the emergency became obvious, the navigator came forward and jettisoned the forward escape hatch whilst the M/U gunner jettisoned the two upper escape hatches. The landing lights were switched on and they were invaluable in judging height, and the navigation lights were also switched on thus giving ample light for boarding the dinghy successfully. The approach was an extended glide assisted by the two serviceable engines, flattened out to a tail-down attitude and dropped on from one foot. The first impact was quite gentle but the second impact was severe, throwing the navigator from his station. The back of the aircraft was broken and floated in two sections.

Radio Procedure

Was S.O.S. transmitted ?	Yes.
Was D.R. (Direct Reckoning) position transmitted ?	Yes, on V.H.F. (Very High Frequency).
Was acknowlegement or fix obtained ?	No. probably due to low height.
Was I.F.F. (recognition signal) action taken ?	Yes.

Narrative

W/Op. set I.F.F. at distress, sent out an S.O.S. clamping the key down just prior to ditching. The S.O.S. was received and a fix obtained but, due to a considerable distance being covered after the fix and subsequent S.O.S's. not being received, the dinghy was not found before the second day.

Escape from Aircraft

What type of multi-seater dinghy was carried ?	Q type.
Was manual release pulled ?	Yes.
If not, did immersion switch work ?	—
Was topping-up required immediately ?	No.
Blowout or valise storage ?	Blowout.
Did it function satisfactorily ?	Yes.
Was dinghy released satisfactorily from aircraft ?	Yes.
Were packs available in dinghy or dinghy stowage ?	Dinghy.

	Pilot	M/U	Nav.	W/Op.	F/Eng.
Did you carry a single seater dinghy ?	No	No	No	No	No
What use did you make of it ?	—	—	—	—	—
What safety equipment was removed from aircraft ?	—	Extra food pack	Torch	Dinghy radio	Verey pistol and cartridges
What exit did you use ?	Pilot's hatch	Break in fuselage	Pilot's hatch	Break in fuselage	Break in fuselage
Any difficulty in leaving through exit ?	No	No	No	No	Yes, due to broken wrist
Were you immersed before boarding dinghy ?	No	Yes	No	Yes	Yes
When was life jacket inflated ?	Before ditching	Before ditching	After ditching	After leaving aircraft	Before ditching
How ? By cylinder or mouth ?	Cylinder	Cylinder	Cylinder	Mouth	Cylinder
If CO_2 bottle was unsatisfactory, state why.	—	—	—	Not known	—

Narrative

Pilot and navigator escaped through pilot's top hatch, walked on to wing and stepped into dinghy which had inflated correctly. They paddled the dinghy and picked up the rest of the crew who had made their escape through the break in the fuselage. Before boarding the dinghy, the W/Op. swam over to the tail portion in an attempt to rescue the body of the rear gunner who had been killed in action. The dinghy radio, Very pistol and cartridges and an escape pack were successfully transferred to the dinghy.

Rescue

How long were you in dinghy ?	3 days.
Did personnel suffer from exposure ?	Slightly, due to rough sea and wet clothes.
Did protective equipment function satisfactorily ?	Yes.
Was dinghy radio operated ?	Yes, at half-hour intervals.
Were pyrotechnics used ?	Yes, to signal passing aircraft.
Did they function satisfactorily ?	Yes.
Was any rescue apparatus dropped ? State when and whether you reached it ?	Airborne lifeboat on third day dropped close.
How were you finally rescued ? State position and time ?	By H.S.L. on 9.5.43, 65 miles W. of ditch.

Narrative

The W/Op. attempted to recover the body of the rear gunner before the tail portion sunk but he was unsuccessful. The wind increased during the first day and the sea anchor was used. Considerable water was shipped but consistent bailing kept the level low. The waterproof apron was spread soon after dawn and this prevented the water from swamping the dinghy. All the crew suffered from sea-sickness as no seasick pills were available in the pack. The sea calmed on the second day and some Horlicks tablets were taken. Strict rationing of water was introduced. Towards evening on the second day a patrolling *Beaufighter* was sighted and was attracted by the Very lights fired. After circling the *Beaufighter* left. A *Warwick* appeared on the third day and an airborne lifeboat was dropped within 50 yds of the dinghy, and a course was flashed by Aldis. No difficulty was experienced in boarding or starting the engines of the lifeboat. Steady progress was made through the night and next morning a High Speed Launch was directed by a patrolling *Mosquito* which had sighted the lifeboat.

Training

	Pilot	M/U	Nav.	W/Op.	F/Eng.
Previous experience in ditching	None	None	None	None	None
Had you prior training for this type of emergency ?	Yes, regularly	Yes, regularly	Yes	Yes	Yes, regularly
Have you seen blow-out demonstration of dinghy ?	Yes	Yes	Yes	Yes	Yes
Have you carried out wet dinghy drill ?	Yes	Yes	Yes	Yes	Yes
Can you swim ?	Yes	Yes	Yes	Yes	Yes
How long had you been in unit prior to ditching?	12 months	15 months	4 months	3 months	4 months

Narrative

Crew were conversant with general ditching procedure but F/Eng. was not conversant with specific procedure for *Halifax*.

Suggestions

In all but foggy weather, the landing light is invaluable for judging the height of approach. The navigation lights give sufficient light to enable the dinghy to be boarded safely.

Remarks by Commanding Officer

A good ditching skilfully carried out. The pilot should have lowered his flaps to reduce his forward speed, which might have saved the aircraft from breaking aft of the M/U turret. The F/Eng. suffered an injury through not taking up the correct ditching station and was perhaps lucky to escape with his life. The Navigator could not have braced himself properly or else he relaxed after the first impact, neglecting the fact that the second impact is invariably more severe. Whilst the feelings of the W/Op. are sympathetically understood, it cannot at any time be considered worth the risk of re-entering the aircraft to retrieve one who is already lost. The pilot was correct in landing parallel to swell. The dinghy drill was effectively carried out as was the handling of the airborne lifeboat.

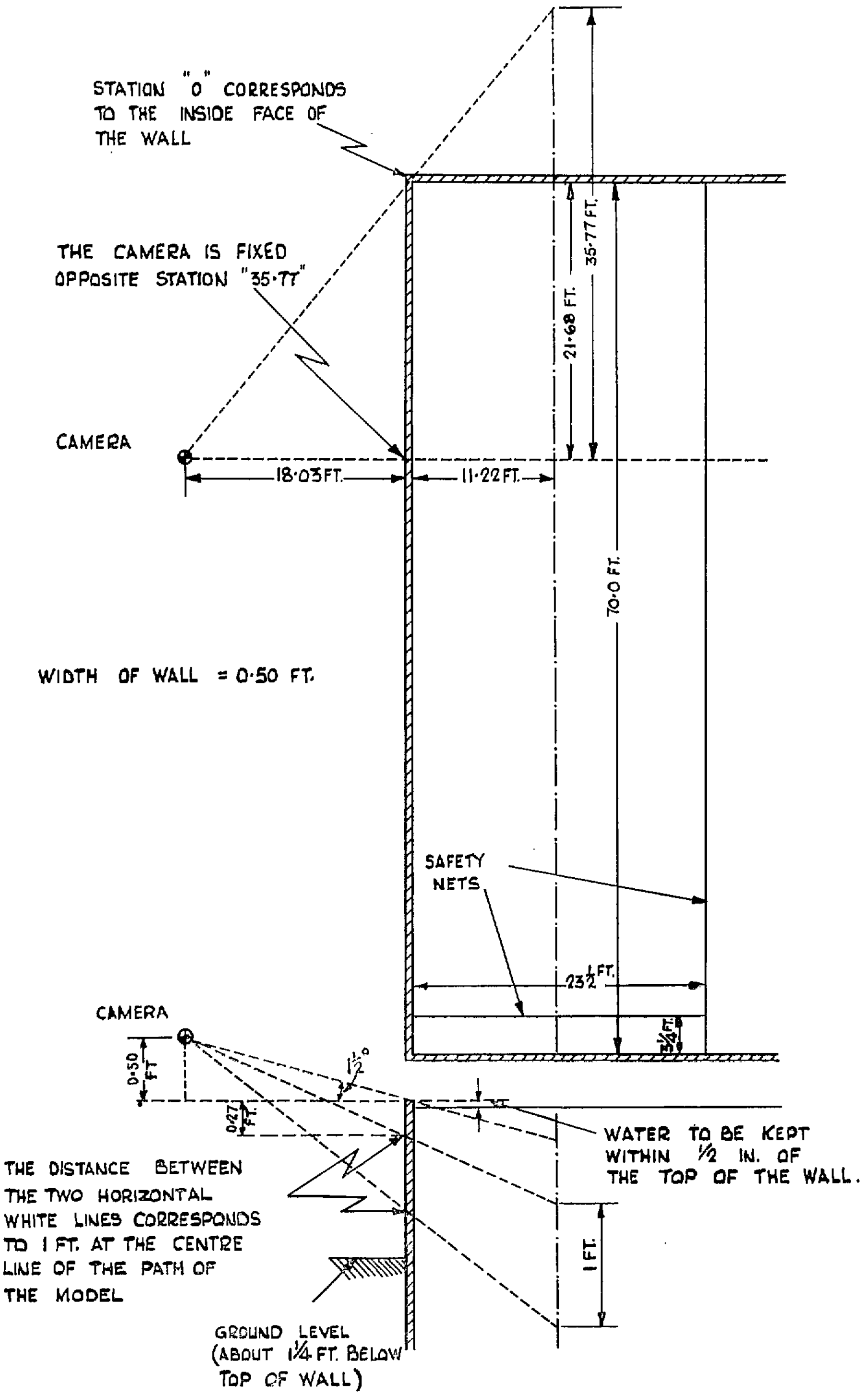


FIG. 1. Layout of Royal Aircraft Establishment Free Launching Tank.

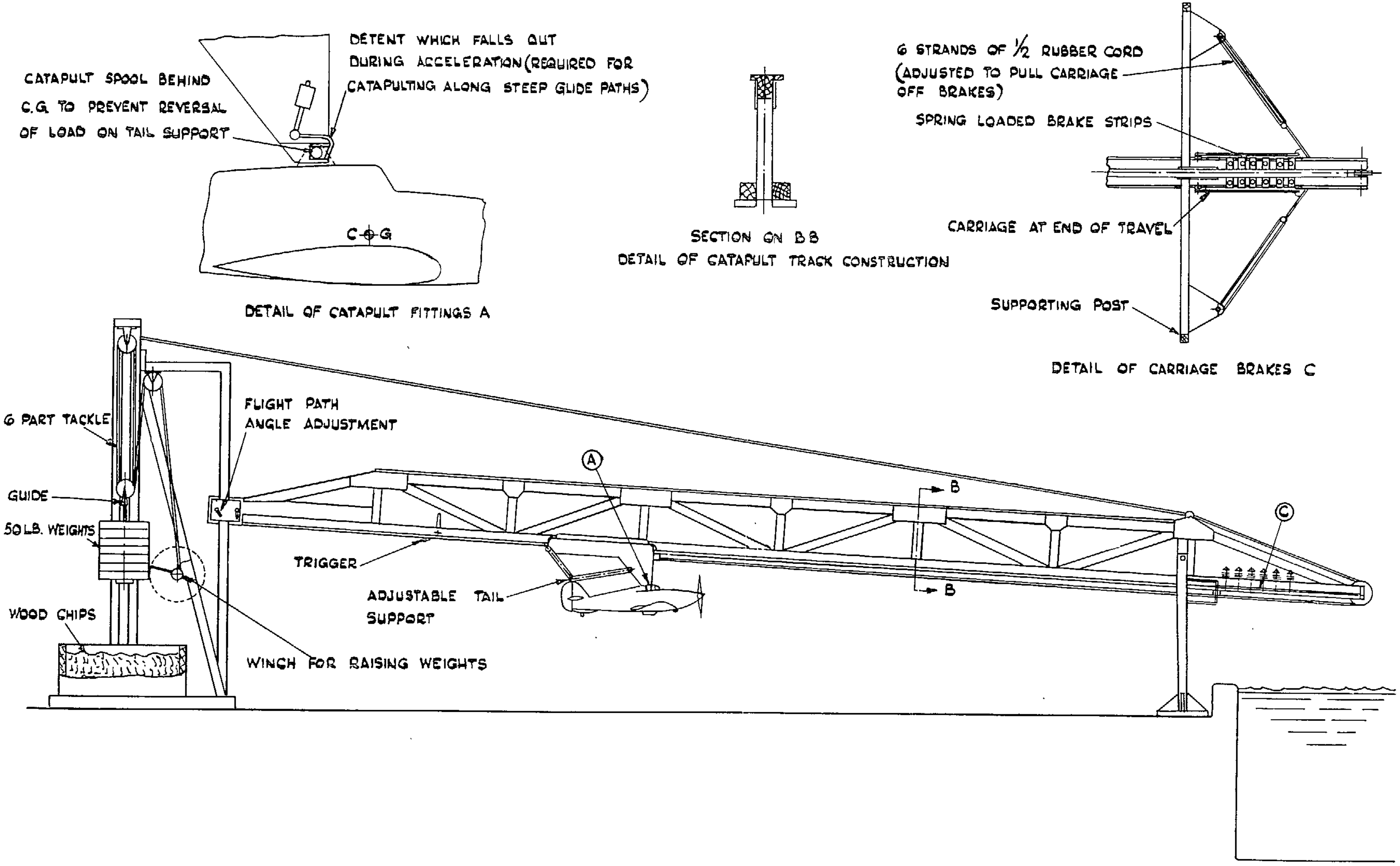
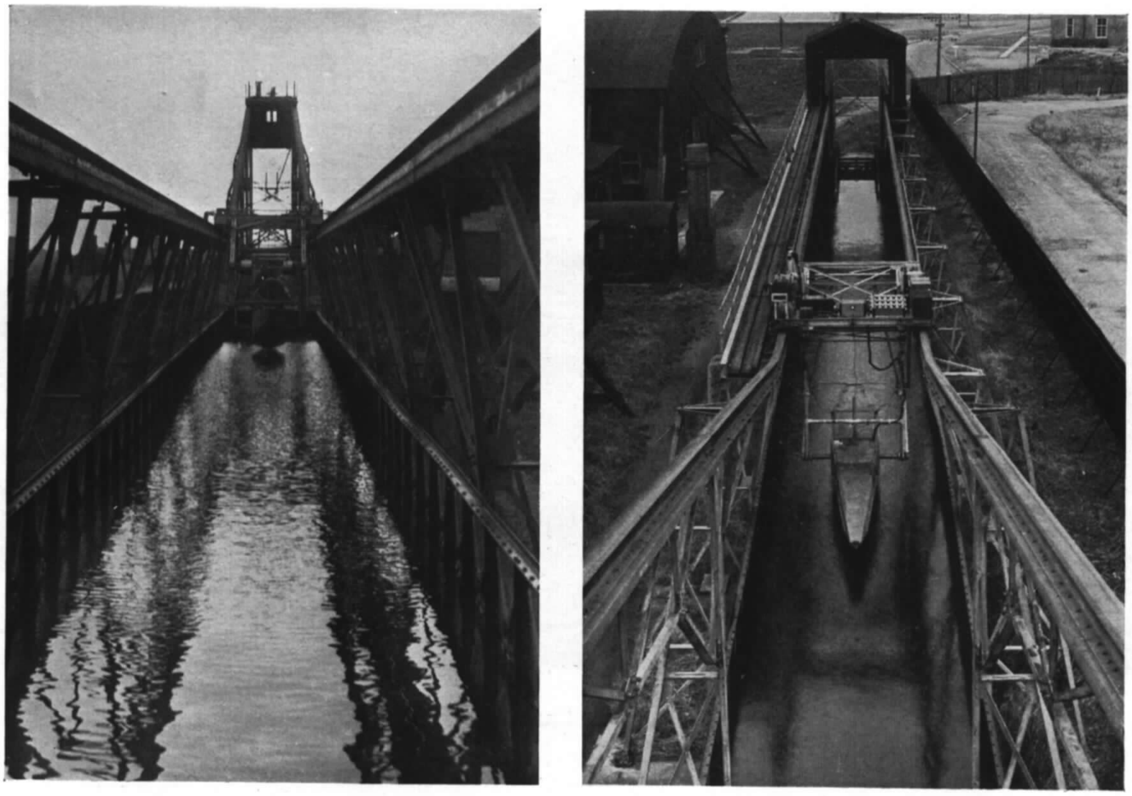


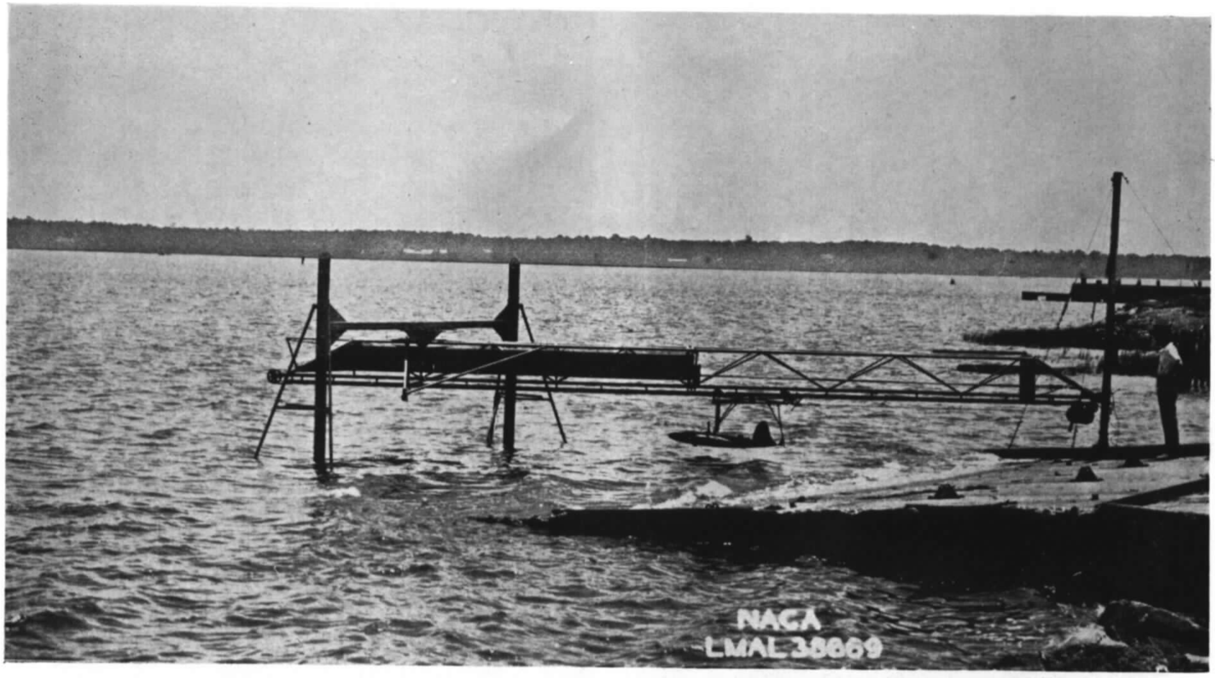
FIG. 2. Details of catapult. Royal Aircraft Establishment Free-Launching Tank.



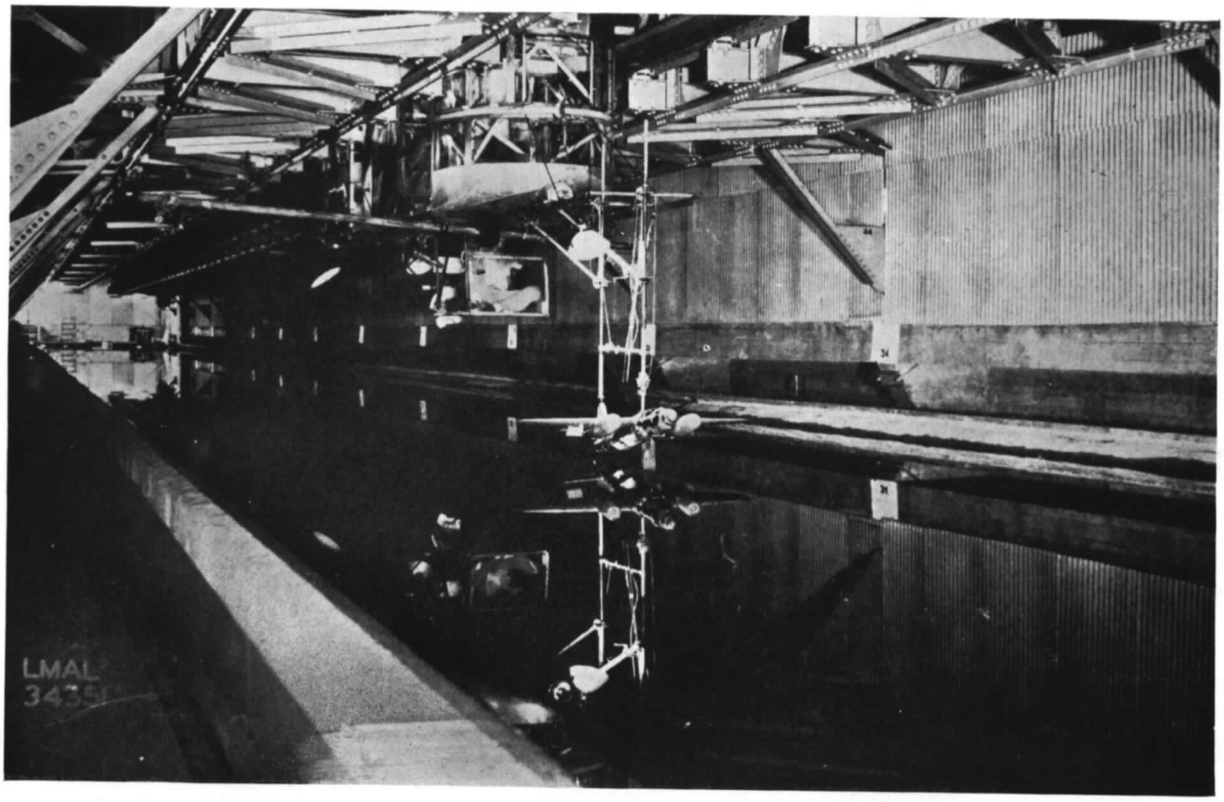
Looking towards the winch house. Looking down from the winch house.

A ditching model on the carriage.

FIG. 3. Hull launching tank. Marine Aircraft Experimental Establishment.



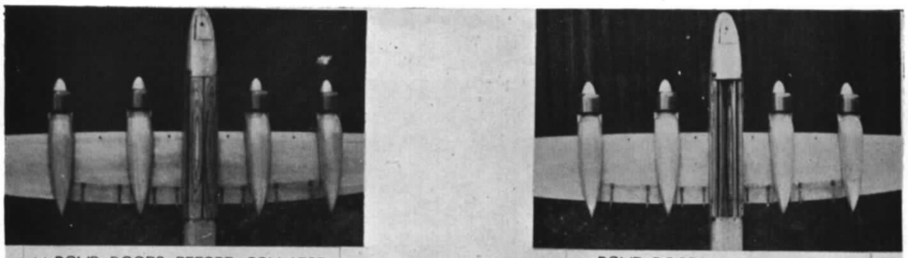
N.A.C.A. Free Launching Tank.



N.A.C.A. tank rigged for testing landplane ditching.

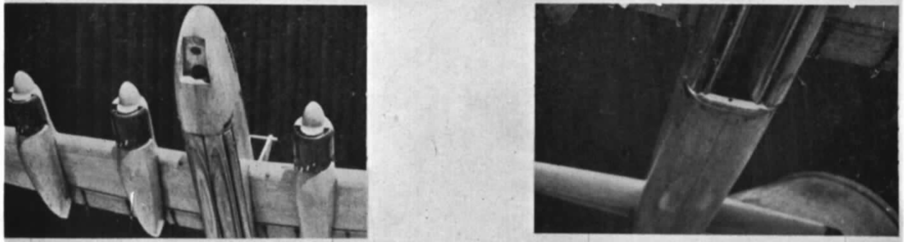
Fig. 4. Views of N.A.C.A. ditching apparatus.

FIG. 5. Typical model of twin-engined bomber showing collapsible flaps and bomb doors. (*Sturgeon.*)



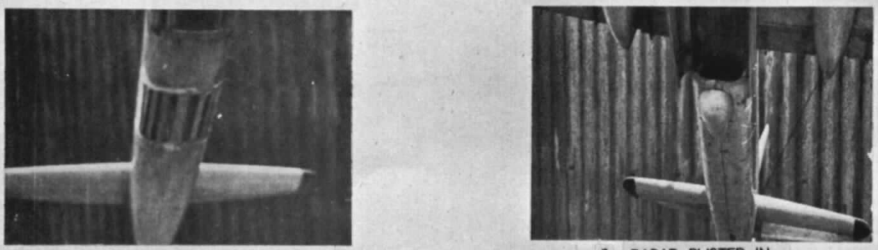
(a) BOMB DOORS BEFORE COLLAPSE.

(b) BOMB DOORS AFTER COLLAPSE



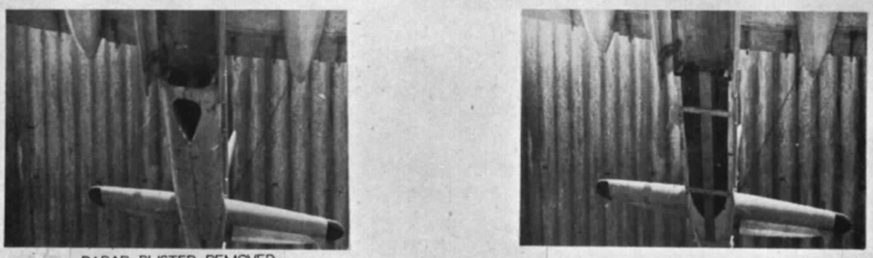
(c) BLOCK REMOVED TO REPRESENT FAILURE OF THE BOMBARDIER'S WINDOW

(d) BULKHEAD AT AFT END OF THE BOMB COMPARTMENT REMOVED TO REPRESENT FAILURE



(e) REPRESENTATION OF WEAK FUSELAGE SKIN USED IN THE TESTS WITH AN INVERTED RAMP THE LATTICED STRUCTURE WAS COVERED WITH PAPER BEFORE DITCHING.

f RADAR BLISTER IN EXTENDED POSITION.



g RADAR BLISTER REMOVED, REPRESENTING BLISTER RETRACTED.

(h) REMOVAL OF SKIN OF REAR UNDERFUSELAGE. THIS WAS TORN OFF IN SOME OF THE TESTS BY WATER PASSING THROUGH THE BULKHEAD AT THE AFT END OF THE BOMB COMPARTMENT.

FIG. 6. Structural weaknesses that can be represented on a dynamic ditching model. (*Windsor.*)

FIG. 7. A dynamic model under construction.

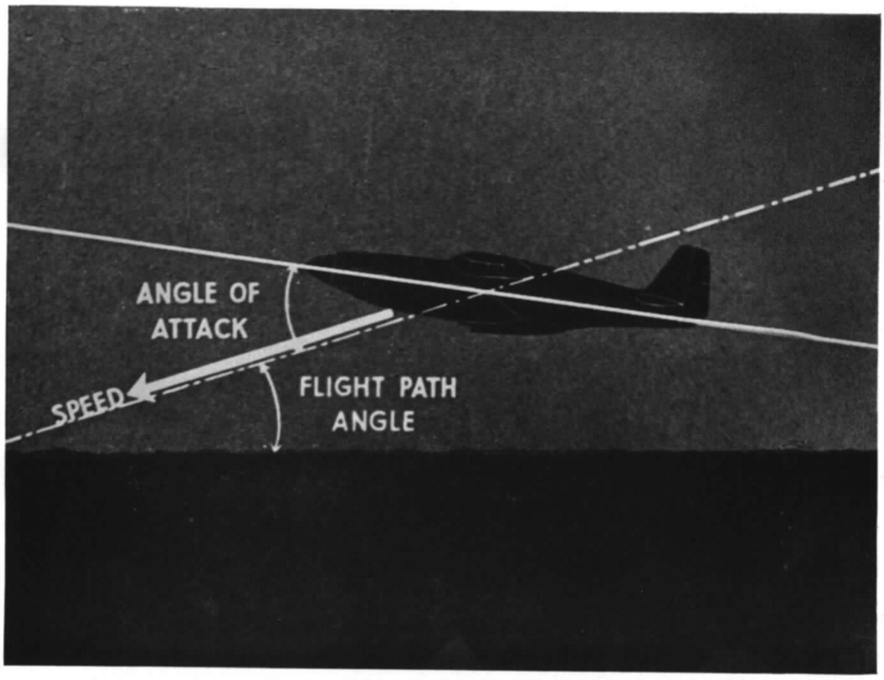


FIG. 8. Approach parameters affecting ditching.

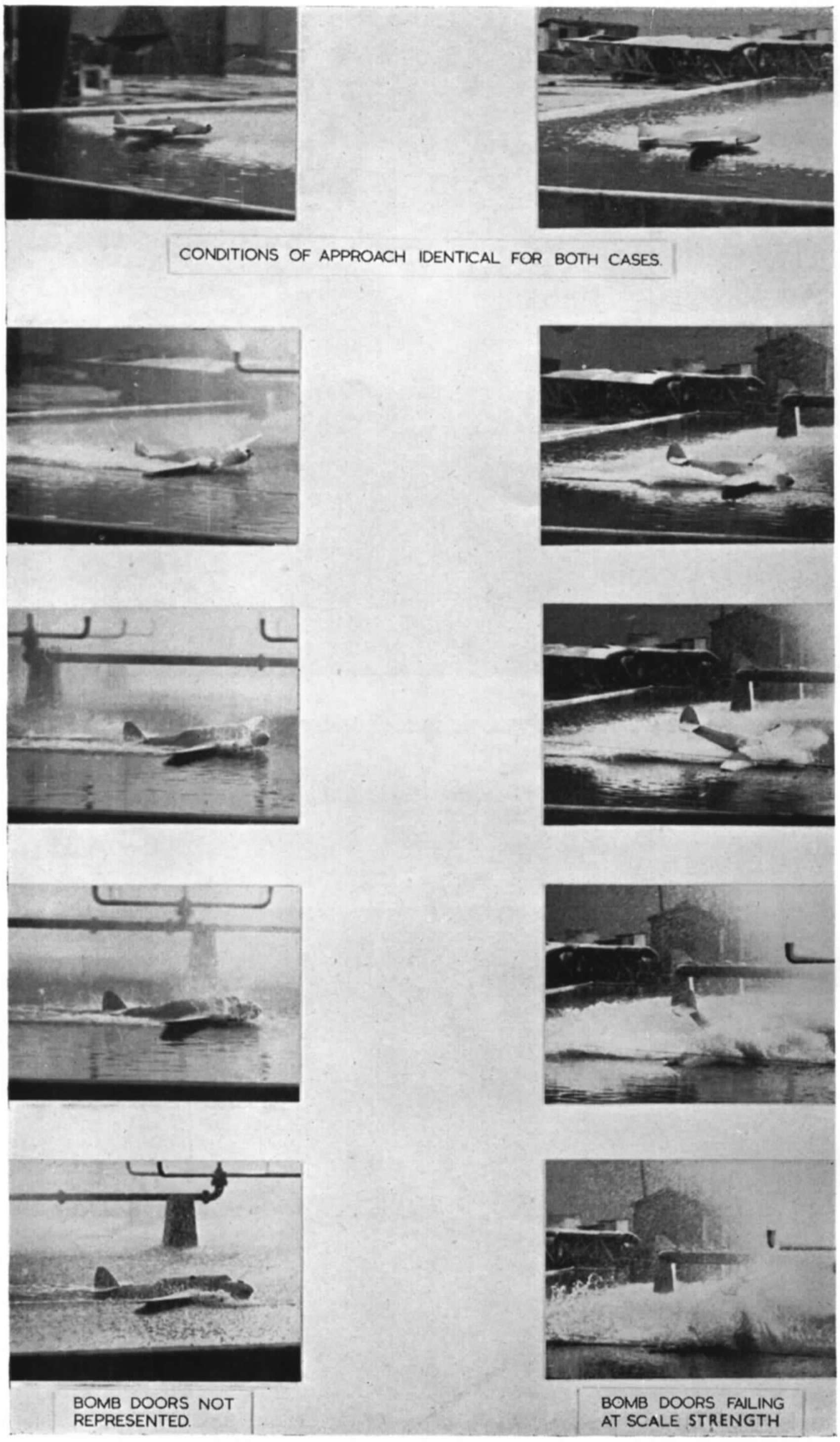


FIG. 9. Effect of bomb doors on ditching. (*Beaufort.*)

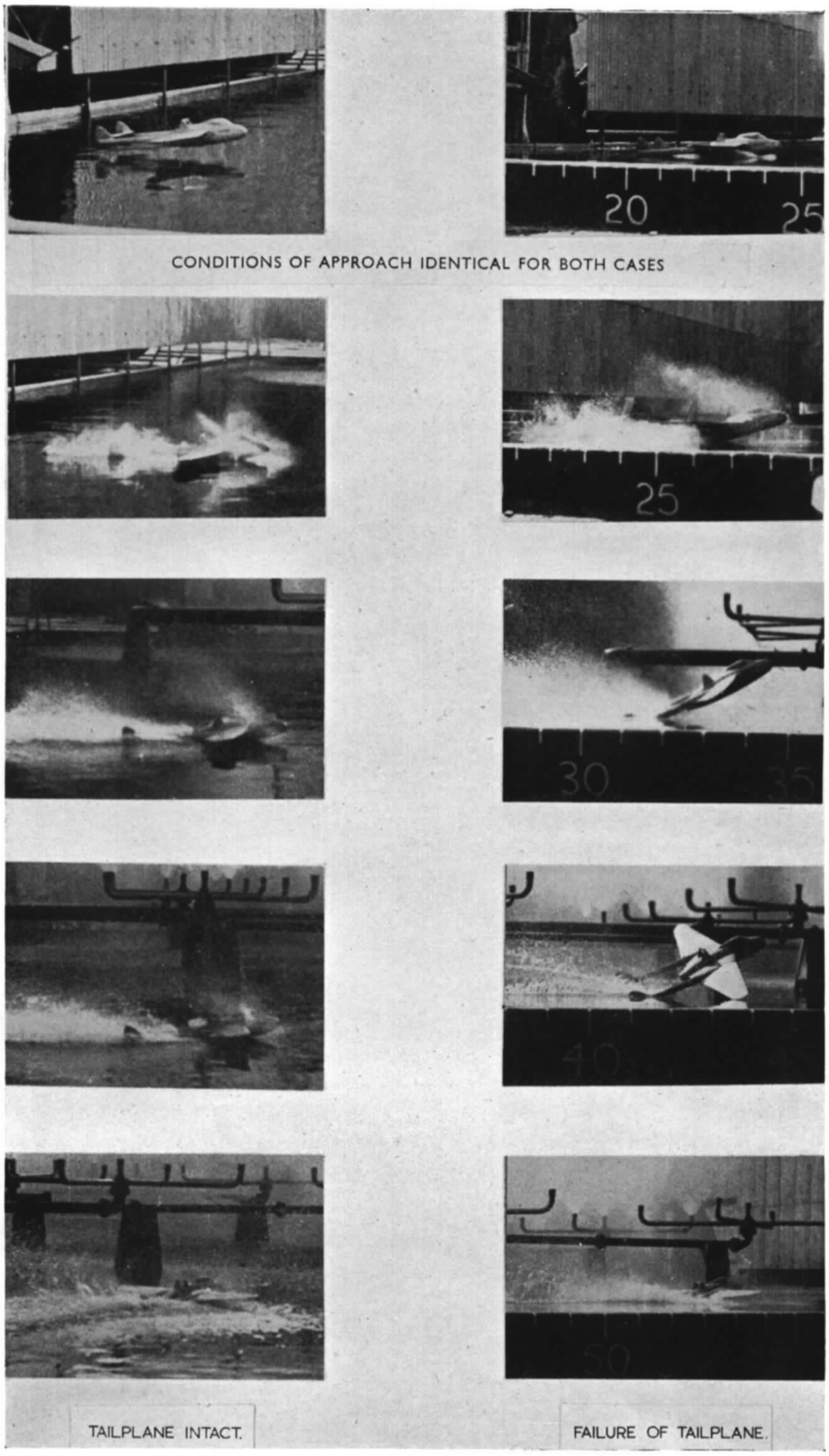
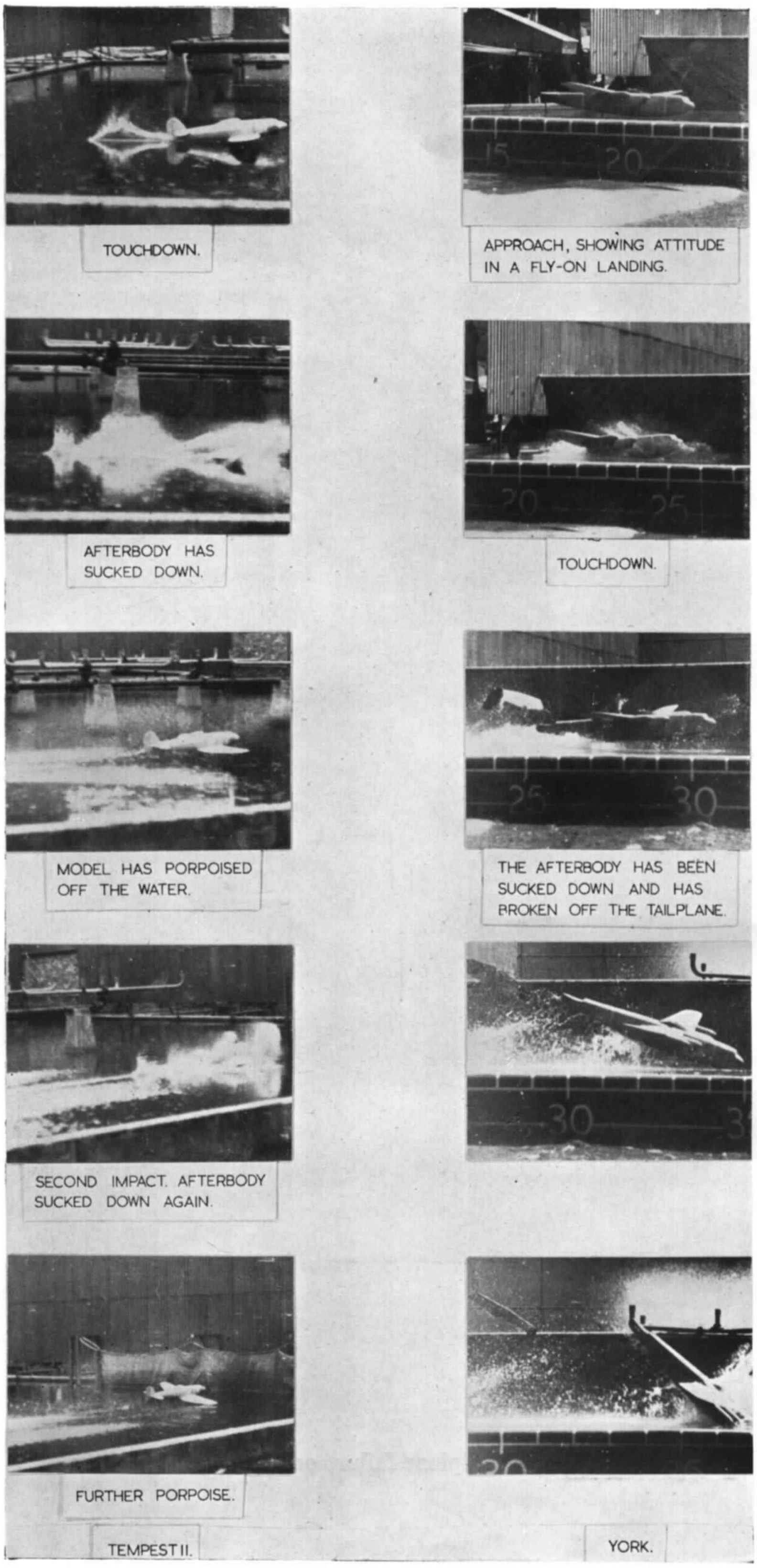


FIG. 10. Effect of tailplane failure on ditching. (*Vampire*.)



TOUCHDOWN.

AFTERBODY HAS SUCKED DOWN.

MODEL HAS PORPOISED OFF THE WATER.

SECOND IMPACT. AFTERBODY SUCKED DOWN AGAIN.

FURTHER PORPOISE.

TEMPEST II.

APPROACH, SHOWING ATTITUDE IN A FLY-ON LANDING.

TOUCHDOWN.

THE AFTERBODY HAS BEEN SUCKED DOWN AND HAS BROKEN OFF THE TAILPLANE.

YORK.

FIG. 11. Effect of afterbody suctions on ditching. (*Tempest and York.*)

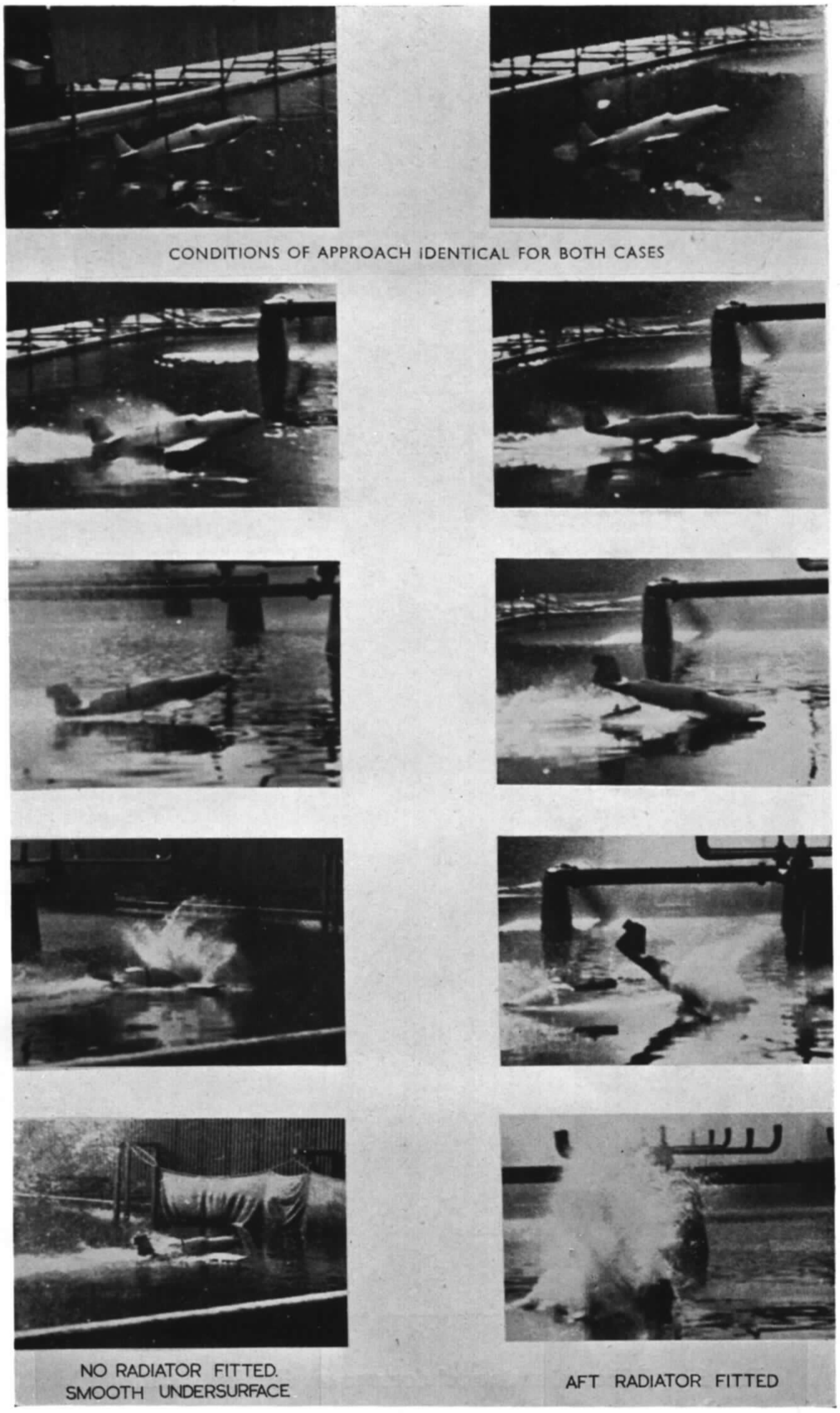


FIG. 12. Effect of aft radiator on ditching. (*Mustang*.)

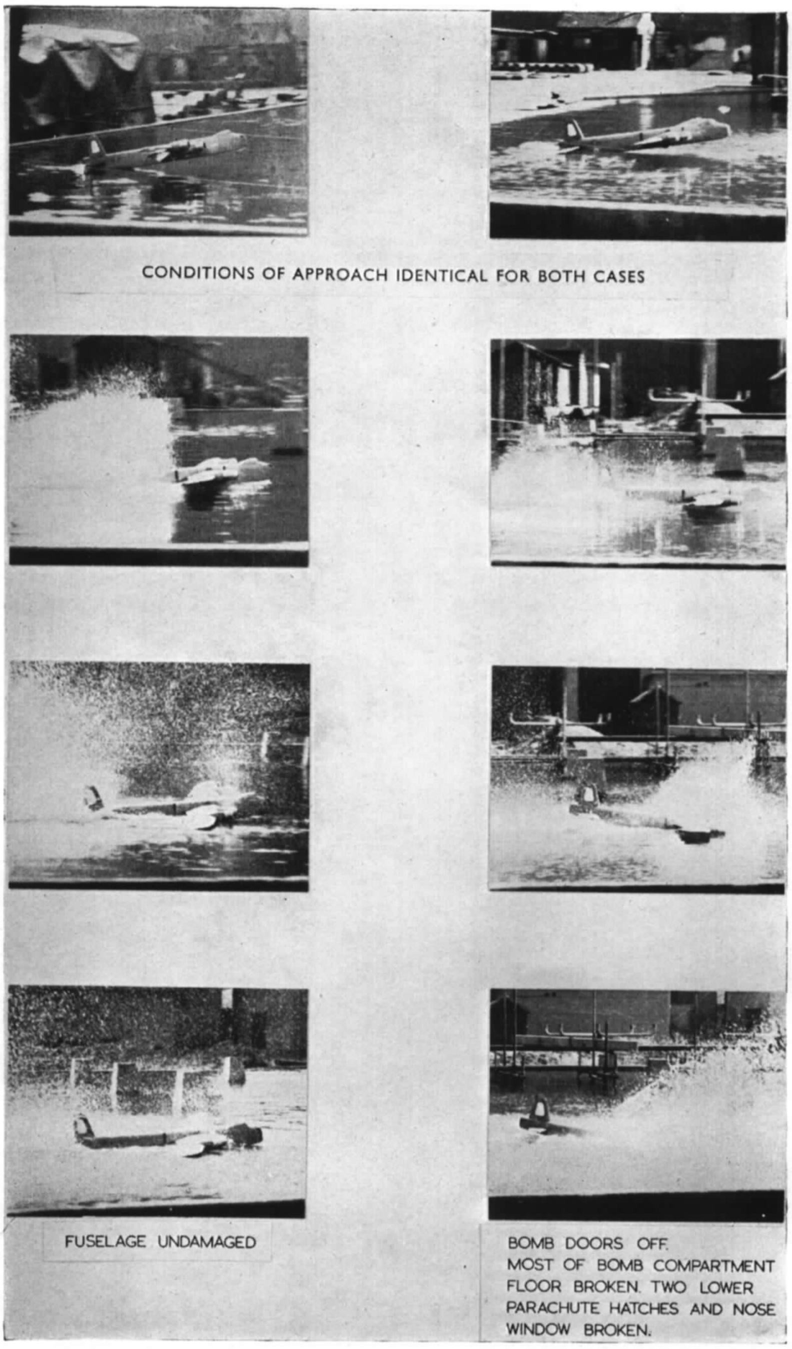


FIG. 13. Effect of structural damage on ditching. (*Stirling*.)

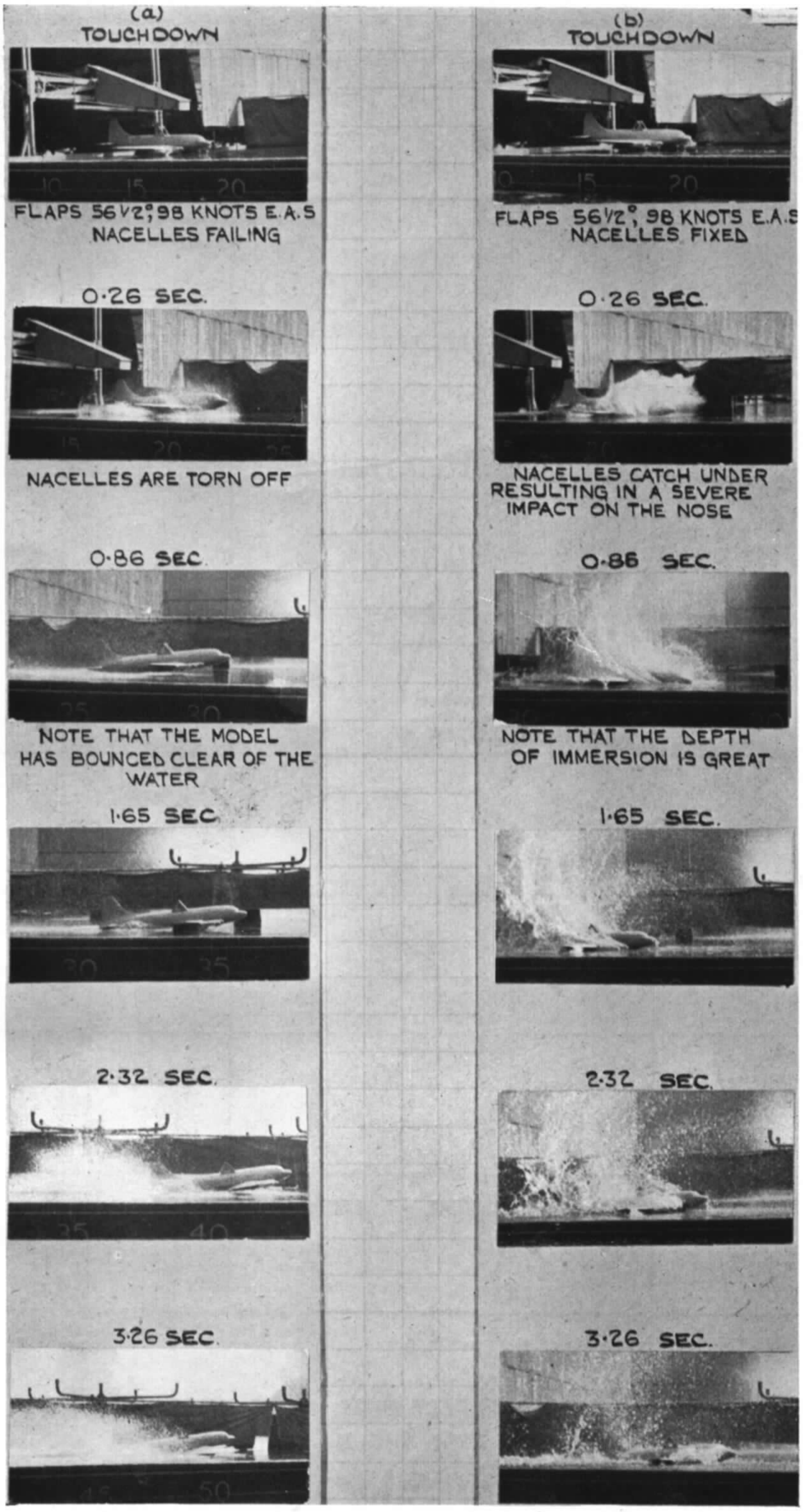
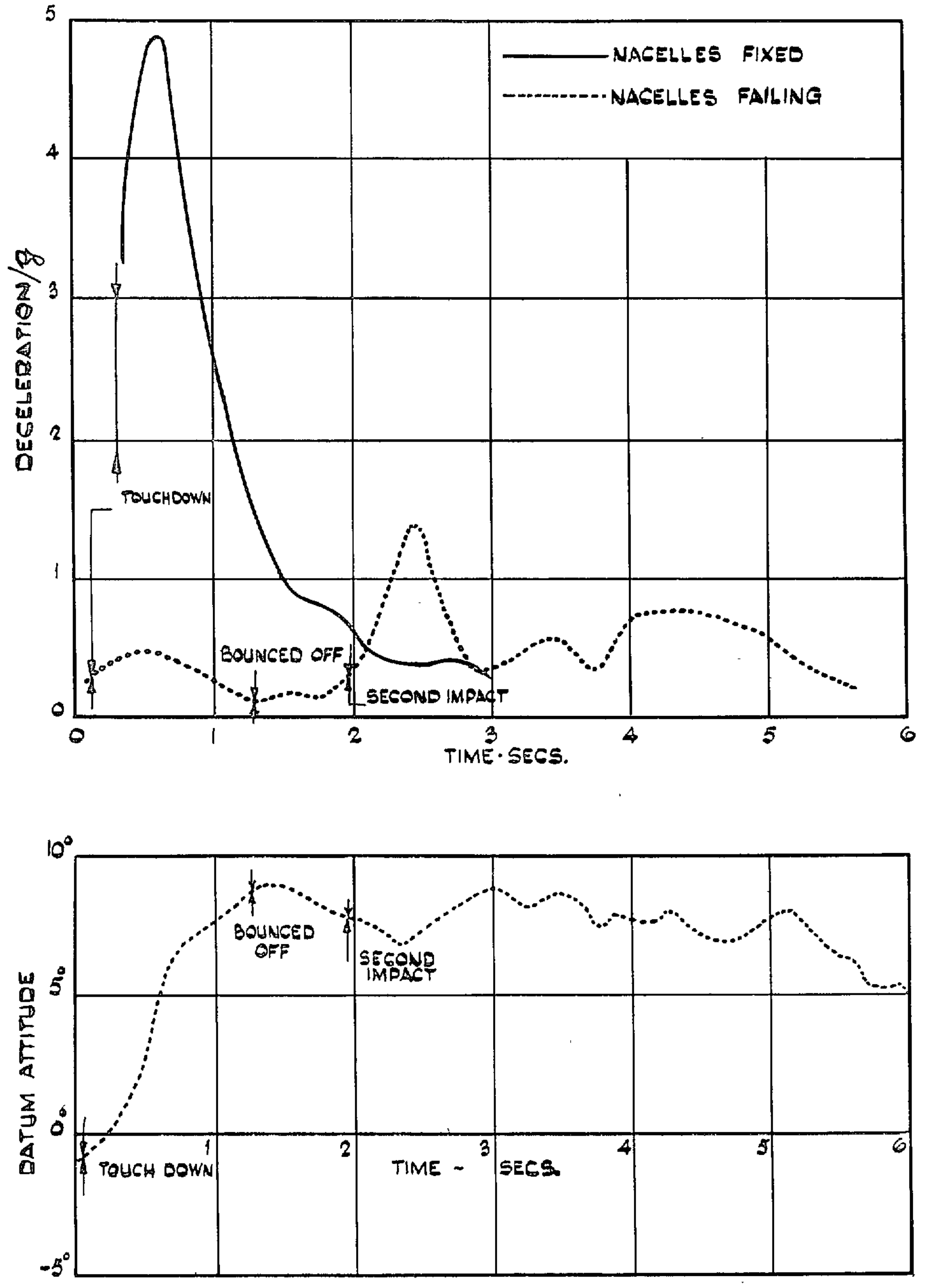


FIG. 14a. Effect of nacelles on ditching. (*Tudor*.)



INITIAL IMPACT SPEED	98 KNOTS.
FLIGHT PATH ANGLE	5°
FLAP SETTING	$56\frac{1}{2}$°

FIG. 14b. Effect of nacelles on ditching. (*Tudor.*)

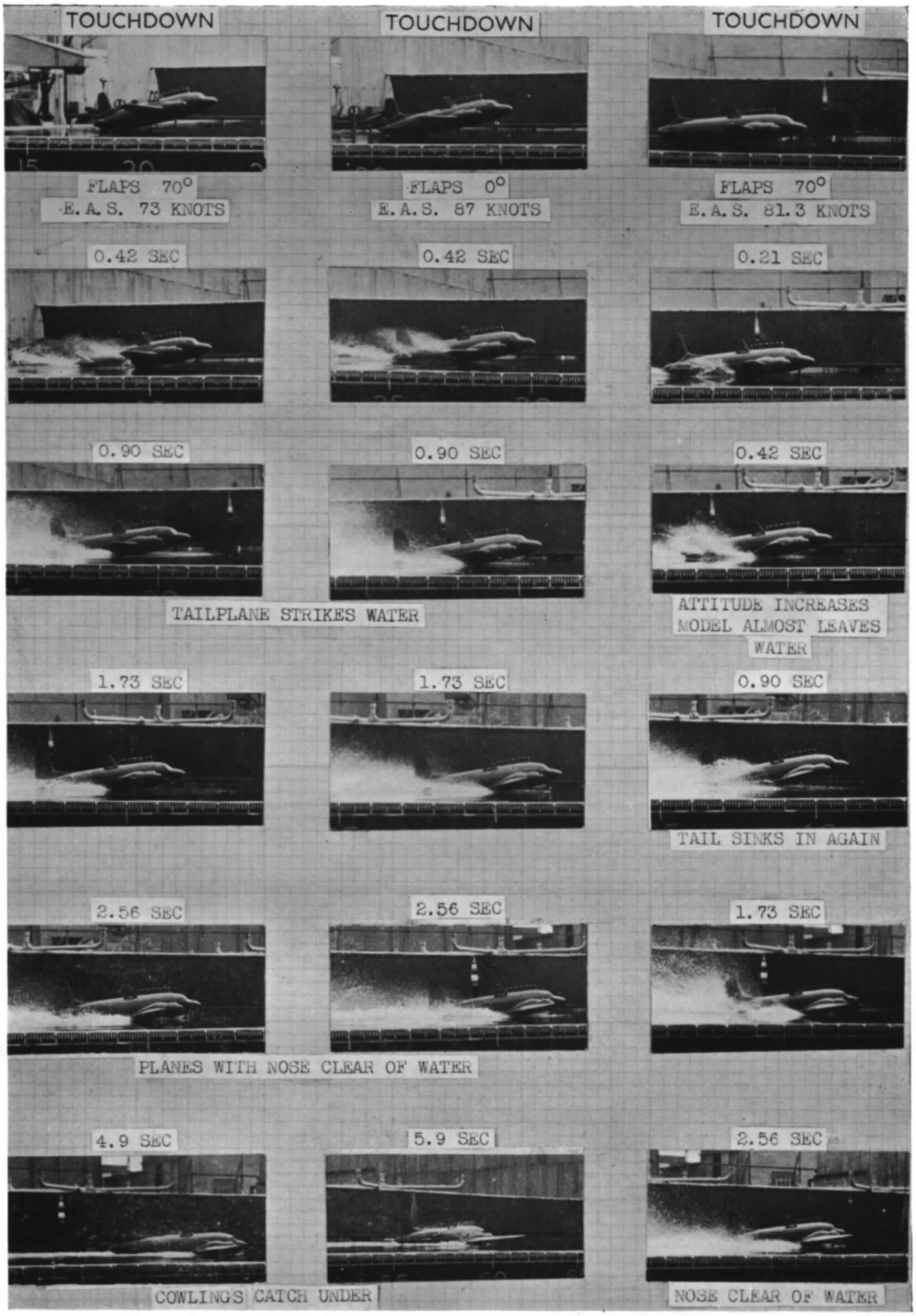
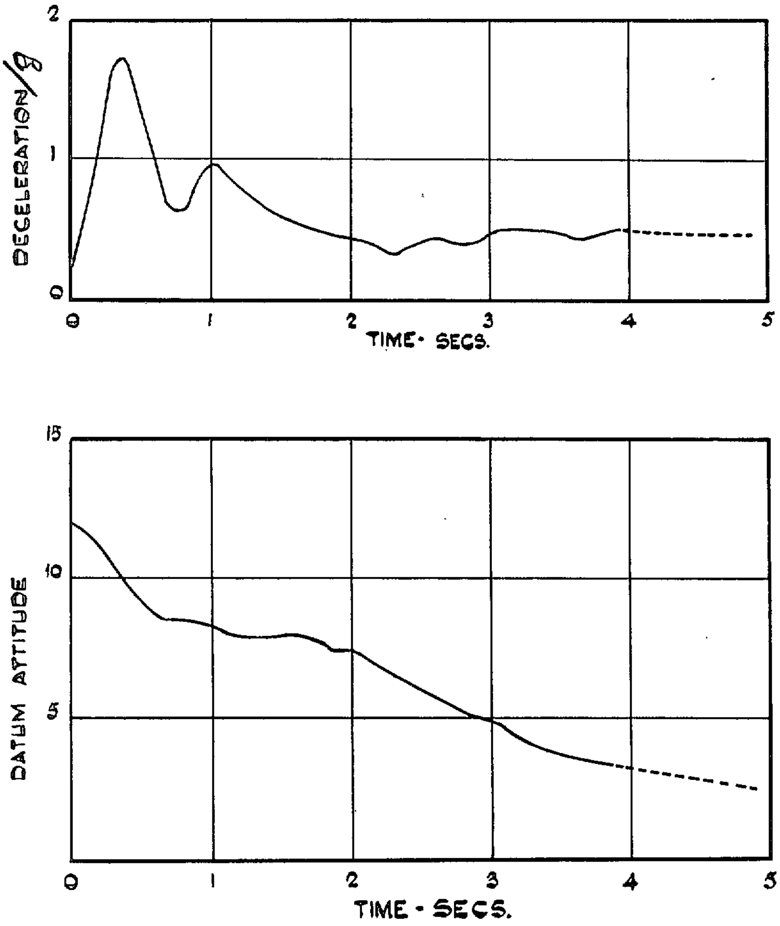
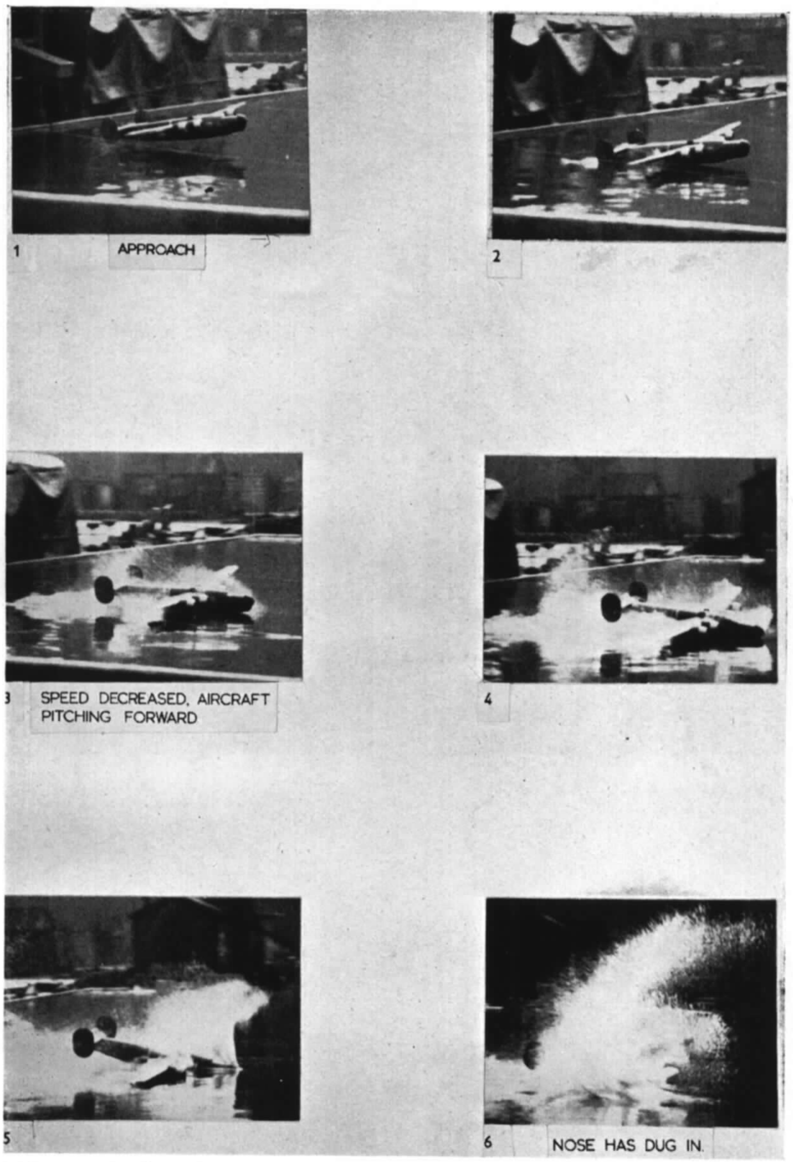


FIG. 15a. Example of good ditching behaviour. (*Viking*.)



INITIAL IMPACT SPEED	73 KNOTS
FLIGHT PATH ANGLE .	1°
FLAP SETTING	70°

FIG. 15b. Example of good ditching behaviour. (*Viking.*)



1 APPROACH

2

3 SPEED DECREASED, AIRCRAFT PITCHING FORWARD

4

5

6 NOSE HAS DUG IN.

FIG. 16. Model-scale ditching. (*Liberator.*)

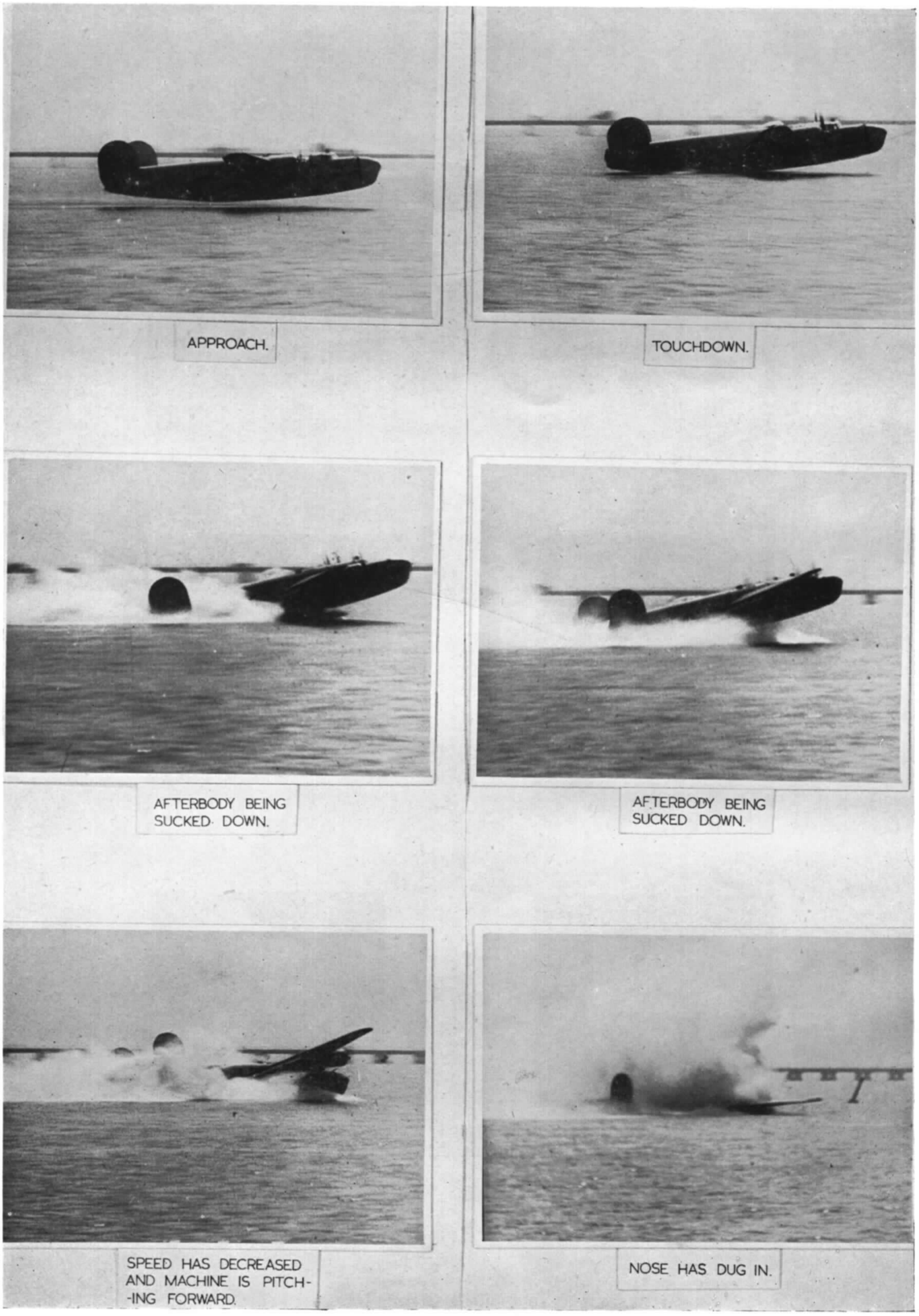


FIG. 17. Full-scale ditching. (*Liberator.*)

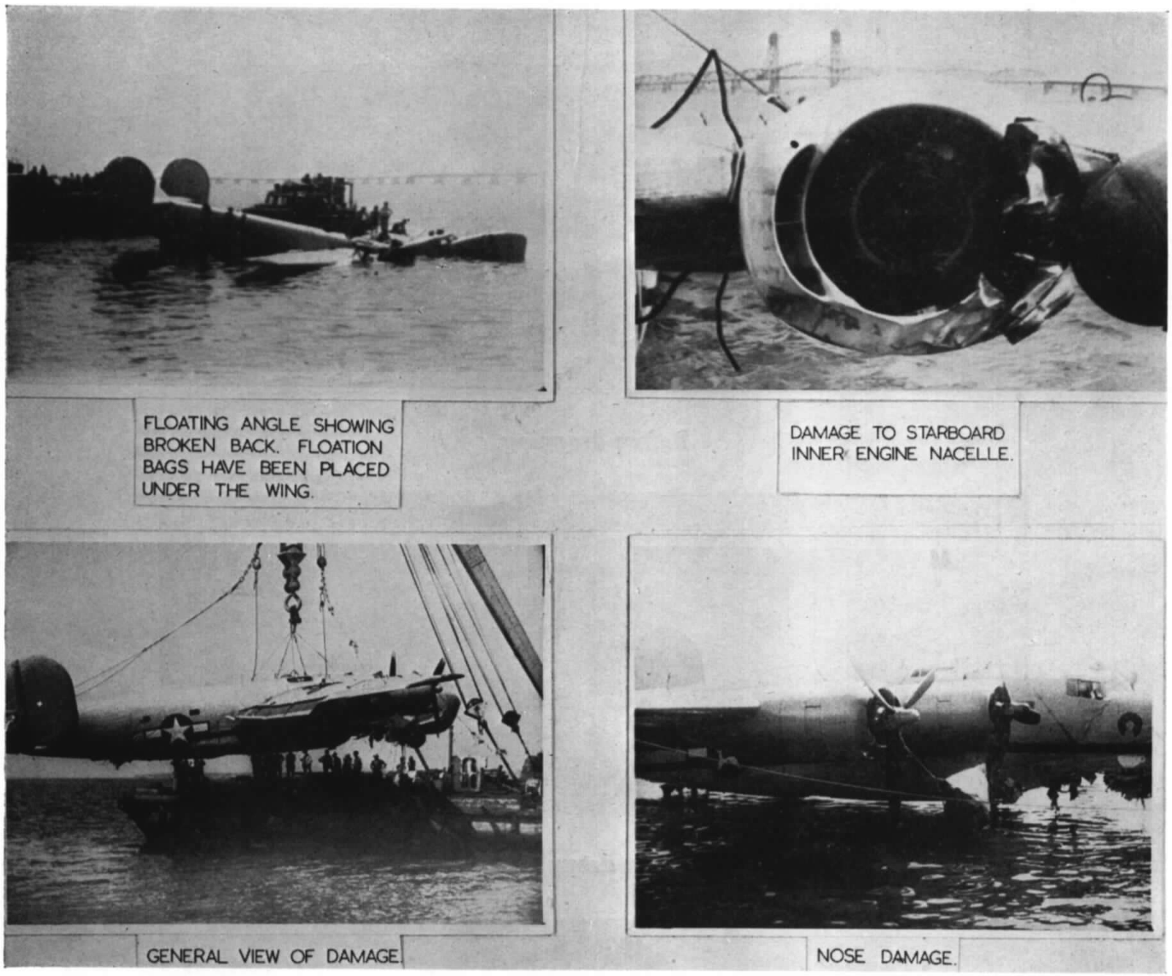
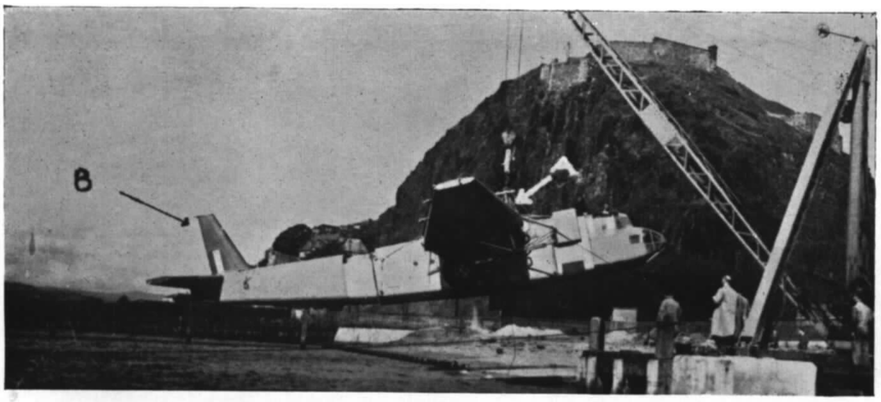
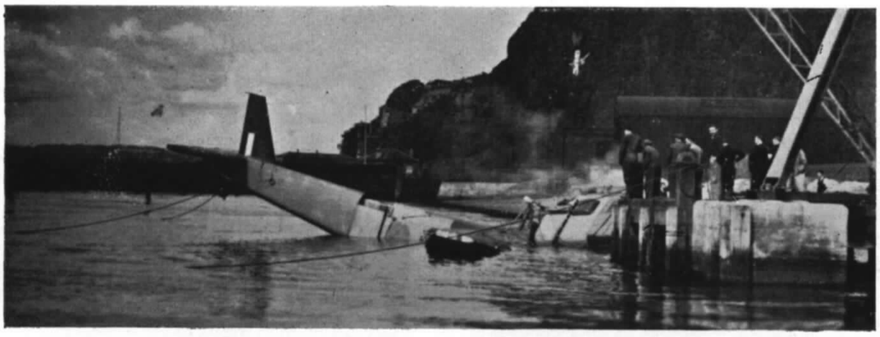


FIG. 18. *Liberator* damage resulting from ditching of Fig. 17 in strengthened condition.

FIG. 19. Damage sustained by *Martinet* in ditching.



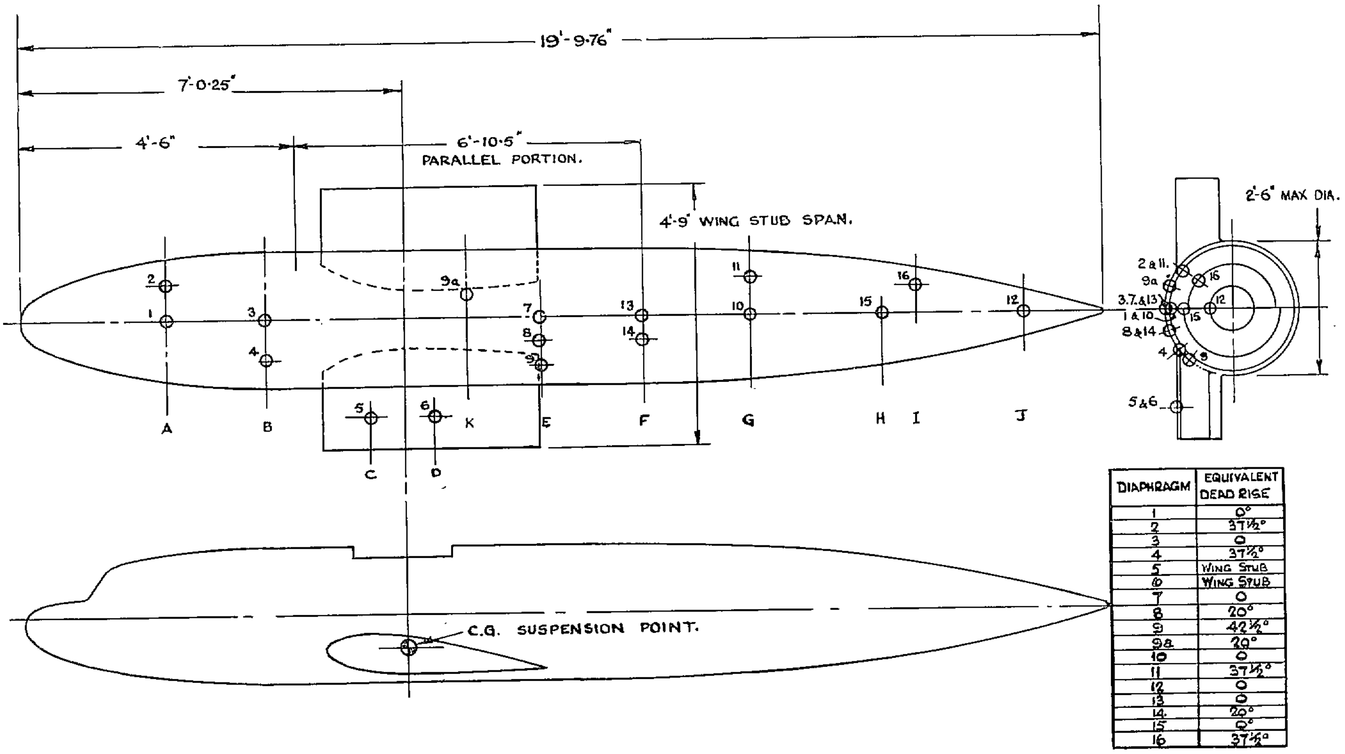
Before dropping.



After dropping.

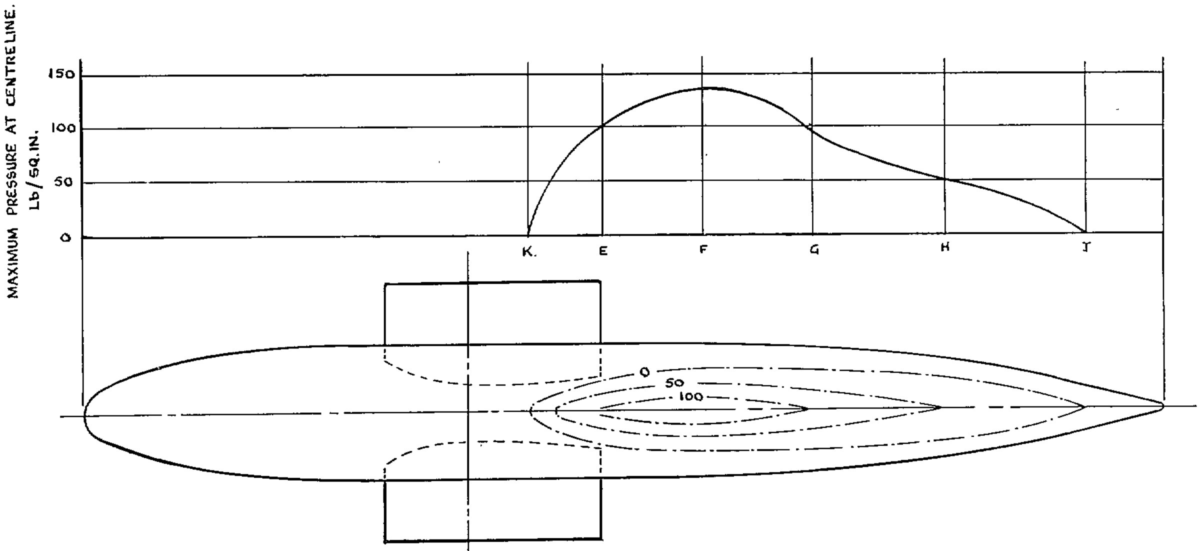
Damage sustained by dropping.

FIG. 20. Dropping full-scale aircraft (*Botha*) at the Marine Aircraft Experimental Establishment.



DIAPHRAGM	EQUIVALENT DEAD RISE
1	0°
2	37½°
3	0
4	37½°
5	WING STUB
6	WING STUB
7	0
8	20°
9	42½°
9a	20°
10	0
11	37½°
12	0
13	0
14	20°
15	0°
16	37½°

FIG. 21a. Quarter-scale model *Tudor I* fuselage.



INITIAL IMPACT SPEED 93 M.P.H.
FLIGHT PATH ANGLE 2·8°
FUSELAGE ATTITUDE TO HORIZONTAL 9°

FIG. 21b. Distribution of maximum impact pressure on bottom of *Tudor I* fuselage.

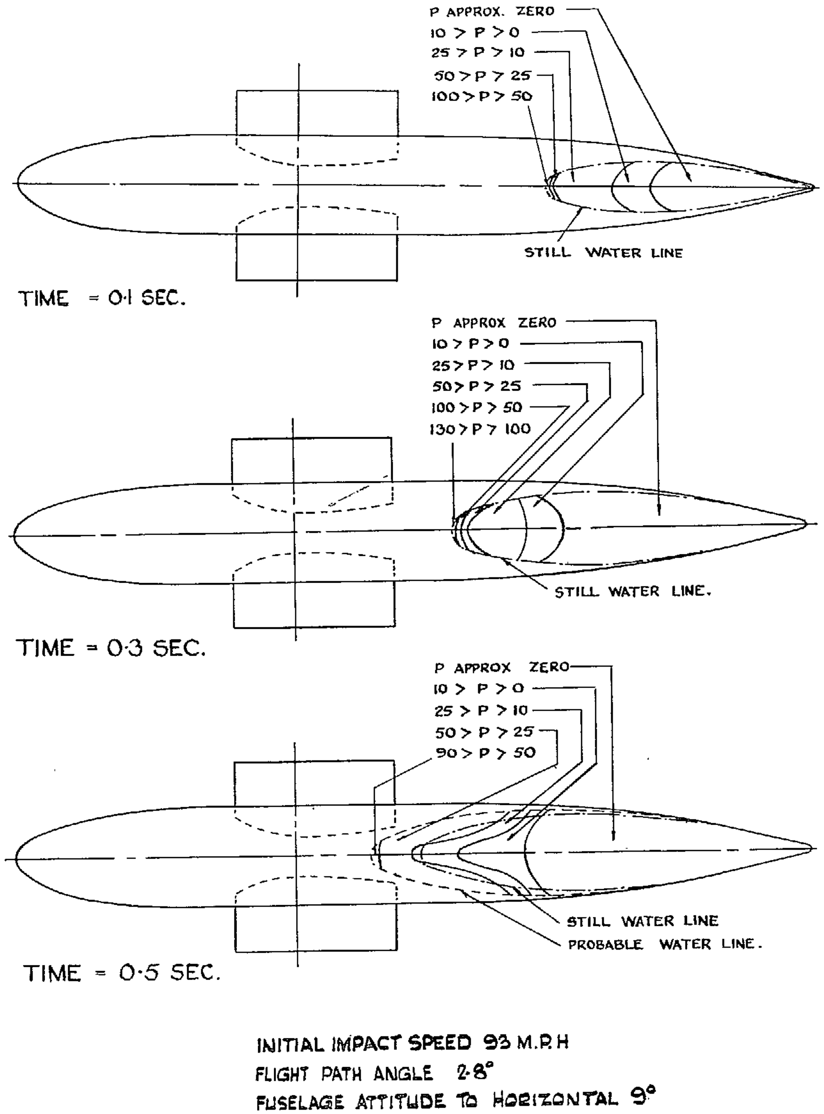


FIG. 21c. Pressure distribution at intervals of 0·2 sec.

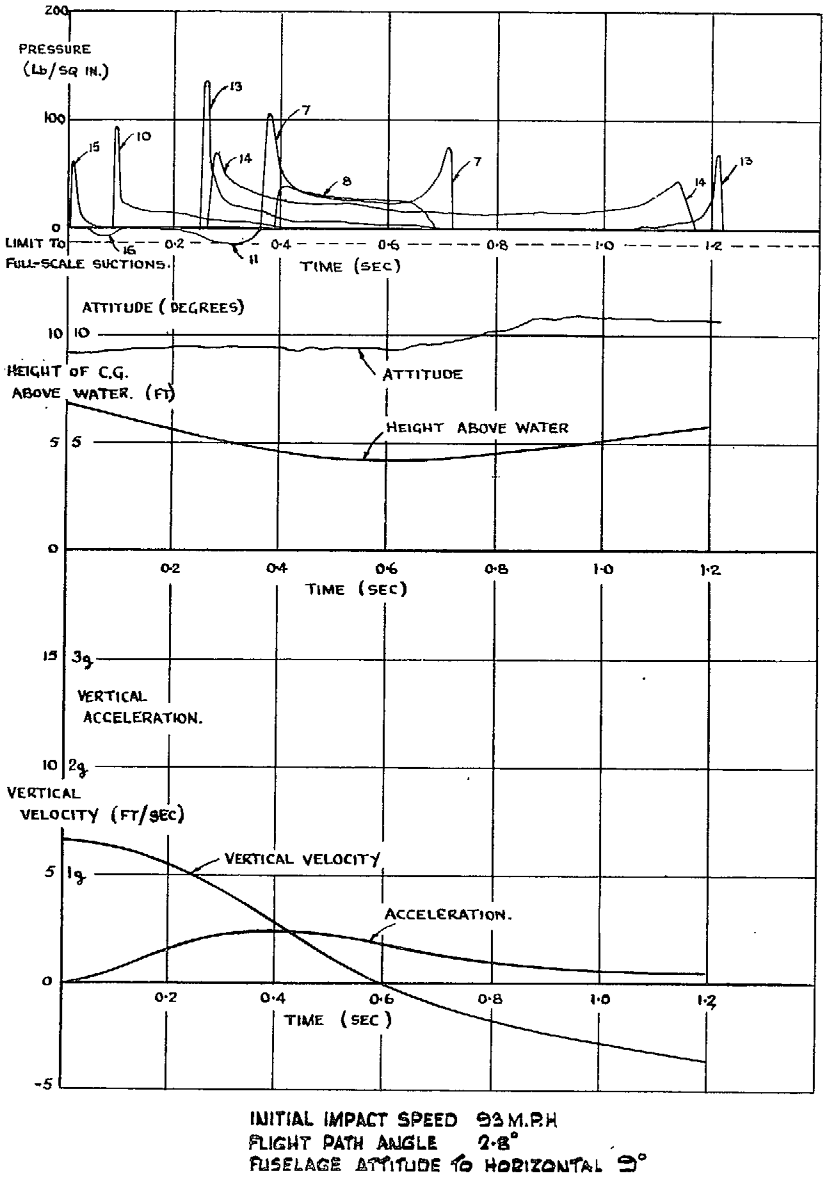


FIG. 21d. Variation of impact parameters during ditching.

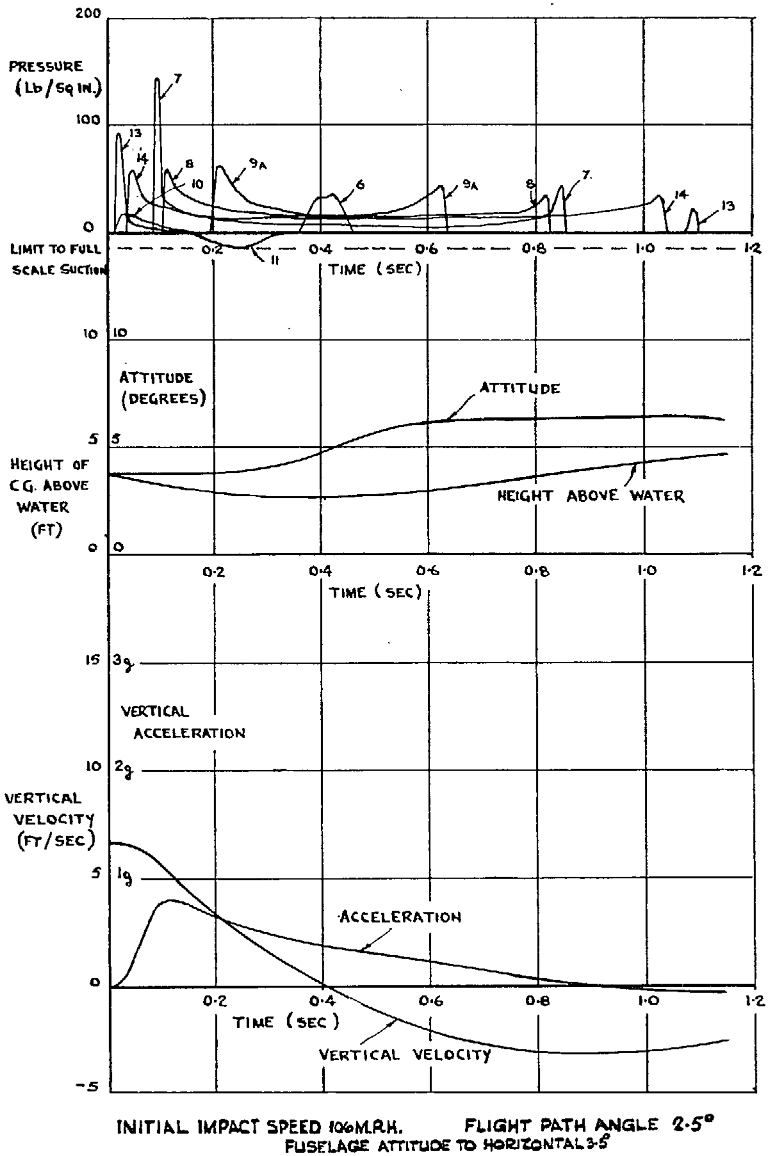


FIG. 21e. Variations of impact parameters during ditching.

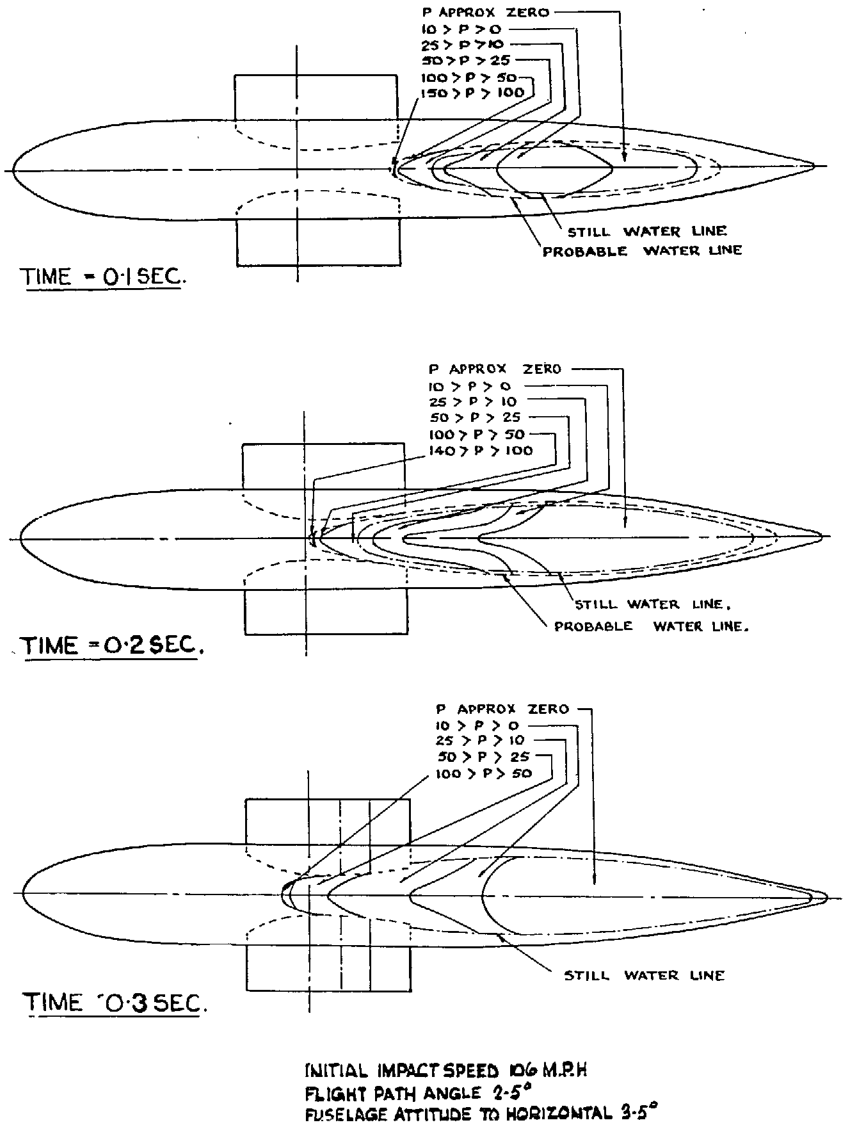


FIG. 21f.—Pressure distribution at intervals of 0·1 sec during ditching.

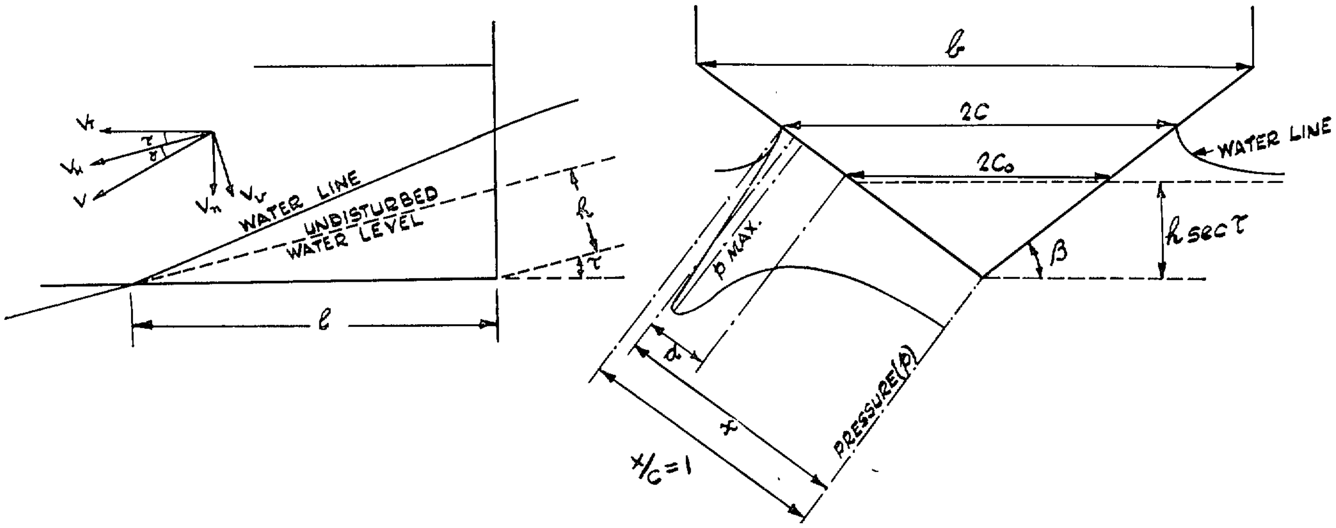


FIG. 22. Conditions during the impact of a plane-faced wedge.

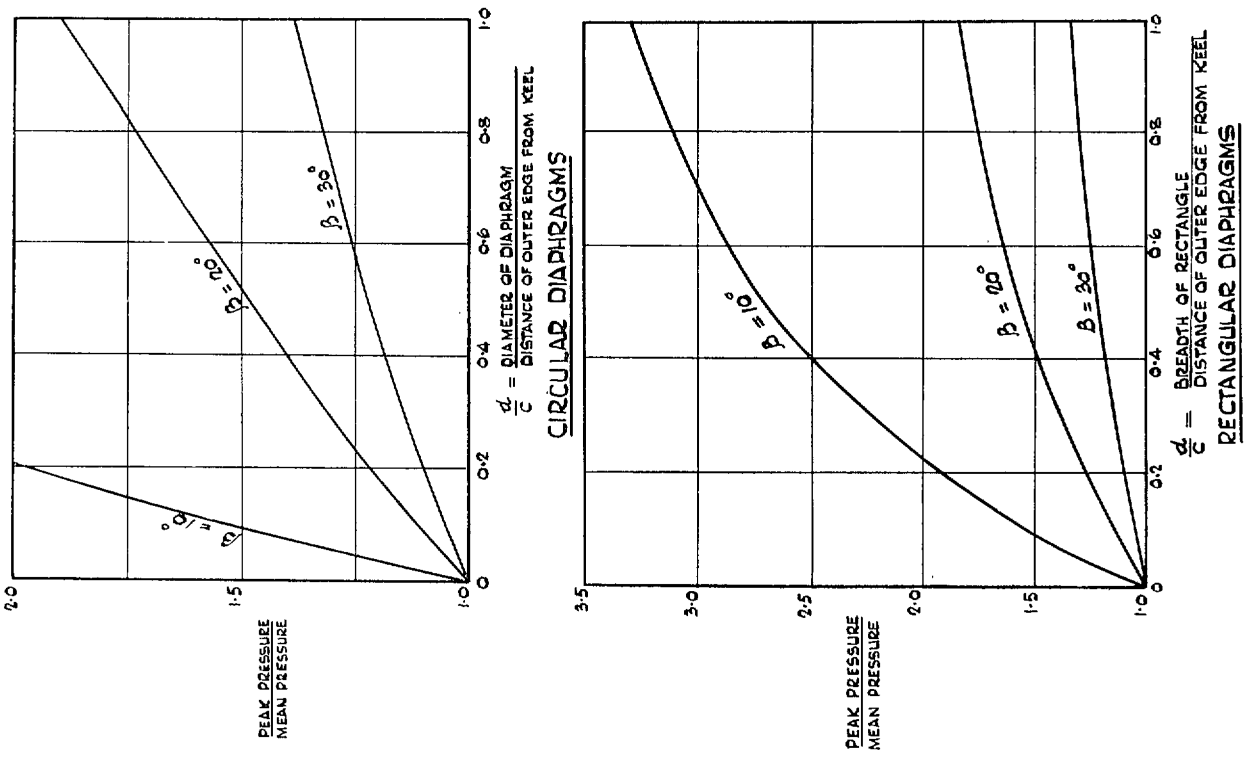


FIG. 23. Variation of peak/mean pressures with proportion of total wetted width over which pressure measured.

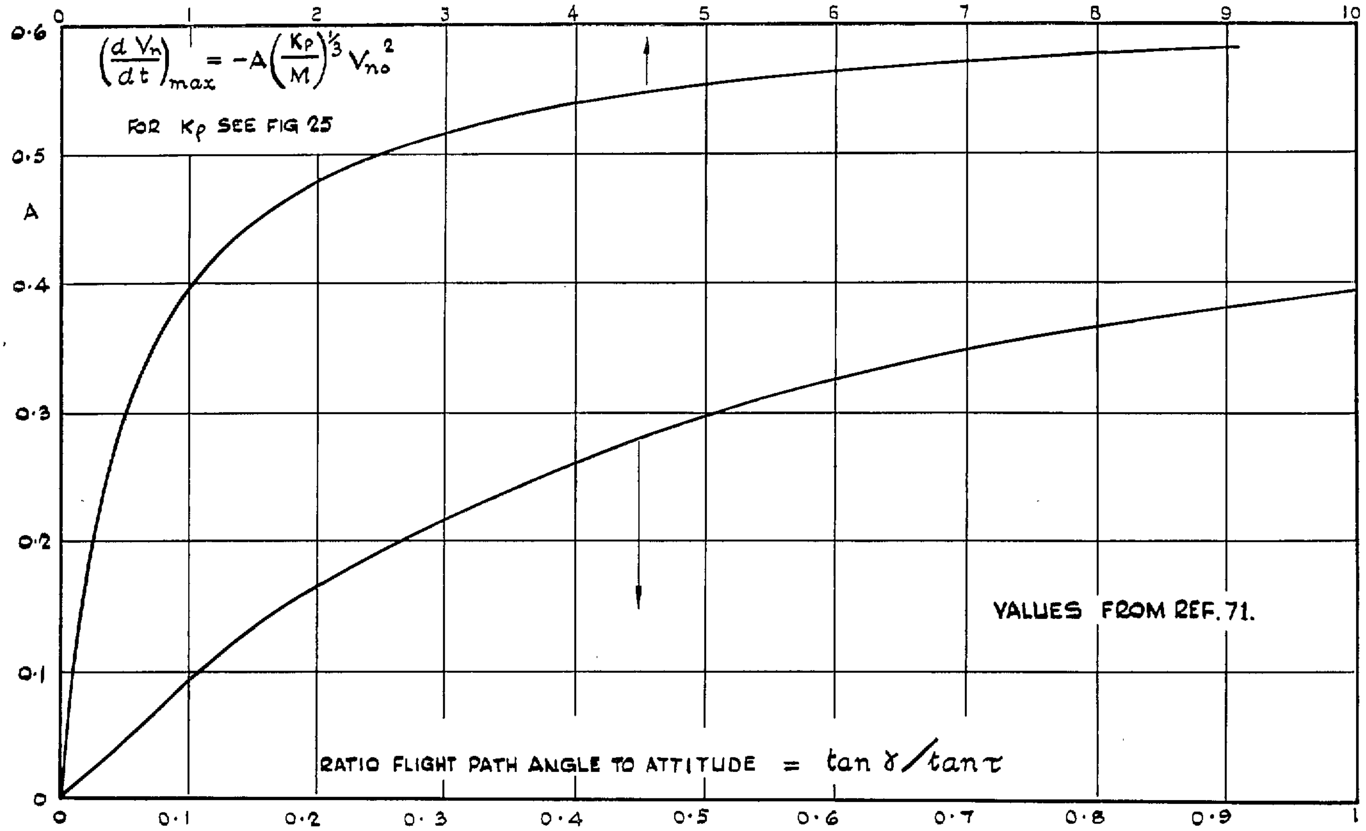


FIG. 24. Maximum water impact force on wedges.
(Approximate values of acceleration factor A.)

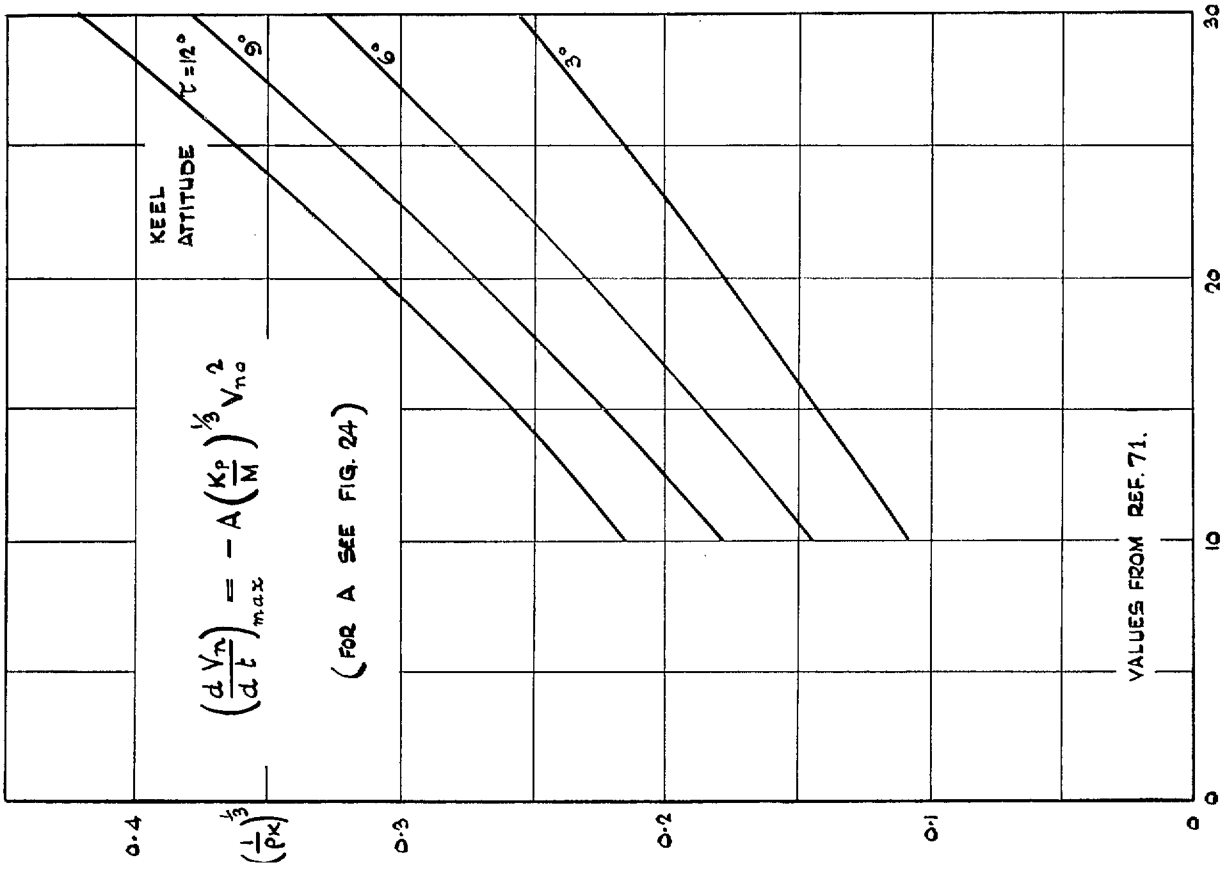


FIG. 25. Maximum water impact force on wedges.
(Approximate values of associated mass constant K.)

(2465) 18/9296 K.5 11/57 Hw.

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