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# Flight Investigation of Some Airworthiness Problems of Civil Boat Seaplanes

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J. TAYLOR, J. E. ALLEN and A. G. SMITH

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# Flight Investigation of Some Airworthiness Problems of Civil Boat Seaplanes

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*Summary.*—A general investigation has been made into measurement, control and performance problems associated with boat seaplane take-off and initial climb. Particular attention was paid to engine failure during take-off and initial climb, and also to the criteria to be used for defining the minimum speed for control in the air.

The aircraft employed was a *Solent* flying-boat of weight 78,000 lb, powered by four Hercules Mark XIX engines.

The general conclusion is that the present methods used for landplanes are also applicable to seaplanes, with certain modifications to meet water-stability requirements and the greater freedom of manoeuvre available with respect to heading and position on the water. Specific conclusions follow.

(*a*) A photo-theodolite technique may be successfully used for measuring seaplane take-offs and landings but is cumbersome and wasteful of labour in practice. Methods are being investigated of recording both distance and height from inside an aircraft.

(*b*) Simulated engine failures at speeds between 30 knots and 108 knots (take-off speed 88 knots) confirm that there is no undue hazard peculiar to seaplanes, apart from a possible one which could result from a combined yaw and pitching followed by porpoising instability in the mid-planing speed range.

(*c*) The effect of cross-wind was inadequately explored, but results indicated that it would increase the minimum control speed on the water. The definition of a cross-wind case should be given in terms of the actual wind speed and heading relative to the aircraft, and not simply in terms of a cross-wind component. A head-wind component considerably helps stability. Separate design cases should be considered for differing operational roles.

(*d*) Waves, short compared with the length of the hull, should have little effect on take-off behaviour or minimum control speed, but long waves, greater than the length of the hull, may render engine-failure cases dangerous if there is inadequate longitudinal stability. Requirements for rough water should, as in the cross-wind case, be considered separately according to the operational roles.

(*e*) The minimum speed for control with one engine cut in the air, $V_{MCA}$, was found to be still the best criterion for safety speed for the climb-away case, but on the *Solent* a maximum factor of $1 \cdot 05\ V_{MCA}$ was found to be ample. The aircraft was in fact safe in practice at $V_{MCA}$. Loss of take-off performance at higher speeds was severe. An alternative standard to this speed was found to be $V_2$, defined by the minimum speed at which 30-deg bank turns of rate $1 \cdot 5$ could be made.

(*f*) The seaplane designer should aim to provide sufficient control in direction and roll to allow the pilot to regain his original course when engine failure occurs at speeds above 90 per cent of the take-off speed, i.e., $V_{MCW}$ should be not more than 90 per cent of the take-off speed which, in turn, should be decided by drag and stability on the water. It is not desirable that seaplanes should have to be held down to excessively high speeds, or re-landed at high speeds at take-off weight in rough water and particularly in swells. The provision of adequate control should not be difficult in sheltered water operation if sufficient float strength be provided. The floats must be designed for water impacts at high planing speed. For operation in long waves, *i.e.*, open sea, it may prove necessary to design hulls of length/beam ratios of about 15 in order to achieve sufficient inherent porpoising stability.

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1. *Introduction.*—Within recent years, the Marine Aircraft Experimental Establishment has been investigating the airworthiness requirements and test techniques for civil boat seaplanes, the range of work being broadly similar to that undertaken on landplanes by the Civil Aircraft Test Section at the Aeroplane and Armament Experimental Establishment[1].

The need for such an investigation has arisen since the war, as a result of the extended scope of civil airworthiness requirements promulgated by the International Civil Aviation Organisation and administered in this country by the Air Registration Board[2]. In particular, the general desire to formulate requirements in terms of quantitative, in addition to qualitative, measurements called for revised test procedures. Extensive flight testing on landplanes has already led to agreed methods, but these did not necessarily apply to seaplanes.

The specific terms of reference were:

(*a*) to investigate and provide data on problems of civil flying-boats, in relation to the international and national airworthiness requirements

(*b*) to establish recommended test techniques

(*c*) to examine possible development features of flying-boat design applicable to civil aircraft.

As a result of discussion between representatives of the Air Registration Board and the Ministry of Supply, the following programme of work was agreed:

(*a*) Measurement of the relevant basic performance characteristics of the aircraft, such as position error, stalling speeds, etc.

(*b*) Investigation of:

- (i) the technique of measurement of take-off and landing distances
- (ii) the effect of engine failure during take-off on performance and handling
- (iii) the relevance to flying-boats of landplane safety speed and power-failure criteria
- (iv) the effect of atmospheric and water conditions, *i.e.*, wind vector, temperature, swell, etc., on take-off and alighting behaviour and performance, with all power units operating
- (v) the effect of braking propellers on water manoeuvrability and landing distances.

Most of the experimental work has been completed and the present report contains an analysis based on a representative selection of results which covers the investigations listed above.

2. *Description of Aircraft.*—External photographs of the aircraft are given in Fig. 1. A general arrangement drawing is in Fig. 2 and aerodynamic and hydrodynamic data in Appendix I.

The aircraft, N.J. 201, was the first production military *Seaford* I and was used by British Overseas Airways Corporation under the name of '*OZZA*' for preliminary assessment of the *Solent* type and later converted specially for these tests. This conversion involved the removal of all turrets and military equipment, and replacement of the former by fairings to the *Solent* profile. The *Seaford* I float chassis was replaced by the latest *Solent* type, which puts the floats 7 ft further outboard. The original Hercules XIX engines were retained, but the exhaust system and air intakes were changed to the *Solent* type. The aircraft was thus hydrodynamically and aerodynamically representative of a four-engined British civil flying-boat of the immediate post-war years, but was inferior in engine power to the later development of the type, in particular to the *Tasman Solent* 4 (Hercules 733 engines).

A fresh-water ballast system was installed for overload tests and for changes of centre of gravity, fourteen tanks being arranged in pairs along the length of the lower deck interconnected by piping, water being transferred by two semi-rotary hand pumps. The tanks were hose-filled from a tanker marine craft and the full water load could be gravity jettisoned in flight in about 15 minutes.

3. *Loadings.*—The *Seaford* was originally designed for the Royal Air Force to have a maximum weight of 71,500 lb[3,4] with an overload of 75,000 lb. This was later increased to 78,000 lb at which weight the type was cleared prior to the production of the *Solent* for B.O.A.C. having higher powered engines. The re-engined *Solent* 4 was accepted for full A.R.B. certificate of airworthiness at 79,000 lb and has been cleared for 80,000 lb in New Zealand.

The aircraft was weighed at M.A.E.E. in three attitudes and the vertical and horizontal c.g. co-ordinates calculated. For exploratory tests, a light weight was used which was later increased in stages to the maximum all-up weight of the type, *viz.*, 78,000 lb.

| Condition | All-up weight (at take-off) (lb) | Centre-of-gravity position | |
|---|---|---|---|
| | | in. aft of datum* | per cent S.M.C.† |
| A | 62,800 | 10·8 | 26·6 |
| B | 63,300 | 14·2 | 28·4 |
| C | 72,600 | 13·8 | 28·2 |
| D | 78,200 | 14·4 | 28·6 |

4. *Instrumentation.*—4.1. *Aircraft.*—The instrumentation was planned to record quantities required for both performance and handling tests in one auto-observer using either F.24 still cameras or Bell-Howell A.4 cine cameras. The former were operated by hand down to intervals of 1½ seconds and the latter were used at 5 frames per second. The instrument panel was concave to the camera in order to avoid reflection and reduction of the intensity of the illumination. The auto-observer, camera, gyroscope and accelerometers were controlled by a master switchboard adjacent to the panel or by a wandering lead from any position on the upper flight deck. Details of the instruments used and the quantities recorded together with their accuracy, are given in Appendix II.

4.2. *Functioning of the Instrumentation.*—All instruments were calibrated prior to the commencement of the trials and checked as necessary throughout the tests. The accelerometer was checked for damping and the pitch recorder for dynamic response. Considerable care was taken to minimise the backlash in control movement and trimmer indications. The control-circuit frictions were measured. Two major difficulties (instrumentation) are recorded here, because of their relevance to general civil trials.

(*a*) *Side-slip indication.*—The vane transmitter was mounted on the end of a horizontal pole near the port wing tip and 4 ft ahead of the leading edge, Fig. 1. This distance is 0·182 of the local chord and is slightly less than recommended. The behaviour of the vane transmitter was satisfactory when airborne but it developed vertical oscillations during take-off and landing, the result of the cumulative effects of flexibility of the wing in bending and twisting of the pole. This was most severe at the lower planing speeds and resulted in erratic readings and damage to the balancing of the instrument. To increase the stiffness of the pole would have been fruitless even if possible, because of the contributions of the wing flexure. Added complications were the impossibility of calibration when afloat (this was done ashore by theodolite), and awkwardness of servicing except in the calmest of seas. The alternative of using a 'Kollsman' yawmeter and a differential pressure gauge was considered, but this was not used because it was considered that the lag in the long pipe lines between the wing tip and the automatic observer would seriously affect the results during manoeuvres.

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* Measured parallel to hull datum line.

† Measured parallel to S.M.C.

(*b*) *Trailing static.*—The trailing static was lowered from the camera hatch under the counter behind the rear step, a position which had been found successful on *Sunderlands.* With this aircraft, however, at speeds exceeding 110 knots severe oscillations were set up in the trailing cable, which travelled outwards from the aircraft and frequently caused failure of the rubber hosing at the trailing static head. The oscillations are thought to be caused by an eddying wake, most probably originating at the main step. An alternative arrangement could be to trail the static from a forward porthole or from the second entrance door, passing the tubing through a fairlead mounted well clear of the hull side.

(*c*) *Time recorder.*—The three-second stop-watch, used at first, gave probably greater accuracy than was justified by the other instruments, but the instrument was found to be difficult to read because of its small inner dial. This was later replaced by a large Veeder counter operated by a Cambridge master contactor indicating at half-second intervals. For time intervals smaller than this, time readings were plotted against the cine-camera frames and interpolated.

4.3. *Auxiliary Instrumentation.*—The wind speed was measured by a hand-held vane anemometer from a motor launch drifting with the tide, the launch being situated midway along the take-off path. The tide speed was measured occasionally during the test series by anchoring the launch and timing the passage of a small floating object as it passed the length of the boat. VHF contact was maintained with the aircraft from the launch. The instrumentation for recording take-off distance is dealt with separately in section 6.

5. *Preliminary Tests.*—5.1. *Position error—Figs.* 3 *and* 4.—Pitot position error was measured against pitot in venturi and found to be negligible at all weights and all airspeeds, *i.e.*, all attitudes. The static error was measured by the aneroid method at 61,000 and 77,000 lb at four flap positions and from 90 knots A.S.I. to 150 knots A.S.I. The static error from 70 to 95 knots was also measured by the trailing static method and these results agree with those found by the aneroid method where the speed ranges overlap.

The variation of combined P.E.C. with flap opening and air speed is shown in Fig. 3, and interpolated curves for all weights in take-off configurations are in Fig. 4. During take-off the air speed was measured by means of pitot in venturi and a static tank giving negligible position error.

5.2. *Stalls.*—The definitions of requirements are given in Appendix III.

In this preliminary investigation, the stalling qualities were determined at weights of 60,000 to 78,000 lb, by pilots differing in skill and experience. Only the power-off cases were investigated, and tests were of an exploratory nature, but some measurements of equivalent air speeds were made, using a trailing static head (*see* section 4.2(*b*)).

Although the A.R.B. regulations require that the initial speed of approach to the stall be 1·4 times the stalling speed to be measured with wings level, it was found that a factor of 1·2 to 1·3 was sufficient from the handling aspect to ensure the required steady decrease of speed of about 1 m.p.h./sec.

Generally, results showed that the present A.R.B. regulations for landplanes may be applied to seaplanes, as would be expected.

The measured stalling speeds and qualitative handling results are summarised in Table 1.

5.3. *Determination of $V_{MCA}$, Minimum Speed for Control in the Air.*—Details of an investigation into the meaning of $V_{MCA}$, and how it can be defined and measured for a four-engined aircraft are given in section 9. In this section the standard definition of Appendix III is used and results given of preliminary tests made to determine its value, which was used in the course of the take-off and landing performance investigation. It was measured at weights of 72,000 and 78,000 lb by a number of pilots differing considerably in skill and experience.

For the first preliminary determination, $V_{MCA}$ was approached by throttling the critical engine (starboard outer) at a speed well above $V_{MCA}$, and gradually decreasing speed until the limits specified in the definition of $V_{MCA}$ were achieved. Sudden engine failure was next simulated at a speed slightly above this, and subsequently at decreasing speeds until $V_{MCA}$ was reached. This speed was found to be 98 knots E.A.S., the limit being decided by the maximum rudder force required to avoid a change of heading of 20 deg.

At $V_{MCA}$, no exceptional skill was required to prevent loss of height or to control the motions resulting from engine failure, even when the aircraft was near the water. Below $V_{MCA}$, controllability did deteriorate, the rudder force became very heavy, and at 90 to 94 knots E.A.S. some rudder oscillation was noticeable.

$V_{MCA}$ was re-assessed at intervals during the trials as different pilots were employed. Consistent results were obtained from all pilots who made the test.

6. *Methods of Measuring Take-off and Landing Performance.*—It has been customary for some considerable time for landplane take-off and landing performance to be measured as the ground distance covered from or to rest, in clearing a standard obstruction height of 50 ft. For seaplanes, however, it has been customary to quote only waterborne times, mainly because this quantity was considered a better measure of the aircraft's take-off safety than its ability to clear an obstacle, when airborne. The technical difficulty of measuring horizontal and vertical distances over water contributed to this point of view. An arbitrary figure of about 60 sec, for the maximum permissible waterborne take-off time, was specified, and experience with many types showed that this criterion gave both reasonable distances in terms of the bases available and acceptable rates of climb after take-off. However, this figure is only applicable to the order of size of aircraft on which it is measured.

With the advent of more stringent international safety requirements for take-off, an empirical dimensional standard of this kind becomes completely inadequate as a guide to the general take-off performance of seaplanes. Indeed, for large seaplanes, it may impose a very severe take-off standard which penalises unnecessarily the earning capacity of the aircraft[5].

Post-war I.C.A.O. and A.R.B. Airworthiness Requirements call for the measurement of waterborne distances, and also the distances to clear 50 ft. The stages of work needed to establish a form of requirement for seaplane take-off and landing performance may be defined in the following parts.

(*a*) The derivation of a method of measuring take-off and landing distances, to and from 50 ft.

(*b*) The correction of the measured distances to standard atmospheric conditions, *i.e.*, corrections for wind speed, air and water density, temperature and humidity.

(*c*) The effect of engine failure on take-off and landing distances, and climb-away speeds.

(*d*) The effect of braking propellers on water manoeuvrability and landing distances.

(*e*) The formulation of quantitative requirements, based on statistical analysis.

The experimental aspects of parts (a) and (c) are reported in the following sections.

Part (*b*) has been considered in detail in Ref. 6.

Part (*d*) has been reported in Ref. 7 in so far as information could be obtained.

Part (*e*) is outside the scope of the present investigation but some relevant information is given in Refs. 5 and 8. The general conclusion is that it is necessary to define a minimum acceptable acceleration to use during take-off, this being in turn dependent on water roughness conditions.

The bulk of the take-off and landing distance measurements made during this investigation have employed either the single-camera method (F.47), or the synchronised 2-camera method (F.47 and Bell and Howell A.4).

Tests have been made to compare the 2-camera method with the Decca navigator, and active development of an integrating accelerometer is proceeding.

6.1. *The Single-Camera Method.*—This method involves taking a continuous photographic record of the aircraft take-off run, at intervals of about one second. The method is described in detail in Ref. 9.

The main disadvantages of the method are that it requires a link between the camera and the test aircraft, the aircraft is necessarily limited to a restricted take-off and alighting run, the camera is expensive and the film reading and analysis laborious. Since the method depends on the measurement of the aircraft image, local atmospheric conditions may also limit its use.

However, properly handled, the method will give accurate results and is capable of a moderate degree of flexibility, provided sufficient camera bases are available.

6.2. *The A. & A.E.E. 2-Camera Method.*—The general principle of this method is that the bearing of the aircraft from either end of a surveyed base-line is continuously recorded during the take-off run by two synchronised cameras. The cameras utilised for this investigation were an F.47 and a Bell and Howell A.4, modified to record time and bearing.

At A. & A.E.E. the two cameras are synchronised by land-line, such that both take exposures simultaneously. The land-line was found to reduce the flexibility of the method greatly at M.A.E.E., and efficient synchronisation was achieved by starting the stop-watches in both cameras and in the aircraft on receipt of a suitable signal from the aircraft.

The Bell and Howell camera was operated at five frames per second, and the F.47 at one frame per second. This allowed simultaneous exposures to be extracted from both film records.

The great advantage of this method over the single-camera method lies in its independence of the size of the aircraft image for a measurement of the position of the aircraft. Thus the range of take-off paths for a given base-line is greatly increased, and the method is operable if the aircraft is at all visible.

The main disadvantage of the 2-camera method is the extra complication of using two cameras in place of one, the additional staff required and the additional chances of mechanical breakdown.

6.3. *The Decca Navigator.*—A comprehensive range of tests have been made both at Felixstowe and Cowes in collaboration with Messrs. Saunders-Roe, to investigate the feasibility of using the standard Decca Navigator equipment as a means of measuring take-off distances. It has the great advantage that, providing Decca coverage is available, the equipment is contained entirely within the aircraft and is, therefore, independent of any shore organisation, apart from the ground transmitter which functions continuously.

The equipment was installed in a *Sunderland* aircraft. The only modification to the standard unit was to fit a stop-watch which could be conveniently photographed with the Decca instruments.

To calibrate the Decca Navigator and to obtain its degree of accuracy the 2-camera method was used as a standard of reference.

The Decca Navigator is a radio equipment which gives the position of the aircraft in terms of co-ordinates referred to a standard grid. The basic principles are given in Ref. 10. For sufficiently small areas, the grid is composed of straight lines.

Providing the indicators within the aircraft are read sufficiently accurately and the lattice is not distorted, the position of the aircraft at any stage of the take-off may be obtained from a continuous record of the Decca Navigator dials. By synchronising this continuous record with the shore cameras, a direct comparison of take-off paths, as indicated by the 2-camera method and by the Decca Navigator, may be obtained.

Preliminary tests were made in the approaches to Harwich Harbour. Only a few take-offs were made. The results of these tests were encouraging, although the take-off paths obtained by the two methods were displaced laterally one from the other by some 500 to 600 ft, and there was a curve in the Decca path not indicated by the 2-camera method. However, the agreement between time–distance-run plots was good. The Decca Navigator Company confirmed that both of these discrepancies were in all probability due to a systematic error in the Decca lattice for the Harwich area, and this could only be determined by calibration. They considered that such shifts were likely to occur in coastal areas, and that if the tests were done away from the distorted area good agreement should result.

Considerable interest was taken in the use of the Decca Navigator as a quick means of measuring take-off distance and more comprehensive tests were made in the Solent area off Cowes. The primary consideration was the application of the Decca for the *Princess* flying-boat trials.

The results of the tests made in the Solent area were not as encouraging as the preliminary tests made in the Harwich area. The general reproduction of the aircraft path was considerably better than in the Harwich area but there was a mean discrepancy between distances run as determined by Decca and as obtained from cine-photograph–theodolite tracking of — 7 per cent, with a scatter of plus or minus 8 per cent. Particular cases differed by 20 to 25 per cent, and this degree of inaccuracy makes the Decca Navigator unsuitable for take-off measurement.

It has not yet been possible to arrive at a suitable calibration of the Decca Navigator, which could eliminate or even reduce such discrepancies.

6.4. *Take-off Distance by Integration.*—The three foregoing schemes suffer from the disadvantage that, in varying measure, they depend on some form of ground equipment. The ideal take-off measurement device is one contained entirely within the aircraft.

From time to time, the possibility of achieving this by doubly integrating forward acceleration has been considered, but the greatest drawback to this scheme has been the difficulty of developing a sufficiently accurate acceleration and attitude measuring device. The cumulative errors of accelerometer, attitude measuring device and system must not exceed the required overall order of about 5 per cent.

There are at least two possible methods of approach. The first involves mounting an accurate accelerometer on a gyroscopically stabilised platform which will maintain the accelerometer at a constant angle, relative to the water surface during take-off. The second involves the correction of the outputs of accelerometers mounted rigidly in the aircraft, by means of a vertical gyroscope. Both methods have obvious advantages and disadvantages, and prototype instruments, embodying both principles, are now being investigated at M.A.E.E.

7. *Take-off Distances and Effect of Engine Failure.*—The aim in the take-off–distance measurements was to provide a basic set of results, which could be used to give the effect of such parameters as climb-away speed, engine-failure speed, and so on.

The technique adopted for all take-offs followed the same pattern. At the start of take-off, the aircraft was aligned with the existing wind direction with the engines throttled, and with the taxi speed at a minimum (usually 3 to 4 knots). On receipt of the starting signal, the pilot opened all four throttles as smoothly and rapidly as possible (3 to 4 seconds to maximum power), and then followed what he judged to be a normal take-off path, easing the aircraft off the water at the specified unstick speed. The aircraft was then held as close as possible to the water, and allowed to accelerate in level flight up to the specified climb-away speed. At this speed, the aircraft was climbed with the pilot attempting to maintain constant speed, without undue ' pull up '.

The highest climb-away speed investigated was fixed by the stipulation given in British Civil Airworthiness Requirements that it must not be less than the aircraft safety speed which is, in turn, defined as the greater of $1{\cdot}15V_{SI}$ or $1{\cdot}1V_{MCA}$. The latter quantity defines the speed for the *Solent*, and it is 108 knots E.A.S. for all weights investigated. The lowest climb-away speed actually investigated was limited by test safety considerations and was 90 to 91 knots E.A.S., *i.e.*, 2 to 3 knots above the unstick speed of 88 knots E.A.S.

A few climbs were made allowing the aircraft to accelerate and climb steadily from unstick, the aim being to arrive at screen height at a pre-determined air speed.

In order to avoid an accumulation of errors, the effect of the appropriate parameters has been confined to the region under investigation, *e.g.*, for the effect of climb-away speed, a comparison of airborne paths only has been given, since the waterborne path will obviously not be affected.

Considerations of control with one engine cut and the techniques developed to do the full-scale tests, are given in section 8.

7.1. *Take-off Distances—All Engines Operating*.—The measured waterborne and airborne distances for two weights are given in Figs. 5 and 6. These have been corrected to zero wind and standard power by the methods of Ref. 6.

The effect of climb-away speed is clearly indicated in Fig. 6, which confirms that, for a reduction in climb speed from 108 to 98 knots E.A.S. a reduction in airborne take-off distance of 900 ft may be expected, *i.e.*, about 18 per cent of the total take-off distance.

Reducing the climb-away speed from 98 to 90 knots gives a further decrease of 600 ft.

The minimum safe climb-away speed, allowing for engine failure, was judged to be 98 knots, i.e., $V_{MCA}$ (Reference sections 6 and 7).

7.2. *Take-off Distance—One Engine Cut at Various Speeds*.—The penalty imposed by an unduly high safety speed is even greater for take-offs with engine failure. The results are given in Table 2, and plotted in Fig. 7 which shows the measured total take-off distances at climb-away speeds of 108 knots E.A.S. ($1{\cdot}1V_{MCA}$) and 98 knots E.A.S. ($V_{MCA}$) for a range of engine-failure speeds. If the engine be cut at the minimum power-failure criterion of 90 knots E.A.S. ($1{\cdot}1V_{MCW}$) there is an increase of 50 per cent in total take-off distance if the climb-away speed is increased from 98 knots E.A.S. to 108 knots E.A.S. This applies to temperate and sub-tropical atmospheric conditions.

Finally, the relative advantages in performance to be gained by climbing away and re-landing after engine failure must be considered. Fig. 8 and Table 3 give the measured accelerate–stop distances for temperate and tropical conditions. These are compared with the corresponding climb-away distances.

Here again, the performance case against high safety speeds is reinforced. The effect of a safety speed of $1{\cdot}1V_{MCA}$ (108 knots) is to set the performance–power-failure point at 95 knots, which lies well above the normal take-off speed of 88 knots. Thus, a pilot having an engine failure between 88 knots and 95 knots E.A.S. must either re-land and thereby run the risk of damaging the aircraft if the re-landing area is disturbed by swell, or must continue and incur a penalty in distance required, which may amount to 2,000 ft if the failure occurs immediately after take-off.

With the lower climb-away speed of 98 knots E.A.S., the performance–power-failure point lies well below the minimum stipulated by the regulations of $1{\cdot}1V_{MCA}$ and, although there is some penalty because the pilot is not allowed to take-off until the minimum power-failure point is reached, there is no question as to the best procedure after this point, since both performance and safety are specified by continuing the take-off.

8. *Control and Stability Following Engine Failure During Take-off into Wind.*—The I.C.A.O. and A.R.B. Airworthiness Requirements are framed to ensure a high degree of safety in the event of accidental engine failure occurring at any stage of a flight. Of all stages, the take-off is the most critical and the relative probability of an engine failure highest. The present British requirements for landplanes have been qualified by the results of exploratory flight tests made in 1944 at A. & A.E.E. on a *Fortress* III[11] and a *Mitchell*[12]. Since then many landplanes have been tested to these requirements.

The general problem of engine failure during take-off has thus been fairly well established for landplanes for some time and a comprehensive review is available[1]. The tests made on N.J.201 were of the same kind as those made on landplanes, the object being to find points of difference in behaviour which would need special regulations for the flying-boat.

The main differences between ground behaviour of landplanes and water behaviour of seaplanes likely to affect engine-cut take-off and landing performance are as follows:

(*a*) It may be dangerous to hold a seaplane down on the water at speeds much in excess of its normal take-off speed. The faster the speed, the finer the planing angle of the forebody, which may lead to severe divergent directional instability or to porpoising. Rough water is likely to throw the seaplane off at high speeds. There is also a large increase in drag at small angles. It is thus usually impracticable to keep a seaplane on the water until it reaches safety speed for climb, as can be done for landplanes with tricycle undercarriages.

(*b*) It is inadvisable to allow a wing float to make a heavy impact at high planing speeds with present-day design requirements. Re-landing with a banked wing is probably more dangerous on a contemporary seaplane than a landplane because the resulting float impact and drag loads will also cause failure or set up excessive yawing moments.

(*c*) The flying-boat is hardly ever restricted laterally in its take-off path to the same extent as the landplane on a runway.

(*d*) The response in yaw of a flying-boat to the initial swing caused by a suddenly throttled engine may differ appreciably from that of a landplane.

The main features of the landplane requirements are the stipulation of a safety speed below which the aircraft should not be climbed away, and a power-failure speed below which the take-off must be abandoned should an engine fail. These two speeds depend on the type and design of aircraft and both considerably affect the take-off performance. The current definitions of these and associated terms for landplanes are given in Appendix III.

Consideration of the control problem during engine failure on the water may be conveniently divided into two speed regions:

(*a*) below $V_{MCW}$, where it is necessary to bring the aircraft to rest in an orderly fashion and avoid structural damage

(*b*) above $V_{MCW}$, where the primary problem is the provision of sufficient inherent stability and control to ensure that performance is not penalised.

8.1. *Tests Made and Piloting Techniques.*—The flight tests were not made as for a full certificate of airworthiness but in a manner likely to bring out the special flying-boat features. Thus, only a representative midrange c.g. position was used and flying was limited to winds less than 10 knots to achieve consistent performance results. Exploratory qualitative tests were made at 62,000 lb weight but most quantitative results were obtained at 72,000 and 78,000 lb.

At the start of the tests the minimum control speed in the air, $V_{MCA}$, was measured and, as the pilots became more familiar with the aircraft, engine cuts were made during the later stages of the waterborne run. Firstly, an inboard engine was progressively throttled back, and when the flying boat was shown to be easily controllable, one outboard engine was progressively throttled. The minimum control speed on the water, $V_{MCW}$, was then found for the most unfavourable engine, which proved to be the starboard outer. Finally, engine failure of the critical engine was simulated at all stages of the waterborne and airborne parts of the take-off.

For the handling tests, the pilot knew which engine was to be throttled, but the decision as to the cut speed and the actual cutting of the engine was made by the senior observer. The pilot was, therefore, more prepared for taking corrective action than would be a pilot meeting accidental failure and consequently during some of the runs artificial delay effects were represented. A pilot will take instinctive action to correct the rate of turn which develops as soon as the engine fails, and therefore normal rudder movements were permitted.

Two forms of aileron recovery were investigated. For the first test, the pilot was allowed to initiate recovery immediately the engine was cut. For the second, a delay of 1 to $1\frac{1}{2}$ seconds occurred before aileron recovery started. No definite stipulation was made on the delay in throttling back the live engines, but wherever possible this followed the initiation of aileron and rudder correction.

8.2. *Results.*—The behaviour following engine cut is summarised in the following table for the whole speed range, water and airborne. Time histories are given in Figs. 9 to 15.

*Qualitative Effects of Suddenly Throttling the Starboard Outer Engine*

Mean Weight : 77,000 lb. Wind speed : Less than 10 knots. Sea : Calm.
All engines at full take-off power before cut. Flaps 1/3. Gills open.

| Speed range I.A.S. (knots) | Approx. time taken to accelerate through the range (secs) | Behaviour and controllability following engine failure |
|---|---|---|
| 10 to 30 | 7·0 | Negligible rudder or aileron control. Aircraft swings and the dead-engined wing drops and there is a probability of float impact before throttling back. The consequences of this are not serious |
| 30 to 45 | 8·5 | Little rudder or aileron control; there is a marked swing and gradual increase of angle of bank with the possibility of float impact. Quick throttling back needed, but no danger |
| 45 to 60 | 8·6 | Aileron control sufficient to stop float impact even with $1\frac{1}{2}$ sec delay. Rudder power insufficient to hold swing. Considerable danger from porpoising if aircraft mishandled when live engines are cut |
| 60 to 82 | 12·1 | Aileron control sufficient to overcome roll. Rudder control insufficient to overcome swing. Easy to throttle back and abandon take-off |
| 82 to 87 Take-off and take-off to 98 knots | 4·0 | Full control; take-off can be continued in the original direction after a very slight lateral change of take-off path. Rudder force exceeds 180 lb |
| 98 and above | | Full control and no change of direction. The rudder force is less than 180 lb |

8.2. (*a*) *Engine-cut speeds below* $V_{MCW}$.—Motions about all three axes are important. Roll because of the danger of float damage, yaw because of the lateral divergence and the possibility of induced roll, and pitch because of the danger of general hull damage.

On the *Solent*, lateral control presented little difficulty. At speeds likely to cause float damage, the ailerons were sufficiently powerful, even with an artificial delay of 1 second, to prevent severe float impact. Aileron control on the *Solent* is good, and should be better still in future designs, and the latest strength regulations on float design should ensure that, even if impact does occur at high planing speeds, no damage will result (Ref. 13). Thus lateral control should not be a great problem on future designs.

The directional motion subsequent to engine failure was occasionally disconcerting, but never dangerous on its own. The *Solent* fin and rudder are insufficiently powerful to allow return to the original heading, if the engine is cut at speeds below 80 knots. Part of this ineffectiveness arises from the large rudder angles required in normal four-engine take-off to overcome the yawing moment due to engine torque effects (Fig. 16). The maximum rate of yaw after engine failure was about 6 deg/sec. There was little tendency for the float on the live-engine wing to immerse when the aircraft was appreciably yawed.

There was no sign of directional instability following the engine failure at any water speed or attitude tested, but there might be a danger of such instability if the planing attitude was allowed to reach too low a value at high planing speeds. The sudden removal of slip-stream lift when all engines were throttled might lead to dangerous and sudden ' hooking '.

The greatest hazard when engine cuts were simulated arose from a combination of yaw and porpoising instability. The most dangerous region was that between 50 and 60 knots water speed. Below this speed range, the aircraft is operating near the region of maximum resistance, and the speed falls rapidly as soon as the engines are throttled. Above this speed range, longitudinal-stability range of incidence increases rapidly and porpoising is not so likely to be encountered.

Figs. 17 and 18 illustrate the development of porpoising in the 50 to 60 knots speed range.

The first example shows a case during which the pilot has maintained a constant elevator angle until well after engine failure, and then allowed the elevator angle to decrease. As soon as all the live engines are cut, the aircraft starts to porpoise.

In the second example, the pilot has allowed the elevators to come down immediately after the live engines were cut, and so brought about severe porpoising. During this latter run, the counter of the aircraft was severely damaged[14]. A general view of the damage is shown in Fig. 19.

There are two probable reasons for this severe porpoising: (i) an effective raising of the lower instability limit, owing to reduced lift when the live engines are cut, (ii) a tendency to run into the lower instability region by misuse of the elevator. The second of these causes is entirely at the control of the pilot and the results of this investigation emphasise the need for keeping the elevator up, after the live engines are cut. The first cause probably contributes the greater part of the instability, and its importance depends on the general porpoising stability characteristics of the aircraft and on the amount of slip-stream lift lost when the engines are cut. In this respect, jet aircraft will probably not suffer so much from engine-cut instability as propeller driven aircraft.

The pilot can help the aircraft through this region by throttling back in stages, *i.e.*, port outer engine throttled back rapidly, followed by gradually reducing power of the inboard engines instead of one rapid movement, as illustrated in Fig. 20. It can be seen that the swing is then controlled, and the instability during this critical region reduced. A time history of a take-off in which the throttles are closed in one rapid movement is given in Fig. 21. The pilot's choice must, however, always consider the relative advantages of keeping clear of porpoising and of reducing forward speed as quickly as possible.

8.2. (*b*) *Engine cut at speeds above* $V_{MCW}$.—The definition of $V_{MCW}$, the minimum speed for control on or near the water, is given in Appendix III in terms of $V_{MCG}$ for landplanes. For the *Solent* tests this definition was ignored with respect to the three considerations listed below, so that in effect the $V_{MCW}$ becomes the minimum speed at which the aircraft's original heading could be regained by use of the aerodynamic controls.

(i) The lateral displacement was not measured and no restriction was placed on lateral displacement because this quantity is not of importance for a seaplane.

(ii) The 180 lb limit on footload was ignored, in order to keep the results more general. If the *Solent* were being tested for a C. of A. acceptance and this criterion was the limiting one on $V_{MCW}$, presumably design action would be taken to ensure that the footloads were reduced.

(iii) All the simulated engine cuts were made with the aircraft proceeding into wind. The effect of the cross-wind was investigated briefly, and it caused $V_{MCW}$ to be increased to take-off speed. The *Solent* trials indicate that this is likely to be true for most flying-boat designs, if the cross-wind stipulation be considered necessary.

Figs. 22 and 23 show some typical aircraft movements after simulated engine failures in the region of $V_{MCW}$ with cross-wind. These confirm that lateral control is not a problem and that the designer's main worry is the provision of sufficient directional stability and control to overcome the yaw due to the dead engine.

8.3. *Effect of Sea Conditions.*—The *Solent* trials were confined to calm seas, but there is enough evidence from other test investigations to allow a fairly conclusive statement to be made on the effect of sea conditions on behaviour after engine failure.

Short, choppy seas (up to 3 feet high and 30 feet long for the *Solent*) should not have a great effect on engine-cut behaviour. The chance of float impact is increased and the necessity for adequate strength in the float structure becomes even more important. Porpoising stability should not be affected, providing the elevators are kept well up. The wind which inevitably accompanies such wave forms will have an ameliorating effect on yaw, but make it more difficult to avoid float impact.

The consequences of engine failure while operating in long waves, *e.g.*, open sea swells, may be much more serious. When the length exceeds that of the aircraft, full scale tests have confirmed that aircraft which are designed for sheltered water operation may porpoise violently. In addition, the loss of lift due to throttling the live engines may produce dangerous pitching during the period of deceleration and this, in combination with yaw, may be disastrous[15].

One obvious cure is to take-off, wherever possible, parallel to the swell crests. The aircraft will then behave as if in calm water. Rapid throttling after engine failure will be necessary to avoid turning into the swell.

If take-off into the swell is unavoidable, two possible techniques may avoid porpoising if an engine cuts. The first is to eliminate yaw by throttling the appropriate engine before removing power completely. Some porpoising will result, but the risk of damage will be greatly reduced. The second is to allow the aircraft to swing until it is planing parallel to the swell and then throttling all engines rapidly. The technique to be used will depend mainly on the space available and the amount of lateral control available to prevent immersion of the wing-tip floats.

8.4. *The Effects of Weight.*—There was little change in behaviour between weights of 72,000 lb and 78,000 lb. At the higher weight the acceleration is less, which affects the performance more than the handling. Aerodynamically the aircraft is the same. Because of the effect of the extra weight on moments of inertia, a reduction in angular velocities following engine failure would be expected, but only of a small order. The extra weight gives extra draft at a given water speed and attitude, and hence also reduces the float clearances a small amount.

8.5. *The Effects of Wind.*—The main effect of wind speed parallel to the take-off path is to increase the control power at a given water speed. This gives greater directional and lateral control at an earlier stage of the take-off and hence probably reduces the value of $V_{MCW}$. Any such change was not obvious in the small range of wind speeds tested, *i.e.*, 0 to 10 knots. The effects on engine-failure behaviour of a downwind take-off would be much more severe especially at slow speeds because of the reduction of the contribution of the fin to the directional stability.

Some cross-wind take-offs were made with winds up to 7 knots. There was some deterioration in overall behaviour with engine cutting for speeds greater than 70 knots (Figs. 22 and 23), but tests below this speed were not made. Two factors will be changed. Firstly, the wind will tend to weathercock the aircraft and change the rudder angle needed for 4-engine take-off and secondly, the wind will tend to bury the downwind float. For this aircraft, wind from the starboard side will reduce the rudder power available for checking the swing, but increase the corrective aileron power available to prevent the wing dropping.

8.6. *Re-landing.*—Re-landing after an engine failure in the air presents no problems other than those associated with normal seaplane landings. However, all the re-landings made were into calm or slightly choppy water. There is no doubt that if a re-landing had to be made into a long swell severe hydrodynamic instability would result unless the pilot could arrange to land parallel to the swell crests.

9. *Definition and Measurement of Minimum Safety Speed.*—The safety speed is that speed which the aircraft must attain during take-off, before it can start its climb away. It is at present defined in British Civil Airworthiness Requirements by the fact that it must not be less than $1{\cdot}1V_{MCA}$ and not less than $1{\cdot}15V_{SI}$. These margins of 10 and 15 per cent respectively are quite arbitrary, being based on past experience. Like all arbitrary margins, their application may lead to anomalous results.

In an effort to rationalise the determination of safety speed, the A.R.B. have produced four alternative definitions[16].

(*a*) $V_{MCA}$, the minimum controlled speed in the air, critical engine cut.

(*b*) $V_1$, the minimum speed in straight, steady flight at which it is possible, by pushing the control column forward, to prevent stalling if all engines are together throttled right back rapidly from maximum take-off power.

(*c*) $V_2$, the minimum speed at which, with the critical engine inoperative, its propeller feathered, flaps at take-off position, engines at maximum take-off power, it is possible to make 30 deg correctly banked turns in either direction.

(*d*) $V_3$, the minimum speed in straight, steady flight, flaps at take-off position, c.g. in a position which allows the aeroplane to be genuinely stalled, and engine power

  (i) symmetrically distributed so that it is equal to the maximum take-off power available from three engines

  (ii) symmetrically distributed by throttling the pair of engines whose effect on lift is the greatest. To allow for gusts this speed is associated with a factor

$$F(V_3) = 1{\cdot}03V_3 + 15(V_3 = \text{m.p.h.}).$$

These alternative definitions were investigated during the stalling trials, with the following results.

9.1. $V_{MCA}$.—This speed had been already determined during the preliminary tests (section 5.3). It was re-assessed specially for this part of the investigation with the same results as before (98 knots E.A.S.).

9.2. $V_1$.—Before measuring $V_1$, the minimum safe gliding speed for an engine-off landing was determined by making simulated landing approaches. For the *Solent* at 78,000 lb, this was found to be 120 knots E.A.S. At speeds below this, there was a danger of impact damage to the aircraft, if the final landing check was slightly misjudged.

The minimum speed achieved when the engines were throttled was 75 knots E.A.S., compared with the engine-off stalling speed of 98 knots E.A.S., and the stalling speed with engines at three-quarters take-off power of 71 knots E.A.S. No control difficulties were experienced when the engines were suddenly throttled at this speed, but there was a loss in height of about 500 feet, before the minimum steady glide-approach speed of 120 knots could be attained.

Below 75 knots, there was some aileron overbalance during the climb and this, in fact, limited the minimum value of $V_1$.

9.3. $V_2$.—No difficulty was experienced in making 30-deg bank turns in either direction, with one engine inoperative, down to a speed of 110 knots E.A.S. Below this speed, correct turns could not be made, because of insufficient aileron control.

Since 110 knots is above the value for safety speed, based on $V_{MCA}$, this investigation of $V_2$ was extended to cover turns over a range of rates of turn. For rates of 1, 1½ and 2, the corresponding minimum speeds were 98, 103 and 108 knots E.A.S. for turns against the dead engine, and 96, 102 and 107 knots E.A.S. for turns with the dead engine.

In turns to port against the dead engine, the rudder forces were high, but the limiting factor for turns in either direction was not so much the control forces or movements as the difficulty experienced in controlling the rate of turn and in keeping a steady air-speed. This explains the relatively small differences between turns to port and turns to starboard.

9.4. $V_3$.—With the engines giving three-quarters of take-off power, steady flight was possible at speed down to 76 knots E.A.S. Some airframe buffeting occurred at speeds below 83 knots E.A.S., but this was not sufficient to make flight at 76 knots unduly uncomfortable.

The aircraft stalled in this condition at 71 knots E.A.S. The stall was relatively innocuous, with some dropping of the port wing.

9.5. *Choice of Safety-Speed Criteria.*—The significance of these results must be considered in relation to the actual behaviour of the aircraft when an engine fails during take-off. To determine this behaviour, a series of take-offs was made, simulating engine failure over a range of speeds between unstick speed and the safety speed.

M.A.E.E. pilots found no difficulty in climbing away at 98 knots with engine failure simulated on the level run or during the climb, and pilots and observers agreed that, for the *Solent,* 5 per cent was ample margin over $V_{MCA}$ to allow for varying pilot experience and aircraft performance. This sets the revised safety speed for the *Solent* at 103 knots, a speed which allows a rate 1½ turn during the climb with the critical engine failed. Thus, $V_{MCA}$ or $V_2$ appear to be reasonable bases for a new safety speed criterion for propeller driven multi-engined aircraft.

The other two speeds, $V_1$ and $V_3$, lie well below the minimum speed for safe take-off with engine failure, and they have by themselves little significance for propeller driven aircraft since they do not involve an assessment of the manoeuvrability of the aircraft with the critical engine failed.

The application of these revised criteria to jet aircraft is beyond the scope of the present investigation.

*Summary of Safety-Speed Criteria*
(*Safety Speed*)

| Criterion | | Knots | Remarks |
|---|---|---|---|
| Symbol | Value E.A.S. (Knots) | | |
| $V_{MCA}$ | 98 | k × 98 | k should be 1·05 for *Solent* |
| $V_1$ | 75 | 91 | Not suitable for *Solent* |
| $V_2$ | 103 | 103 | Suitable if based on rate 1½ turn |
| $V_3$ | 76 | 76 | Not suitable for *Solent* |

10. *Cross-wind Performance—All Power Units Operating.*—An investigation was being made at the M.A.E.E. of the general problem of cross-wind performance, with all power units operating, to determine the lateral component of wind velocity at and below which it was safe to take-off and land, irrespective of the side from which the wind is blowing. Particular reference was made to:

(*a*) the comparative values of the limiting cross-wind component on the port and starboard bows

(*b*) the effect of wing angle on the limiting cross-wind component

(*c*) the possibility of using a ' curved take-off ' technique in restricted waterways, where the aircraft is required to take-off outside the limit of out-of-wind angle, *viz.*, take-off commenced on the desired heading, swung to an angle just below the maximum for safe cross-wind performance through the hump and the original heading regained when the aircraft is fully planing.

These problems were not solved, as the tests were not completed before flight tests were stopped.

10.1. *Tests Made and Piloting Technique.*—The tests were not made as for a full Certificate of Airworthiness, but to bring out the special features associated with the flying-boat.

The tests were done in moderate seas, and only the representative midrange c.g. position was used.

Take-offs were made with out-of-wind angles up to 90 deg, but did not cover a complete range of limiting wind velocities. Only a few landings were done with the wind on the starboard bow.

For all take-offs the same technique was used, *viz.*, the aircraft was positioned to the desired heading, all throttles opened up rapidly to take-off position and then throttled differentially to maintain the desired heading. However, to ensure that the take-off performance was not penalised, and for consistency of results, full power was always applied at 55 to 60 per cent of the take-off speed.

The approach speeds were of the order of 105 to 110 knots, with the inboard engines throttled and slight differential throttling of the outboard engines to maintain a straight course. Touch-down was made at speeds of 85 to 90 knots.

10.2. *Take-offs.*—The results obtained on the *Solent* at 78,000 lb indicate that there is a limiting out-of-wind angle for a given wind speed, rather than a safe cross-wind component. This view is supported by the results of tests done on a *Solent* 3 at M.A.E.E.[15]. It is also supported by the qualitative data given in Table 4 and illustrated in Fig. 24. The line drawn in Fig. 24 indicates the limit for margin directional control for the *Solent* and *Sunderland* aircraft, with the wind on the starboard bow.

On the *Solent,* as tested, with the wind on the starboard bow, the near limiting out-of-wind angle was 65 deg with a wind strength of 10 knots.

At angles (out of wind) greater than 65 deg, and with wind strengths of 6 to 10 knots, directional stability was beyond the pilot's control. At the limiting condition, differential throttling and full port rudder were necessary up to 50 knots. In the planing region, *i.e.*, 50 knots to unstick, directional control was impaired by the excessive foot load rather than by rudder movement.

Lateral control was satisfactory throughout the take-off run. A take-off in the near limiting conditions is shown in Fig. 25. Take-offs at angles (out of wind) of 70 deg and 90 deg with wind strengths of 6 to 10 knots respectively, showing aircraft movements, are given in Figs. 26 and 27. A straightforward cross-wind take-off with a wind of 15 knots at 40 deg on the starboard bow, is shown in Fig. 28.

Only one take-off cross-wind was done with the wind on the port bow, and this was made 80 deg out of wind in a wind speed of 7 knots. Control movements on this take-off are plotted in Fig. 29. Very coarse rudder movements were necessary to maintain the desired heading, and lateral control was very poor. The starboard float was touching the water for the major part of the run, and practically full aileron was required to raise the starboard wing at 50 to 60 knots. Aileron force was, however, very slight, being about 10 lb.

This take-off is included in Fig. 24 and indicates that, although original heading was maintained with some difficulty, it was near the limiting condition for satisfactory cross-wind performance at that wind speed and out-of-wind angle.

10.3. *Landings.*—The landings were made with the wind on the starboard bow. The results obtained indicated that, for the range of out-of-wind angles and wind velocities done, directional and lateral control was adequate.

It is difficult to bring out any special features for the flying-boat, on account of the few cross-wind landings made on the *Solent.*

11. *Conclusions.*—The present airworthiness requirements for handling, controllability and performance during take-off and landing may be applied in principle to seaplanes, with suitable modifications to the definition of safety speed on the water and the choice of take-off speed. The general results and recommendations determining this general conclusion are set out below in terms of the different investigations made.

It is an essential associated design requirement that porpoising stability should be good, both with and without propeller slip-stream when this is present. At least two design categories should be considered, *i.e.*, sheltered and open water, the second case being the only one in which operation across the swell should be necessary. In the open-sea case the attainment of sufficient stability may well require the use of hulls having overall length/beam ratios greater than 12 and also afterbody lengths greater than the forebody length. In very-severe-water design cases an auxiliary aid, such as a highly loaded water ski, might also be necessary, for example, for air/sea rescue applications.

11.1. *Measurement of Take-off Distance.*—The airworthiness criterion for the take-off of seaplanes has been in the past that the time to unstick should not exceed 60 seconds. The I.C.A.O. and A.R.B. regulations now require measurement of distance to unstick and clear a 50-ft obstacle, the total distance being decided by operational conditions. The M.A.E.E. view is that the best criterion is to define the minimum acceleration on the water, the values depending on the operational role, *e.g.*, $0 \cdot 03g$ in calm sheltered water, $0 \cdot 05g$ in normal sheltered water conditions and $0 \cdot 1g$ in swells in the open sea, and a minimum climbing angle in the air. Such limitations are non-scalar and as such do not penalise large seaplanes. In the seaplane case there is usually ample water distance and direction, whereas in the landplane case the criterion will usually be the length and width of run-way available.

Measurement of the distance to 50 ft can be made by methods very similar in principle to those employed for landplanes, with detailed modifications to take account of the effect of the taxying speed when fully throttled, tide, variation of attitude during take-off and the fact that it is not usually possible, or feasible, to mark out a tape line for take-off or landing as on a land runway. The first two are normally measured by means of a low-water-speed instrument operating with a pitot head at a constant depth or a shore-based camera. The third, *i.e.*, attitude, is measured during take-off and landing run with a gyro-controlled pitch recorder. Change of attitude is important because it can affect materially the water drag and can also affect the position-error correction. The latter is also measured by the use of a static tank for take-off measurements, but otherwise has to be based on the calibration of the aircraft in terms of attitude in the air or, when the requirements are exacting, by means of uniform-speed runs over a measured distance on the water. The distances are best measured at present by the two synchronised cine-camera method developed by the Aircraft and Armament Experimental Establishment at Boscombe Down. For seaplanes, this requires two land bases on the extremities of a measured base line from which the take-off and climb distances to 50 ft can be obtained by triangulation. Synchronisation of the cameras is simply made in M.A.E.E. experience by the use of stop-watches operated on a signal given from the aircraft.

The single camera and a navigation method have also been tested. The first is successful but is less exact than the two-camera method and requires considerably more computation. It is also more difficult to find a suitable base position because of visibility and resolution problems. The second method is based on the Decca Navigator but proved insufficiently accurate for the short distances involved. The difficulty seems to be that local conditions in a sea area affect the Decca broadcast lattice in an unpredictable fashion, and to an extent which, in view of the comparatively small distances concerned, is important. The implied principle of carrying the instrumentation in the aircraft is, however, very desirable and a measuring device is being developed at the M.A.E.E., Felixstowe, which integrates acceleration both forwards and upwards to give any required range. The basic principle is not new but, it is hoped, has now some possibility of realisation because of improvement in the technique of accurate accelerometer and gyroscope design.

11.2. *Distances to 50 ft and the Effect of Safety Speeds.*—It is at present required that the aircraft should not be climbed below safety speed, which for the *Solent* is $1 \cdot 1 V_{MCA}$ (108 knots), and must not continue a take-off if an engine fails below a minimum speed of $1 \cdot 1 V_{MCW}$ (88 knots). The speed of 88 knots is also the take-off speed used throughout in the *Solent* tests. Exploration of the effect of change of climb-away speed showed that, as in comparable landplane tests, there is a severe penalty for too high a value. For the *Solent* it is possible to decrease the airborne distance by 50 per cent, or the total distance by 20 per cent, for a speed decrease of 108 to 98 knots. A further decrease of climbing speed to 90 knots gives a further large reduction of airborne distance.

With the engine cut, the effect of climb-away speed is even more pronounced. A reduction of total distance to the order of 50 per cent is possible by reducing climbing speed from 108 to 98 knots for a wide range of engine-cut speeds.

The measured power-failure speeds above which the distance to take-off to 50 ft is less for climb-away than for re-land are respectively 85 ($1.05 V_{MCW}$) and 96 knots ($1 \cdot 2 V_{MCW}$) for climb-away speeds of 98 ($V_{MCA}$) and 108 knots ($1.1 V_{MCA}$). It follows that a pilot will be expected to re-land for an engine failure between the take-off speed of 88 knots and the power-failure point of 96 knots if the safety speed is 108 knots. In practice, the seaplane pilot would normally much prefer to carry on and accept the greater distance rather than accept the greater risk of a re-land at full weight and high speed if any swell was running. At the lower climb-away speed the failure point is below take-off speed and the pilot would continue take-off.

11.3. *Safety Aspects Defining Power Failure and Climb-away Safety Speeds.*—Safety requirements defining whether or not a pilot should carry on or throttle back in the event of engine failure on the water will differ in the case of seaplanes and landplanes, if only because there is no case for restricting severely the lateral and directional deviation necessary on a narrow run-way of limited length. There are also the special hazards of loss of lateral stabilisers and porpoising instability near take-off speed, which may be met when operating across a long swell.

The *Solent* tests showed that $V_{MCW}$ can safely be defined in terms of the minimum take-off speed at which original heading can be regained when the worst engine is cut (82 knots). Loss of lateral control occurs at a much lower speed (45 knots). The most dangerous take-off speed-range engine cut is from 45 to 60 knots, the early planing range just above the hump speed where bad swing can develop, leading into possible severe porpoising instability if recovery action is not properly taken. Above 60 knots recovery is straightforward.

The achieved $V_{MCW}$ should be such that the safety power-failure speed is equal to, or less than, the take-off speed in order to avoid the re-land case in rough water and swells. Take-off speed should be decided by stability and drag requirements and not $V_{MCA}$ or $V_{MCW}$.

In cross-winds this speed would be higher, particularly for contemporary designs which do not specifically cater for cross-wind cases. In the cross-wind case generally it would be quite reasonable to accept a change of heading when an engine is cut, of the order of at least 20 deg. The same concession could also be reasonably made in the head-wind case.

At low speeds, certainly up to the hump speed of 45 knots, there is little danger from an engine cut, but floats must be strong enough for the associated impact and fully immersed cases. The floats would also be subjected to fairly severe impact loads at high speeds in rough water and in swells.

In the air it was found perfectly safe to climb away at $V_{MCA}$, and generally, for the four-engine case, it appears that not more than $1{\cdot}05 V_{MCA}$ should be necessary to give a safe climbing speed. The limiting condition defining $V_{MCA}$ is the power of the rudder. Further, the safety speed should be as near take-off speed as possible to obtain the best climb performance at take-off at the wing loading of the *Solent.*

11.4. *Methods of Defining Safety Speed for Climb.*—The tests on the *Solent* confirmed that the best definition of the minimum safe climb-away speed in the case of four-engine aircraft is that based upon $V_{MCA}$, i.e., controllability with the critical engine cut. In the case of the *Solent,* the speed required for safety being $1{\cdot}05 V_{MCA}$, an alternative definition was found to be $V_2$, defined as the minimum speed at which it is possible to do correctly banked 30-deg turns at rate 1·5 with the critical engine cut. Two other definitions gave speeds which were too low, *i.e.*:

(*a*) the minimum glide speed, $V_1$, possible without stalling the aircraft by forward movement of the stick, with all engines throttled back

(*b*) the minimum speed for control, with the engines giving three-quarters of the take-off power.

11.5. *Cross-wind Requirements.*—The most interesting feature of the take-off cross-wind performance is that there is a limiting out-of-wind angle for a given wind speed rather than a limiting cross-wind component, because a head-wind component helps stability and control. Definitions of limiting cross-wind performance should therefore be defined in terms of angle relative to the path of the aircraft and strength of wind. The limiting conditions were found to be loss of directional control arising either because of insufficient differential throttling thrust or lateral control. In the case of the *Solent,* as designed, there is also a limiting rudder force. It was also found that lateral control was often poor, especially in rough water, and fairly severe float-impact cases were possible over the whole take-off speed range, the most severe occurring in the speed range up to 60 knots.

$V_{MCW}$ is increased in a cross-wind, but it was not possible to obtain other than a qualitative assessment in the time available. In landing, conditions are much less severe but, again, the test range was very limited.

A cross-wind case is normally only required to operate in restricted water areas, or to take-off parallel to long waves in the open sea. There should therefore be at least two categories of cross-wind requirements, sheltered water and open sea.

## LIST OF SYMBOLS

| | |
|---|---|
| $V_{MCA}$ | The minimum control speed, with one engine cut, take-off climb condition (knots) |
| $V_{MCW}$ | The minimum control speed, with one engine cut, take-off condition, on the water (knots) |
| $V_{S1}$ | A stalling speed or minimum steady-flight speed, E.A.S., with take-off flaps, engines throttled back (knots) |
| $V_{S0}$ | A stalling speed or minimum steady-flight speed with wing flap in the landing position E.A.S., engines throttled back (knots) |
| $V_W$ | Wind speed (knots) |

*Definitions*

| | |
|---|---|
| T.A.S. | The true air speed relative to undisturbed air (knots) |
| E.A.S. | Equivalent air speed (knots) |
| I.A.S. | Indicated air speed (knots) |
| Take-off safety speed | A speed used in determination of take-off performance (E.A.S. for flight requirements) (knots) |
| S.M.C. | Standard mean chord |

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# APPENDIX I

## *Aircraft Data*

### *Hull*

| | |
|---|---|
| Maximum beam | 10·75 ft |
| Beam at step | 10·27 ft |
| Step depth at keel | 12·79 in. |
| Step/beam ratio* | 9·92 per cent |
| Forebody length : | |
| Front perpendicular to step chine | 36·1 ft |
| Front perpendicular to step centroid | 34·2 ft |
| Afterbody length: | |
| Front step at keel to aft step at keel | 34·8 ft |
| Forebody/beam ratio* | 3·35 |
| Afterbody/beam ratio* | 3·23 |
| Forebody length to step centroid/beam at step | 3·33 |
| Step fairing (in terms of step depth)† | 1 : 3·5 |
| Step included angle in plan at keel | 124° 35′ |
| After keel angle to forebody keel (at step) | 7·1 deg |
| Forebody keel angle to hull datum | 1·8 deg |
| Hull overall length | 89·6 ft |

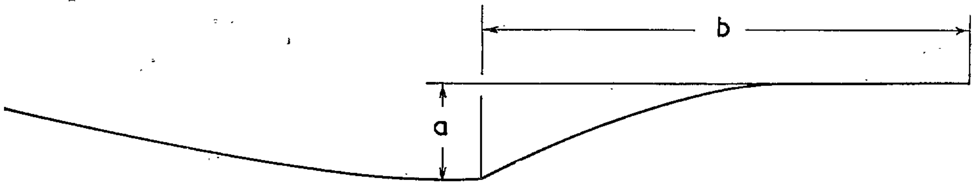
### *Wings*

| | |
|---|---|
| Section | Gottingen (Mod) |
| Gross area | 1,687 sq ft |
| Span | 112·8 sq ft |
| S.M.C. | 14·97 ft |
| Distance of S.M.C. leading edge in front of step | 7·93 ft |
| Aspect ratio | 7·54 |
| Washout | 0 |
| Dihedral (to mid-thickness 30 per cent chord) | 3 deg |
| Sweepback (normal to aerofoil datum line) | 4 deg |
| Incidence to hull datum | 6° 9′ |
| Aileron movement (measured) | 18·6 deg up<br>17·0 deg down |

---

* Based on maximum beam.

† Step faring ratio = *a*/*b* when *a* and *b* are as in the sketch:



### *Tailplane*

| | |
|---|---|
| Section | R.A.F. (Mod) |
| Area, excluding elevators and tabs | 163·5 sq ft |
| Span | 42·43 ft |
| Elevator area, including tabs | 102·3 sq ft |
| Dihedral (to lower surface measured at stub) | 6 deg |
| Leading-edge height above datum | 16·19 ft |
| Tailplane setting to hull datum | 4 deg |
| Elevator movement (measured) | 17·3 deg up<br>18·0 deg down |

### *Fin and Rudder*

| | |
|---|---|
| Area of fin, excluding rudder | 112·82 sq ft |
| Rudder area, including tabs | 82·18 sq ft |
| Rudder movement (measured) | 15 deg port<br>14·5 deg starboard |

### *Flaps* (Gouge type)

| | |
|---|---|
| Total area | 286·24 sq ft |
| Span | 38·1 ft |
| Flap chord/Wing chord | 32·75 per cent |
| Deflection (measured) | 7·35 deg |
| 1/3 | 7·35 deg |
| 2/3 | 16·32 deg |
| Maximum | 25·0 deg |

### *Engines*

Four Hercules XIX giving 1,700 b.h.p. at 2,800 R.P.M., and + 8¼ p.s.i. boost pressure for sea-level take-off.

### *Propellers*

4-bladed left-hand tractor

| | |
|---|---|
| Type | De Havilland D.9/446/1 |
| Diameter | 12·75 ft |
| Solidity, at 0·7 radius | 0·141 |
| Gear ratio | 0·444 : 1 |
| Section | Clark Y |
| *T/c* at 0·7 radius | 6·8 per cent |

# APPENDIX II

## *Instrumentation*

The following quantities were recorded in the automatic observer:

| Quantity | Method of measurement | Range and accuracy |
|---|---|---|
| *Aerodynamic controls* | | |
| Aileron<br>Rudder<br>Elevator } Forces, angular movements and trimmer positions | Desynn system. Aileron and elevator forces measured by R.A.E. twin-axis control-wheel force recorder, fitted to the second pilot's control column in lieu of wheel. Rudder force measured by R.A.E. type pedal force recorders | |
| Flap angle .. .. .. | Desynn angular movement recorder .. | 25 deg $\frac{1}{4}$ deg |
| *Aircraft orientation and position* | | |
| Pitch angle .. ..<br>Roll angle .. .. | Indicated by microammeter from Anschutz horizontmutter electrical gyroscope. These readings were checked during the tests by comparison with bubble inclinometers reading to 1/10 deg over range of 8 deg | *Range :* Pitch 50 deg<br>Roll 90 deg<br>*Accuracy :* $\frac{1}{4}$ deg during take-off and landing manoeuvres. Correct to 1/6 deg in steady conditions |
| Rate of yaw and roll .. | R.A.E. rate gyroscope with desynn indicator | 10, 25 and 50 deg per second |
| Direction .. .. .. | Compass repeater from standard R.A.F. distant-reading compass | 360 deg 1 deg |
| Sideslip .. .. .. | R.A.E. desynn vane recorder .. .. | *Range :* ± 30 deg<br>*Accuracy :* $\frac{1}{2}$ deg |
| *Airspeed E.A.S.* .. .. | (*a*) Pitot head and static vent<br>(*b*) Pitot in venturi and trailing static<br>(*c*) Pitot in venturi and static reservoir (capacity 200 cu in.) | Low reading A.S.I.<br>*Accuracy :* 1 knot |
| *Altitude* .. .. .. | (*a*) Kollsman sensitive aneroid altimeter<br>(*b*) Radio altimeter Type AYF | *Accuracy :* ± 10 ft<br>Unreliable during initial climb and final approach. Later abandoned |
| *Acceleration* | | |
| Longitudinal acceleration | R.A.E. type 2–2 desynn accelerometer mounted rigidly to the main spar near c.g. | — 0·3 to = 1·0*g*<br>*Accuracy :* 0·01*g* |
| Normal acceleration .. | Kollsman visual V.G. recorder .. .. | Not used in automatic observer |
| *Engine Power* | | |
| Torque .. .. .. | 4 Bristol type torquemeters with steel capillary tubing and Bourdon type gauges | 0–800 lb 1 lb p.s.i. |
| Engine speed .. .. | 4 electric R.P.M. indicators .. .. .. | |

| Quantity | Method of Measurement | Range and Accuracy |
|---|---|---|
| *Miscellaneous* | | |
| Time | 3-second timer stop-watch. Later replaced by master contactor driving a Veeder counter | 1/200 second. Indicates each $\frac{1}{2}$-second. By interpolation of film frames accuracy = 1/20 second |
| Fuel contents | 4 'gallons gone' indicators | |
| Event lights | These operated by human observer to indicate events not recorded elsewhere, *e.g.*, landing and take-off points, arbitrary end of recording, etc. | |
| Air temperature | Balanced bridge air thermometer | |
| Water contact<br>Means of indicating the time of making or breaking contact with the water | Make and break electrical circuit dependent on external pressure on diaphragm, between hull of flying-boat and water | Operation instantaneous. Used in automatic observer and visually on pilot's coaming by indicator lights |

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# APPENDIX III

The various take-off speeds and safety criteria, adopted in the *Solent* investigation and used throughout this report, are based on the current definitions in British Civil Airworthiness Requirements, except where otherwise stated in the text of the report.

The appropriate definitions extracted from B.C.A.R. are given below. The section and paragraph numbers refer to those in B.C.A.R.

## Chapter D2–3

2.2. *Power-failure Point.*—This is the point at which sudden complete loss of power from the power-unit, critical from the performance aspect in the case considered, is assumed to occur. If the critical power-unit varies with the configuration, and this variation has a substantial effect on performance, either the critical power-unit shall be considered separately for each element concerned, or it shall be shown that the established performance provides for each possibility of single power-unit failure.

2.2.1. The power-failure point shall be selected by the applicant for each take-off distance and run required and for each emergency distance and (subject to 2.8.1) may be before or after take-off safety speed is reached, provided that the pilot is provided with a ready and reliable means (*e.g.*, the air-speed indicator) of knowing when the applicable power-failure point has been reached.

*Note.*—The operational relationship between the power-failure points assumed in matching the performance available to the characteristics of a particular aerodrome is intended to be limited by Operating Regulations but may be so chosen (from those established in accordance with this paragraph) that the maximum advantage is taken of the characteristics of the take-off strip in question.

2.2.2. If the power-failure point used in establishing an emergency distance occurs after the start-of-climb point, it shall be demonstrated that the aeroplane can readily be re-landed from that point.

2.3. *Emergency distance required.*—This is:

| | |
|---|---|
| for aeroplanes with two power-units | 0·95 |
| for aeroplanes with more than two power-units | 1·0 |

times the distance taken, with all power-units operating, to reach the power-failure point from a standing start and, after simulated power-unit failure at this point, to stop if a landplane, or to bring the aeroplane to a speed of approximately 3 miles (5 kilometres) per hour if a seaplane.

*Note.*—The distance determined as above, but unfactored, is referred to as the accelerate-stop distance.

2.4. *Take-off Run Required.*—This is whichever is the greater of the following:

1·15 times the distance taken with all power-units operating to accelerate from a standing start to take-off safety speeds with the aeroplane held on or close to the ground throughout.

1·0 times the distance taken to accelerate from a standing start to take-off safety speed assuming the critical power-unit to fail at the power-failure point.

*Note.*—The take-off run required will normally be determined from data derived in establishing the one-power-unit inoperative take-off distances to 50 ft.

2.5. *Take-off Distance Required.*—This is:

| | |
|---|---|
| for aeroplanes with two power-units | 0·95 |
| for aeroplanes with more than two power-units | 1·0 |

times the distance taken to reach a height of 50 ft above the take-off surface, with the failure of the critical power-unit at the power-failure point.

*Note.*—The detail conditions for this case are given in 2.8.

2.8. *Mandatory Conditions.*—2.8.1. *Airspeed—emergency distance.—When establishing the* emergency distance required, the airspeed at the power-failure point shall be not less than $1{\cdot}1\ V_{MCG}$.

2.8.2.—*Airspeed—take-off run and distance.*—When establishing the take-off run required and take-off distance required the airspeed shall be:

when determining the power-unit-inoperative performance, not less than the take-off safety speed from the start of the transition (from flight on or near the ground to steady climbing flight) onwards,

when determining the all-power-units operating performance, not less than the take-off safety speed from a height of 50 ft, or the end of the transition, whichever occurs first, onwards.

## Chapter D2–8

4.1. $V_{MCA}$—*Minimum Control Speed in Free Air* (*take-off*).—4.1.1. *Qualities required.*—There shall be determined a speed, $V_{MCA}$, which shall be such that if, in initially steady conditions, sudden complete failure of the critical power-unit occurs at or above this speed, it is possible, with the critical power unit still inoperative and without the thrust from the remaining power-units being reduced, to recover control and thereafter maintain straight steady flight at the same speed. From the time at which the power-unit becomes inoperative until the aeroplane is once more settled in straight steady flight at the initial air-speed, a rudder pedal force of 180 lb shall not be exceeded, nor shall exceptional skill be required to prevent loss of height (other than that, if any, which is implicit in the loss of performance), change of heading in excess of 20 deg or the attainment of an attitude which would be dangerous if the aeroplane were on, or close to, the ground. When straight steady flight has been regained in the conditions prescribed the rudder pedal force shall not exceed 180 lb and the associated angle of bank shall not exceed 5 deg.

4.1.2. *Associated conditions.*—The requirements of 4.1.1. shall be met in the following conditions:

| | |
|---|---|
| Wing-flaps | In the take-off position, throughout.<br>*Note.*—$V_{MCA}$ will need to be determined for more than one wing-flap position, if the applicant elects to change the wing-flap position at some point in the net flight path. |
| Landing Gear | Retracted, throughout. |
| Cooling Gills | For each engine, in the position used for establishing the take-off distance required. |
| Engine Conditions | Up to the moment at which the critical power-unit becomes inoperative, all power-units shall be operating at maximum take-off power conditions.<br>*Note.*—*See* D2–1, App., regarding simulation of power-unit failure. |

| | |
|---|---|
| Propeller Conditions .. | The propeller controls for each power-unit shall be in the recommended take-off position throughout. In the case of fully automatic feathering or pitch-coarsening where this leads to the propeller of the inoperative power-unit becoming feathered, the increase in $V_{MCA}$ which would result if the automatic feature were inoperative shall be investigated.<br>*Note.*—If this increase exceeds 10 per cent, the Board will consider, in the light of the particular circumstances, whether the value of $V_{MCA}$ should be increased. |
| Trim .. .. .. | Each trimming control shall be in the recommended take-off position throughout. |
| General .. .. | The aeroplane shall be airborne and ground effect negligible and, prior to the critical power-unit becoming inoperative, the aeroplane shall be in straight steady flight with wings level. |

4.1.3. *Maximum values.*—The value of $V_{MCA}$, determined in accordance with 4.1.1. and 4.1.2. (for the wing-flap position obtaining at the 50 ft height point) shall not exceed:

$1{\cdot}3V_{S1}$ for Group A,

$1{\cdot}2V_{S1}$ for Groups C and D

where,

$V_{S1}$ corresponds to maximum sea-level take-off weight and the conditions prescribed in 4.1.2. other than ‘ Engines ’ and ‘ General ’.

4.2. $V_{MCG}$—*Minimum Control Speed on or Near the Ground.*—

*Note.*—Demonstration of compliance with the requirements of this paragraph will not be required if the value of $V_{MCG}$ which it is desired to establish, is equal to or greater than $V_{MCA}$.

4.2.1. *Qualities required.*—There shall be determined a speed, $V_{MCG}$, which shall be such that, if sudden complete failure of the critical power-unit occurs during take-off and becomes evident to the pilot at or above this speed, it is possible, without the thrust from the remaining power-units being reduced, or brakes being used, to recover control and thereafter maintain a straight path parallel to that originally intended. From the time at which the power-unit becomes inoperative to the time at which recovery to the parallel path is complete, it shall be possible to prevent excessive yaw or lateral displacement, or the attainment of a dangerous attitude, without the need for exceptional skill or for a rudder pedal force in excess of 180 lb. The speed so determined shall not be critically affected by a wet runway surface or by a cross-wind component, from the most adverse side, up to 7 m.p.h.

4.2.2. *Associated conditions.*—The requirements of 4.2.1 shall be met in the following conditions:—

| | |
|---|---|
| Wing-flaps .. .. | In the take-off position throughout. |
| Landing Gear .. | Extended throughout. |
| Cooling Gills .. .. | In the recommended take-off position throughout for all power-units. |
| Engine Conditions .. | Up to the moment at which one power-unit becomes inoperative, all power units shall be operating at maximum take-off power conditions<br>*Note.*—*See* D2–1, App., regarding simulation of power-unit failure. |

| | |
|---|---|
| Propeller Conditions | The propeller controls for each power-unit shall be in the recommended take-off position throughout. In the case of fully automatic feathering or pitch-coarsening where this leads to the propeller of the inoperative engine becoming feathered, the increase in $V_{MC}$, which would result if the automatic feature were inoperative shall be investigated. |
| Trim | Each trimming control shall be in the recommended take-off position throughout. |
| General | The general conditions of acceleration, attitude, contact with or height above the take-off surface, at the time the power-unit failure becomes evident to the pilot, shall be not more favourable than those obtaining at the critical point of each one power-unit inoperative take-off path determined in accordance with D2–3. |

## Chapter D2–11

3. *Stalling Speeds.*—3.1. *Definitions.*—The following definitions are applicable to the Flight Requirements:

3.1.1. *Measured stalling speed.*—The measured stalling speed is the speed at which a large amplitude pitching or rolling motion, not immediately controllable, is encountered when the manoeuvre prescribed in 3.2.2. is executed. An uncontrollable pitching motion of small amplitude associated with pre-stall buffeting, shall not be taken as indicating that the stalling speed has been reached.

3.1.2. *Measured minimum steady flight speed.*—The measured minimum steady flight speed is the minimum steady speed obtained, with the elevator control in the most rearward possible position, when the manoeuvre described in 3.2.2 is executed. This speed does not apply where. the stalling speed defined in 3.1.1. occurs before the elevator control reaches its stop.

3.1.3. $V_{SO}$ denotes the measured stalling speed (if obtainable), otherwise the measured minimum steady flight speed. It is associated with the following conditions:

| | |
|---|---|
| Weight | Except where otherwise prescribed, equal to that prescribed in the requirement, referring to $V_{SO}$ which is being considered. |
| Centre of Gravity | In the position, within the allowable landing range, which gives the maximum value of measured stalling speed or minimum steady flight speed. |
| Wing-flaps | In the appropriate maximum landing position as prescribed in each requirement which refers to $V_{SO}$. |
| Landing Gears | Extended. |
| Cooling Gills | Substantially closed. |
| Engine Conditions | All engines either idling with throttles closed or developing not more than sufficient power for zero thrust at a speed not greater than 110 per cent of the measured stalling speed or minimum steady flight speed. |
| Propeller Conditions | All propeller pitch controls in the positions recommended by the applicant for normal use during take-off. |

3.1.4. $V_{SI}$ denotes the measured stalling speed (if obtainable) or the minimum steady flight speed. It is associated with the following conditions:

| | |
|---|---|
| Engine Conditions .. | All engines either idling with throttles closed or developing not more than sufficient power for zero thrust at a speed not greater than 110 per cent of the measured stalling speed. |
| Propeller Conditions .. | All propeller controls in the positions recommended by the applicant for normal use during take-off. |
| All Other Conditions .. | The aeroplane in all other respects (for example, weight and configuration) in the particular condition associated with the requirements in connection with which $V_{SI}$ is being used as a factor to specify a required characteristic. |

3.2. *Determination.*—3.2.1. *Values to be determined.*—The measured stalling and/or minimum steady flight speeds of the aeroplane shall be established for those conditions of loading, configuration and power, for which such knowledge is necessary in order that compliance with the requirements may be determined; if not already included in these speeds, the value of $V_{SO}$ corresponding to maximum sea-level landing weight and the maximum sea-level landing position of the wing-flaps shall also be established. All measured stalling and minimum flight speeds shall be determined in accordance with 3.2.2. and 3.2.3. and the definitions of 3.1, as appropriate.

3.2.2. *Flight technique.*—The aeroplane shall be trimmed for a speed approximately 1·4 times the stalling speed to be measured. From a value sufficiently above the stalling speed to ensure a steady rate of decrease, the speed shall be reduced, in straight flight at a rate not exceeding 1 m.p.h. per second, until the measured stalling speed or minimum steady flight speed, as defined in 3.1, is reached.

# TABLE 1

## *Summary of Behaviour at Stall*

(*a*) *Weight :* 60,000 *lb. Cowl Gills Shut. Oil Louvres* ¼ *open*

| Flap position | Air-speed at stall | | Warning | Results | Loss of height* (ft) | Recovery |
|---|---|---|---|---|---|---|
| | A.S.I. (knots) | E.A.S. (knots) | | | | |
| 1/3 | 82 | 85 | Buffet at 90 knots.. .. | Stall straight .. .. .. | 420 | Easy and straightforward by slight forward pressure on elevator control |
| 2/3 | 77 | 76 | Buffet at 88 knots.. .. | Stall straight. Slight nose drop | 400 | Easy and straightforward by slight forward pressure on elevator control |
| (*b*) *Weight :* 72,000 *lb. Cowl Gills Shut. Oil Louvres* ¼ *open* | | | | | | |
| 1/3 | 86 | 89 | Buffet at 95 knots.. .. | Tendency for port wing to drop, with sharp falling away of nose | 530 | Slight forward pressure on elevator control |
| 2/3 | 80 | 84 | Buffet more pronounced at 93 knots | Tendency for port wing to drop, with slight aileron snatch and rudder oscillation | 450 | Full port aileron required to raise port wing. Aileron force heavy. Elevator control eased forward to increase speed |
| (*c*) *Weight :* 78,000 *lb. Cowl Gills Shut. Oil Louvres* ¼ *open* | | | | | | |
| 1/3 | 94 | 96 | Buffeting more pronounced as stall is approached | Port wing drop, but not excessively. Control regained quickly but aileron force heavy. Full aileron control required | 800 | Straightforward by easing control forward |
| 2/3 | 84 | P.E.C. not measured | Buffet at 95 knots and became more severe 2 to 3 knots from stall | Lateral stability deteriorates. Port wing drops but not excessively, when control was brought still further back. A pitching oscillation occurred and vibration was excessive | 500 to 600 | Easy and straightforward. Coarse lateral control required to raise dropped wing |

*Note.*—In all cases, the control movement required to stall the aircraft was slight, and elevator force moderate.
Flap position : 1/3 extended, take-off.
2/3 extended, landing.

---

* Height loss from stall to recovery at $1{\cdot}2V_{SI}$ and $1{\cdot}3V_{SO}$.

## TABLE 2

*Variation of Airborne and Total Distances with Engine-Cut Speed*
*Mean Weight* 77,000 *lb*

| Take-off E.A.S. (knots) | Climb Speed E.A.S. (knots) | Engine-Cut Speed E.A.S. (knots) | Airborne Distance in ft. | | Standard waterborne and airborne distance in ft |
|---|---|---|---|---|---|
| | | | Uncorrected | Corrected for climb speed | |
| | | | | (108 knots) | |
| 87 | 106 | 89 | 4,780 | 5,029 | 7,899 |
| 85 | 106 | 88 | 4,650 | 4,945 | 7,815 |
| 84 | 106 | 99 | 3,860 | 3,834 | 6,704 |
| 88 | 106 | 98 | 2,955 | 3,203 | 6,073 |
| | | | | (98 knots) | |
| 88 | 101 | 99 | 1,830 | 1,517 | 4,287 |
| 90 | 98 | 92 | 1,743 | 1,808 | 4,678 |
| 87* | 98 | 89 | 2,550 | 2,168 | 5,038 |
| 88 | 101 | 83 | 3,665 | 2,808 | 5,678 |
| | | Tropical | | | |
| | | | | (108 knots) | |
| 89 | 111 | 110 | 3,030 | 2,570 | 6,170 |
| 88 | 111 | 100 | 4,210 | 3,620 | 7,220 |
| 89 | 112 | 112 | 3,080 | 2,620 | 6,220 |
| 86 | 110 | 104 | 3,600 | 3,045 | 6,645 |
| 90 | 112 | 103 | 2,450 | 3,320 | 6,920 |
| 90 | 106 | 103 | 2,530 | 3,010 | 6,610 |
| | | | | (98 knots) | |
| 89 | 112 | 103 | 2,610 | 1,320 | 4,920 |
| 87 | 103 | 103 | 2,090 | 1,477 | 5,077 |
| 88 | 102 | 99 | 1,800 | 1,373 | 4,973 |
| 88* | 112 | 85 | 4,580 | 2,270 | 5,870 |
| 87* | 112 | 85 | 4,890 | 2,400 | 6,000 |
| 86* | 112 | 85 | 5,880 | 2,880 | 6,480 |
| 87* | 102 | 86 | 2,380 | 1,770 | 5,370 |

* Distances plotted against take-off E.A.S. because engine cut before take-off.

## TABLE 3

*Variation of Total Distances with Engine-Cut Speed (Accelerate-Stop)*
*Mean Weight :* 77,000 *lb*

| Take-off E.A.S. (knots) | Engine-cut speed E.A.S. (knots) | Power (b.h.p.) | Airborne—re-land and standard take-off distance (Corrected for power 1,580) (ft.) |
|---|---|---|---|
| 85 | 100 | 1,513 | 7,874 |
| 87 | 101 | 1,484 | 8,027 |
| | Tropical | | |
| 88 | 99 | 1,483 | 9,170 |
| 89 | 108 | 1,484 | 9,985 |
| 87 | 83 | 1,510 | 6,120 |
| 90 | 97 | 1,479 | 8,040 |
| 89 | 110 | 1,483 | 9,855 |
| 86 | 85 | 1,491 | 6,300 |
| 90 | 107 | 1,479 | 9,800 |

## TABLE 4

*Cross-wind Take-off Performance*
*Wind Starboard of Take-off Path*

| Aircraft | W/V (knots) | Out-of-wind angle (deg) | Sea conditions | Lateral component | Head component | Remarks |
|---|---|---|---|---|---|---|
| *Solent* N.J. 201 .. | 13 | 10 | 1 ft chop | 2·3 | 12·8 | Directional control satisfactory. Differential throttling used up to 45 knots |
| | 12 | 20 | 1 ft chop | 4·1 | 11·3 | Slight deviation in heading, up to 40 knots. Full power at 50 knots |
| | 12·5 | 25 | 1½ ft chop | 5·8 | 11·1 | |
| | 16·5 | 30 | 1½ to 2 ft chop | 8·25 | 14·3 | Differential throttling up to 52 knots. Directional control satisfactory 52 knots to take-off |
| | 15·5 | 35 | 1½ ft chop | 8·9 | 12·7 | Differential throttling up to 50 knots. Original heading maintained |
| | 17 | 40 | 2 ft chop | 10·9 | 13·4 | Full rudder movement and differential throttling required up to 42 knots. Swinging to starboard but original course regained at 50 knots |
| | 15 | 40 | 2 ft chop | 9·6 | 11·5 | 3/4 rudder movement required up to 30 knots. Differential throttling used to maintain heading up to 45 to 50 knots. Port rudder force 140 to 120 lb. Directional control 50 knots to unstick satisfactory |
| | 10·5 | 45 | 8 in. chop | 7·4 | 7·4 | Directional control satisfactory with full power at 50 knots |
| | 7 | 50 | 8 in. chop | 5·4 | 4·5 | Original heading maintained, with slight differential throttling up to 45 knots, half-rudder travel required. Port pedal foot load 80 to 100 lb. Course maintained 50 knots to unstick with no undue difficulty |
| | 8 | 60 | 8 in. chop | 6·9 | 4·0 | Differential throttling required up to 45 knots to counteract tendency to swing to starboard. Directional control 50 knots to unstick adequate |

TABLE 4—*continued*

| Aircraft | W/V (knots) | Out-of-wind angle (deg) | Sea conditions | Lateral component | Head component | Remarks |
|---|---|---|---|---|---|---|
| *Solent* N.J. 201 —*contd.* | 10 | 65 | 8 in. chop | 9·1 | 4·2 | Full rudder movement, and differential throttling required up to 40 knots. Port pedal foot load 100 to 160 lb. Rudder power just adequate to maintain straight path, 50 knots to unstick |
|  | 10 | 70 | 8 in. chop | 9·4 | 3·42 | Directional control was difficult throughout the take-off. Full port rudder and port outer engine throttled back were required to halt an appreciable swing to starboard. Port pedal load was 150 lb. Directional control improved after full power available was used on the port outer, but the foot load was heavy, 80 to 120 lb, with about half travel of full rudder movement |
|  | 6·5 | 90 | 3 to 6 in. chop | 6·5 | — | Full port rudder and differential power halted the swing at about 40 knots, but deviation from original heading increased when full power was used at 45 knots. Port foot load was about 100 to 130 lb, with about 70 per cent of rudder movement at unstick. |
| *Sunderland* III (Ref. 17) | 15 to 20 | 50 | Slight | 11·4 to 15·3 | 9·6 to 12·8 | Start of take-off made with starboard aileron in the extreme up position and with full port rudder. Engines opened up to full power, excepting the port outer, which was running at 1,000 r.p.m. The aircraft started to swing to starboard, and was corrected by throttling the port outer engine. As the aircraft gathered speed, the port outer was opened up to half power and attained a speed of 43 knots in the planing attitude. At this stage, pitching instability commenced and a further swing to starboard was corrected by throttling the port outer engine. As the aircraft was now running into confined waters, the take-off was abandoned. On closing the throttles, the port wing dropped sharply, the port float was damaged and the wing submerged to the outer engine. |

TABLE 4—*continued*

| Aircraft | W/V (knots) | Out-of-wind angle (deg) | Sea conditions | Lateral component | Head component | Remarks |
|---|---|---|---|---|---|---|
| *Solent* 3 (Ref. 15) | 20 | 75 | 1 ft chop on confused swell | 19 to 25 | 5·2 | Uncontrollable porpoising set up. Take-off abandoned at 54 knots. As the engines were throttled, aircraft hit swell and was thrown off the water, re-landing port wing down, and damaging the port mainspar |
| | 10·5 | 60 | 6 in. chop | 9·1 | 5·25 | Marginal cross-wind take-off. |
| | 10 | 50 | 6 in. chop | 7·6 | 6·4 | Coarse rudder movement used, but take-off straightforward |

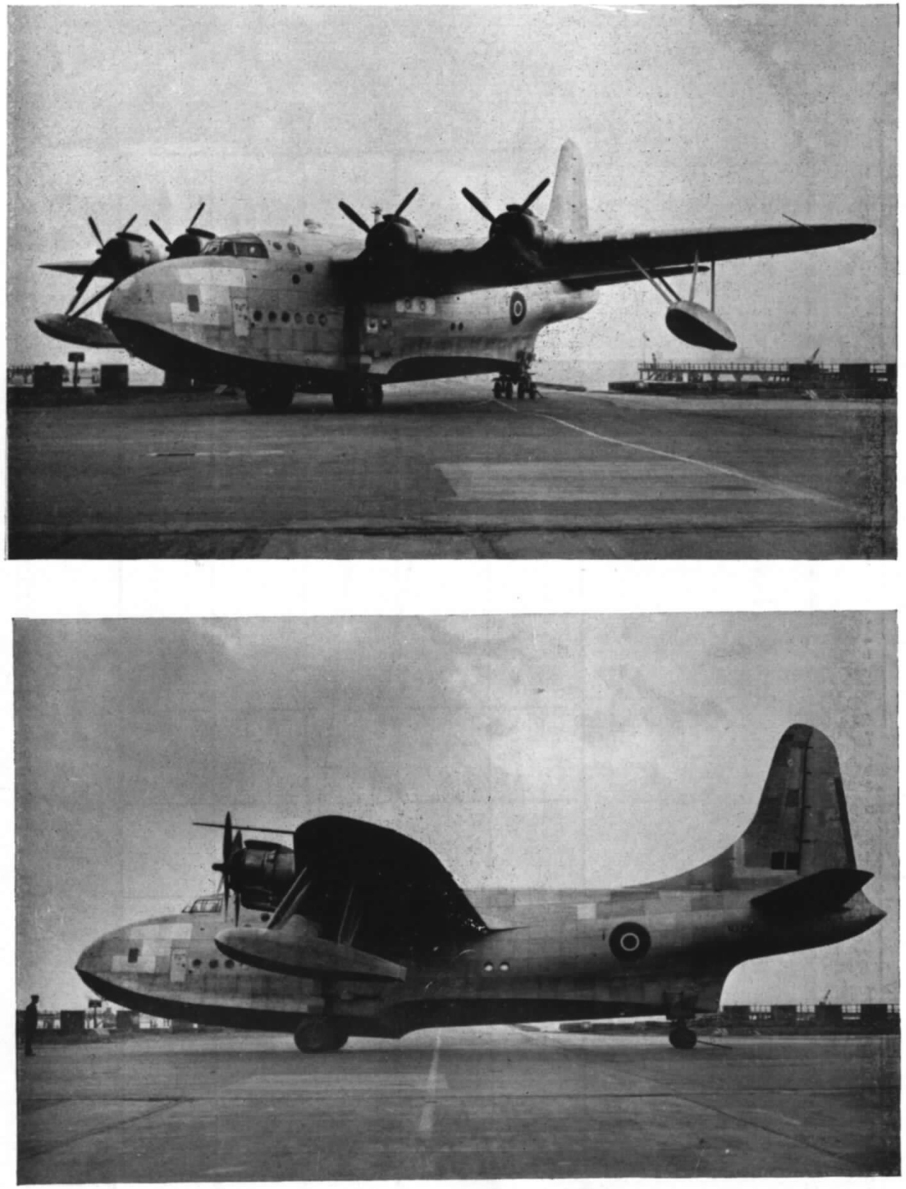


FIG. 1. *Seaford—Solent* N.J.201.

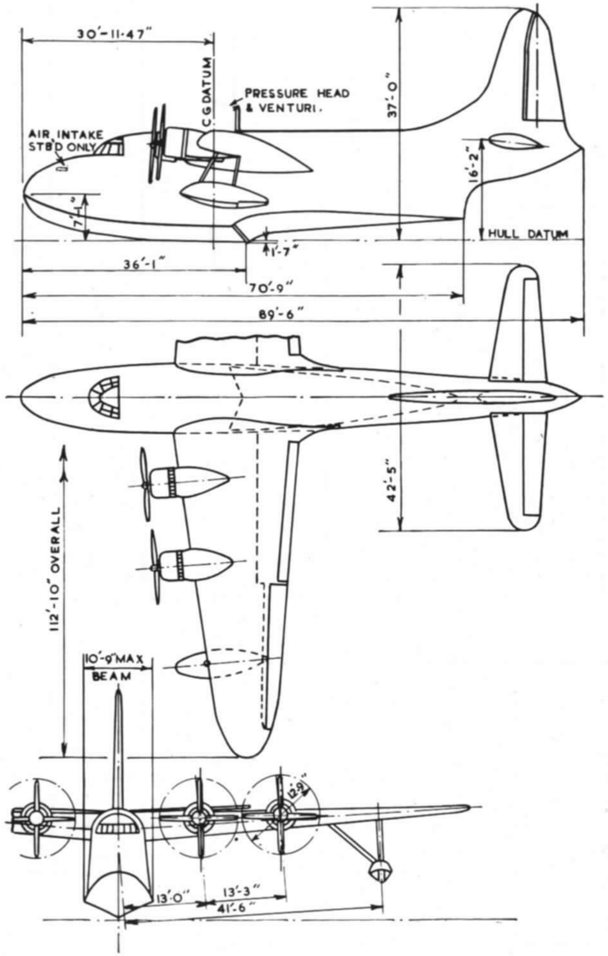


FIG. 2. General arrangement. *Solent* N.J.201.

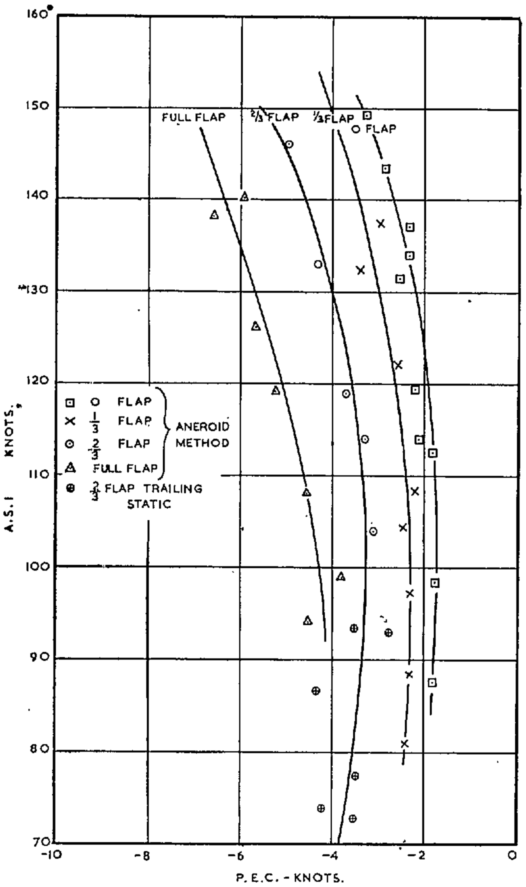
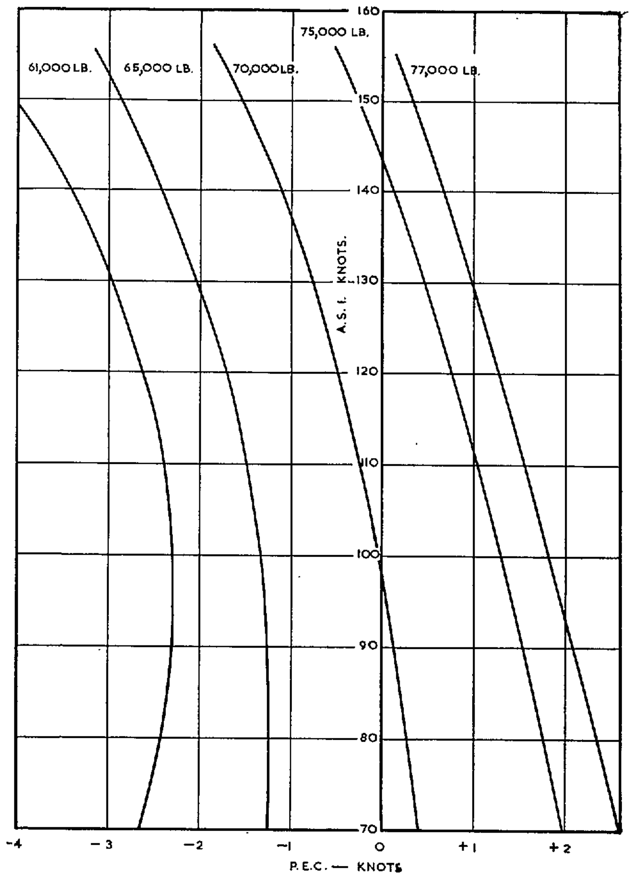


FIG. 3. Position-error correction. Weight : 61,000 lb.



$\frac{1}{3}$ FLAP. GILLS FULLY OPEN. AIRCRAFT IN TAKE-OFF CONFIGURATION.

FIG. 4. Position-error correction. All weights.

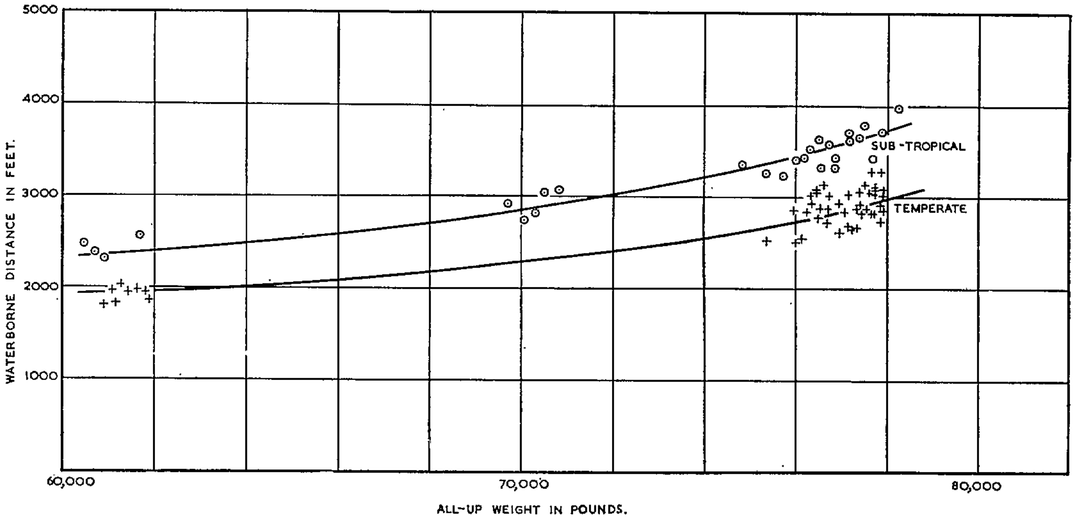


FIG. 5. Variation of waterborne distance with weight. Take-off speed 88 kt.

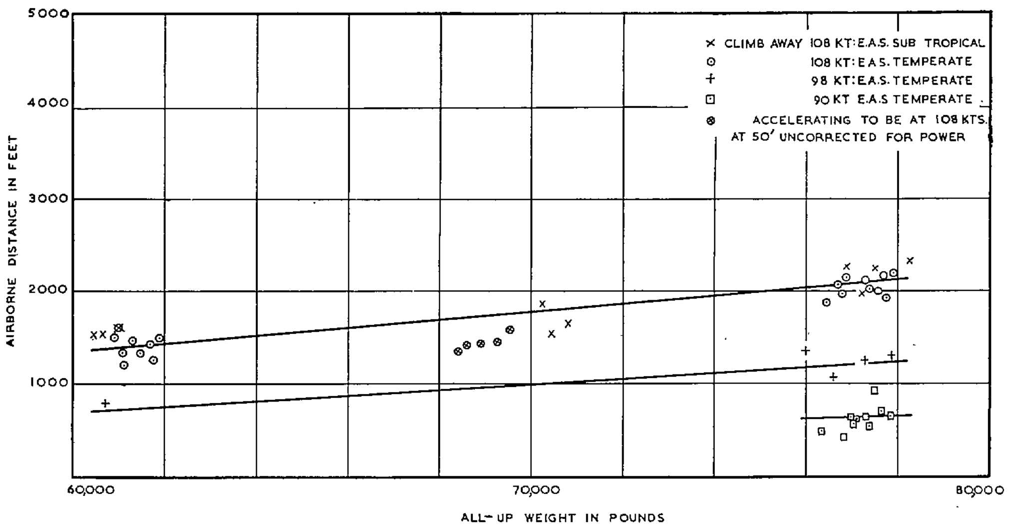


FIG. 6. Variation of airborne distance with weight. Take-off speed 88 kt.

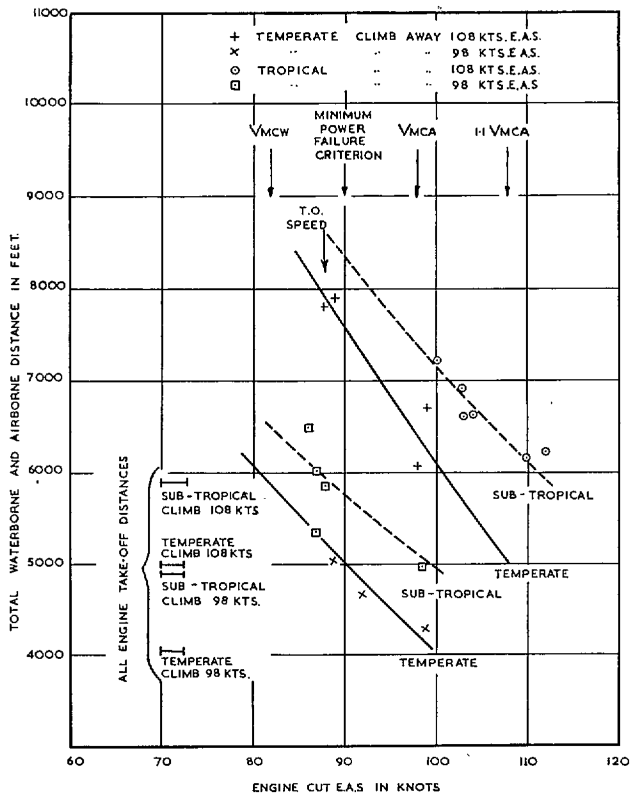


FIG. 7. Variation of total waterborne and airborne distance with engine-cut speed. Mean weight: 77,000 lb.

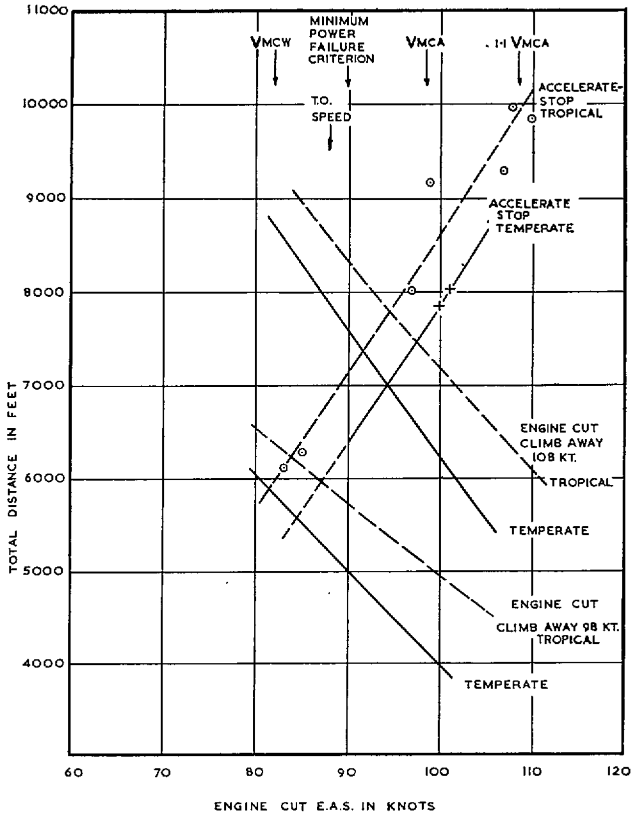


FIG. 8. Accelerate-stop and climb-away distances. Mean weight: 77,000 lb.

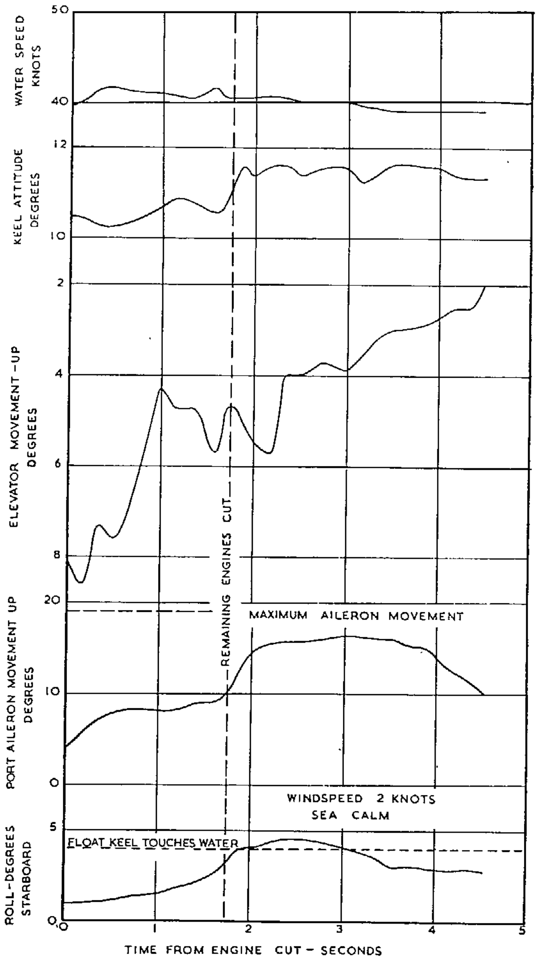


FIG. 9a. Time history of engine failure. Mean weight: 77,000 lb. Speed: 42 knots. No correction delay.

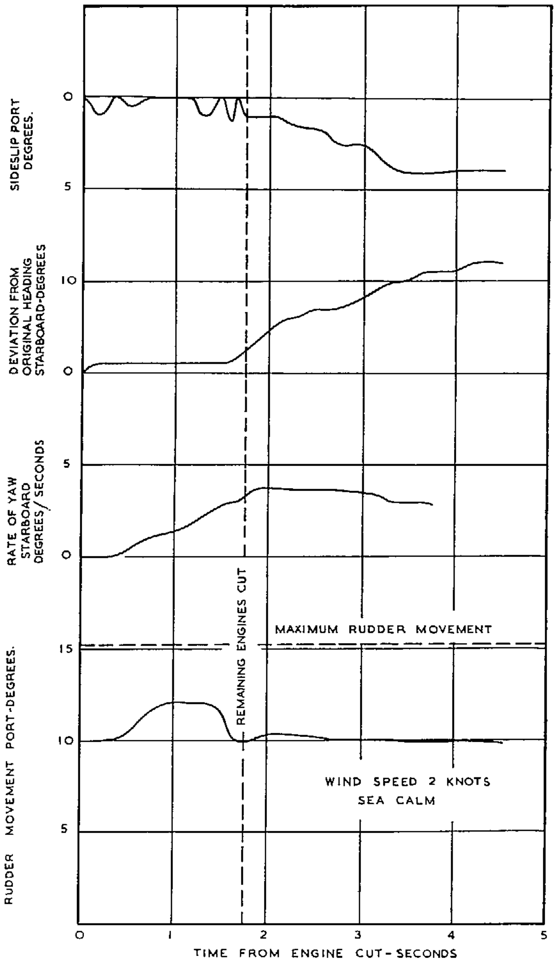


FIG. 9b. Time history of engine failure. Speed: 42 knots. No correction delay.

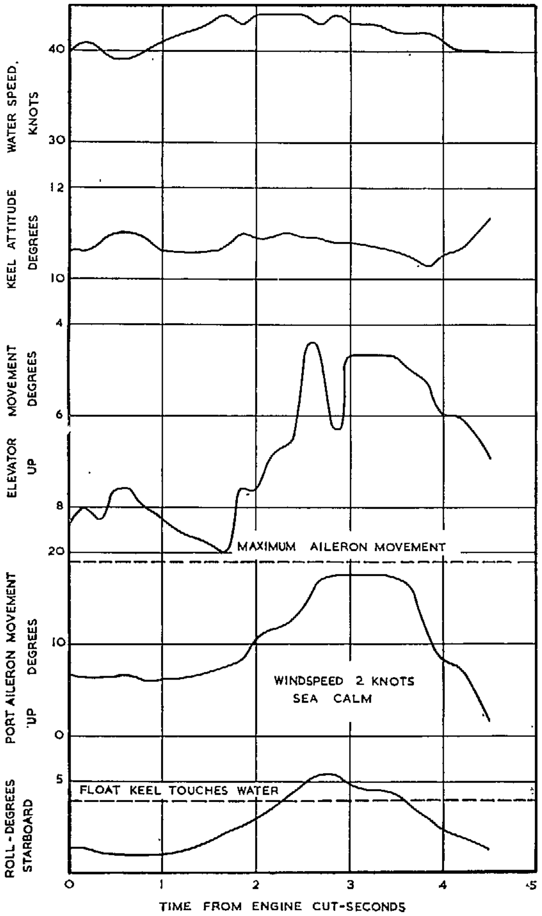


FIG. 10a. Time history of engine failure. Mean weight: 77,000 lb. Speed: 38 knots. Correction delayed.

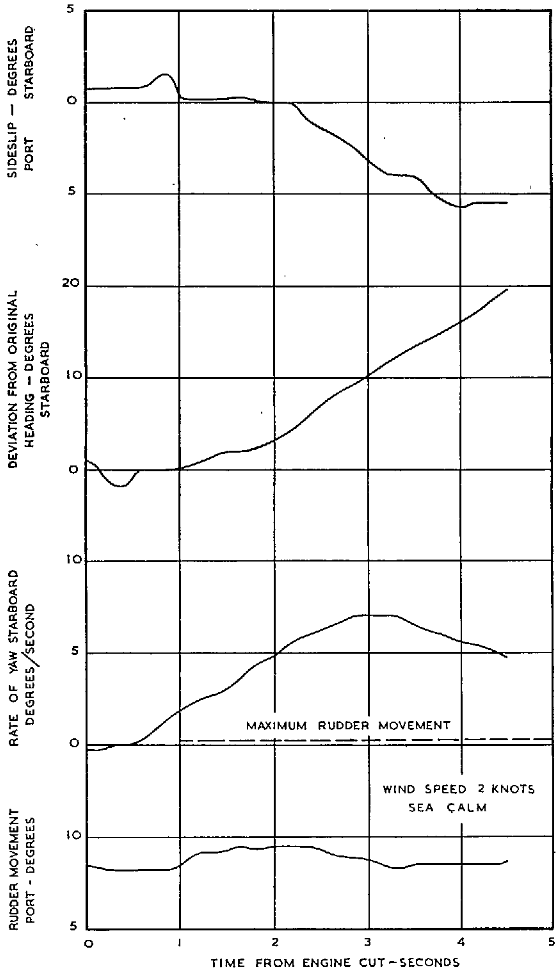


FIG. 10b. Time history of engine failure. Speed: 38 knots. Correction delayed.

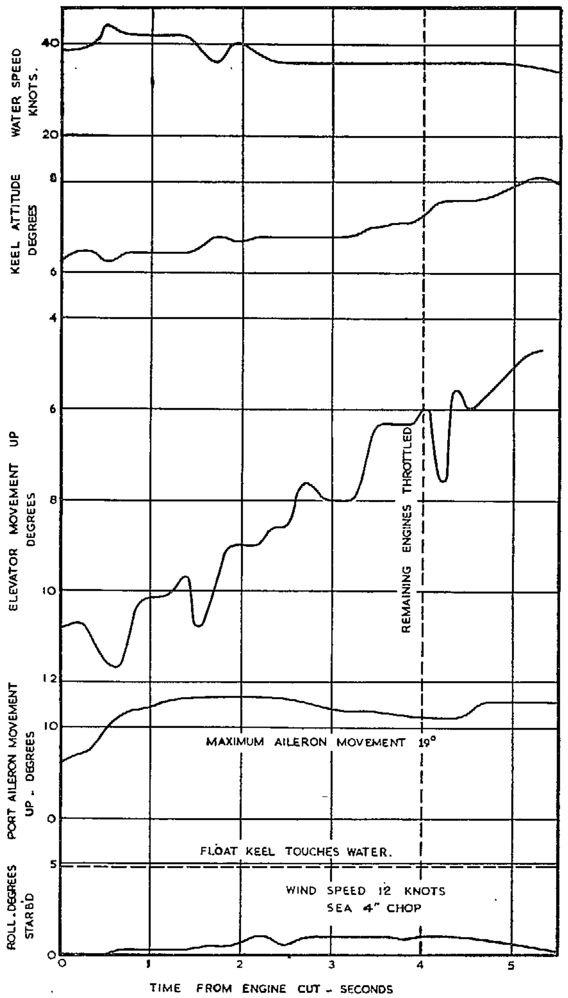


FIG. 11a. Time history of engine failure. Mean weight: 77,000 lb. Speed: 40 knots. No correction delay.

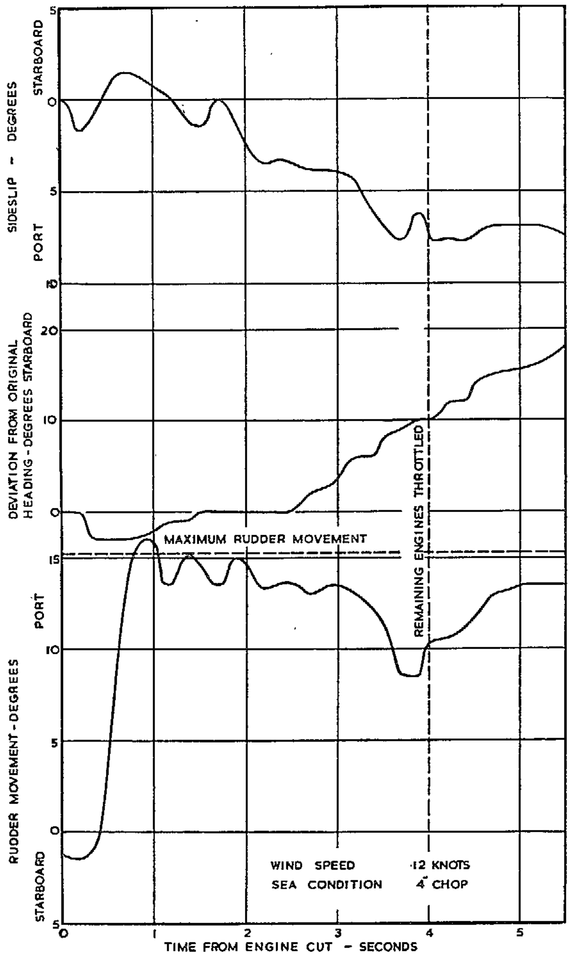


FIG. 11b. Time history of engine failure. Speed: 40 knots. No correction delay.

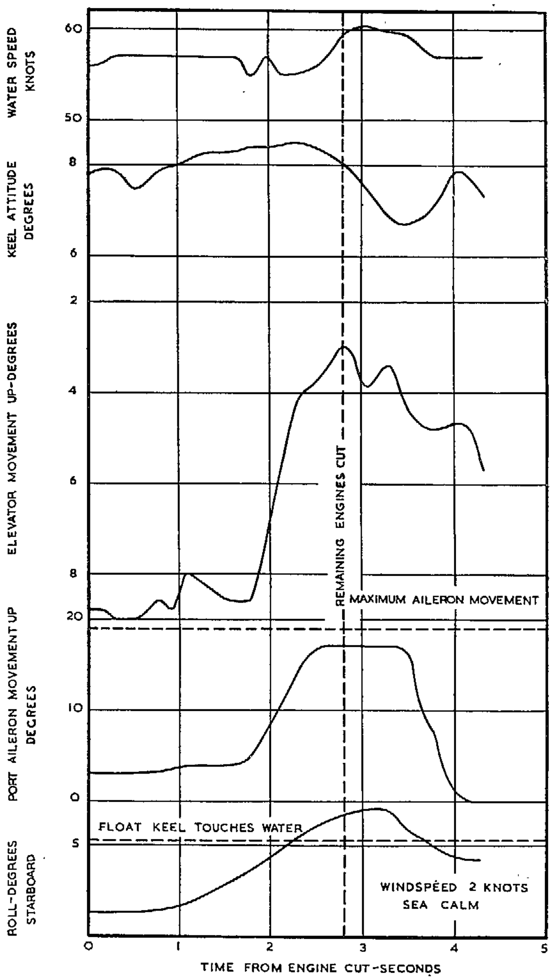


FIG. 12a. Time history of engine failure. Mean weight: 77,000 lb. Speed: 56 knots. Correction delayed.

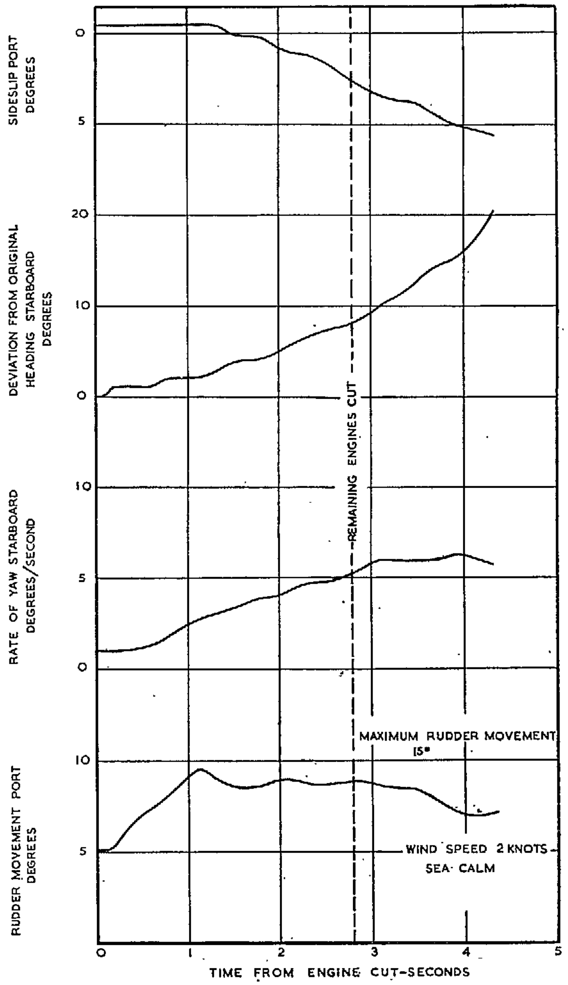


FIG. 12b. Time history of engine failure. Speed: 56 knots. Correction delayed.

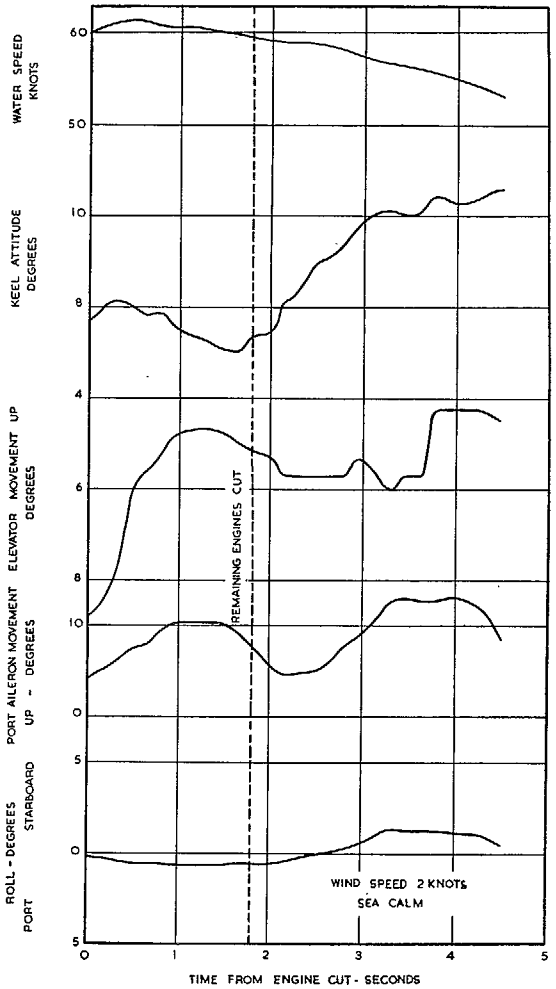


FIG. 13a. Time history of engine failure. Mean weight: 77,000 lb. Speed: 60 knots. No correction delay.

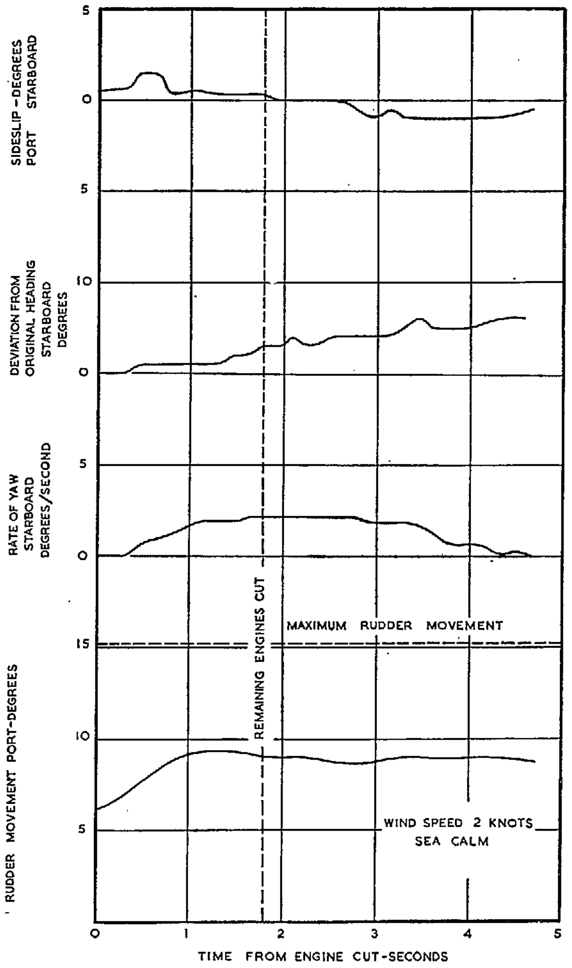


FIG. 13b. Time history of engine failure. Speed: 60 knots. No correction delay.

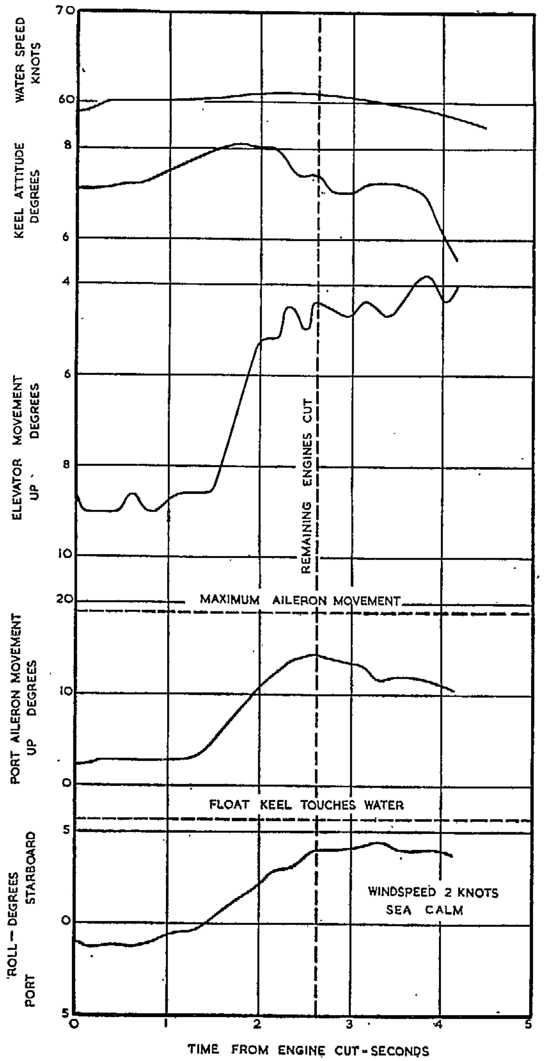


Fig. 14a. Time history of engine failure. Mean weight: 77,000 lb. Speed: 60 knots. Correction delayed.

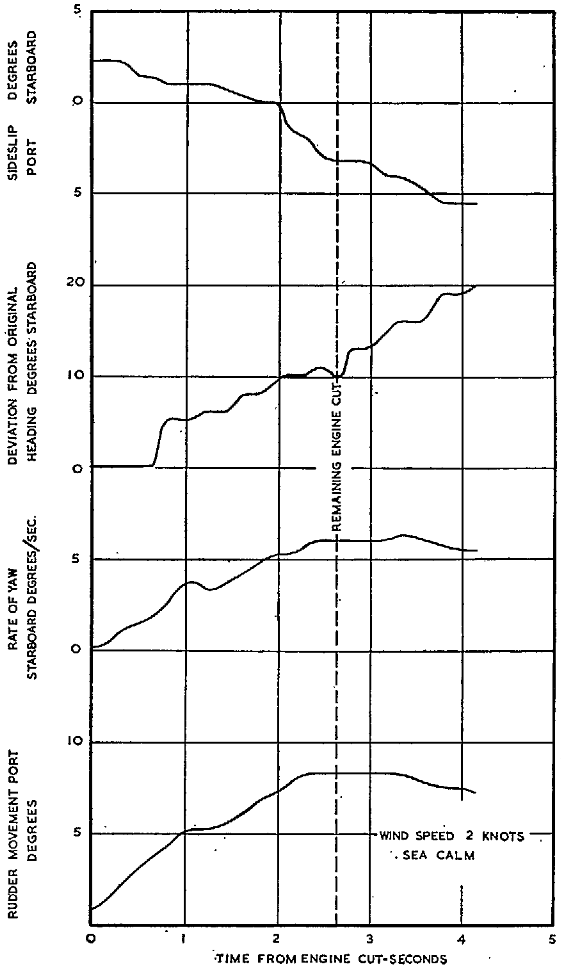


Fig. 14b. Time history of engine failure. Speed: 60 knots. Correction delayed.

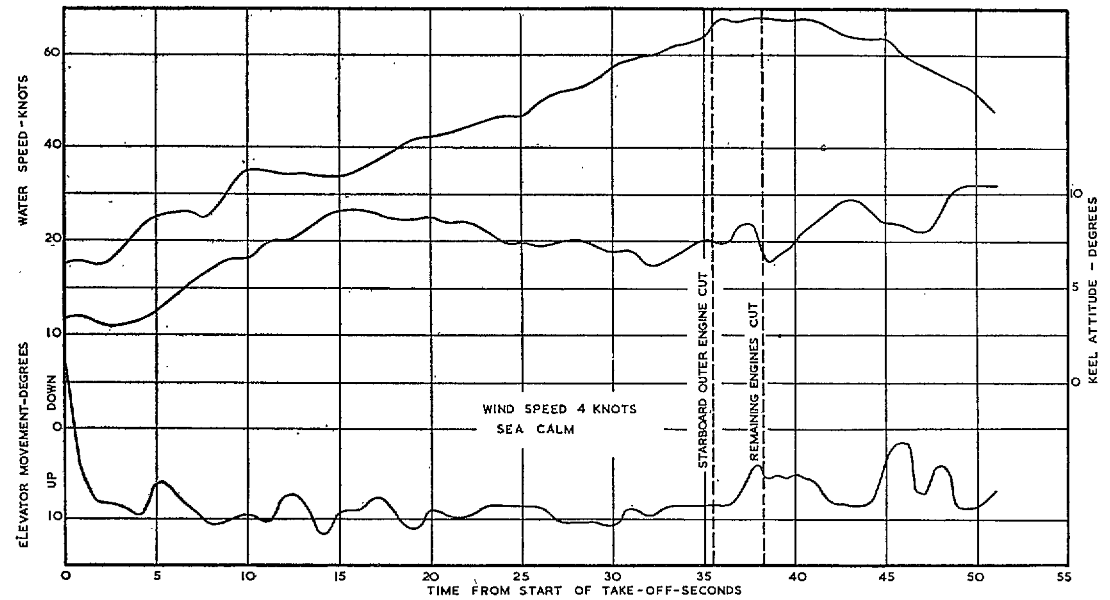


FIG. 15a. Time history of engine failure. Mean weight : 77,000 lb. Speed : 66 knots. Correction delayed.

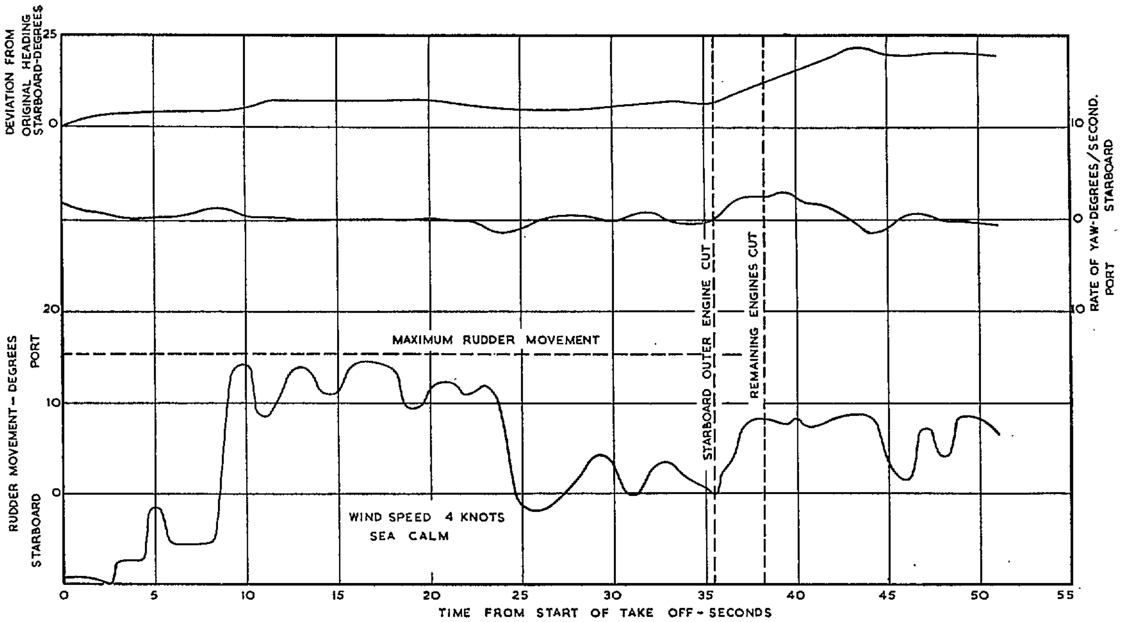


FIG. 15b. Time history of engine failure. Speed : 66 knots. Correction delayed.

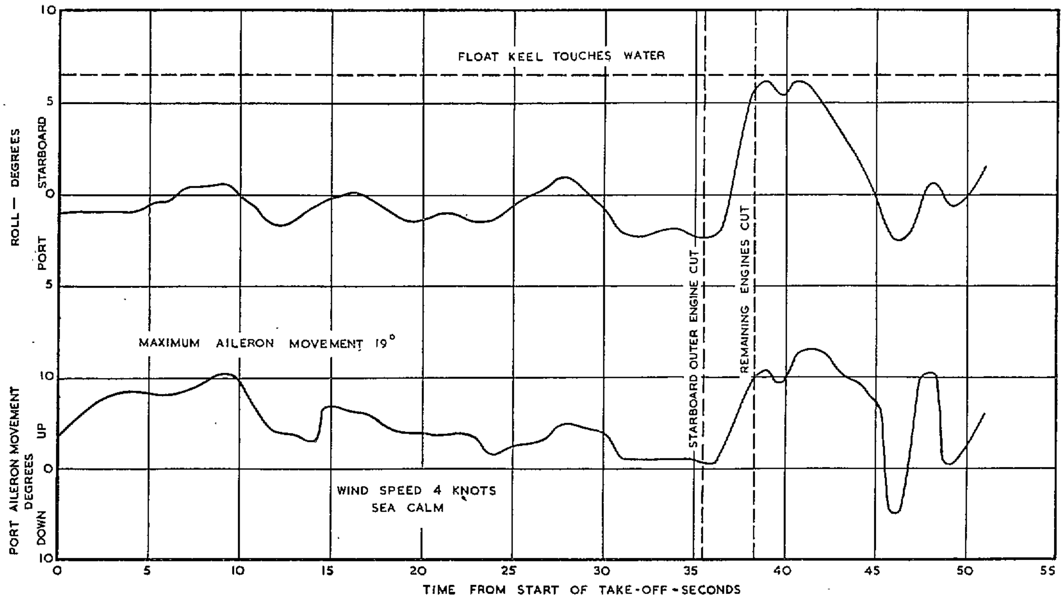


FIG. 15c. Time history of engine failure. Speed: 66 knots. Correction delayed.

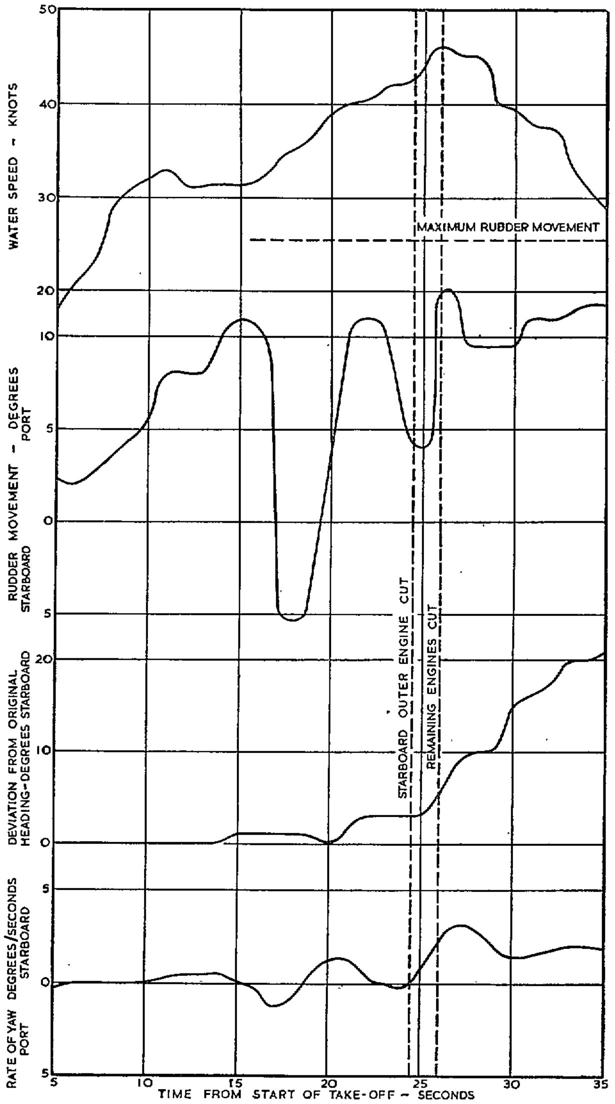


FIG. 16. Rudder movement to overcome engine torque effects. Mean weight: 77,000 lb.

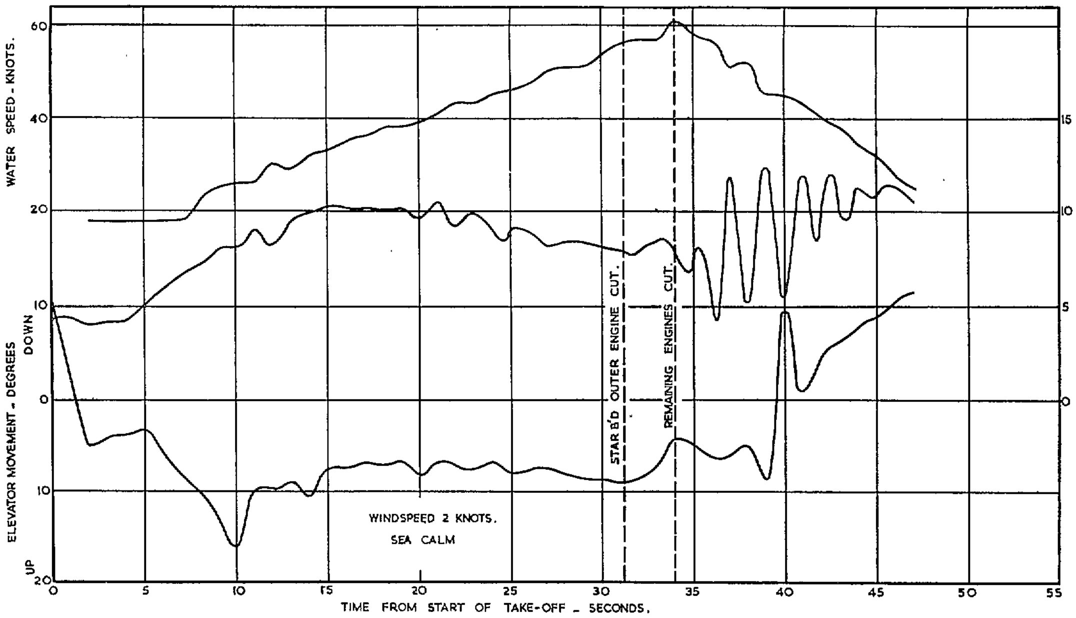


Fig. 17a. Example of porpoising after engine failure. Mean weight : 77,000 lb.

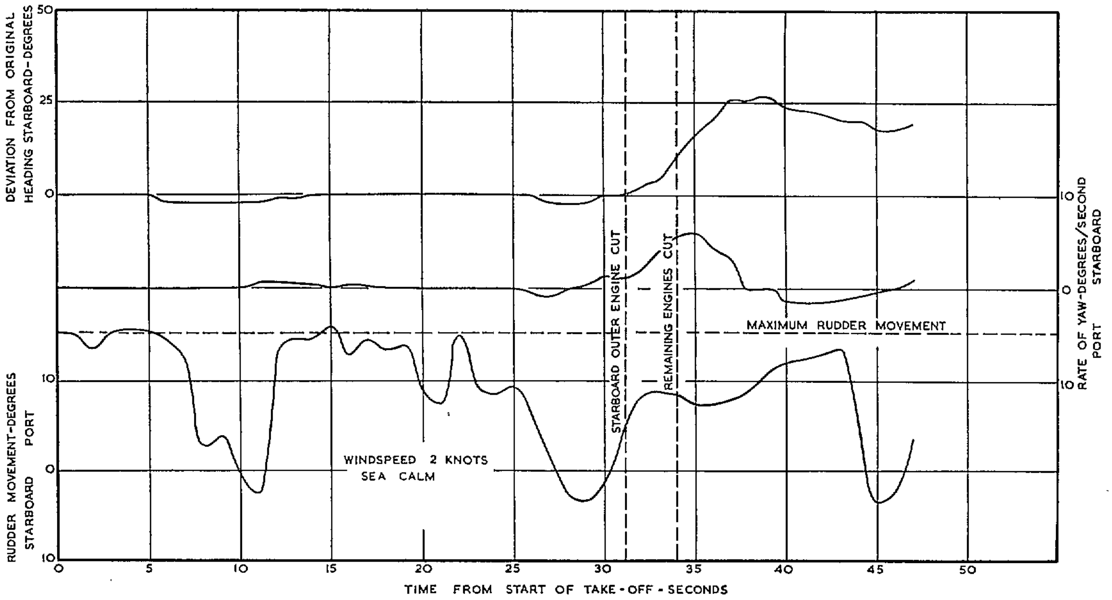


Fig. 17b. Example of porpoising after engine failure.

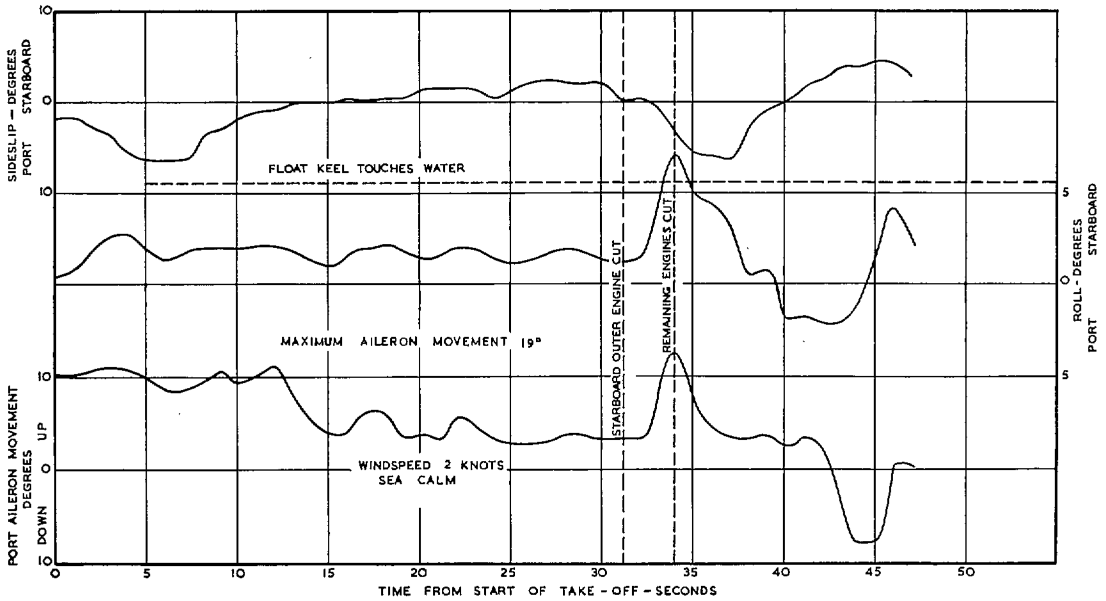


FIG. 17c. Example of porpoising after engine failure.

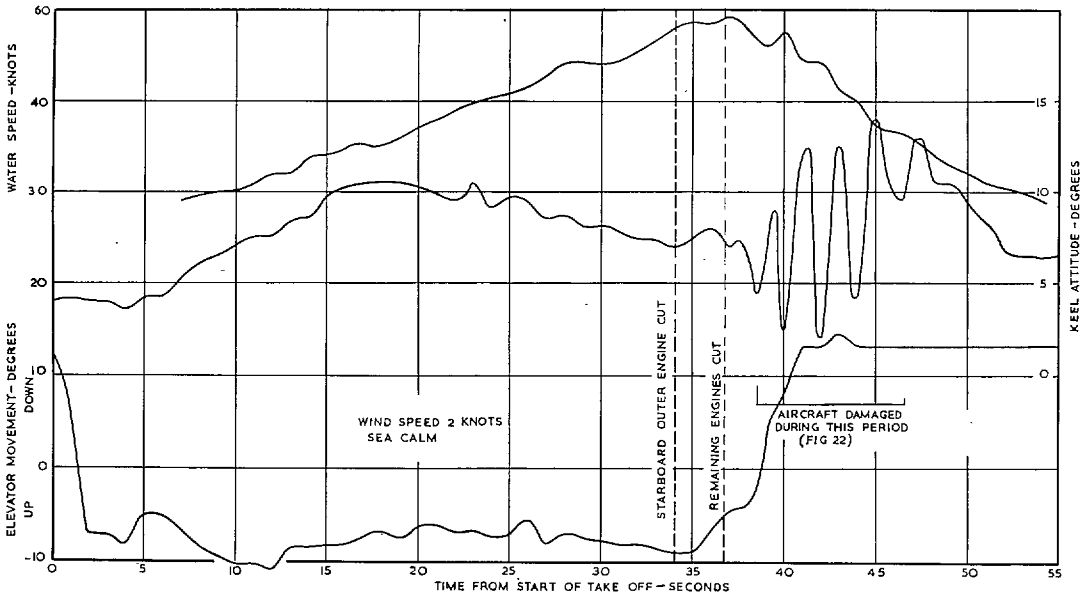


FIG. 18a. Example of porpoising after engine failure. Mean weight 77,000 lb.

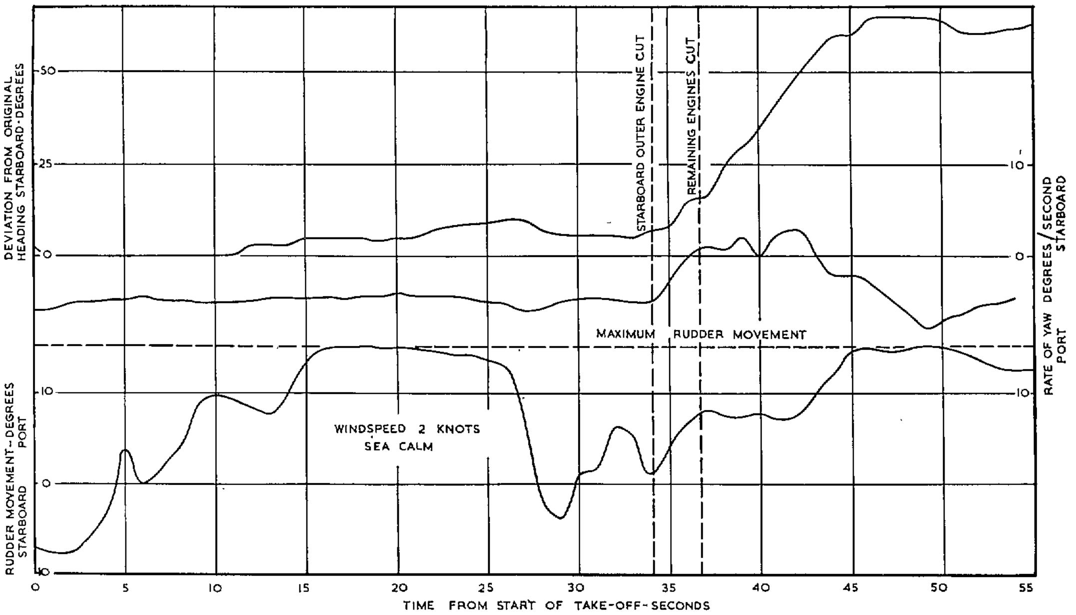


FIG. 18b. Example of porpoising after engine failure.

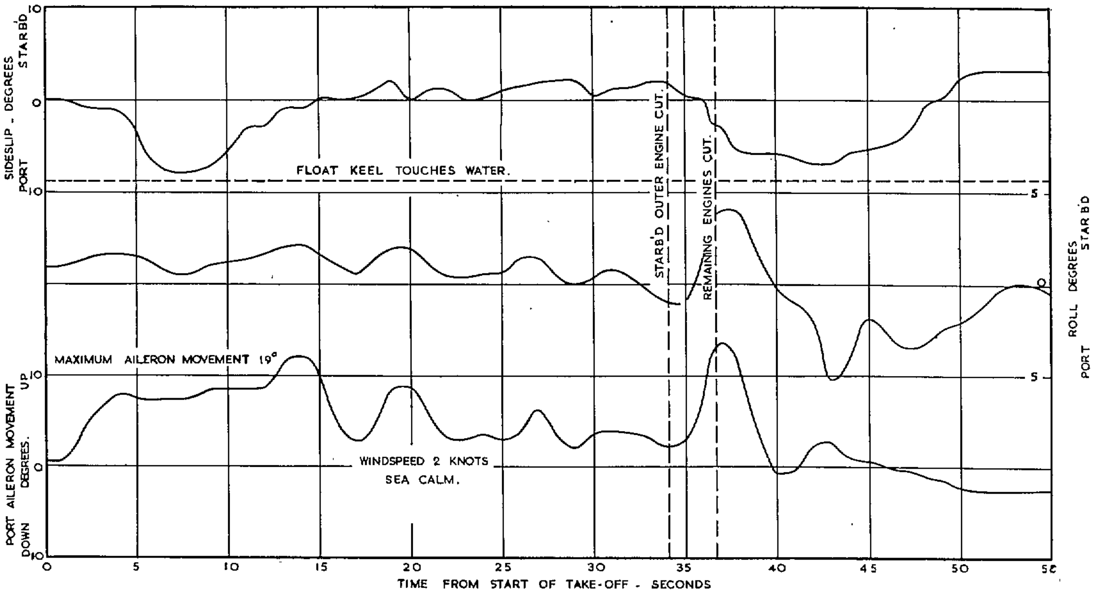


FIG. 18c. Example of porpoising after engine failure.

FIG. 19.

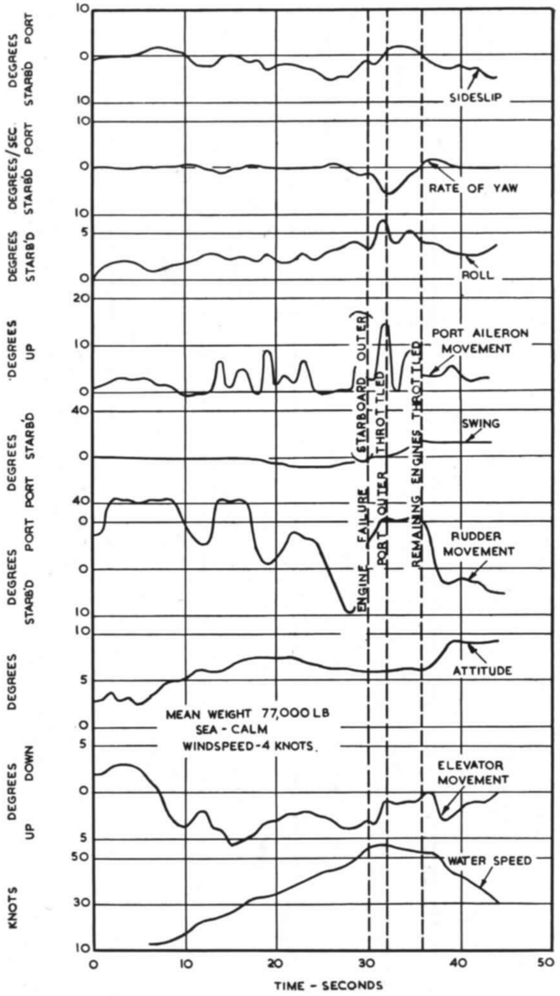


FIG. 20. Time history of run with engine failure at 58 kt I.A.S. Remaining engines throttled in stages.

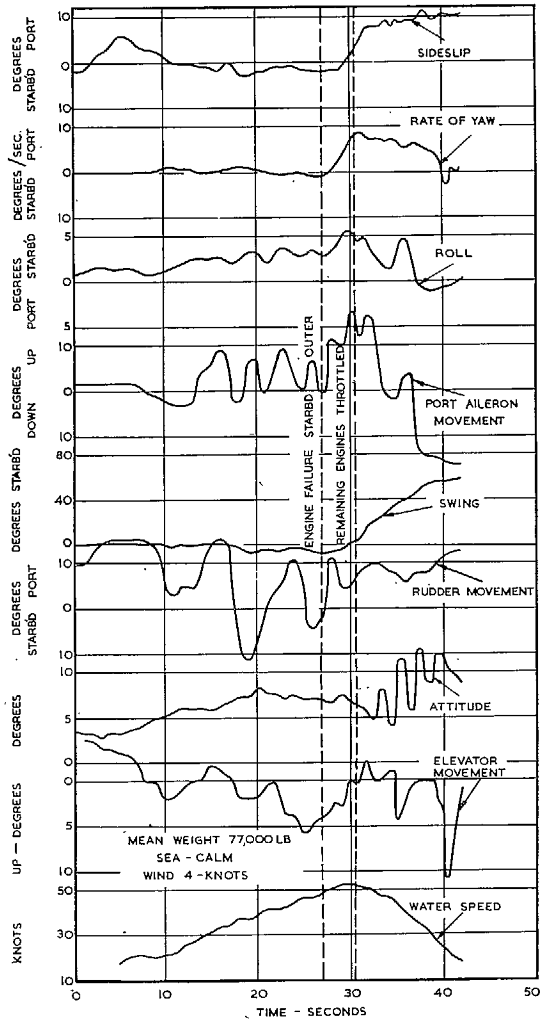


Fig. 21. Time history of run with engine failure at 50 kt I.A.S. Remaining engines throttled rapidly.

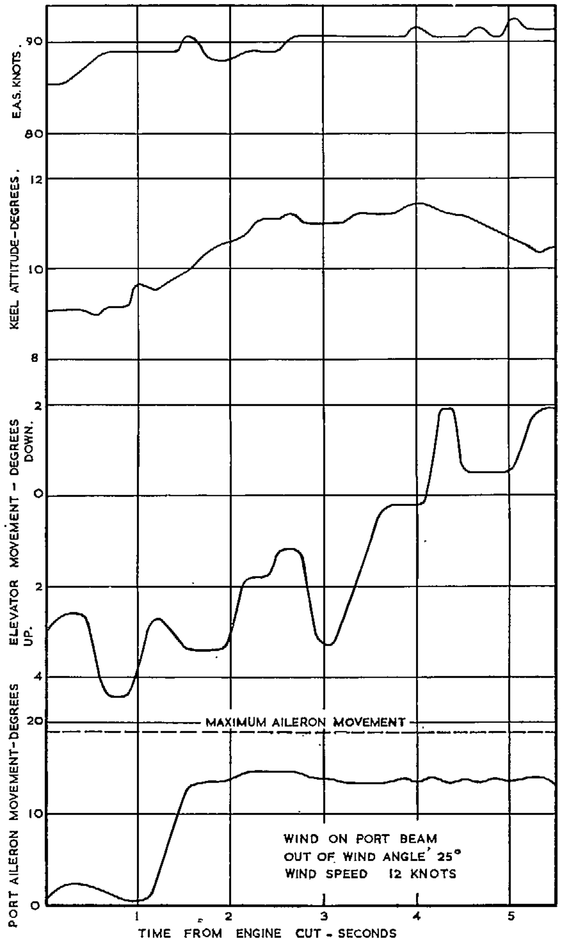


Fig. 22a. Time history of engine failure in cross-wind. Mean weight: 77,000 lb. Speed: 85 knots. Cross-wind component: 5 knots.

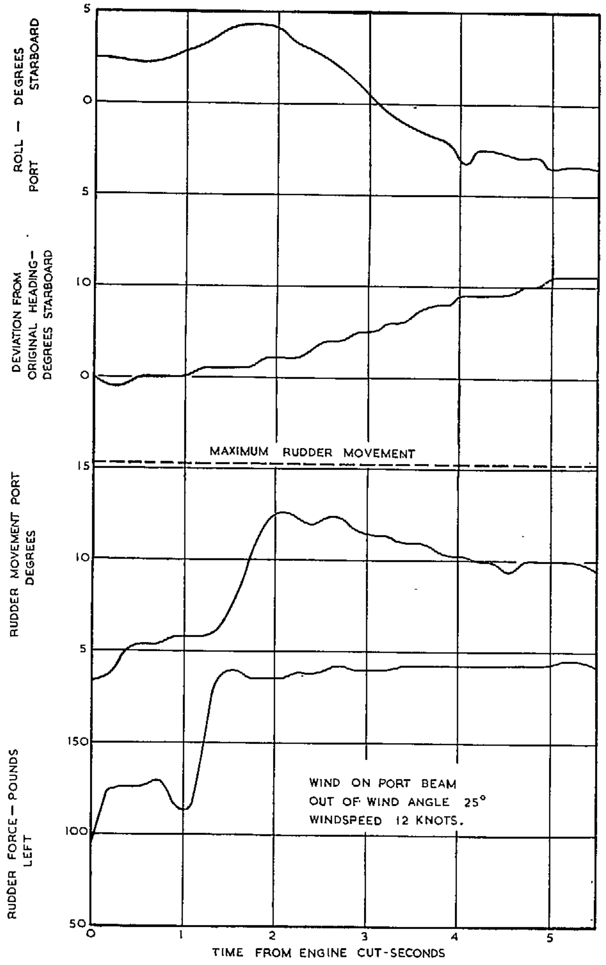


FIG. 22b. Time history of engine failure in cross-wind. Speed: 85 knots. Cross-wind component: 5 knots.

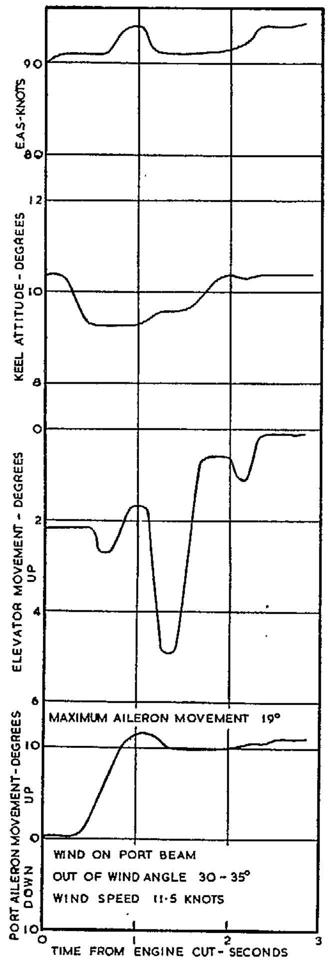


FIG. 23a. Time history of engine failure in cross-wind. Mean weight: 77,000 lb. Speed: 90 knots. Cross-wind component: 6 knots.

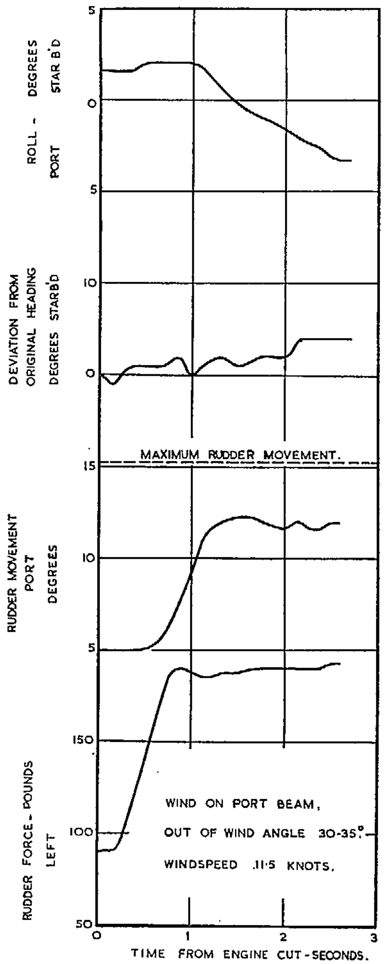


FIG. 23b. Time history of engine failure in cross-wind. Speed: 90 knots. Cross-wind component: 6 knots.

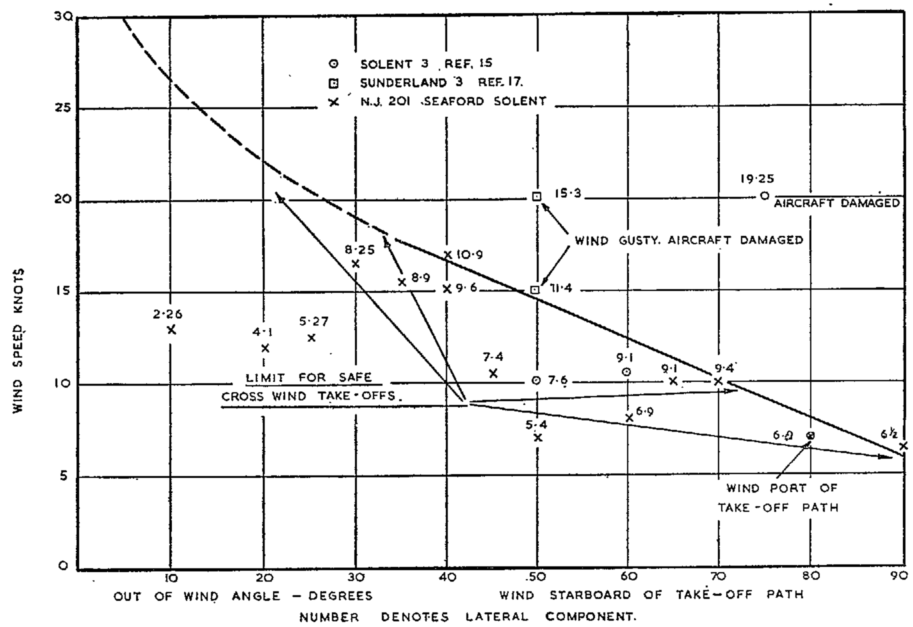


FIG. 24. Take-off cross-wind. Performance limitations.

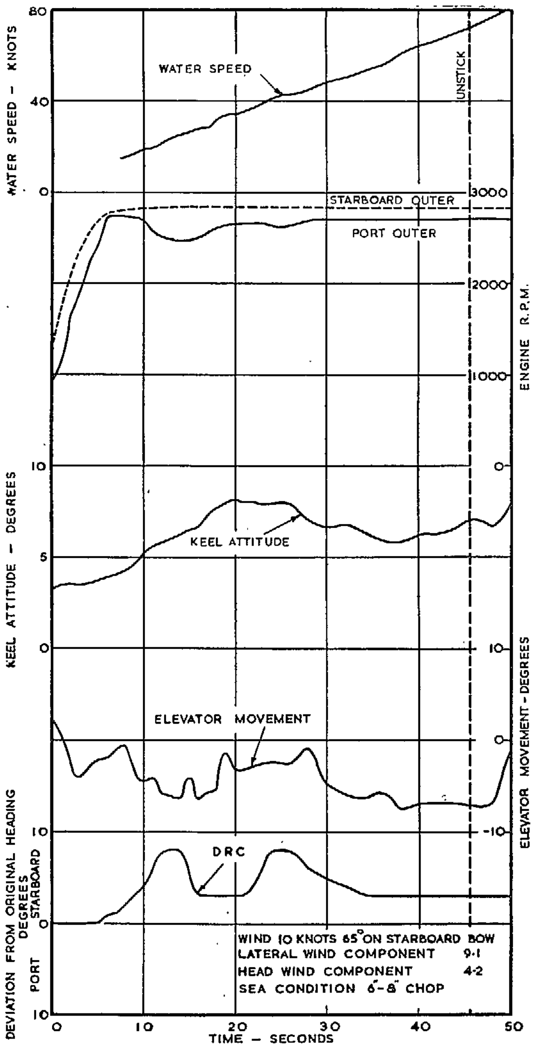


Fig. 25a. Time history of marginal cross-wind take-off (78,000 lb).

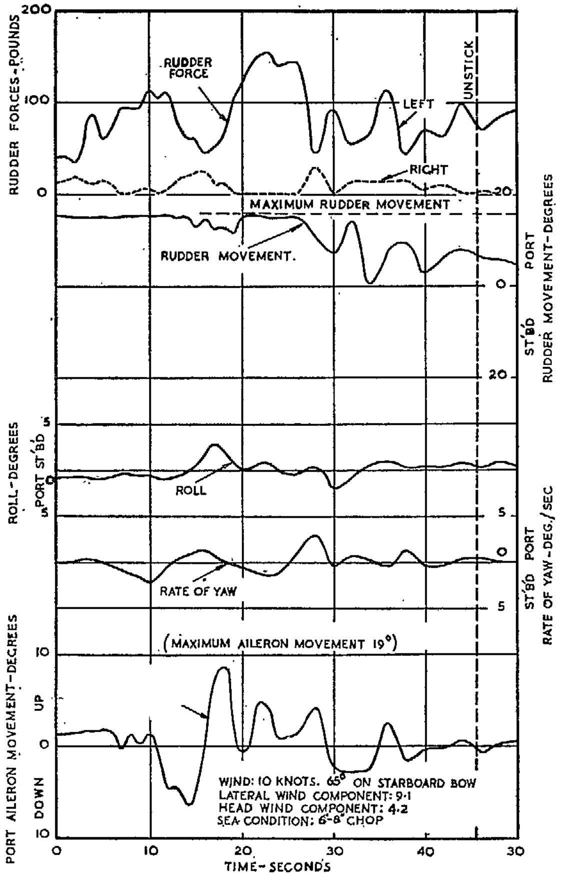


Fig. 25b. Time history of marginal cross-wind take-off (78,000 lb).

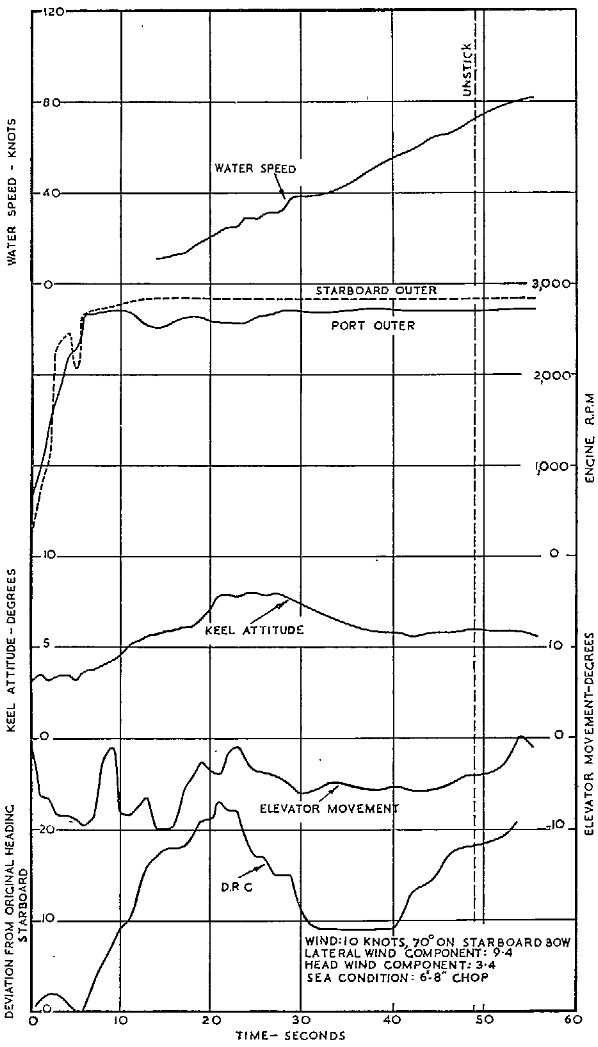


FIG. 26a. Time history of cross-wind take-off (78,000 lb).

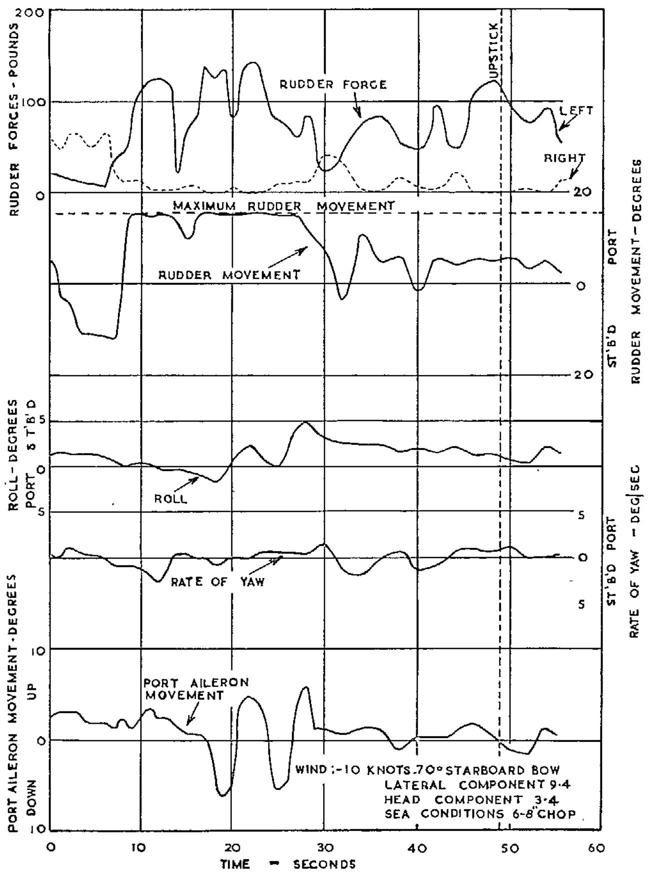


FIG. 26b. Time history of cross-wind take-off (78,000 lb).

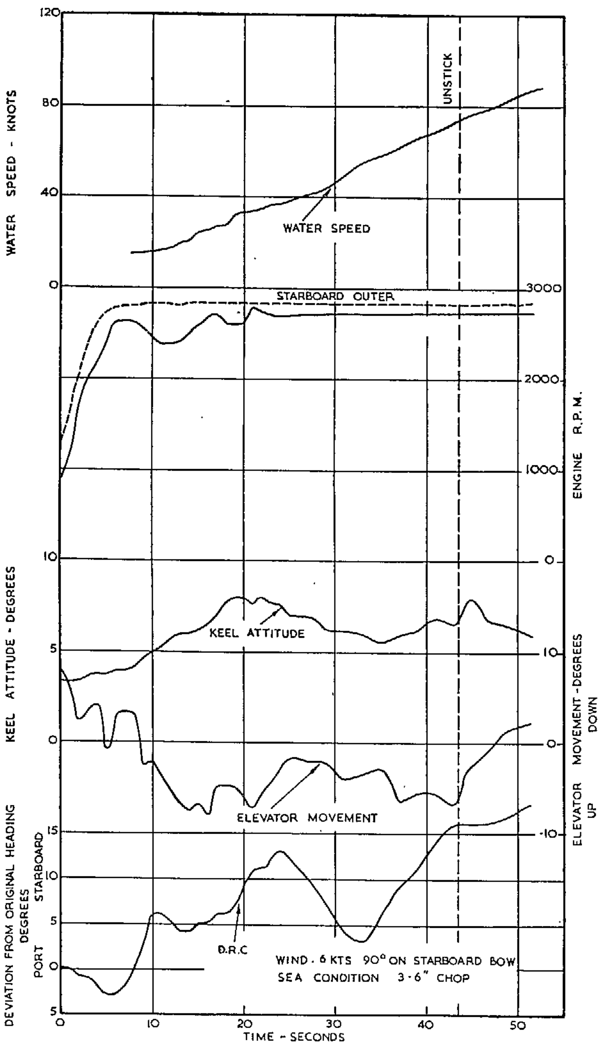


FIG. 27a. Time history of cross-wind take-off (78,000 lb).

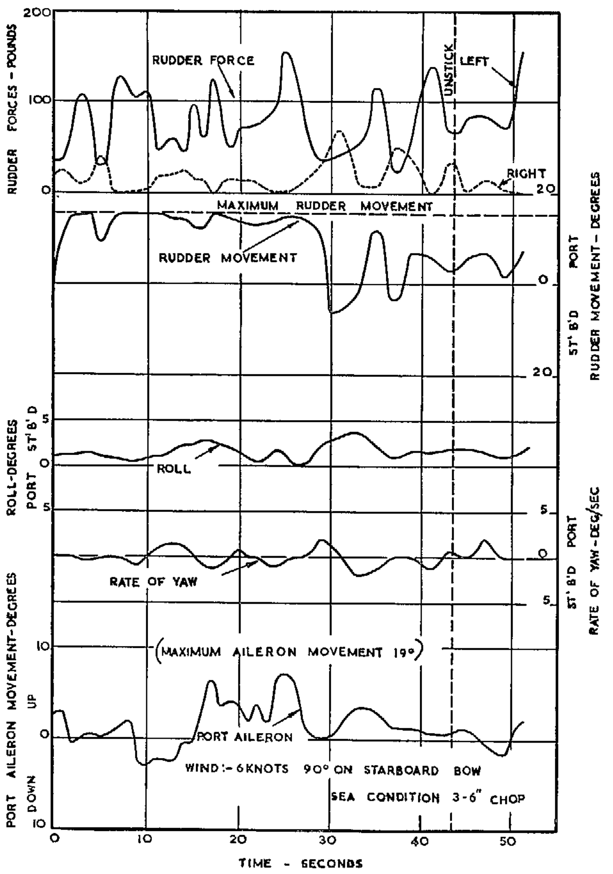


FIG. 27b. Time history of cross-wind take-off (78,000 lb).

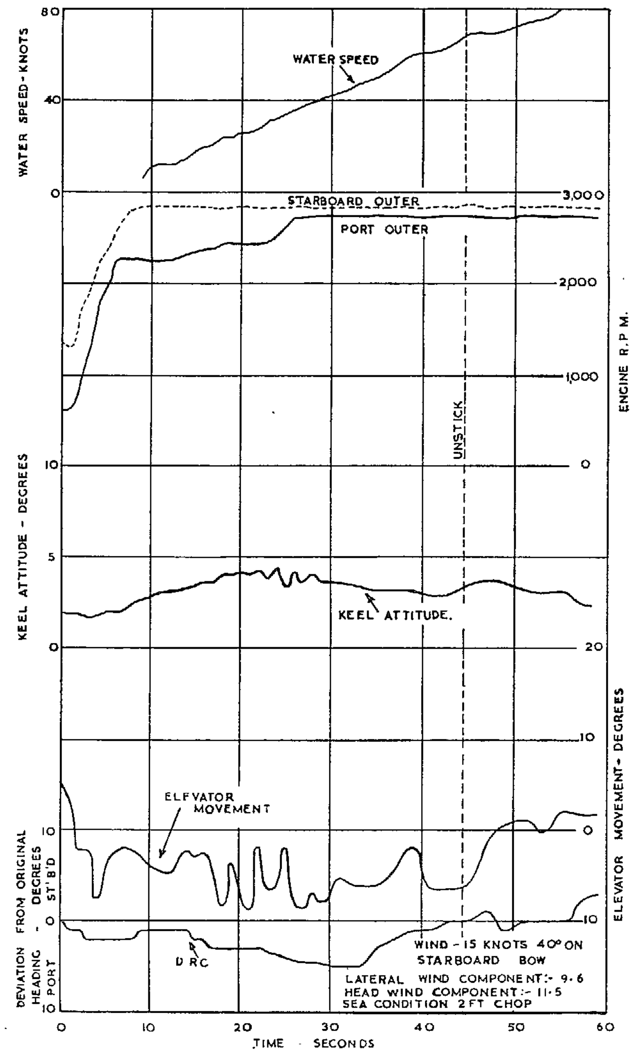


FIG. 28a. Time history of cross-wind take-off (78,000 lb).

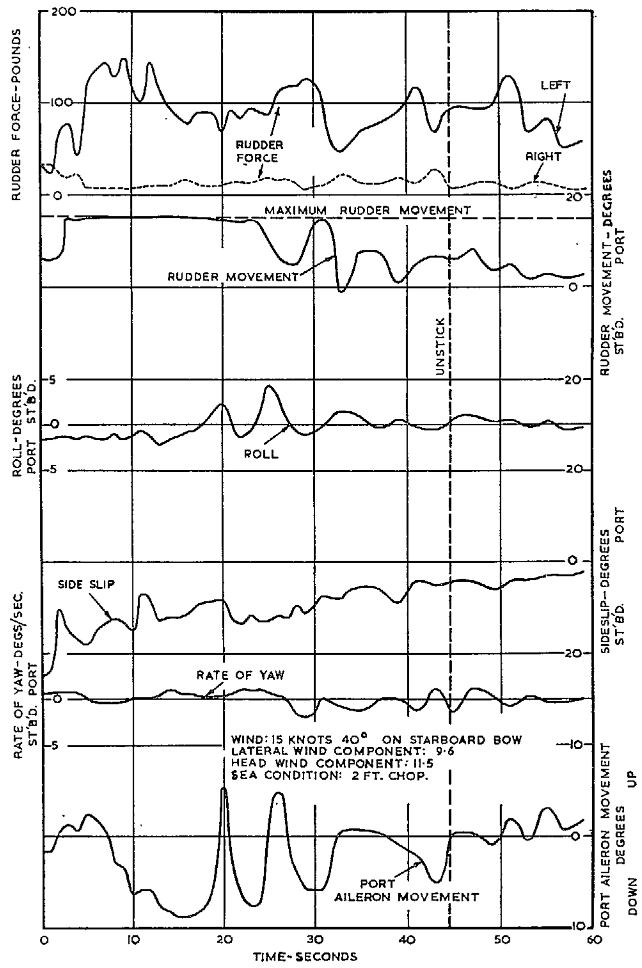


FIG. 28b. Time history of cross-wind take-off (78,000 lb).

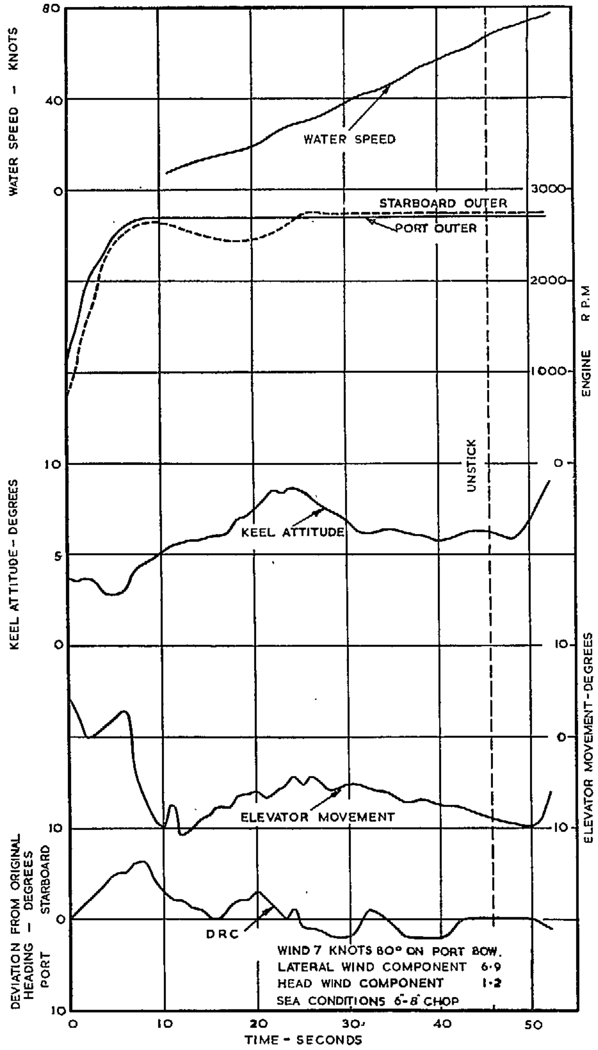


FIG. 29a. Time history of cross-wind take-off (78,000 lb).

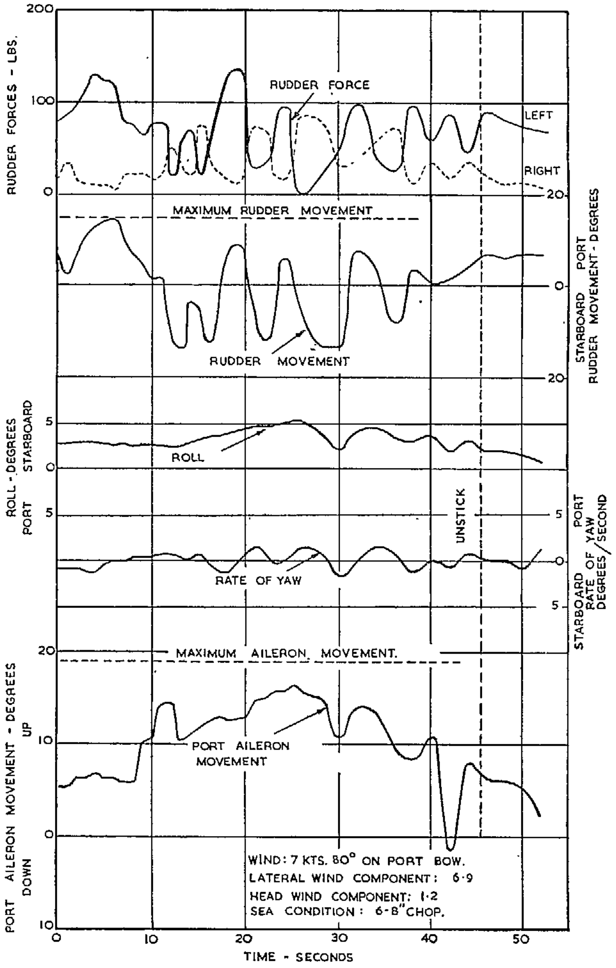


FIG. 29b. Time history of cross-wind take-off (78,000 lb).

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