REPORT OF OPEN SEA LANDING TESTS AND STUDY

Conducted at the

U. S. COAST GUARD AI

SAN DIEGO, CA

OCTOBER, 19 , 1945

[redacted]

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UNITED STATES COAST GUARD

ADDRESS REPLY TO:
COMMANDANT
U. S. COAST GUARD
HEADQUARTERS
WASHINGTON 25, D. C.

OAV
10 January 1958
A10

From: Commandant
To: CAPT D. B. MacDIARMID, FOURTEENTH Coast Guard District, Honolulu, T. H.

Subj: Open Seaplane Study - 1945, by Captain D. B. MacDiarmid

Ref: (a) Capt. MacDiarmid (o) ltr dtd 22 April 1957
(b) Comdt (OAV) ltr dtd 18 April 1957 (A10)

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J. D. McCUBBIN
By direction

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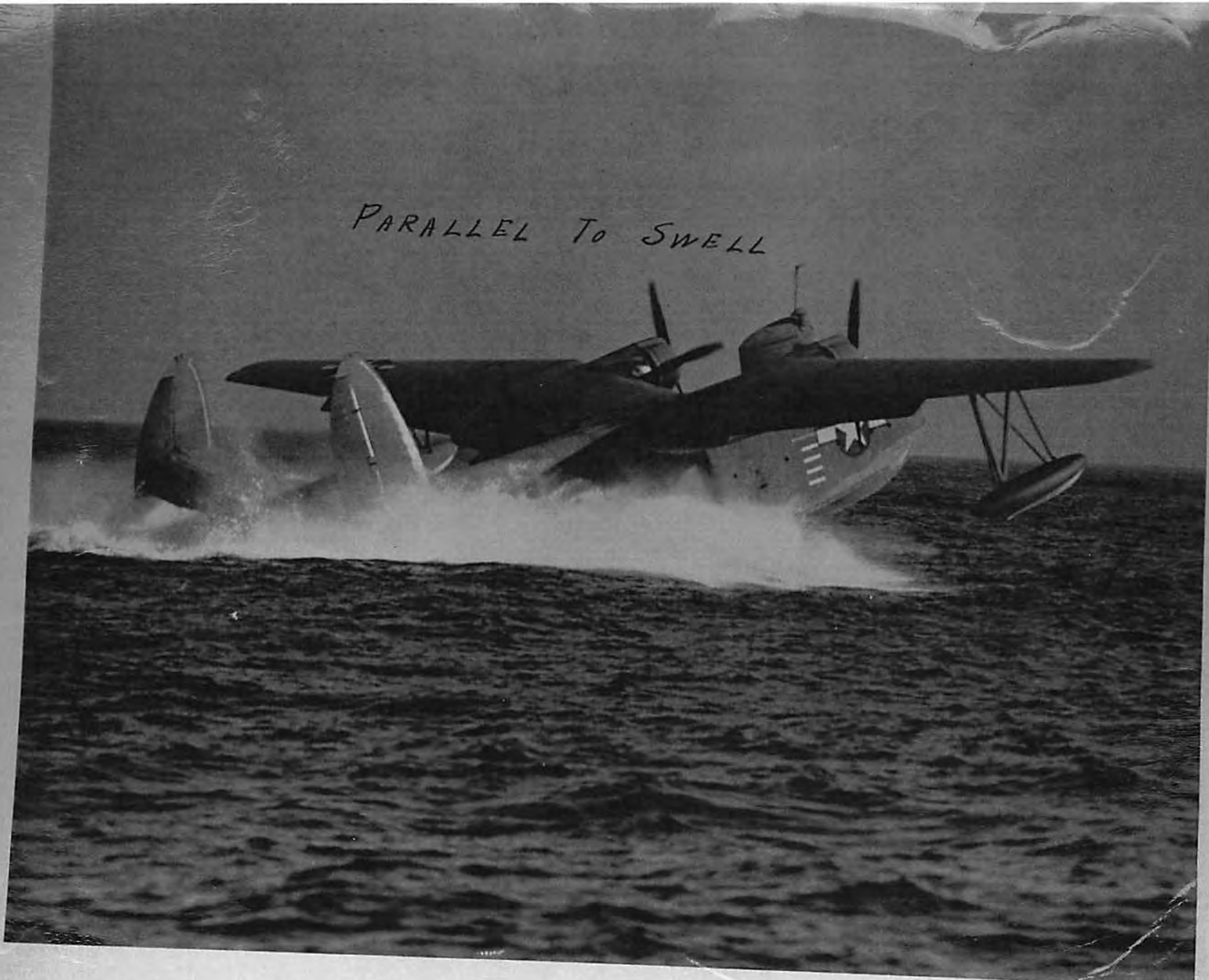

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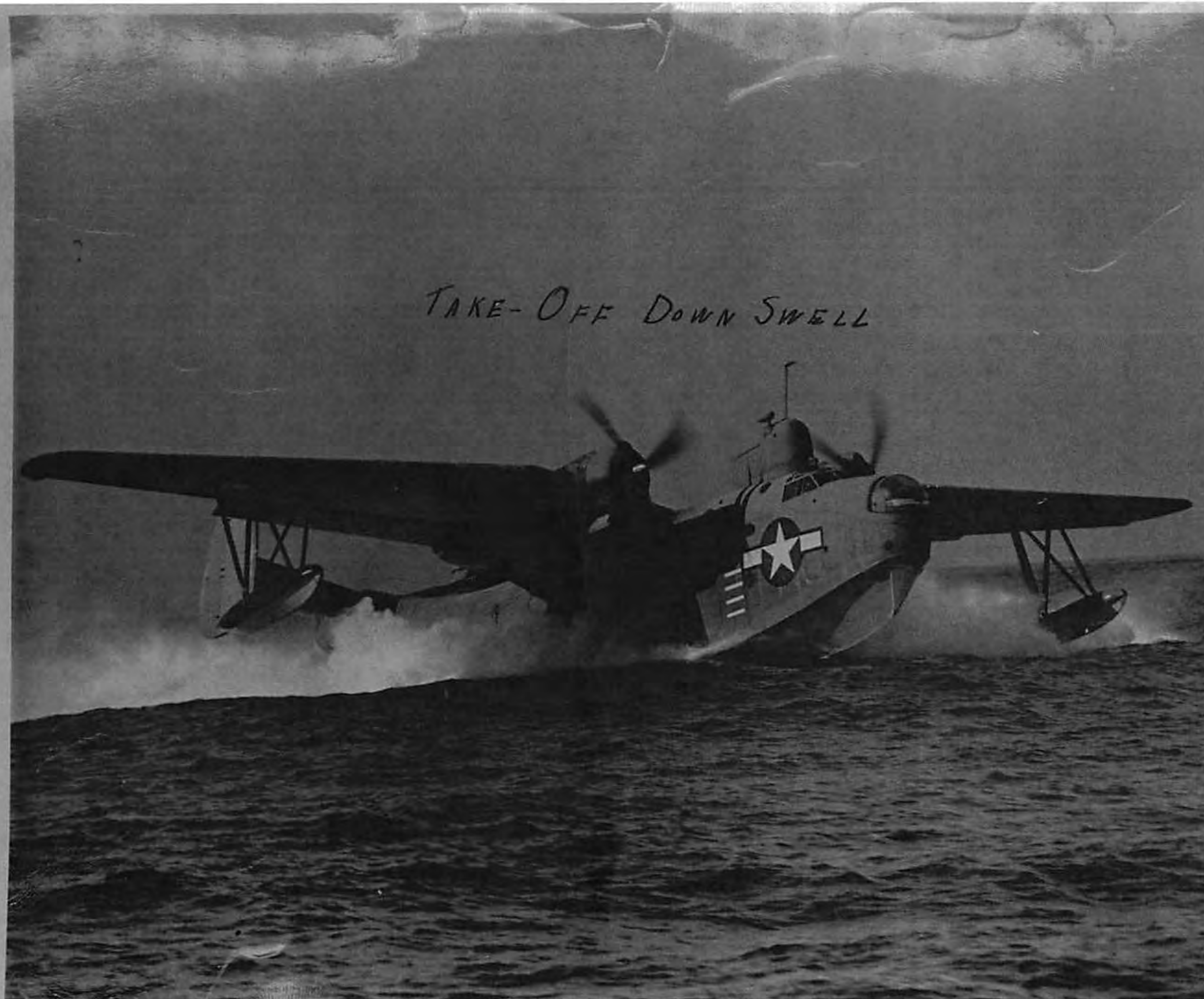

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INTRODUCTION

Air Sea Rescue operations in the San Diego area have required occasional open sea landings to rescue crash survivors who were drowning or injured or plainly suffering from severe shock. The rescue pilot has been unable to find any helpful published doctrine or instructions to guide him in such landings; and often on requesting advice from an older pilot would be told, "Every case has to be judged on its merits," and no more. The plain fact was that the pilot who had made the successful open sea landing had done the job with so many things pressing on his mind in addition to the actual landing that afterwards he could not remember clearly just how he had made the landing and take-off. So many planes have been lost or badly damaged in open sea landings that an objective study of pilot technique and doctrine supported by tests made as far as possible under controlled conditions and recorded by observers, cameras, and stress registering instruments, became very desirable. This is a report of such a study and experiments.

The long held and generally accepted conclusion that all seaplane landings should be made into the wind, if possible, was first substantially challenged by a Pan-American pilot who made a down swell, down wind experiment in the middle of the Pacific Ocean. His report of the success of this landing and take-off in the long Pacific swell was widely discussed by seaplane pilots in the Navy and Coast Guard.

It is obvious that no sound analysis of what happens during landings and take-offs under varying conditions of sea and wind is possible without considerable study of the forces, forms, and velocities involved and how these affect one another and the seaplane.

The available authorities on waves were cordial and generous with advice, but it was quickly apparent from discussion with them and from study of available published material that most of the information on wave and sea motion and its forms and forces was inadequate for a well done study of the relationship of wave phenomena to seaplane landings and take-offs. The mechanics of a complex sea, in particular, are very obscure; and probably a clear understanding of these would help to throw a great white light on some of the baffling forces that sometimes suddenly disconcert seaplane pilots in the middle of a landing or take-off run at sea.

A discussion of wind, waves and swell will be found as a part of this report.

The landing and take-off tests supporting this report were made off the coast of Southern California.

The principal hazard to seaplane landings and take-offs in this area is the long fast Pacific swell which originates usually in the violent storms of the Western Aleutians, and is influenced by the various storms through which it passes enroute here. These swells exhibit a height on arrival here of from three to twelve feet, a velocity of fifteen to forty knots, and the length between swells of from one hundred to thirteen hundred feet. Local winds generate shorter seas from various directions and of heights from one to eighteen feet, and rarely of the same period as the Pacific swell.

During these tests, landings and take-offs were made on all headings with regard to the swell, that is, up and down swell and parallel to the swell and quartering the swell up and down; and on all headings with regard to the wind, that is, up and down wind and cross wind and with the wind on the bow and on the quarter. Landings and take-offs were made by eleven different pilots varying in experience from 3,600 hours to 600 hours.

Deliberate attempts were made to use various landing techniques such as holding the nose very high, dragging the nose, relieving bounces by quick application of power, "sitting them out" with the nose high, fighting tendencies to plane off by quick and radical use of the elevators, and similar variations in take-off technique. Each pilot was encouraged to try his own ideas freely, and the merit and effectiveness of these ideas was analyzed and criticized freely by the other pilots. It is believed that the aviator riding as co-pilot learned as much in each test as the pilot. A total of fifty-four landings and take-offs were made giving the equivalent of one hundred and eight instances of pilot experience and impressions. An attempt was made to keep careful records of landing and take-off running time and air speeds and accelerations in bow, center of gravity, step, and tail, on all tests, with simultaneous movie records of the appearance of the sea from the pilot's position, of the pilot's cockpit during the landing and take-off, and of the plane itself from a boat alongside during each landing and take-off. Many of these records were disappointing due to failures of the instruments, distraction of the recorder, and failure of the movie record due to the operators bouncing in a crash boat, or the crucial point of the picture being obscured by spray, or the camera running out of film at the wrong moment.

On a number of occasions when particular sea conditions considered important to this study existed for a brief period, test landings and take-offs were made without any or only a part of the instruments recording, rather than miss the opportunity while waiting instrument adjustments.

Generally speaking, the records and pictures do not reflect the true conditions encountered. From them some simple landings and take-offs look difficult and vice versa, due to variations of technique being used and the large element of luck in these landings, and the differing abilities of the photographers to get pictures showing the swells truly.

It is understood that this is a highly controversial subject and the test pilots have already found that other pilots who have made one or two open sea landings under service conditions and who have previously been unable to give a coherent picture of just how they handled them, are immediately upon getting this data, old masters who are prepared to state authoritatively that (a) the report is misleading, (b) the seas in their localities are entirely different and these techniques would be suicide for them, (c) that this series of tests has been completed only by good luck, (d) that open sea landings are very easy and this discussion is much ado about nothing, (e) that open sea landings are impossible and the idea should be given up entirely, etc., etc.

At the start of aviation, enthusiasts were discouraged by the comment that man was not intended to fly like the birds. Man can now fly higher and farther and faster than the best of the birds, but the albatross and the petrel still put the aviator's battle with the sea to scorn. Whether the human flier will outclass these creatures in their element, too, depends only on the brains and courage and determination applied to the problem.

SECTION I - A.

DESCRIPTION OF OBJECTIVE AND SCOPE OF TESTS AND STUDY

Tests were planned to make landings and take-offs in the open sea under progressively more severe conditions to determine:

(1) What heading with respect to the local sea, Pacific swell, and the wind, is best for landings and take-offs under conditions to be found in these waters.

(2) What characteristics or qualities of various conditions of sea and wind constitute special hazards to aircraft landing or taking off.

(3) What pilot techniques could best be employed to make successful landings and take-offs under various conditions of sea and wind.

(4) What merit the PBM-3 airplane has as a rescue plane for this type of work.

(5) What special weaknesses the PBM-3 airplane may exhibit in this work and to analyze these and recommend specific alterations where possible to cure them.

(6) By careful observation and analysis of recorded data, what stresses on the aircraft incident to open sea operations under various conditions indicate hazards of structural failure possibly not previously known or understood.

(7) What advantages and disadvantages are encountered in carrying and using JATO gear for rough water landings and take-offs.

I - B

SECTION I - B.

OPEN SEA LANDING TESTS, PBM-3C, BUNO 6586

U. S. COAST GUARD AIR STATION
SAN DIEGO, CALIFORNIA

OCTOBER, 1944 to MARCH, 1945

Conclusions on the study of open sea landings here were:

A. SEA AND WIND.

1. That judging sea conditions by eye is very difficult because a locally formed sea may conceal a long fast swell beneath it.

2. That sea conditions in this area are usually the result of several wave systems, only one of which strikes the eye as a distinct pattern, and that groups of waves whose heights are equal to the sum of the heights of the wave systems in the phases which form them advance with a velocity nearly one half of the average velocity of the two wave systems.

3. That observers usually underestimate the length of most waves and the heights of low waves, and overestimate the heights of big waves.

4. That a spot or instant can be selected where the principal wave systems are in opposite phase and the crests of one fill the troughs of the other, and that a landing at the approach edge of such an area will provide the best conditions possible in the existing sea.

5. That there are often relatively smooth spots in an otherwise rough sea which persist too long to be explained by the temporary coincidence of wave systems in opposite phase. These are probably due to wind and ocean current. Such areas, where conveniently located, provide the smoothest seaplane landing or take-off surface available.

6. That swells in deep water not in the process of generation or

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change under wind influence have approximately the form of a sine curve. The fronts of the swells are no steeper than the backs.

7. That the Eastern Pacific swell is usually travelling at between twenty and forty knots, but that the actual translation of water is practically negligible.

8. That the actual energy in the swell which may affect an aircraft is small, but that the hills and valleys caused in the sea's surface by the swell affect an aircraft landing or taking off almost the same as dips or bumps in a runway affect a land plane. That a take-off into the swell is more difficult than a take-off down swell only because the aircraft is hitting the swells oftener and hitting more of them.

9. That a plane is not "thrown off" the water by a rough sea, but actually planes off due to the inclination of the water's surface over which it is running, and Newton's law that a moving body will continue in a state of uniform motion until acted upon by an external force.

10. That the best direction for a landing or take-off in a well defined swell with winds of less than twenty knots is parallel to the swell. That in the presence of several definite wave systems, the sea should be studied very carefully by the pilot and an attempt made to land on a heading which will not run directly into the face of either wave system and which will bring the wind on the bow rather than on the quarter if it cannot be brought ahead. Such conditions are very difficult and dangerous, and the pilot should be alert for the unexpected. Experienced and careful pilots have found themselves running into a high and ugly wave in the middle of their landing run and had the airplane taken right out of their hands. A landing can be made with safety parallel to the swell either on the crest or in the trough.

11. That the second choice of landing or take-off heading in a long fast swell is directly down swell. Such a landing should touch down on the

crest of the swell or within a few feet past it.

12. That the last and poorest choice of landing in a long ocean swell is into the swell unless the wind is so strong from that direction that no other landing or take-off heading is considered safe. Such a landing should touch down on the crest of a swell or within a few feet past it.

13. That a landing and take-off in a rough or complex sea is a dangerous undertaking at best, and that its successful accomplishment involves considerable luck as well as skill.

B. PILOT'S DOCTRINE AND TECHNIQUE.

I. Landing.

1. That the airplane should be touched down at the slowest possible air speed.

2. That a stalled landing should be very carefully planned and executed lest a stall intended to drop a few inches on to the crest of a swell, miss the crest and fall eight or ten feet into the trough.

3. That with winds of less than twenty knots the direction of the wind is a consideration to the pilot definitely second to the necessity of planning a landing or take-off run with regard to the swell alone.

4. That the best landing approach in a regularly formed sea with light winds is parallel to the swell touching down on the crest of the swell. Touching down in the trough while running parallel to the swell does not embarrass the pilot very much. The popular fear that a wing tip float will probably be dragged in on such a landing is not supported by experience. If the landing is cross wind, the pilot may either crab into the wind as necessary, slip slightly, or approach with wings level and ignoring drift. The sidewise motion does not appear to affect the landing characteristics of the plane when stalled on in the open sea nearly as much as it does in a

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smooth harbor, probably because there are so many other factors affecting the landing that this one becomes relatively unimportant.

5. That the second best landing heading in a well formed and regular swell is down swell touching down on the crest of a swell or within a few feet beyond it and making every effort to prevent the airplane from being thrown high in the air as she planes up over successive swells. To accomplish this, the nose should be deliberately pushed down as the plane races up the back of a swell and approaches the crest. As the plane starts to fall back on again, the nose should again be pulled up. This technique requires very fast pilot reaction, but is believed safer than to hold the nose high at all times because the principal damage suffered in these tests was from the shock of falling back on hard after a high bounce.

6. That a landing should be made into a fast swell only when the wind is blowing from that direction with a force so great that a landing on any other heading will be very hazardous due to the wind. Landings have been made here cross wind and down wind in winds of fifteen knots without breakage.

7. That a landing quartering the swell is better than a landing directly into the face of the swell.

8. That the pilot's final decision on his landing direction should be a compromise between first, attempting to land parallel to the swell or down swell and without running into the face of a second wave system possibly concealed beneath the first, and second, bringing as much of the prevailing wind ahead as possible.

9. That the pilot should, if possible, study the sea from a height of about two thousand feet to detect any large ocean swell which might be concealed by the swell which is the only one apparent at low altitude. He should then drag the sea at about twenty or thirty feet on headings all around the compass to note on which headings the sea appears easiest. The

direction of the wind, unless it be twenty knots or more, should always be considered a hazard secondary to the sea conditions in planning a landing.

10. That the final approach for the landing should be dragged in low a mile or so short of the proposed landing spot with the propellers in low pitch, the flaps down full, and the tabs set to require a slight down pressure on the yoke. This approach should be made at not to exceed fifteen knots above the stalling speed of the aircraft as loaded. A careful watch should be kept on the sea well ahead during this run; and if the sea ahead suddenly appears relatively smooth, the aircraft should be stalled on as quickly and as short as possible. Running the plane's speed out on the landing can be done with the plane's nose very high or dragging the nose slightly, but the pilot should in either case be alert to play the nose of the plane up and down to ease the shock of its passage through the waves and to avoid planing off the top of any wave higher than is absolutely necessary as long as he has control with his elevators.

11. That a pilot contemplating a landing in the open sea should make an orderly study of that sea checking the following points particularly:

(a) From two thousand feet or higher, is a definite ground swell perceptible? If so, turn and parallel it and set the directional gyro on zero.

(b) Drop a smoke float on the water and circle it keeping it sharply in sight. As it rises on the crest of a swell, start timing it with a stop watch or sweep second hand. Count its passage over three or five or so successive swells, and clock it again on the crest of a swell. Divide the total time in seconds by the number of swells passed to get the period of the swell in seconds. The velocity of the swell in knots is roughly equal to three times the period of the swell in seconds. The distance between successive swells in feet is equal to approximately five times the square of the period of the swell expressed in seconds. Now the pilot knows a little about the swell.

(c) Go down to several hundred feet and study the swell again. Fly parallel to it. If your directional gyro is not very close to zero or 180, the wave system you are now looking at is entirely different from the one you measured at two thousand feet. If there are prominent groups of swells larger than their fellows but all swells appear from the same direction, assume that two wave systems of different periods are rolling the same direction. Measure the period and compute the length and velocity of the swell noted at low altitude just as you did the big ground swell which you now cannot see.

(d) Estimate the force and direction of the surface wind by seaman's eye from the surface sea condition and the smoke float observed at very low altitude.

(e) Make a wide circle at forty or fifty feet steadying momentarily on cardinal points to observe on which heading the sea appears less boisterous. The pilot's best heading for a landing is probably the one on which the sea appears smoothest when observed from low altitude if such a heading will not throw him into the face of either observed wave system.

(f) Study the sea looking for groups of waves which appear markedly higher than those about them. If such waves are strikingly apparent, the landing is apt to be either very easy if the landing run avoids the seas in phase or very dangerous if it strikes them.

(g) Having weighed what he has learned about the swell, the surface conditions, and the wind, the pilot should decide on a heading for his landing which will give him a minimum hazard of running into the face of either swell and which will provide the best promise of a relatively smooth and short runout of speed after landing.

II. Take-Offs

1. That the greatest difficulty--though not the greatest danger--in any take-off other than into the wind is in getting the aircraft up to steerable speed on the heading desired.

2. That the best take-off heading is parallel to the swell unless this requires a cross wind run in a wind of twenty knots or more.

3. That it is practically impossible to start a cross wind take-off run in the open sea with the PBM-3 airplane, starting the take-off heading from rest. The solution to this is to head either down wind or up wind and accelerate to steerable speed and then ease around parallel to the swell for the take-off run. Accelerating speed down wind is believed better than up wind as the spray and pounding are less, and the plane can be brought from down wind to cross wind much more handily than from up wind to cross wind.

4. That a take-off run parallel to the swell may be accomplished either on a constant heading or by easing the nose around down wind to stay on the crest of a selected swell. The latter election is almost instinctive with the pilot and does not require a turn of more than a few degrees.

5. That the aircraft should be dragged off at the earliest possible moment regardless of whether it slaps successive waves or not.

6. That the second best take-off heading in a well formed and regular and fast moving swell is down swell disregarding the wind unless it be twenty knots or more. The best technique for the down swell take-off is to accelerate the aircraft until it is running as fast as it can without planing off the tops of the swells, the nose being jockeyed up and down freely to hold it on. This run should be continued patiently until a condition with a large swell with smaller swells ahead is overtaken, or overtakes the aircraft; then the plane should be nosed down at the top of the swell, the throttles opened smartly to take-off power and every effort made to reach take-off

speed and stay in the air when the aircraft planes off on the top of the next swell overtaken. This operation sounds difficult in the telling, but has been found surprisingly easy when smartly executed.

7. That a take-off into the swell in a calm or light winds is to be avoided like death. Such take-offs have been accomplished in these tests in a high slow moving swell; but in a long low Pacific swell moving at twenty-five knots, the pilot found when he headed into the swell and accelerated that the swells were coming at him so fast they gave the impression of a very rough high sea. Under the same conditions, a down swell cross wind take-off was made smoothly and easily. If the pilot decides that he must make a take-off into the swell, the technique is the same as for a down swell take-off, that is, to get as much way as possible on the aircraft without planing off and then suddenly race down the back of a long swell and attempt to stay in the air when she planes off at the next swell. Pilots should be warned that in a take-off into the fast swell, the aircraft will strike successive swells so fast that the affect is pounding rather than planing.

8. That the pilot will probably be surprised at the difficulty he meets in steering while taxiing in a moderate sea, and should be warned that he must use power sparingly in a complex sea (one formed by two vigorous wave systems coming from sources thirty degrees or more apart) because under these conditions he can very easily lose a wing tip float. Recourse here must be taken to sea anchors, possibly streamed from forward to get a better turning effect. The PBM with dead engines will drift down wind in a fresh wind faster than a raft which has no drogue out.

9. That in the presence of a complex sea and a fresh wind, the pilot faces his most difficult take-off problem. Under these circumstances he

should select a take-off heading which will avoid going directly into the face of either swell system and which will still bring the wind ahead if possible. Then taxiing as fast as he can and still maintain good control of his plane and not damage his hull or wing tip float; he should study the sea ahead until he observes a distinct lessening of its violence, at which time he should advance his throttles smartly to take-off power and attempt to drag the aircraft off by the time he strikes the very rough sea beyond. If a wing tip float is lost or damaged in the final take-off run and the pilot still has lateral control, his judgment as to whether to continue or throttle back should be colored by the knowledge that his plane will almost surely roll over and sink when the damaged float fills with water. Throttling back and facing this problem may still be preferable to attempting to fly out an aircraft which may have a badly damaged wing or suffer one subsequently from the swinging float or float struts.

11. That on all take-offs the co-pilot should carefully check everything that the pilot does to be sure that if he has picked up his flaps for easier steering in some stage of his maneuvers, they are put down again as the pilot desires before the take-off attempt; that the throttles do not creep; that windshield wipers are turned on or off as desirable; that emergency power is taken from the engines as the pilot calls for it; that jets, if used, are fired when the pilot signals for them; and generally double check all of the pilot's routine.

C. JET ASSISTED TAKE-OFF

1. That the use of jet or rocket power to assist in making a quick take-off is one of the most important contributions to safe seaplane operations in rough water ever made.

2. That the use of JATO gear during these tests improved the control

of the aircraft.

3. That if the jets are fired after the airplane has got good steerage way, the failure of one jet to fire does not substantially affect the controllability of the airplane; and will not embarrass any competent pilot except in that he receives only half the jet thrust expected.

4. That the best doctrine for the use of jets in rough water take-offs recommended herein is to fire maximum jet power immediately after take-off power is taken from both engines.

5. That the liquid jet installation, two units, gives three thousand pounds total thrust for approximately forty seconds and weighs over seventeen hundred pounds for the two loaded units. The solid units weigh approximately two hundred pounds apiece and give a thrust of one thousand pounds per unit for twelve seconds. By firing four units in pairs of two with a two second overlap, a two thousand pound thrust for twenty-two seconds may be had. By firing four units simultaneously, a four thousand pound thrust for twelve seconds may be had. If the take-off doctrine recommended by this report is employed on a PBM-3 airplane stripped for rescue work, the airplane should be got off the water in its final run in ten seconds or less with the use of jets; so it is recommended that using solid jets, all four jets be fired simultaneously. The solid jets when once fired cannot be turned off. In contrast the liquid jets can be turned on and off as many times as the pilot desires until the forty seconds of fuel has been burned out. This flexibility of operation of the liquid type jet is very valuable as a blast of jet may be used to get a plane out of trouble in a bad landing and the plane will still be able to land, do its job and make a jet assisted take-off. Improved liquid jet propellants which will cut the total weight of these units by possibly fifty per cent should make the liquid jets superior to the solid

for rescue work. Until this improvement is available, the solid jets are considered preferable for rough water operations because of their big weight advantage.

6. That JATO gear should be carried for all rough water operations.

D. ENGINEERING AND STRUCTURAL

1. That the PBM-3 airplane is very strong and probably has the best hull available for rough water work.

2. That the structural failures encountered in these tests, (a) skin wrinkling, (b) fairing damage, (c) deformation of engine mount wing stiffeners, (d) rivet weeping, (e) float and flap damage, were not attributable to either design or construction flaws in the aircraft.

3. That the damage to the JATO unit supports was due to an error in dimensions of the support when manufactured which was corrected in the field at the expense of the bearing area on the rear fitting.

4. That the installation of wing float strut braces (BuAer Bulletin No. 26) effectively protects the strut assembly from failure under reasonable side thrust on the floats. The side of one float was dished in, and the aircraft was taxied two miles through a rough sea to protected waters without any sign of failure in the strut brace assembly though the float was buried much of the time.

5. That the hull bottom design is particularly good and permits easy landings at all attitudes including extreme stalled dropped on landings.

6. That the aircraft shows good controllability characteristics down to and past stall if the pilot is alert to apply generous aileron and elevator and remembers that it is necessary to lead with the controls on a heavy aircraft much more than on a light one.

7. That the position of the pilot well above the water is very valuable in providing him good visibility and consequently a good opportunity

to study the sea.

8. That the R 2600-12 engines are the weakest part of this airplane; and even after installation of the engine fans, this engine exhibits a tendency to burn out the ignition harness in some spots when extensive taxiing is undertaken. In addition, the airplane is believed to be underpowered.

9. That no alterations to the structure of this airplane are recommended.

SECTION II

SECTION II

INSTRUMENTS, INSTRUMENTS DESIGNED
and INSTRUMENT INSTALLATIONS

ACCELEROMETER DATA

RECORDS OF WIND AND SWELL CONDITIONS

TABULATION OF AIR-BORNE OBSERVERS' DATA

LOAD DATA

ENGINEERING ANALYSIS

INSTRUMENTS, INSTRUMENTS DESIGNED

and

INSTRUMENT INSTALLATIONS

INSTRU-
MENTS

22.

INSTRUMENTS

As a result of the determination of the scope in the previous paragraph, the following instruments were recommended and furnished for making the tests: Four NACA 2 component recording accelerometers, one NACA synchronous recorder timer, and one Hathoway landing analyzer, with calibrations. The instruments and their serial numbers follow:

(a) NACA accelerometers
   (1) No. 293 received from BAR, Columbus, Ohio, November 9, with film container No. 210.
   (2) No. 295 received from Langley Field, October 10, with film containers No. 202, 203, 204 and 205.
   (3) No. 324 received from American Steel Foundry, Hammond, Indiana, October 10, with film containers No. 231 and 232.
   (4) No. 326 received from Langley Field, October 10.

The following supplementary film containers were received from AMES laboratory, at the special request of the Air Station, on November 20: M-1, M-6, M-13, M-21, M-22 and M-24.

(b) Hathoway analyzer Serial No. 1, received from NAES, Philadelphia, October 24.

(c) Synchronous recorder received from NAES, Philadelphia, on October 24.

SUPPORTING INSTRUMENTS

As additional instrument aids in connection with the test, the station employed:

(a) Two motion picture cameras 35MM mounted on the airplane
(b) Hydrobal
(c) NACA inclinometer
(d) Three motion picture cameras 35MM, power driven, for use on surface craft
(e) Wave meter
(f) Portable Anemometer

GENERAL DESCRIPTION

The instruments recommended all required 12 Volt direct current power source. Provisions were made to supply this from storage battery, and the wiring diagram is attached to this report. From Martin report No. 1785, locations were selected for the placing of the accelerometers to fall in the general vicinity as employed in the Martin tests.

Instrument Location	Nose	Center of Gravity	Step	Tail
(1) Preliminary tests, Martin	(1) 25	(1) 360	(1) 675	(1) 900
(2) Rough tests, Martin	(2) 10	(2) 340	(2) 712	(2) 892
(3) Air Station tests	(3) 16 3/8	(3) 369	(3) 679	(3) 897 3/8

One half inch wooden platforms were built at each of these stations as recommended in the instructions furnished with the two component accelerometers.

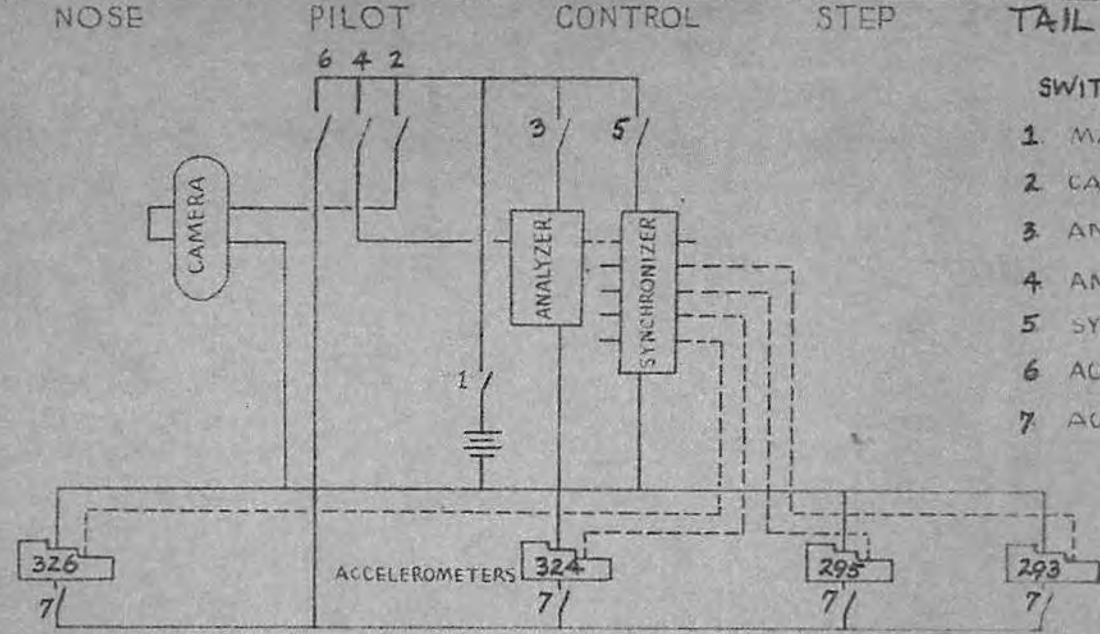
Due to the blurring of the records of the instruments at the step and tail during JATO take-off, shock mountings were tried December 7. Tests were continued with original installation.

The Hathoway instrument was mounted adjacent to the accelerometer at the center of gravity location. The synchronous recorder was located at this point also. While the master control was located at the center of gravity, the test controls were mounted on the instrument board directly in front of the co-pilot and adjacent to the control for the jet take-off. The control switches were installed so that they could be operated individually or collectively.

The hydrobal is a device brought out by the Martin Company for determining the weight carried and the center of gravity. One cell was located on station 136 7/8 and another at station 687 7/8. Prior to beginning the tests, the airplane was weighed in an empty condition, without gas and oil, without the jet equipment, but with the instrumentation installed. Careful control of the weight and the center of gravity was maintained throughout the range of the tests.

One camera was mounted above the pilot's cockpit for the purpose of keeping a running record of the sea into which the landings were made and from which the take-offs were conducted. Another camera was installed in the pilot's cockpit to record the flight and engine instrument readings. Pictorial records of these flights were made from at least one surface boat.

The wavemeter was manufactured in accordance with specifications furnished by the Scripp's Institute, La Jolla, California. It consisted of an aluminum alloy tube of sufficient length and diameter to float a large metal disc damper at a level 30 fathoms below the surface. The wave (swell) heights are obtained by observing the maximum and minimum exposure of the tube.



SWITCHES

1. MASTER
2. CAMERA
3. ANALYZER, ALT.
4. ANALYZER
5. SYNCHRONIZER
6. ACCELEROMETER
7. ACCELEROMETER, IND.

CHECK OFF - BEFORE FLIGHT

PILOT SWITCHES 2, 4, 6 "OFF"

CONTROL SWITCHES 1, 3, 5 "OFF"

7 "ON"

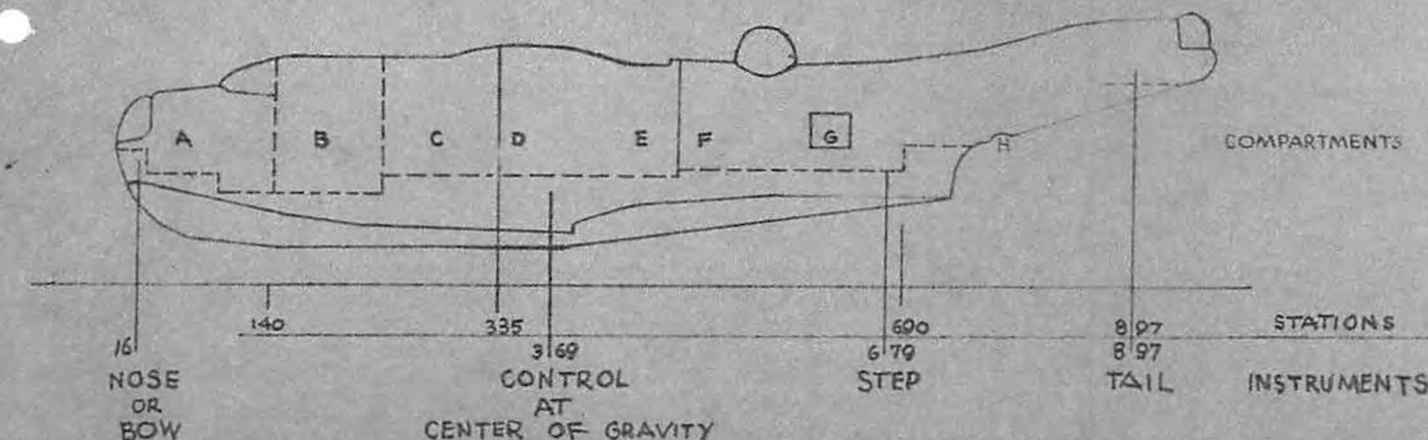
CHECK OFF - BEFORE TEST

CONTROL SWITCHES 1, 5 "ON"

TEST - EITHER LANDING OR TAKEOFF

PILOT SWITCHES 2, 4, 6 "ON"

NOTE - FOR BEST RESULTS THE SWITCHES 2, 4, 6 SHOULD BE RETURNED TO "OFF" IN 30 SECONDS.



PBM-3C AIRPLANE 6586

WIRING FOR INSTRUMENTS OFF SHORE TESTS

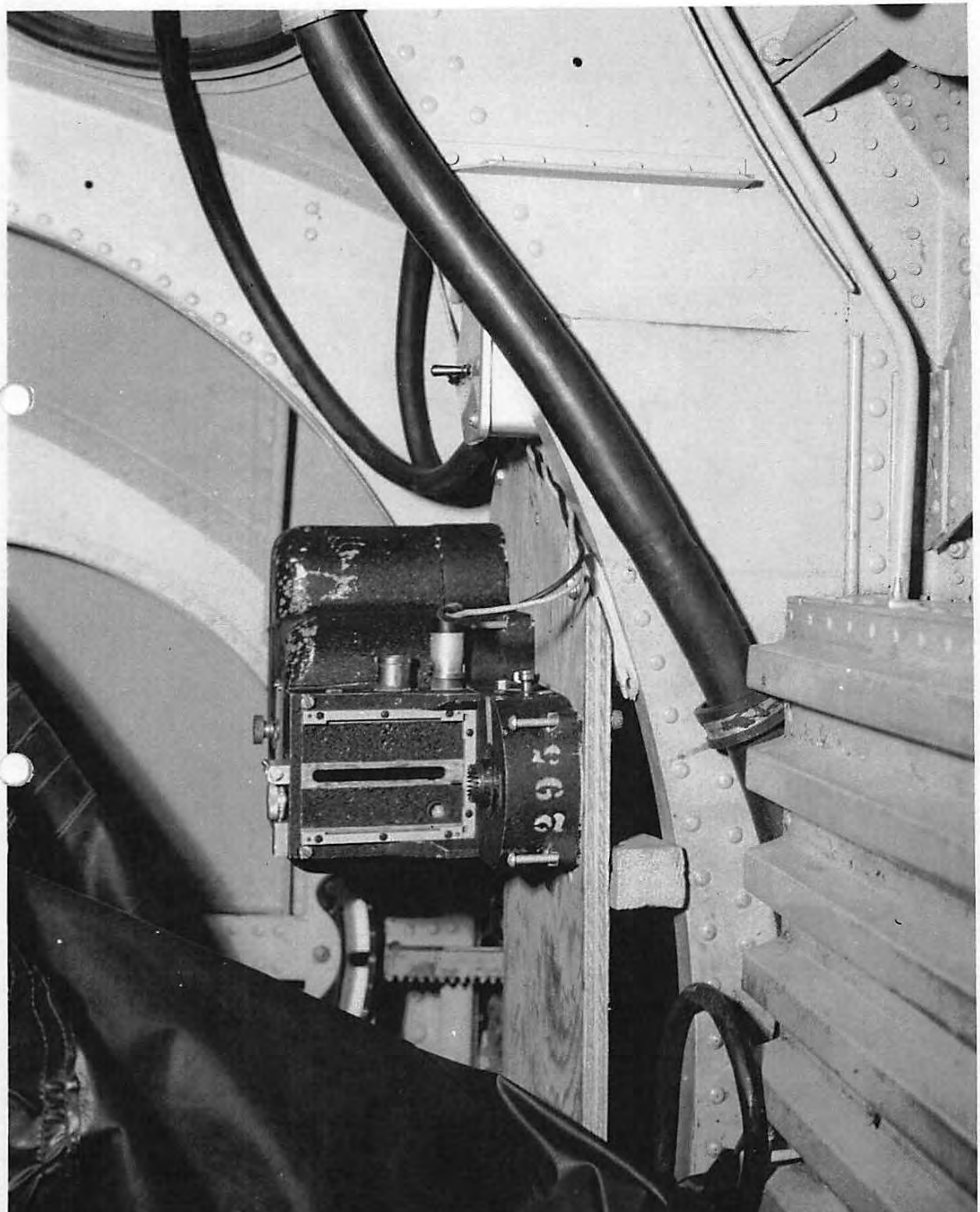
U.S. COAST GUARD AIR STATION
SAN DIEGO, CALIF.

DRAWN: DEC. 1, 1944
TRACED: MARCH 1, 1945

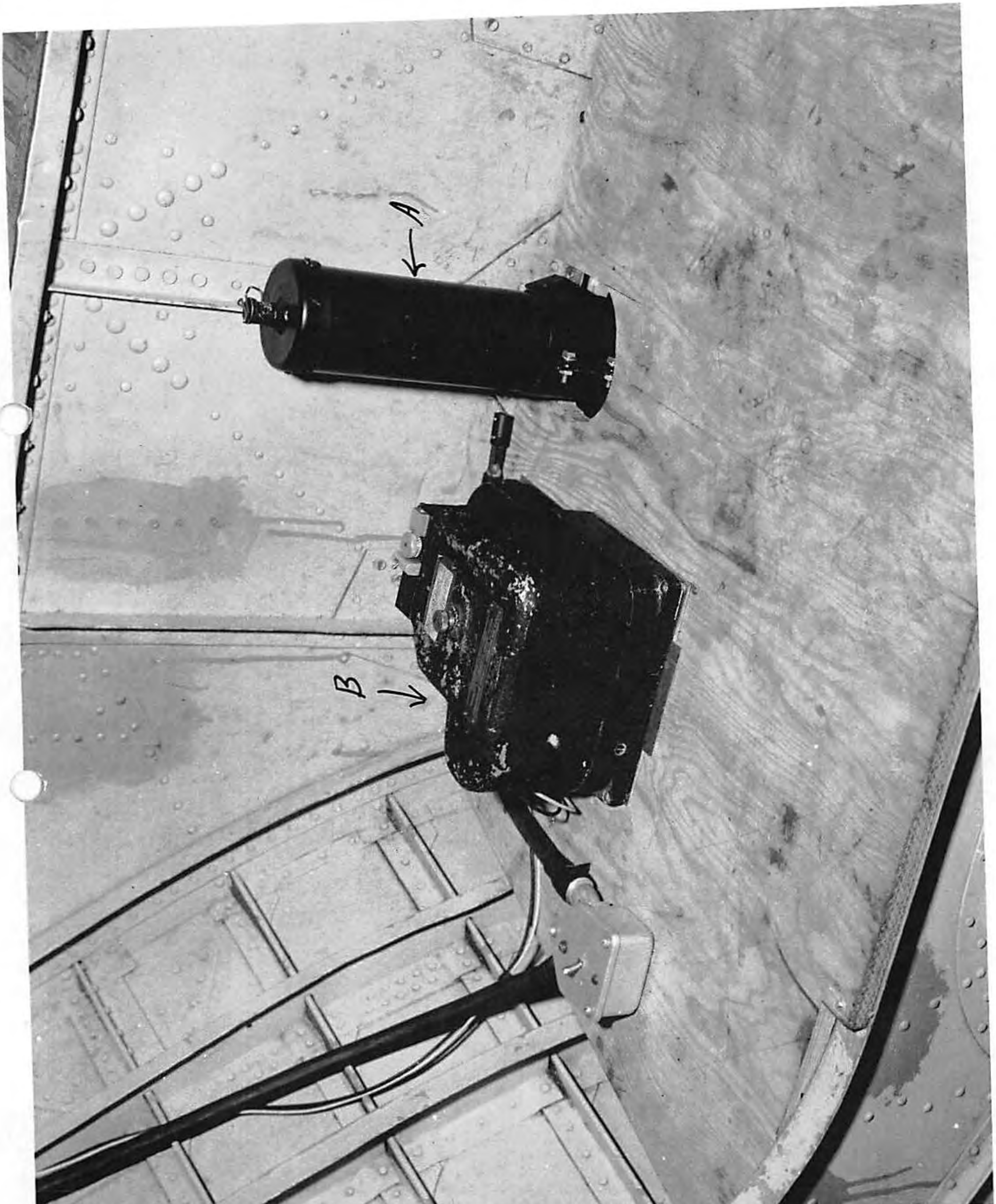
1. View shows starboard side of forward bunk compartment looking forward. Hathoway flight analyzer is indicated by the letter A, synchronizer or time by the letter B, and the NACA two component accelerometer by the letter C. Installation of these instruments is at center of gravity and the instruments are referred to in the data as 'control' instruments.


A
B
C
324

2. This view shows NACA two component accelerometer installed in bow, looking forward. (Actually accelerometer #326 was used in this position.)

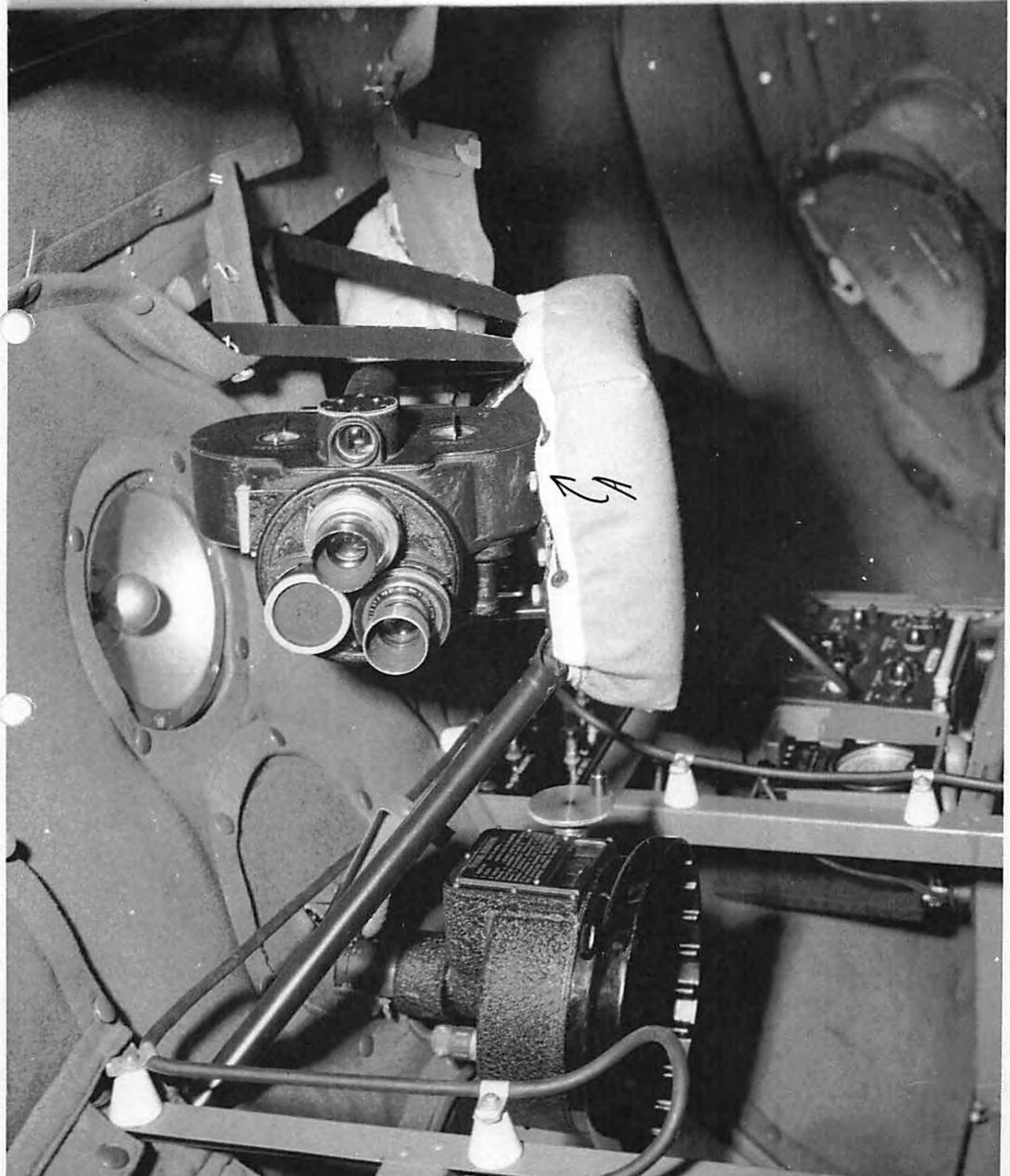


3. View of second step looking aft. Instrument labelled A is the Hydrobal. Instrument labelled B is NACA two component accelerometer.


A
B

4. View of NACA two component accelerometer installed in tail compartment, looking aft.

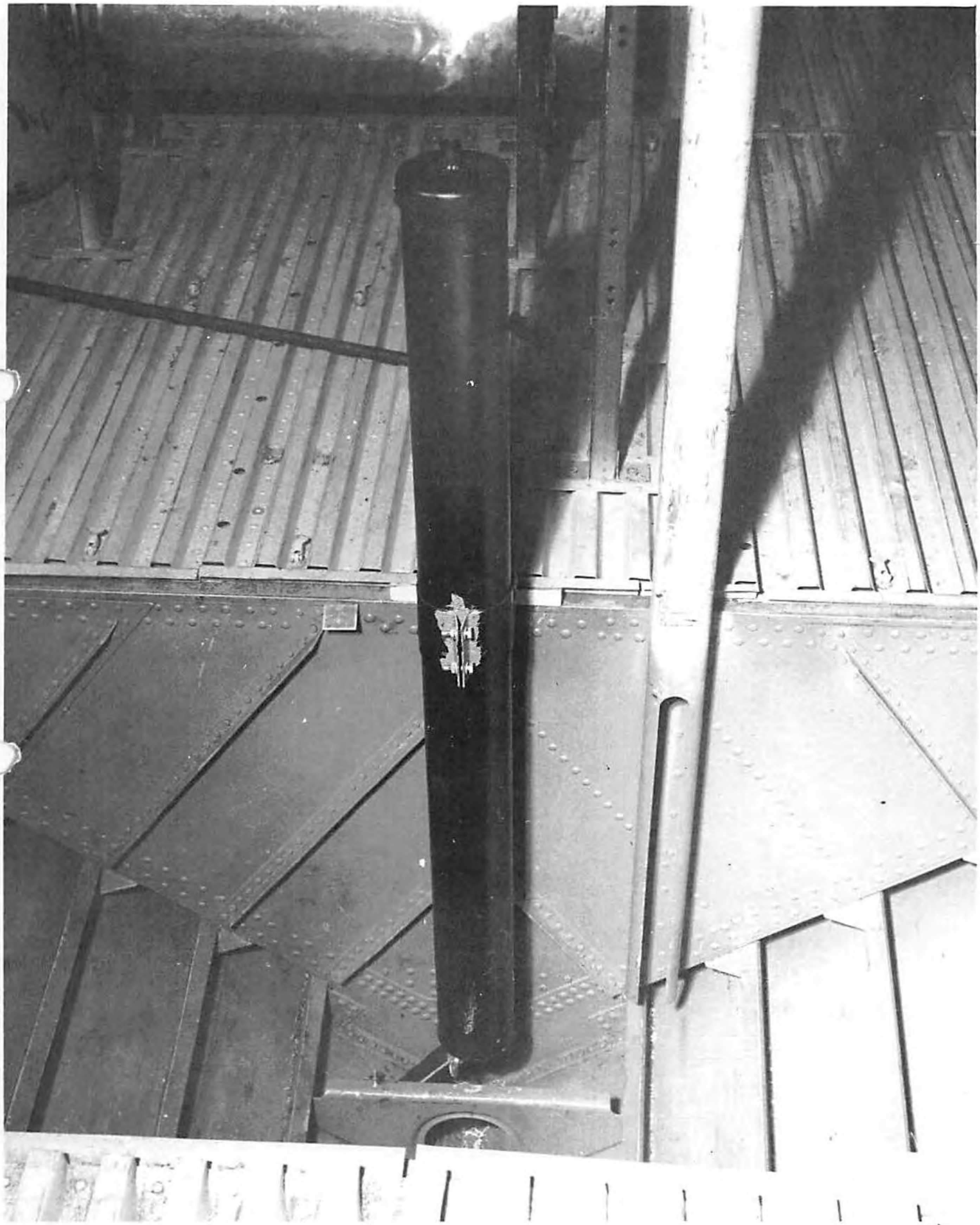
5. Looking aft on flight deck this view shows motion picture camera (A) installed on overhead amidships for the purpose of recording flight instrument readings.


CA

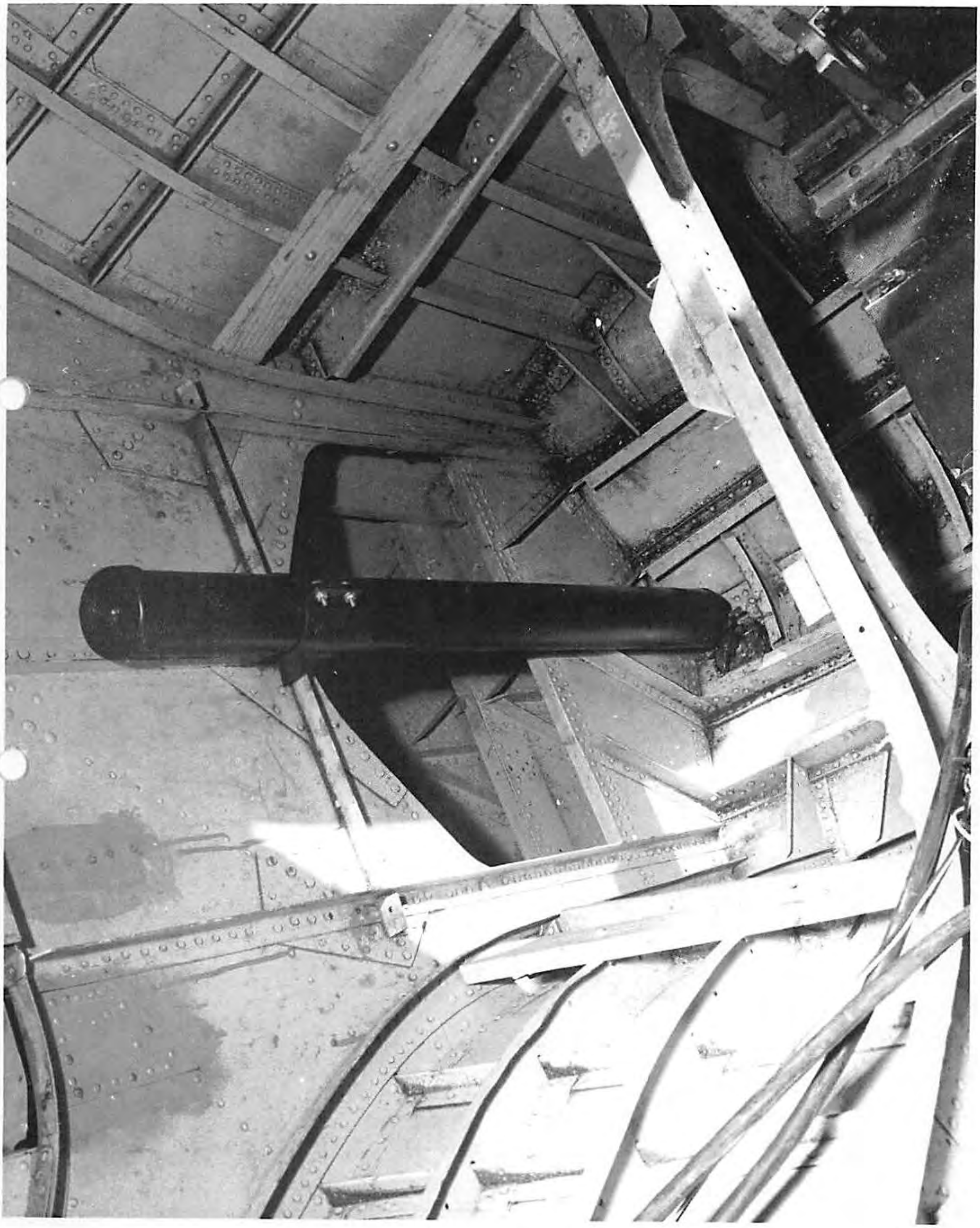
6. Looking aft at motion picture camera installed just forward of radar spinner housing on exterior of plane giving pilot's view of sea conditions.

38.

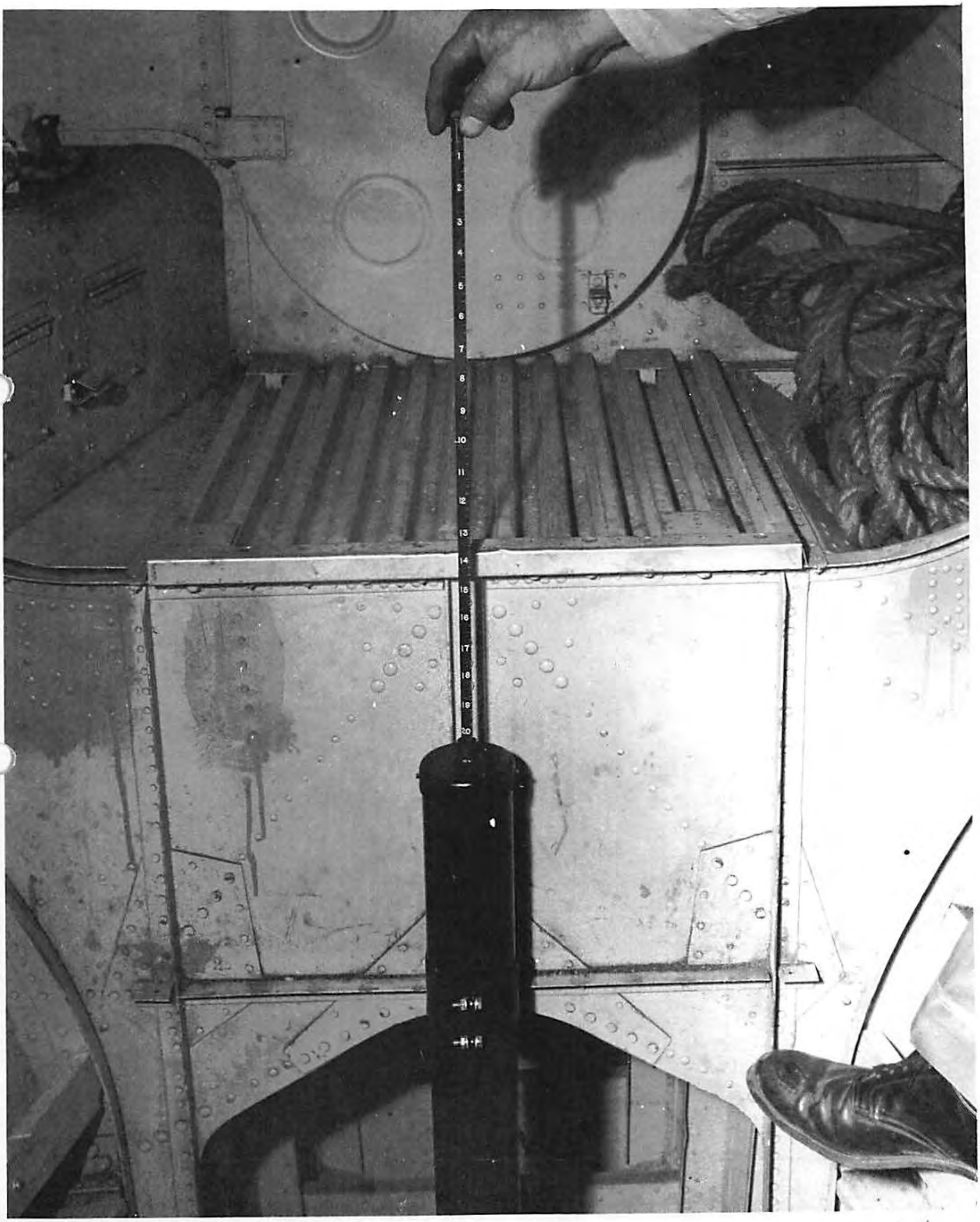
7. View looking aft in forward galley showing installation of hydrobal. Section of flooring has been removed.



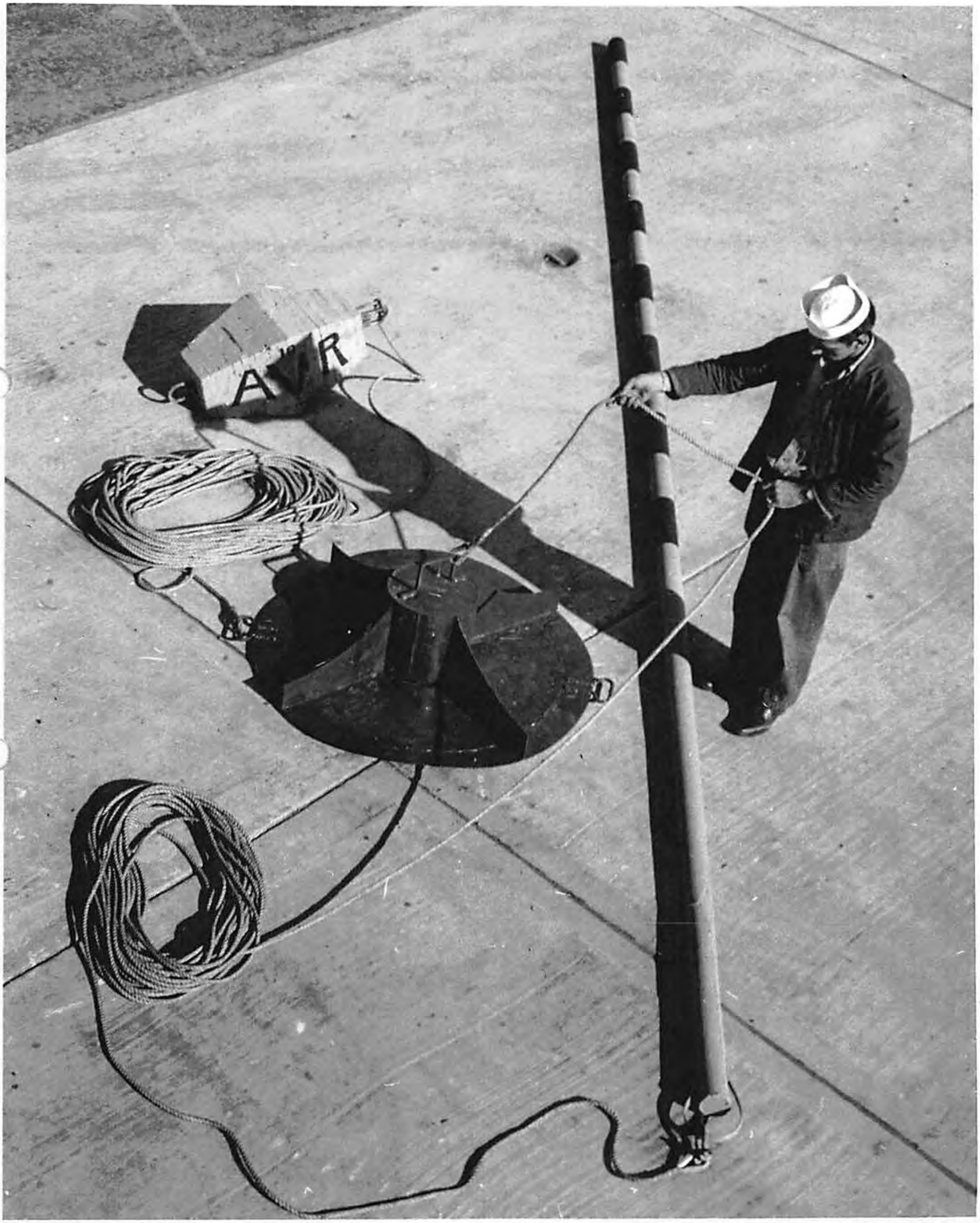
8. Looking aft at second step. This is full length view of hydrobal. Flooring has been removed, allowing view of bilges.



9. Showing hydrobal with gauge extended--location second step looking aft.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

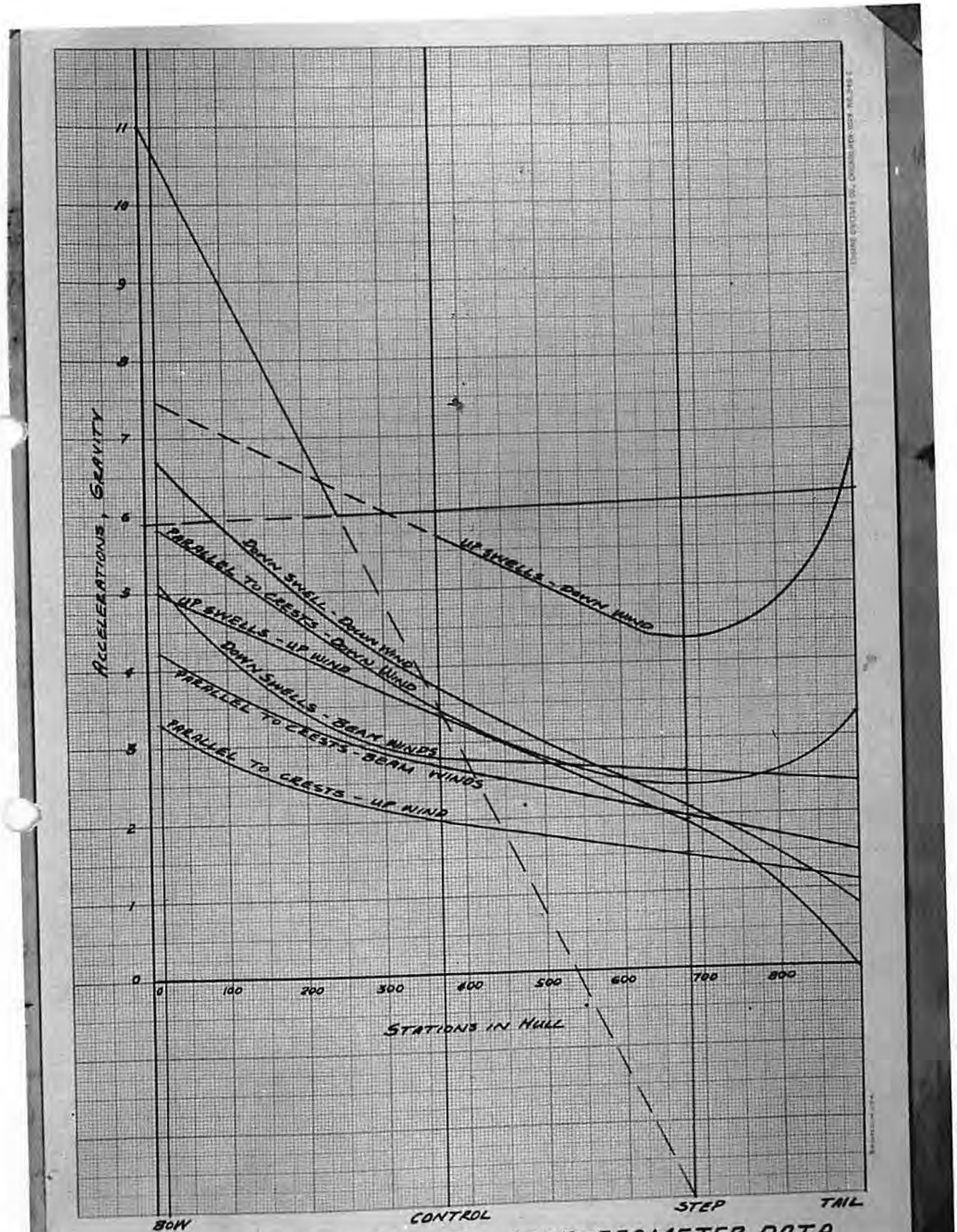
10. View of wave meter used in measuring period and height of swells.



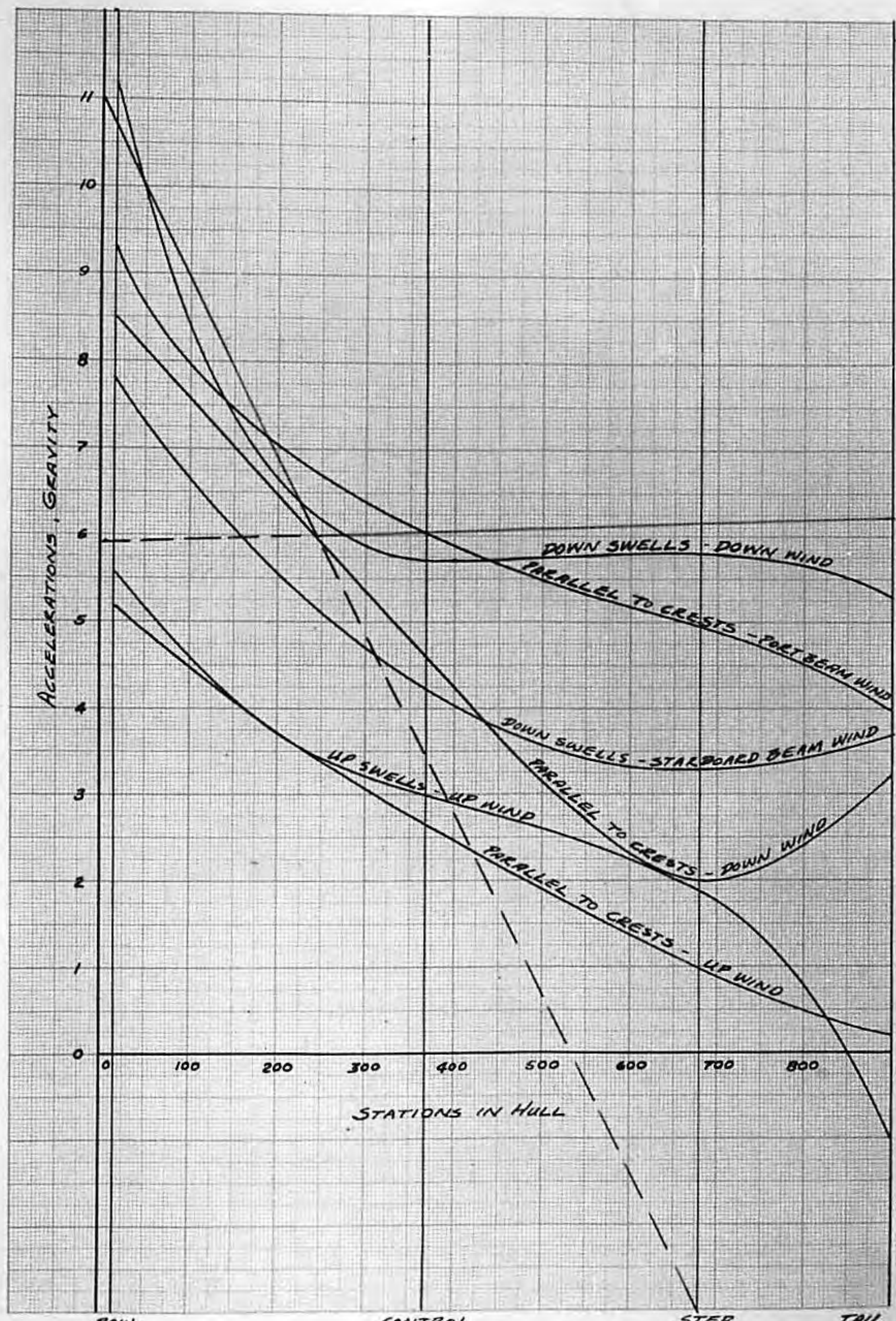
ACCELEROMETER DATA

ACCEL. DATA

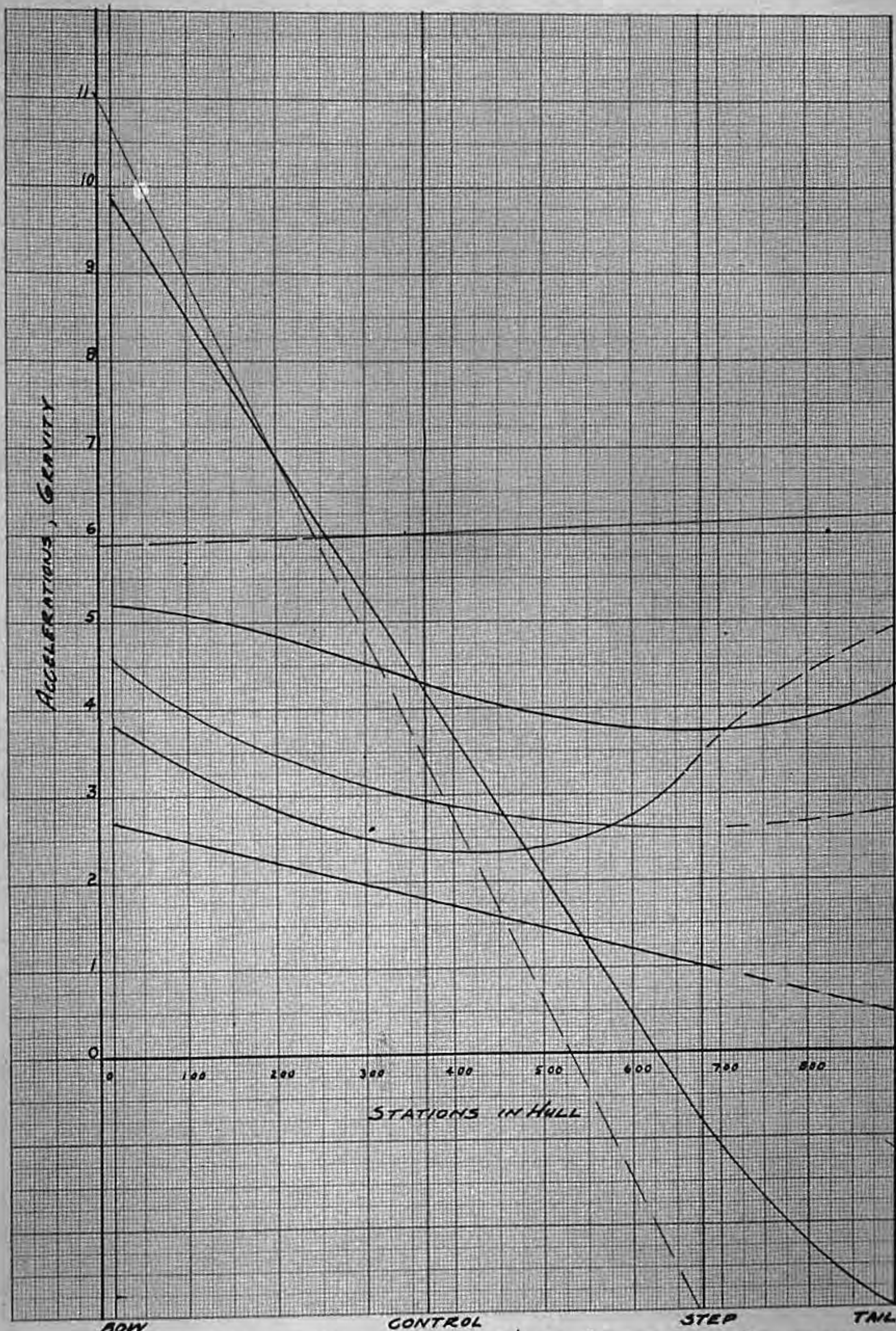
The two following plates show analyses of measured accelerations. The line indicating average conditions for down-swell down-wind operations is misleading because it included data from several very bad operations whose troubles were attributed to pilot error. Actually the down-swell down-wind landing and take-off is greatly preferable to an up-swell up-wind landing or take-off in moderate winds.



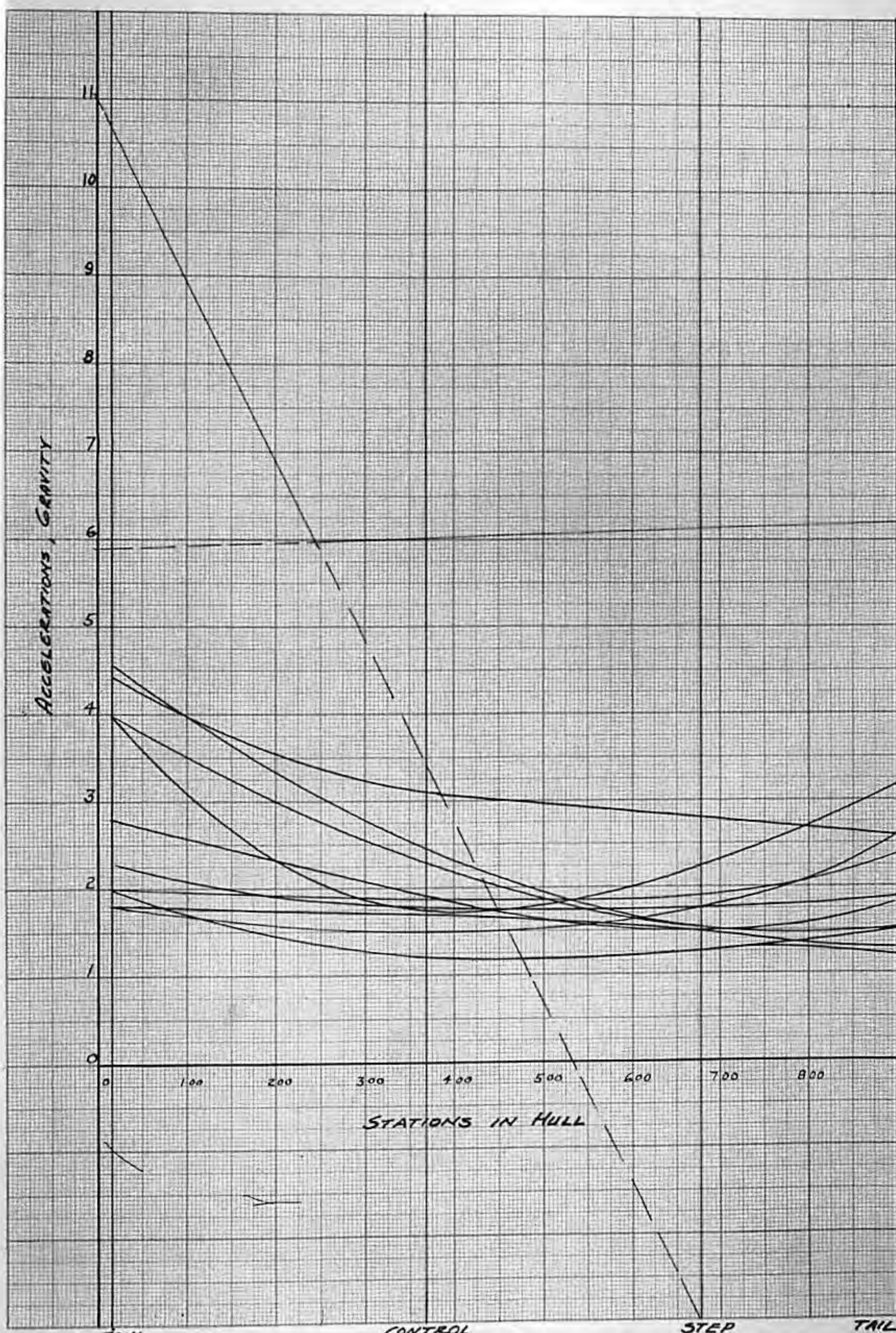
AVERAGE CONDITIONS - ACCELEROMETER DATA



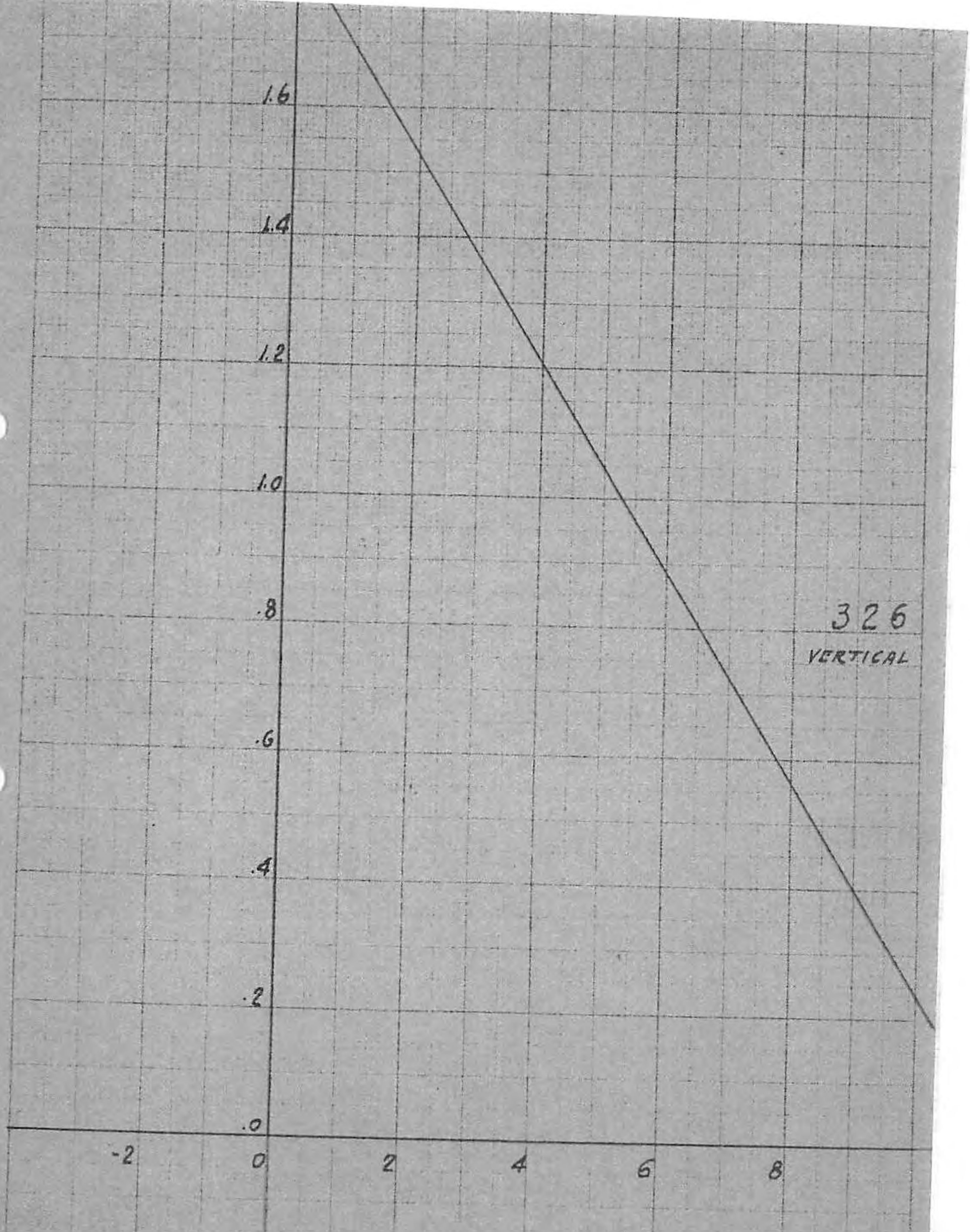
MAXIMUM CONDITIONS - ACCELEROMETER DATA



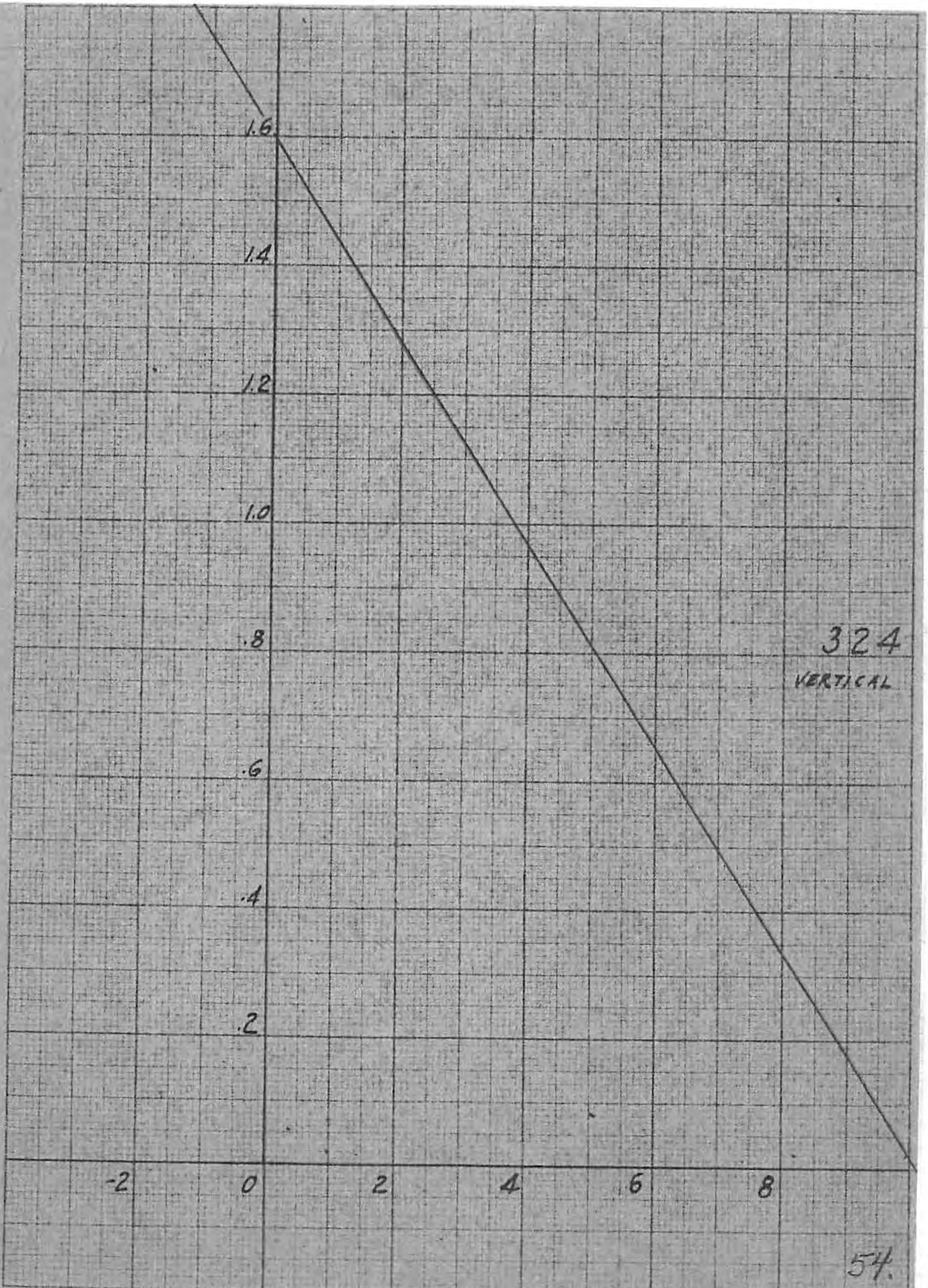
DOWN SWELL - DOWN WIND TAKEOFFS & LANDINGS

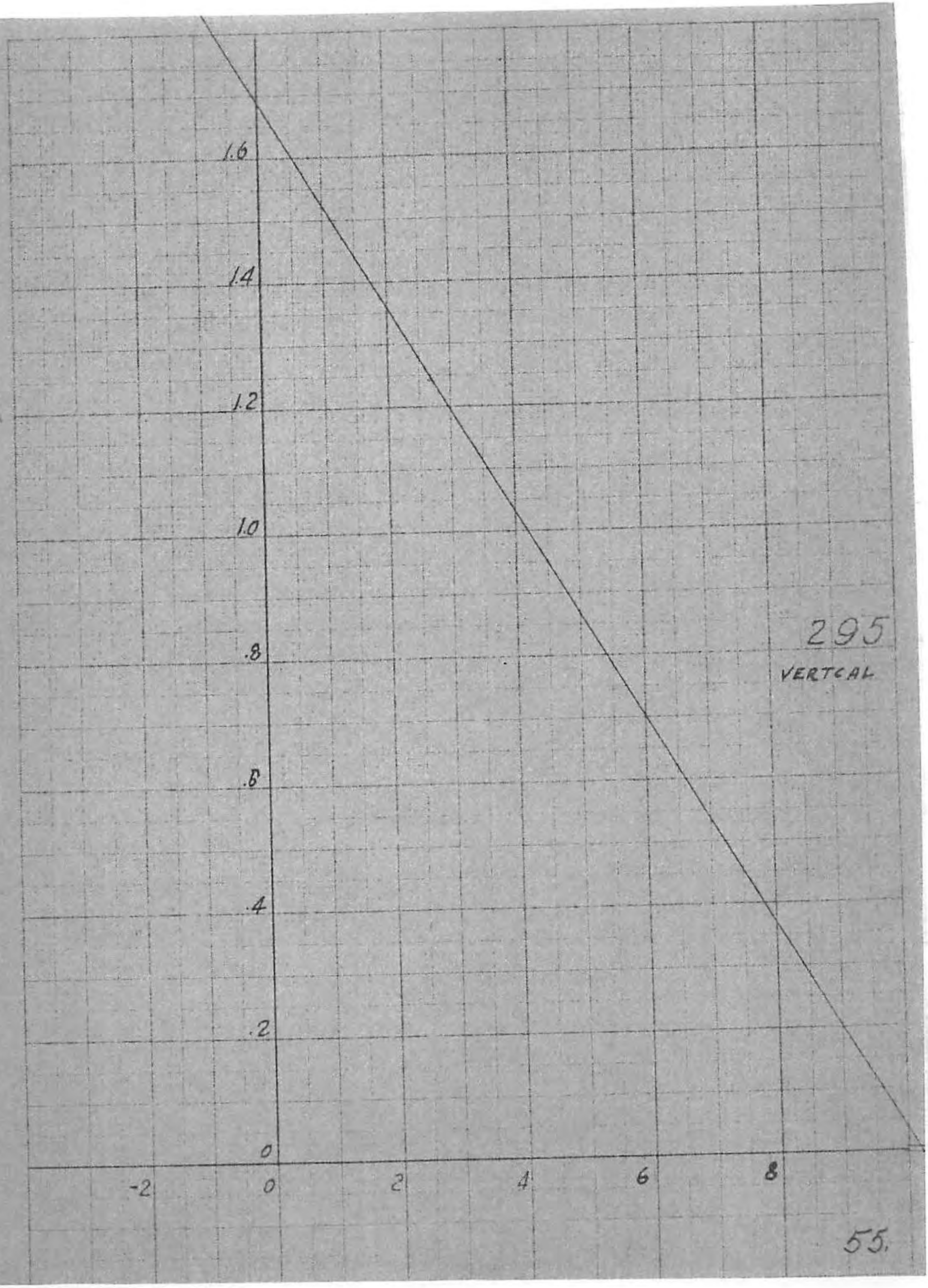


PARALLEL TO SWELL CRESTS - BEAM WINDS



ACCELEROMETER CALIBRATION DATA


1.6
1.4
1.2
1.0
.8
.6
.4
.2
-2
0
2
4
6
8
324
VERTICAL


1.6
1.4
1.2
1.0
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0
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4
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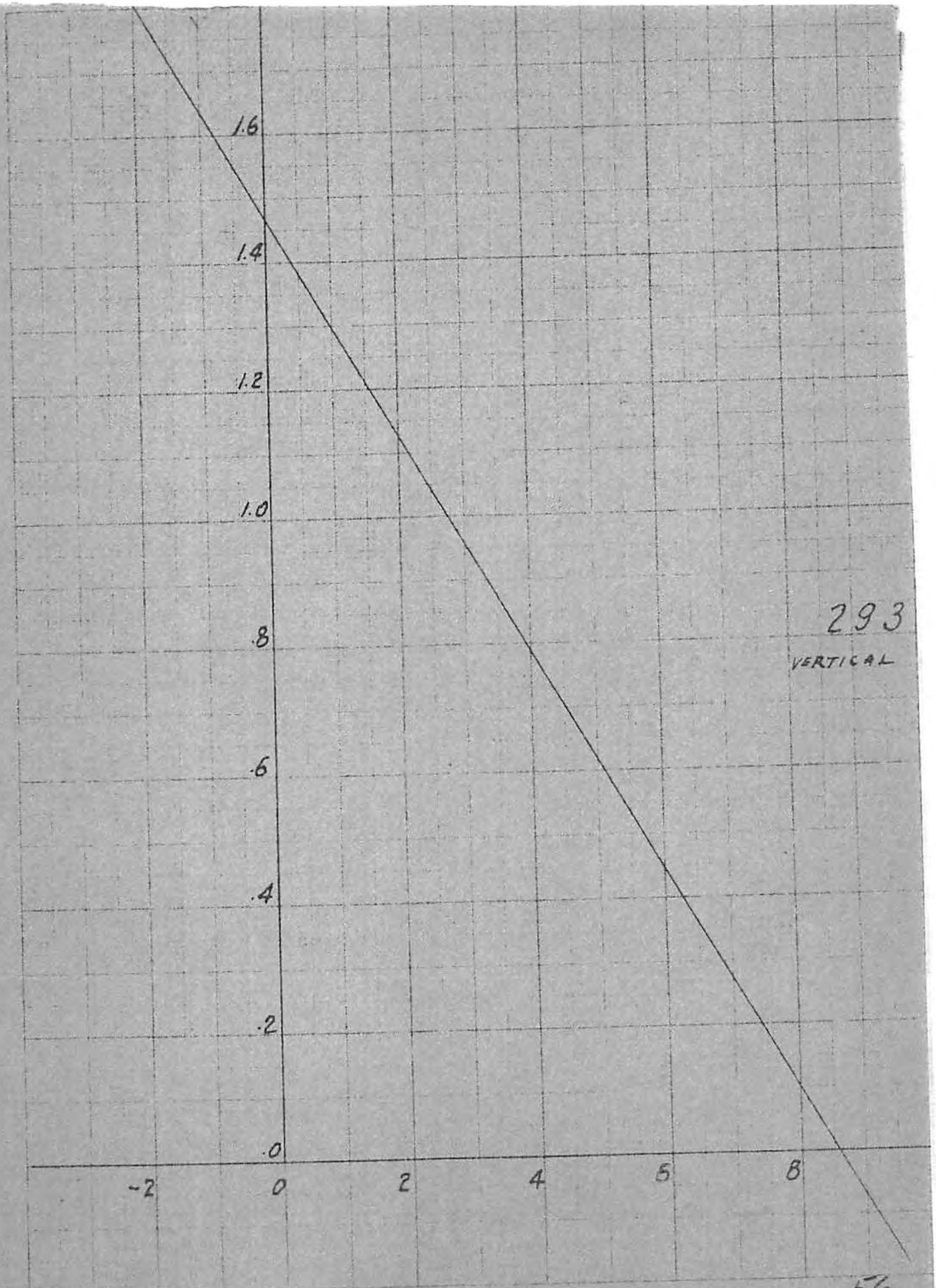
8
295
VERTCAL


1.6
1.4
1.2
1.0
.8
.6
.4
.2
.0
-2
0
2
4
6
8
293
VERTICAL

SELECTED BUMP

	Accelerometer, Vertical Component										Analyzer, Vertical Component		
	Time Secs	Bow	Cont-rol	Step	Tail	Time Secs	Bow	Cont-rol	Step	Tail	Time Secs	c.g. Accel.	Speed Knots
November 24, 1944													
1 L.	7½	4.4	3.1	2.8	2.6						7½		
1 TO	21½	4.6	2.9	2.6	-						21½		
2 L.	3½	-	5.9	3.65	-	10½	-	2.8	2.8	-	3½		
2 L.	7	-	3.6	3.0	-						7		
November 28, 1944													
2 L.	5	4.5	3.4	2.6	2.0	9	5.7	3.7	1.75	-1.6	5		
2 L.	7	5.7	3.3	1.5	.9						7		
3 TO	2	5.6	3.0	1.9	-1.0						2		
3 TO	5	3.2	2.1	-	3.0						5		
4 L.	1	2.0	1.9	1.9	2.4						1		
4 L.	3½	1.8	2.0	1.9	1.9						3½		
December 1, 1944													
1 L.	2	4.6	2.5	1.5	1.5	11	-.[illegible]	.8	[illegible].7	4.[illegible]	2		
1 L.	7	4.2	2.0	1.3	- .3						7		
1 TO	4	3.6	2.2	2.0	- .2	10	2.1	1.7	1.4	1.3	4		
1 TO	6½	2.7	2.0	1.6	1.6						6½		
2 L.	2	5.6	-	2.0	-	6¼	2.9		.3	- .5	2		
2 TO	8	3.0		2.1	1.8						8		
3 L.	5-3/4	4.2				14	5.4				5-3/4		
3 L.	10-3/4	2.5									10-3/4		

SELECTED BUMP

	Accelerometer, Vertical Component										Analyzer, Vertical Component		
	Time Secs	Bow	Cont -rol	Step	Tail	Time Secs	Bow	Cont -rol	Step	Tail	Time Secs	c.g. Accel.	Speed Knots
December 2, 1944													
1 L.	4½*	7.1	3.7	- .6	- .9						4½*		
1 L.	2½*	6.7	3.0	3.5	-1.0						2½*		
1 TO	8½	5.6	2.6	- .5	-2.3						8½		
1 TO	11	4.0	2.3	1.5	1.5						11		
2 L.	5	5.1	5.1	5.8	9.1	10½	9.9	4.3	- .8	-3.0	5		
2 TO	113/4	9.6	5.0	- .8	-3.3	133/4	6.1	4.0	- .2	-	113/4		
December 12, 1944													
1 L.	2	3.6	1.8	2.2	3.0						2		
1 TO	7½	2.0	1.6	1.3	.2						7½		

* TIME FROM END OF RUN

SELECTED BUMP

Accelerometer, Vertical Component										Analyzer, Vertical Component		
Time Secs	Bow	Cont -rol	Step	Tail	Time Secs	Bow	Cont -rol	Step	Tail	Time Secs	c.g. Accel.	Speed Knots
December 14, 1944												
1 TO 5	2.6	1.5	1.3	- .3						5		
1 TO 11½	2.9	2.1	1.5	.3						11½		
2 L. 63/4	-	5.7	4.3	6.7						63/4		
2 TO 6½*	7.8	4.2	3.3	3.7	3*	5.6	2.7	[illegible]	-1.0	[illegible]		
ATT. 4½*	3.3	1.8	2.1	1.0						4½		
3 TO 7	1.8	1.7	1.5	1.3						7		
4 L. 1	4.0	1.7	2.3	3.2						1		
4 TO 4	7.2	5.8	2.0	1.7						4		
January 6, 1945												
1 TO 19½	2.8	1.8	1.5	1.8						19½		
2 L. 0	-1.0	2.2	4.3	5.8	73/4	11.2	5.7	5.8	5.3	0		
January 20, 1945												
1 L. 10	9.3	6.0	5.0	4.0	0	-.6	1.9	3.6	4.5	0		
1 L. 1½	4.4	2.6	2.1	1.7						1½		
January 30, 1945												
1 L. 1½*	2.3	1.8	1.8	1.9						1½		
1 TO 4*	2.0	1.2	1.3	1.5						4		
2 L. 1*	1.8	1.5	1.8	2.6						1		
2 TO 93/4	2.0	1.4	1.3	1.2						93/4		

*TIME FROM END OF RUN

SELECTED BUMP

	Accelerometer, Vertical Component									Analyzer, Vertical Component		
Time Secs	Bow	Cont -rol	Step	Tail	Time Secs	Bow	Cont -rol	Step	Tail	Time Secs	c.g. Accel.	Speed Knots
3 L. 6¼	2.7	1.8	2.0	1.6						6¼		
4 L. 0	2.9	2.5	2.1	2.2						0		
February 6, 1945												
1 L. 1	5.2	2.7	1.0	.2						1		
1 L. 6	2.8	1.4	2.2	2.6						6		
2 TO 33/4	2.8	1.9	1.6	1.6						33/4		
2 L. 1	5.1	4.0	3.0	1.6						1		
2 L. 83/4	8.5	4.6	2.0	3.2						83/4		
2 TO 12	3.1	2.1	2.8	3.3						12		
T & G 0	-	4.4	-	-						0		
February 9, 1945												
1 L. 7½	4.9	3.2	2.3	1.9						7½		
February 10, 1945												
1 L. 2¼	4.1	2.7	-	2.1						2¼		
2 L. 5	9.1	3.8	-	-2.5						5		
2 L. 3	5.9	2.7	-	-1.8						3		

[redacted]

SELECTED BUMP

Accelerometer, Vertical Component										Analyzer, Vertical Component		
Time Secs	Bow	Cont -rol	Step	Tail	Time Secs	Bow	Cont -rol	Step	Tail	Time Secs	c.g. Accel.	Speed Knots
3 L. Max	6.3	3.2	2.6	-						Max		
3 TO Max	3.6	1.9	-	2.0						Max		
4 L. Max	-	4.2	-	-						Max		
4 TO Max	-	3.5	-	-						Max		
February 15, 1945												
1 L. 2 3/4	4.6	2.3	2.0							2 3/4		
1 TO 6	3.4	2.1	1.9							6		
2 L. 3	2.7	2.0	2.0							3		
2 TO 2	3.5	2.8	2.3							2		
3 L. 1	3.8	2.4	3.4							1		
3 TO 5½	2.7	1.8	1.0							5½		

RECORDS OF WIND AND SWELL CONDITIONS

(Some landing tests were made without
or with incomplete records.)

WIND & SWELL

SWELL INFORMATION

	SCRIPP'S METHOD								AVR BOAT			
OPER-ation	Swell Heading	Period Seconds	Speed Knots	Length Feet	Height Feet	Where Taken	Swell Heading	Speed Knots	Height	Where Taken	Wind Heading	Speed Knots
NOV. 24	Record not available						W	20	8'	Pt. Loma	W	5
NOV. 28	Record not available						W	10	3'	Pt. Loma	W	5
DEC. 1	WNW	10	30	500	6	La Jolla	SW	15	-	Pt. Loma	WNW	15

SWELL INFORMATION

Operation	SCRIPP'S METHOD								AVR BOAT			
	Swell Heading	Period Seconds	Speed Knots	Length Feet	Height Feet	Where Taken	Swell Heading	Speed Knots	Height	Where Taken	Wind Heading	Speed Knots
DEC. 2	WNW	10	30	500	5	La Jolla	WNW	20	8'	Pt. Loma	WNW	15
DEC.12	WNW	15	45	1125	3	La Jolla	W	--	-	San Slemen-te	S	3

SWELL INFORMATION

	SCRIPP'S METHOD								AVR BOAT			
Oper-ation	Swell Heading	Period Seconds	Speed Knots	Length Feet	Height Feet	Where Taken	Swell Heading	Speed Knots	Height	Where Taken	Wind Heading	Speed Knots
DEC. 14	WSW	8,16	24,48	320 1280	4	La Jolla	WSW	25	6'	Pt. Argu-ello	E	4
JAN. 6	W	15	45	1175	5	La Jolla	W	19	7'	Santa Cruz	SSW	2
JAN. 20	NW	8	24	320	5-7"	La Jolla	NW	12	8'-10'	Pt. Loma	NW	12
JAN. 30	WNW	13	39	845	3	La Jolla	WNW	45	*4'	Pt. Loma	W	8

* WAVE METER AND TIME METHOD

SWELL INFORMATION

	SCRIPP'S METHOD							AVR BOAT				
Operation	Swell Heading	Period Seconds	Speed Knots	Length Feet	Height Feet	Where Taken	Swell Heading	Speed Knots	Height	Where Taken	Wind Heading	Speed Knots
FEB. 6	NW	13	39	845	5	La Jolla	WSW	16	2'	Pt. Loma	NW	5
FEB. 9	WNW	8	24	320	6	La Jolla	W	36	*8'	Pt. Loma	W	20
FEB. 10	NW,W	6,10	18,30	180 500	4	La Jolla	W	24	*4',6'	Pt. Loma	Sw	7

* WAVE METER AND TIME METHOD (FEB. 9)

* WAVE METER AND TIME METHOD (FEB. 10)

SWELL INFORMATION

Operation	Swell Heading	SCRIPP'S METHOD Period Seconds	Speed Knots	Length Feet	Height Feet	Where Taken	Swell Heading	Speed Knots	AVR BOAT Height	Where Taken	Wind Heading	Speed Knots
FEB. 15	WNW	5	15	125	4	La Jolla	WNW	35	6'	Pt. Loma	WNW	13

TABULATION OF AIR-BORNE

OBSERVERS' DATA

OPERATION	DIRECTION OF MOTION RELATIVE OF WIND AND SWELL	NUMBER BOUNCES	AIRSPEED KNOTS	POWER	SETTING	RATE OF DESCENT FEET	REMARKS
	OFFSHORE TESTS PT. LOMA 11/24/44						
TOUCH & GO	PARALLEL TO SWELL-WIND ON STARBOARD BEAM	-	65	18"	2100	-	
LANDING	PARALLEL TO SWELL-WIND ON STARBOARD BEAM	2	70	15"	2100	175	
TAKEOFF	DOWN SWELL-DOWN WIND	3	60	43"	2600	-	
LANDING	PARALLEL TO SWELL-WIND ON STARBOARD BEAM	4	65		QATT	100	
TAKEOFF	DOWN SWELL-WIND ON STARBOARD QUARTER	3	65	47"	2750	-	BOOST MANI-FOLD
	OFFSHORE TESTS PT. LOMA 11/28/44						
LANDING	PARALLEL TO SWELL-WIND ON PORT BEAM	0	60	15"	1200	150	
TAKEOFF	UP SWELL & WIND	3	50	44"	2500	-	
LANDING	UP SWELL & WIND	4	65	15"	1500	150	
TAKEOFF	UP SWELL & WIND	2	60	44"	2600	-	
LANDING	UP SWELL & WIND	2	60	14"	1100	1 60	
TAKEOFF	UP SWELL & WIND	3	55	44"	2600	-	
LANDING	PARALLEL TO SWELL-WIND ON PORT BEAM	0	60	15"	900	-	
TAKEOFF	UP SWELL & WIND	0	59	43"	2600	-	
	OFFSHORE TESTS PT. LOMA 12/1/44						
LANDING	PARALLEL TO SWELL-WIND ON PORT BEAM	4	65	14"	950	200	
TAKEOFF	PARALLEL TO SWELL-WIND PORT BEAM	4	60	44"	2600	-	JET ON 8SEC
LANDING	UP SWELL & WIND	4	65	16"	950	200	
TAKEOFF	UP SWELL & WIND	2	68	42"	2550	-	JET ON 15SEC
LANDING	PARALLEL TO SWELL-WIND ON PORT BEAM	4	67	18"	900	200	
TAKEOFF	UP SWELL & WIND	4	62	43"	2600	-	JET ON 12SEC

OPERATION	DIRECTION OF M[illegible]ION RELATIVE TO WIND [illegible]D SWELL	NUMBER BOUNCES	AIR-SPEED KNOTS	[illegible]WER	SETTING	RATE OF DESCENT FEET	REMARKS
OFFSHORE TESTS PT. LOMA 12/2/44							
LANDING	PARALLEL TO SWELL-WIND ON PORT BEAM	1					
TAKEOFF	SWELL & WIND ON STARBOARD QUARTER	5					
LANDING	DOWN SWELL-DOWN WIND	3		NO PLANE OBSERVER CARRIED			
TAKEOFF	DOWN SWELL-DOWN WIND	6					
OFFSHORE TESTS SAN CLEMENTE 12/12/44							
LANDING	PARALLEL TO SWELL-UP WIND	2	60	12"	950	200	
TAKEOFF	PARALLEL TO SWELL-UP WIND	3	65	43"	2700	-	
LANDING	PARALLEL TO SWELL-DOWN Wind	2	63	12"	950	200	
TAKEOFF	UP SWELL-WIND ON PORT BEAM	4	60	43"	2700	-	
LANDING	UP SWELL-WIND ON PORT BEAM	2	63	13½"	1300	200	
TAKEOFF	DOWN SWELL-WIND ON STARBOARD BEAM	5	65	43"	2650	-	JET
LANDING	DOWN SWELL-WIND ON STARBOARD BEAM	3	63	10"	2150	200	
TAKEOFF	DOWN SWELL-WIND ON STARBOARD BEAM	2	68	43"	2700	-	JET
LANDING	PARALLEL TO SWELL-UP WIND	2	63	12½"	1500	200	
TAKEOFF	DOWN SWELL-WIND ON STARBOARD BEAM	2	60	43"	2700	-	JET
LANDING	DOWN SWELL-WIND ON STARBOARD BEAM	3	63	12"	1100	200	
TAKEOFF	DOWN SWELL-WIND ON STARBOARD BEAM	4	60	44"	2700	-	JET
LANDING	DOWN SWELL-WIND ON STARBOARD BEAM	3	60	11"	1200	200	
TAKEOFF	DOWN SWELL-WIND ON STARBOARD BEAM	3	65	43"	2700	-	

OPERATION	DIRECTION OF MOTION RELATIVE TO SWELL AND WIND	NUMBER BOUNCES	AIR-SPEED KNOTS	POWER SETTING		RATE OF DESCENT FEET	REMARKS
OFFSHORE TESTS PT. ARGUELLO 12/14/44							
LANDING	SWELLS ON STARBOARD QUARTER-UP WIND	2	65	12½"	1400	200	
TAKEOFF	SWELLS ON STARBOARD QUARTER-UP WIND	3	60	43"	2650	-	
LANDING	UP SWELL-WIND ON PORT QUARTER	6	65	14"	1800	100	
TAKEOFF	DOWN SWELL-WIND ON STARBOARD BOW	5	63	42"	2650	-	
LANDING	DOWN SWELL-WIND ON STARBOARD BOW	2	60	15"	1800	200	
TAKEOFF	PARALLEL TO SWELL-WIND ON STARBOARD QUARTER	6	65	46"	2750	0	
LANDING	PARALLEL TO SWELL-WIND ON STARBOARD QUARTER	3	63	15"	1800	100	
TAKEOFF	PARALLEL TO SWELLS-WIND ON PORT BOW	6	62	44"	2700	-	
LANDING	DOWN SWELL-UP WIND	2	60	15"	1700	100	
TAKEOFF	DOWN SWELL-WIND ON STARBOARD QUARTER	5	68	43"	2700	-	JET
OFFSHORE TESTS SANTA CRUZ CHANNEL 1/6/45							
LANDING	PARALLEL TO SWELL- WIND ON STARBOARD BEAM	5	63	14"	900	50	
TAKEOFF	PARALLEL TO SWELL-WIND ON STARBOARD BEAM	2	62	40"	2600	-	
LANDING	DOWN SWELL-DOWN WIND	5	60	14"	1000	50	
OFFSHORE TESTS PT. LOMA 1/20/45							
LANDING	PARALLEL TO SWELL-WIND ON PORT BEAM	4	63	16"	2050	100	
OFFSHORE TESTS PT. LOMA 1/30/45							
LANDING	PARALLEL TO SWELL-WIND ON STARBOARD BEAM	0	45	10"	1200	150	
TAKEOFF	PARALLEL TO SWELL-WIND ON STARBOARD BEAM	1	65	42"	2600	-	
LANDING	PARALLEL TO SWELL-WIND ON PORT BEAM	1	65	11"	1500	200	
TAKEOFF	PARALLEL TO SWELL-WIND ON PORT BEAM	1	65	42"	2650	-	

14.

OPERATION	DIRECTION OF MOTION RELATIVE TO WIND AND SWELL	NUMBER BOUNCES	AIR-SPEED KNOTS	POWER	SETTING	RATE OF DESCENT FEET	REMARKS
LANDING	DOWN SWELL-WIND ON S STARBOARD QUARTER	0	68	12"	1600	100	
TAKEOFF	DOWN SWELL-WIND ON STARBOARD QUARTER	0	60	43"	2650	-	
LANDING	UP SWELL-WIND ON PORT BOW	0	55	10"	1400	150	
TAKEOFF	UP SWELL-WIND ON PORT BOW	3	65	43"	2650	-	
OFFSHORE TESTS PT. LOMA 2/6/45							
LANDING	PARALLEL TO SWELL-UP WIND	0	63	17"	1900	50	
TAKEOFF	PARALLEL TO SWELL-UP WIND	1	65	42"	2625	-	
LANDING	PARALLEL TO SWELL-DOWN WIND	0	60	16"	2200	100	
TAKEOFF	PARALLEL TO SWELL-DOWN WIND	5	60	43"	2700	-	
TOUCH & GO	UP SWELL-WIND ON STARBOARD BOW	3	63	15"-43"	1900-2700	50	PORT JET
OFFSHORE TESTS 2MILES W. PT. LOMA 2/9/45							
LANDING	PARALLEL TO SWELLS-WIND ON PORT BEAM	3	60	11"	1200	250	
TAKEOFF	PARALLEL TO SWELLS-WIND ON PORT BEAM	1	55	42"-46"	2600	-	BOOST MANI-FOLD
OFFSHORE TESTS PT. LOMA 2/10/45							
LANDING	PARALLEL TO SWELL-WIND ON STARBOARD BOW	1	60	11"	1400	100	
TAKEOFF	PARALLEL TO SWELL-WIND ON STARBOARD BOW	1	62	42"	2700	-	
LANDING	PARALLEL TO SWELL-WIND ON PORT QUARTER	5	62	12"	1400	50	
TAKEOFF	PARALLEL TO SWELL-WIND ON PORT QUARTER	1	60	41"	2650	-	

OPERATION	DIRECTION OF MOTION RELATIVE TO WIND AND SWELL	NUMBER BOUNCES	AIR-SPEED KNOTS	POWER	SETTING	RATE OF DESCENT FEET	REMARKS
LANDING	DOWN SWELL-WIND ON STARBOARD QUARTER	0	60	12"	1100		
TAKEOFF	DOWN SWELL-WIND ON STARBOARD QUARTER	1	58	43"	2700	-	
LANDING	UP SWELL-WIND ON PORT BOW	3	63	14"	1300	300	
TAKEOFF	UP SWELL-WIND ON PORT BOW	3	60	47"	2700	-	
LANDING	UP SWELL-WIND ON STARBOARD QUARTER	4	60	10"	1200	400	
TAKEOFF	UP SWELL-WIND ON STARBOARD QUARTER	1	58	44"	2650	-	
OFFSHORE TEST 2MILES W. PT. LOMA 2/15/45							
LANDING	PARALLEL SWELL-WIND ON STARBOARD BEAM	3	67	11"	1300	50	
TAKEOFF	PARALLEL SWELL-WIND ON STARBOARD BEAM	4	75	43"	2700	-	
LANDING	PARALLEL SWELL-WIND ON PORT BEAM	0	65	12"	1400	50	
TAKEOFF	PARALLEL SWELL-WIND ON PORT BEAM	3	72	43"	2650	-	
LANDING	DOWN SWELL-WIND	0	65	10"	1200	50	
TAKEOFF	DOWN SWELL-WIND	3	68	42"	2650	-	JETS ON

LOAD DATA

(Weight and balance totals are shown on Recapitulation Sheet, Section VI.)

PBM-3C (C 86) FOR ROUGH WATER TESTS

WEIGHTS ADDED AND REMOVED	Pounds Added	Inches Arm	Pounds Removed	Inches Arm
1. Accelerometer	13	19		
2. Platform	3.5	21		
3. Floor	3.5	128		
4. Floor and Water			4.3	128
5. Hydrobal	4.5	136		
6. Bunks - one mattress			33	375
7. Platform	9½	365		
7a. Box	14	347		
8. Analyzer	25	369		
9. Accelerometer & Shockmount	13	371		
10. Synchronizer	3	379		
11. Batteries	40	345		
12. Wiring and Switches	60	370		
13. Platform			8.0	680
14. Platform	15	680		
15. Accelerometer & Shockmount	13	684		
16. Hydrobal	4.5	688		
17. Platform	6.0	897		
18. Accelerometer & Shockmount	13	901		
First Compilations 10-28-44				
5c 3½# tubing Navand 369 Air Speed	3.5	280		
5a Camera	16.4	140		
5b Camera	14.6	180		
2a Inclinometer	2.75	90		

1 November, 1944

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NOVEMBER 17, 1944 DISPOSITION OF USEABE LOAD OFF PT. LOMA

B	C	D	E	F	G
MacDiarmid	Stewart	Finney		Larsen	Smith
Wall		Berry		Strickler	Maney
Newmeyer				Weiss	Monroe
Johnson					Kosmansici
Bittinger					Shroder
Noble					

INST. NO.	MAGAZINE NO.	
293 Tail	202	205
295 Step	203	210
324 C.G.	204	231
326 Bow	205	232
	1st Landing	1st Takeoff

NOVEMBER 24, 1944 **DISPOSITION OF USEABLE LOAD** **OFF PT. LOMA**

B	C	D	E	F	G
MacDiarmid	Stewart	Finney		Turpin	Smith
Weed				Hall	Haney
Watt				Whitham	Martin
Singleton					McCarm
Johnson					Buttinger
Noble					

INST. NO.	MAGAZINE NO.		
293 Tail	202	M 22	
295 Step	203	210	M21
324 C.G.	204	231	M13
326 Bow	205	232	
	Touch & Go		2nd Landing
	1st		1140
	1100 0-4		
	1st Landing		
	1110		

202 Stopped at #6
M22 Film came loose from drum

Hydro-Bal reading taken after flight, one man missing from after station
FORWARD 14 5/8 inch — Aft 9½ inch
27.9% — 40,200 lbs.

NOVEMBER 28, 1944 DISPOSITION OF USEABLE LOAD OFF PT. LOMA

B	C	D	E	F	G
Weed	Marshall	Finney	1600#		Haney
Davis			Jato		Johnson
Singleton					Monroe
Schroder					Smith

INST. NO.	MAGAZINE NO.	
293 Tail	202	M 21
295 Step	203	M 6
324 C.G.	204	M 13
326 Bow	205	M 21
	2nd Landing	3rd T.O.
	1418	4th Landing

1st Landing	1407	Off Shore (no ins)
1st T.O.	1413	Off Shore (no ins)
2nd T.O.	1418	Off Shore (no ins)
3rd Landing	1433	Off Shore (noins)
4th T.O.	1453	Off Shore (no ins)

New Batteries installed in ship 3 pairs hot shot 6

205 Upper half - starting end fogged

72

DECEMBER 1, 1944 DISPOSITION OF USEABLE LOAD OFF PT. LOMA

B	C	D	E	F	G
Weed Bootebom Hall Singleton	Noble	Finney Stewart	1600# Jato		Johnson Larson Meiss Turpin

INST. NO.	MAGAZINE NO.				
293 Tail 295 Step 324 C.G. 326 Bow	202 203 204 205 1st Landing 1516	M 1 M 6 M 13 M 21 1st T.O. 1527 (Jet)	M 24 210 232 2nd Landing 0-4-1535 2nd T.O. Jet 1545	 231 3rd Landing 1555	 3rd T.O. 1605 Jet

293 Mag. 202 M-1 M-24 marker and reference getting progressively worse.

295 Mag. 203 M6 210 all heavy on light
210 shaded on bottom - early end is bulb loose?

326 205 M21 232 231 Cloudy lower edge getting progressively
worse Fwd A arupovent blocked out on 231

DECEMBER 2, 1944 DISPOSITION OF USEABE LOAD OFF PT. LOMA

B	C	D	E	F	G
MacDiarmid	Sievera	Finney	1600#		Smith
Weed			Jato		Johnson
Singleton					Haney
Larson					Schroder

INST. NO.	MAGAZINE NO.		
293 Tail	202	M 21	232
295 Step	203	M 13	231
324 C.G.	204	M 22	M 24
326 Bow	205	M 1	M 6
	1st Landing	2nd Landing	2nd T.O.
	1435	1456	1507
	1st T.O.		
	1445		

DECEMBER 12, 1944 DISPOSITION OF USEABE LOAD OFF SAN CLEMENTE

B	C	D	E	F	G
MacDiarmid	Smith	Finney	1600#		Larson
Bender			Jato		Weiss
Keller					Stewart
Hall					Noble

INST. NO.	MAGAZINE NO.
293 Tail	202
295 Step	203
324 C.G.	204
326 Bow	205
	0-3 1706
	1st Landing
	San Clemente

DECEMBER 14, 1944 DISPOSITION OF USEABLE LOAD OFF POINT ARGUELLO

B	C	D	E	F	G
MacDiarmid Gould Hall Nevymer	Noble	Finney	1600# Jato		Stewart Smith Larson Weisz
INST. NO.	MAGAZINE NO.				
293 Tail 295 Step 324 C.G. 326 Bow	202 203 204 205 1-8 1st T.O. 1054	M 1 M 22 M 13 M 21 1-6 2nd Landing 1106 6-0 T.O. attempt 1115	210 M 6 231 232 2nd Landing 1150 0-3 3rd T.O. 1155 3-8 4th Landing	M 24 203 204 205 4th T.O. 1-7 1240 7-0 5th Landing 1245	M 1 M 22 M 13 M 21

JANUARY 6, 1945 DISPOSITION OF USEABLE LOAD OFF SANTA CRUZ CHANNEL

B	C	D	E	F	G
MacDiarmid Davis Singletom Hall	Schroder	Finney	1600# Jato		Smith Neumeyer Stewart Johnson Johnson

INST. NO.	MAGAZINE NO.	
293 Tail 295 Step 324 C.G. 326 Bow	202 203 204 205 1204 1st T.O.S.C. all Ins 1-0	M 1 M 22 M 13 M 21 Landing 1219 all Ins

1st Landing not recorded except on Hathamay Ins.

2nd T.O. not recorded except on Hathamay Ins.

Camera on deck failed to take

Leader not spliced to film

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JANUARY 20, 1945 DISPOSITION OF USEABE LOAD OFF PT. LOMA

B	C	D	E	F	G
MacDiarmid	Noble	Finney	1600#		Schroder
McMullen			Jato		Pollard
Hall					Turpin
Neumeyer					Palmore
					Singleton
					Ardoin

INST. NO.	MAGAZINE NO.
293 Tail	202
295 Step	203
324 C.G.	204
326 Bow	205
	1045
	Landing
	all Int
	Camera Lost
	Jet

Bow Camera jammed at 50 ft., opened to clear jam then pictures taken with remainder

Camera repaired 1-27-45

JANUARY 30, 1945 DISPOSITION OF USEABE LOAD OFF PT. LOMA

B	C	D	E	F	G
MacDiarmid	Stewart	Finney	1600#		Larson
McMullen		Schroder	Jato		Palmore
Barry					Weisz
Singleton					

INST. NO.	MAGAZINE NO.			
293 Tail	202	M 1	M 24	
295 Step	203	M 22	M 6	
324 C.G.	204	M 13	231	
326 Bow	205	M 21	232	
	1-4 1718	1-7 1748	1-7 1800	4th T. O.
	1st Landing	2nd T.O.	3rd T.O.	not recorded
	off shore			
	1730	1755	4th Landing	
	1st T.O.	3rd Landing	1803 Lan	
	1734			
	2nd Landing			

1St T.O. 1625 Bay
1635 Touch & Go S. Bay

Hand Camera jammed on boat - loose drive feet.

85.

FEBRUARY 6, 1945 DISPOSITION OF USEABE LOAD OFF PT. LOMA

B	C	D	E	F	G
McMullen MacDiarmid Singleton Hall	Noble	Finney	1600# Jato		Smith Schroder Stewart Turpin Barry

INST. NO.	MAGAZINE NO.			
293 Tail 295 Step 324 C.G. 326 Bow	202 203 204 205 1550 1-5 1st Landing	M 1 M 22 M 13 M 21 1610 1-9 Landing	M 24 M 6 231 232 1615 T.O.	210 1-9 1623 Touch & Go Jets

FEBRUARY 9, 1945 DISPOSITION OF USEABE LOAD OFF PT. LOMA

B	C	D	E	F	G
Davis MacDiarmid	Abrams	Finney	no Jet carried		Neumeyer Berry Noble Austing Diogurdia Virok Weiss

INST. NO.	MAGAZINE NO.	
293 Tail	202	
295 Step	203	
324 C.G.	204	
326 Bow	205	
		1st T.O 1640 no ins

Fuel	150 each wing	300
Hull Fwd	Empty	
Center	175	175
Aft	475	475
		950

FEBRUARY 10, 1945 DISPOSITION OF USEABE LOAD OFF PT. LOMA

B	C	D	E	F	G
MacDiarmid Davis Singleton	Abrams	Finney	1600# Jato		Koski Holmes Hoolihan Berry Virok Larson

INST. NO.	MAGAZINE NO.			
293 Tail 295 Step 324 C.G. 326 Bow	202 203 204 205 1-6 1505 Landing 3-3 1518 2nd Landing	M 24 M 22 M 13 M 21 1-6 1525 2nd T.O. Landing 1537	M 1 M 6 231 232 T.O. 1542	210 Landing 1550 T.O. 1553

1st T.O. not recorded

Used Everything

FEBRUARY 15, 1945 — DISPOSITION OF USEABLE LOAD — OFF PT LOMA

B	C	D	E	F	G
MacDiarmid Trubey Storm Hoolihan	Abrams	Finney	1600# Jato	Rescue Gear 125 Ft.	Diogurdia Smith Vandergaff Palmore Weisz

INST. NO.	MAGAZINE NO.		
295 Step 324 C.G. 326 Bow	203 204 205 Landing 1-5 1430 T.O. 1435	M 22 M 13 M 21 Landing 1-5 1442 T.O. 1446	M 6 231 232 Landing 1-4 1452 T.O. Jet 1456

FUEL

Fwd	0 after returning to station
Center	160
Aft	220
R Wing	185
L Wing	185
	750 gal.

ENGINEERING ANALYSIS

ENGINEERING ANALYSIS
PBM3c - 6586
Offshore Tests

Excluding difficulties with instruments, cameras etc., the injuries sustained by the airplane pertain to (1) the Jato bottles and (2) to secondary structures or (in a few cases) (3) to equipment.

The Jato is entirely an accessory up to this writing and not regular PBM-3 equipment. Injuries to four Jato bottles occurred-- on December 2nd while taking off, on landings January 6th and January 20th. On January 6th one bottle was lost overboard. On the other three bottles the forward support was cracked after the bottles slipped off the rear support. See Photo 527-B.

The losses all occurred on operations of considerable severity-- well above average conditions encountered even on normal off shore landings. The losses would not have occurred in sheltered operations. A discrepancy in dimensions of Jato bottle and support developed at time of manufacture which was corrected in the field at the expense of the bearing area on the rear fitting. (Photo 572). With rough operations it is believed the forward support springs sufficiently to permit this slippage.

In order to continue the tests a temporary repair was effected by clamping the rear support and bracing the forward support. (See Photo 571).

For future (standard) installations, the support supplied for the airplanes should be modified to match the bottle dimensions. The feature of recovery by parachute could thus be retained. It is believed the original bearing surface is sufficient when the forward brace is stiffened.

An interesting side light on the Jato and its effect on the control of way occurred when defective wiring set off the port Jet only--February 6th. The pilot reported adequate control although the airplane was already in a left skid at the time the jet was applied.

Structural failures include, (1) rivet popping, (2) skin wrinkling, (3) fairing damage, (4) wing stiffener and (5) float and flap damage.

The rivet popping and skin deformation occurred sporadically but without destroying immediate buoyancy, stability or mobility at any time. Fairing damage was annoying because it permitted the entrance of spray.

The wing brace (Photo 517) was found damaged by routine inspection after the operations at Port Arguello. As a precautionary measure all major points of alignment had been checked and no permanent deflection found. The most severe operation on this day was the second landing and it is probable that this was the only operation that could have damaged this member. A new member was installed of a later (and better) design.

91.

The wing tip float and flap were damaged by water action on the landing of January 20th. Despite the considerable damage buoyancy, stability and mobility on the water was maintained. Flight was not attempted. In many designs where heavy shock loads are imposed on floats, the bracing gives way and stability is completely lost.

While momentary shock peaks were recorded in several instances which approach or exceed the design allowance, most of the operations were below the design characteristics. Comparison with rough water acceptance tests may not be conclusive, but it appears that at least maximum conditions were rather more severe during the present tests.

The structural design appears rather well balanced; no recommendations are made to cover the few weaknesses disclosed, lest extra weight might overcome any advantages. In work of this type weight must be carefully controlled; knowing the conditions necessary to cover rescue flights. The factors concerned with successful landing operations are stalling speed, time in coming to rest, and controllability during this period. It would appear from the results that these are met rather successfully, however there have been instances where the control was inadequate or the operation occurred so quickly that the elevators were not used.

When the problem of take-off is considered, the sequence of operations is reversed and along with the above considerations, additional power would be most advantageous. The Jato units have demonstrated their advantage on several occasions and despite their weight (approximately 800# each) are recommended for standard operations of this sort. The present power plant is barely adequate for normal operations and is considered to be below the best average reserve for seaplane operations.

A word concerning planes for new procurement for air sea rescues may not be out of place. No specific type, size or power is contemplated. However, where all other conditions are adequate, greater consideration to controllability on the water and shortening of landing could probably be supplied with suitable vanes controllable from the cockpit.

In comparing the sea with rough water conditions at Norfolk, several variations will be noted in prevailing conditions.

	NORFOLK	SAN DIEGO
Waves	3½' to 4' (estimated) choppy	3' to 6' (measured) swells
Wind	35 to 40 knots	15 knots

Swells rather than winds characterized the seas to be operated in at San Diego. The Scripp's Laboratory reports that swell speeds range from 20 to 50 knots in this vicinity.

SUMMARY

So far as engineering data can indicate, landing and taking off <u>parallel to the crests</u> is recommended. Beam winds of 15 knots intensity offer no serious <u>difficulty</u>.

Additional power--larger engines or Jets--should be provided for offshore operations.

The faults in the Jato support must be corrected in standard installations.

Structurally the plane meets the rugged requirements of offshore operation so far as indicated by conditions prevailing in this vicinity.

Buoyancy, stability and mobility were not impaired during these tests, but unlimited operations were not recommended. Occasionally winds and swells may prevail that will not permit the best approach. The pilot must use his best judgment as to whether the conditions fall outside recommended practice.

SECTION III

DESCRIPTION OF TESTS

SECTION III

SECTION III

DESCRIPTION OF TESTS

The Coast Guard Air Station at San Diego was authorized by Chief of Naval Operations letter dated 30 July, 1944, and received here 4 September, 1944, to make open sea landing tests with the PBM-3 airplane for which authority was requested by Coast Guard Air Station, San Diego, letter dated 20 May, 1944. Action was immediately started to get physical possession of PBM-3C airplane BUNO 6586 which had been designated for the tests, to get JATO equipment on the station and the necessary pilots checked out in its use, to draw up and accomplish the instrument recording plan, obtain and calibrate the instruments, obtain the services of a man capable of making analyses of the instrument stress records so that indications that the tests were putting excessive stresses on the aircraft would be quickly available, obtain services of the necessary photographers and assure that proper cameras and film and processing facilities were available, and acquire or develop facilities for accurately determining actual wind and sea conditions existing at the time and place the tests were conducted.

The airplane required an engine change before it was ready for use. This was accomplished at NAS, San Diego. Wing float strut braces (BuAer Bulletin No. 26) were installed.

An immediate study undertaken to determine the ideal instrumentation for these tests suggested that the best engineering analysis of the tests should be based on the records of oscillographs with pickups at the bow, center of gravity, the tail, several points on the chine, and several points in the wing so that from the records we could determine not only the stresses and strains involved, but what oscillations occurred and just where the nodes were. Discussions of structural failure problems with design engineers leads to the belief that many structural failures that are difficult to explain on the basis of measured stresses may be more properly attributable to oscillation or vibration phenomena. To consider the problem from this angle, it would be necessary to study the plane both as a rigid body and as a flexible body in which stresses have a very close relationship to time.

On inquiry it was quickly apparent that the bureau felt that the engineering aspect of these tests was being over-emphasized and that oscillographs would not be supplied, so the plan of instrumentation was changed to one involving the use of four NACA two component accelerometers and one Hathoway landing analyzer. The accelerometers were installed in the nose, center of gravity, step, and tail; and the Hathoway instrument, at the center of gravity. The last of the instruments was received November 9, 1944. Some of the instruments were injured in shipment.

Mr. Henry S. Cocklin, Aeronautical Engineer, U. S. Coast Guard, had reported to this station 8 October, 1944, and his assistance and advice on these tests were invaluable. Mr. Cocklin did all the work of running down instruments lost in transit, getting damaged instruments repaired, getting the instruments installed and calibrated, and finally organizing and coordinating the records and making the engineering analysis for this report and the final arrangement of the movie record of the tests. After considerable delay and difficulty, all of the instruments were got in working order, calibrated and installed in the aircraft; cameras and photographers were obtained, a Hydrobal was installed in the plane, the plane was checked on scales for weight and balance, the air speed meters calibrated, and on 17 November tests were started. A portable anemometer carried aboard the photographer's boat gave accurate recordings of the wind, but the earlier records of the sea conditions were based on the estimates of observers and these estimates varied widely between several observers estimating the same sea. Wide inquiries were made as to the existence or availability of any sort of device to measure the height and speed of a swell accurately. After some experimentation, it was determined that the speed of a swell could be measured with fair accuracy by having a crash boat run with the swell and synchronize its speed to stay in phase with the swell. The speed of the crash boat was then taken as the speed of the swell. The Scripps Institute of Oceanography at La Jolla recommended a wave meter buoy consisting of a thin spar buoy balanced to float vertically and with the one foot divisions painted in contrasting colors up the spar. The spar is attached to a wide metal pan like a big mushroom anchor which is suspended 180 feet down. The theory of operation is that the tendency of the spar to float up on a swell will be counteracted by the pull of the mushroom 180 feet below which is in still water. This device probably underreads a little, but was the best available. Readings were taken at the lowest water level and at the highest water level on the spar, and the difference recorded as the height of the swell. Later it was discovered that the Institute of Oceanography at La Jolla made regular recordings of swell conditions in this vicinity, and their observations and data were used wherever possible.

The first landings were made off Point Loma to test the instruments on 17, 18 and 19 November. A total of eight landings and take-offs were made in a swell estimated from eight to eleven feet, and a wind from almost calm to ten knots, to place stresses on the instruments in order to check their smooth operation and to work out an orderly plan of operation on the basis of a sound knowledge of the problems involved. All of these first eight landings were made in a relatively slow swell, and the landings were made parallel to the swell and down swell and into the swell to determine the controllability of the airplane in this work before attempting to land near a boat. All of these landings were very carefully done, without hurrying and without attempting to land close to a given spot to make photographic records. The highest shock encountered was $4\frac{1}{2}$ g; and though the airplane gave the impression of being banged about pretty roughly, post flight inspections revealed no indications of damage.

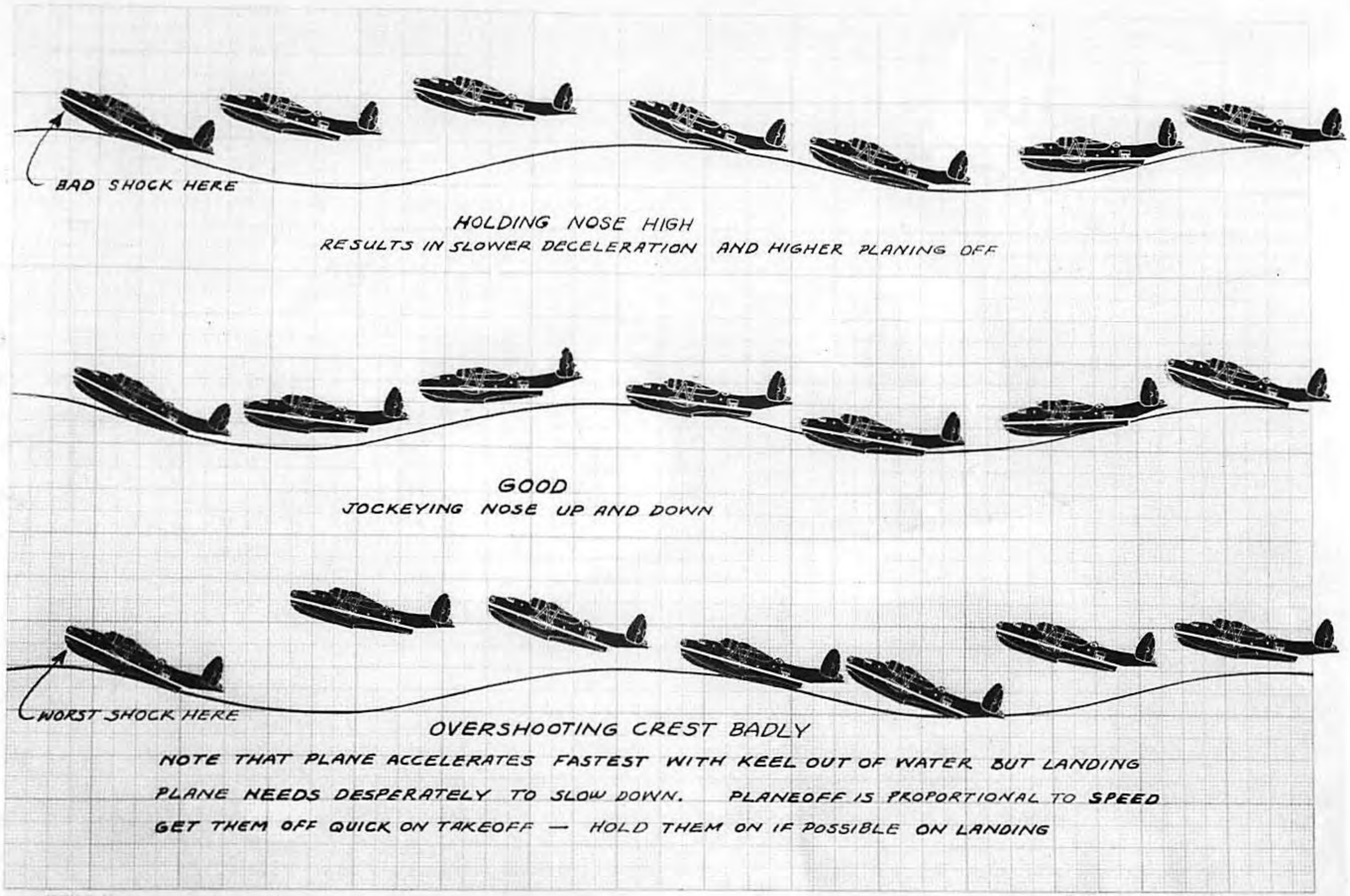
On 24 November, the first good records were obtained; and tests were continued making landings and take-offs on all headings around the compass, taking the wind or swell on approximately all relative bearings from the plane to determine which of these was best for given sea conditions. At the start of the tests there were some spirited arguments between pilots taking part as to the relative merit of power on and power off landings; but shortly after the tests began, the power on advocates conceded that a better and slower open sea landing could be made by making the approach as though a power on landing were to be made but cutting the throttles back and then heaving the yoke back hard just before the instant of stall. (At the end of the tests the argument was re-opened and it appears that a reasonable conclusion is that each pilot should make his own best and slowest landing.)

On 2 December, while making a down swell take-off in an eight foot sea over a three foot, twenty-five knot swell with fifteen knots of wind astern, the take-off was fumbled in the cockpit due to a misunderstanding between the pilot and co-pilot as to when the co-pilot took the throttles. The co-pilot failed to fire the jets through fumbling, and the throttles worked back to thirty-seven inches while the pilot was fighting the yoke to keep the airplane under control. During the long run (seventy seconds), a sea was overtaken where the eight foot local waves were in phase with the three foot Pacific swell underneath, and the airplane took a violent pounding in this sea. One jet unit was torn loose from its supports and swung from one end. The accelerometers registered $8\frac{1}{2}$ g. Post flight inspection revealed oil canning in the wing root fillets, and a crack in the crown skin just aft of the radome. The hull otherwise showed no signs of damage. Repairs were completed by 12 December and the tests continued. The progress of the tests was retarded by a long, disappointing period of good weather; and flights were made to Point Arguello, two hundred miles up the coast, to find desirable swell conditions. It was found that operations at Point Arguello were clumsy and unsatisfactory because photographers had to be sent to Santa Barbara the day before and then taken some fifty miles in a crash boat to the scene of the tests. Long delays followed while the records were being got back and developed and analyzed.

During the tests at Point Arguello, a landing was made into the swell which was a long six foot, twenty-five knot swell from the Northwest over-riding a four foot, forty-eight knot, Pacific ground swell from the West. The landing was made with a five knot wind astern. The landing was very hard. Subsequent repeated attempts to take off on the same heading were unsuccessful. Take-offs parallel to the swell and down swell in this same sea were very easy. Post flight inspection of the plane after these tests, which had registered a maximum of 5.5 g acceleration, disclosed that the engine mount support assemblies were deformed. Compression stresses had caused the aluminum hat section flanges to separate between the end of the riveting at each end of the flange. After the aircraft was repaired and again ready for use, there was a long delay waiting for more substantial seas to continue the tests. Finally on 6 January, the equipment was set up and the plane taken to Santa Cruz channel about one hundred and fifty miles North of here for further tests. On this occasion, the sea was found to be short and relatively high with a very low wind. The sea here was much more of a rip than a true deep water sea. These seas were curving from the West around Point Carrington. A landing was made parallel to the swell and cross wind, and the plane went on very comfortably and stayed on. From taxiing about to feel out the sea on various headings, it was apparent that this sea condition was different from any encountered in our previous thirty-three landings. A take-off was made parallel to the swell and cross wind, and the plane dragged off very nicely with a maximum shock of $2\frac{1}{2}$ g. A second landing was made down swell down wind. This swell was seven feet high and advancing at nineteen knots. The wind was four knots or less. The plane was dropped on full stall at sixty knots about ten feet past the crest of the swell where the pilot wanted to land. The plane settled on very comfortably and rode along for a considerable way when it overtook a small swell and planed into the air about six feet. When the airplane settled on again, it hit the back of a swell very hard and bounced off. When the plane fell on the third time at a speed of about forty-seven knots, it stayed on; but on the last bounce the port jet unit was torn completely out of its fitting and went by the board. The starboard unit was torn loose at one end and swung below the beaver tail like a pendulum. The plane was taxied to sheltered waters where the remaining unit was removed and an inspection was made of the plane at anchor. No signs of strain could be found in the engine mount supports, or wing attachment fittings, or the hull generally, so it was taken off and flown home. When the plane was hauled out, it was discovered that the hull was damaged along the chine which was wrinkled on the port side from the main step forward, a distance of seven feet, nine inches; four rivets were removed to inspect for signs of shear. There was no evidence of shear. The wrinkled chine was made tight by calking with zinc chromate compound. Twenty-four rivets at various places on the bottom at the left side of the keel in the area between the main step and twenty-four inches forward of the main step which were weeping were replaced. Three stringers on the left side of the keel just forward of the step which were slightly deformed were straightened and a stiffener installed. Both the NACA landing analyzer and one accelerometer at the center of gravity indicated over 11 g for this landing. Mr. Cocklin stated that he did not believe the accelerations were really as much as 11 g. Careful inspection revealed no other damage to this airplane than that just described.

As a result of this landing, pilots were persuaded of two things, first, that this is about the ruggedest hull ever put into an airplane, and second, that something strange is happening in some wave systems which results in very different forces being present in two wave systems that look on the surface to be very much alike.

At this stage in the tests, it appeared very desirable to learn a lot more about wave motion and possible mysterious forces present in a tumbled sea that were not understood by anyone here. Inquiries were directed to the U. S. Naval Institute and to the University of California's Oceanographic Institute at La Jolla, California. The Naval Institute supplied a list of authorities on the subject, and the Institute of Oceanography sent an oceanographer to conduct a discussion on wave motion and forces for the pilots flying the tests and supplied reference material for study. After these matters were given some study, a number of previously held beliefs were discarded and some of the mysteries of wave motion and forces were cleared up. There appears to be a great void, however, in the available knowledge of the forces involved in wave motion and especially in complex wave motion. Lieutenant Commander O. S. Reading, USC&GS, suggested that a study of waves employing photogrammetrics might contribute some of the missing answers. Considering all of the valuable equipment going into the sea these days, The sketch opposite illustrates three different, typical landing sequences in landings across a single, simple swell system. The severe shocks encountered in these tests were the result of falling on hard after planing too high off a previous swell. The high planing is attributed to (a) excessive speed while running up the back of a swell and (b) holding nose high. The middle sequence represents an almost perfectly handled cross swell landing for this type of sea. A landing parallel to the swell in this same sea would be much easier.


BAD SHOCK HERE
HOLDING NOSE HIGH
RESULTS IN SLOWER DECELERATION AND HIGHER PLANING OFF
GOOD
JOCKEYING NOSE UP AND DOWN
WORST SHOCK HERE
OVERSHOOTING CREST BADLY
NOTE THAT PLANE ACCELERATES FASTEST WITH KEEL OUT OF WATER BUT LANDING
PLANE NEEDS DESPERATELY TO SLOW DOWN. PLANEOFF IS PROPORTIONAL TO SPEED
GET THEM OFF QUICK ON TAKEOFF — HOLD THEM ON IF POSSIBLE ON LANDING

it seems reasonable that a thorough study of this problem from all angles would pay dividends.

After the study of wave motion, the very hard down swell landing in the Santa Cruz channel was explained by the presence of a complex sea. The principal mystifying point before had been that the airplane though slowing down hit on the same bad position on the backs of three successive swells. The earlier assumption was that the period of the swell was constant and that only an object moving at constant speed could stay precisely in phase with it. The wave motion study explained that of two wave motions simultaneously present in the sea, usually one is concealed beneath the other and that great waves whose heights are equal to the sum of the heights of the two systems when in phase, advance with a speed different from either. A low ceiling at the time of the tests had not permitted climbing to detect the hidden Pacific swell.

On 12 January a landing and take-off were made five hundred miles West of San Diego. This landing was interesting from a number of angles. To begin with, less than twenty miles away in any direction the wind was light and the sea was calm except for the long fast Pacific swell which was from West Northwest travelling about thirty knots and was about six feet high. Locally a hard, short sea seven feet high was rolling from North by West under the influence of an eighteen knot unsteady wind. The plane was brought in with the wind and short sea on the port bow and with the concealed ground swell rolling from a little abaft the port beam. The landing was planned to touch down at such a point that the landing runout would end approximately on the wind line through a raft floating on the sea. The plane was stalled on precisely on the top of one of the short seas, and ran her way out almost without leaving the water but pounding very hard in this tumbled sea. The take-off was made after feeling out the sea on various courses and speeds approximately into the wind (in this tumbled sea the pilot did not believe he could turn down wind without losing or badly damaging a wing tip float in the turn) on a heading almost parallel with the ground swell and with the wind and short sea on the port bow. The plane was taxied fast taking the pounding as it came and advancing as fast as possible without planing off the tops of the waves. Very suddenly a relatively flat space appeared about one point on the starboard bow, the plane was turned to it, throttles were advanced quickly to take-off power and the jets were fired. The aircraft planed off the top of the first big sea at the end of the relatively smooth area and between jets and throttles was held off. The plane suffered no damages from this landing and take-off except a breaking of minor equipment not a part of the hull or fittings. This was probably as difficult a landing and take-off as any made during those tests, not because of the height of the sea, but because of its complex character; and the success of this landing and take-off is attributed as much to luck as to skill.

On 20 January a landing was made off Point Loma in a ten foot, twenty-four knot sea and sixteen knots of wind from about twenty degrees to the right of the sea. The landing was made parallel to the swell and with the wind just forward of the port beam. The airplane was stalled in and ran a short way before planing off to about three feet. When the plane fell back on again, it struck a wave with the right wing tip float which was a little lower than the left, and the plane being at that time drifting to the right, the side of the wing tip float and the right flap were damaged.

On 30 January the tests were continued, this time attempting a technique of deliberately dragging the nose of the airplane on the latter part of the run up the backs of waves. Previously the nose had been held high always during the runout of speed after a landing. The theory of the benefits to be gained by the nose dragging technique was (a) that the aircraft would slow down faster, and (b) that it would plane off the top of a wave at a lower angle of attack and reduce the lift still being obtained from the wings. This technique was tried out in fourteen landings in seas varying from three to six feet in height travelling at a velocity of from thirty-nine knots down to fifteen knots and winds from five to fifteen knots. Landings and take-offs were made on all cardinal headings with respect to the swell and wind. During all of these tests, the wind and swell direction coincided. The tests were very successful and indicated that this technique has considerable merit; however, in order to use it effectively, the pilot had to exhibit very fast reactions lest he fail to lead with his controls enough to keep the plane's nose at the proper attitude at the proper time. The results of all of these landing tests indicated over and over that a landing in a sea of any severity, and especially in a complex sea, is not a job for an inexperienced pilot and is going to be very dangerous and possibly very difficult for even the best pilot with the equipment now available.

A very striking thing about these tests has been the fact that in fifty-four landings in seas of varying severity, every well stalled landing has been initially good, and the start of each landing run has seemed to the pilot easier than he expected, and that each time a plane was damaged, the damage was done at that stage in the landing run where the plane had too much speed to be kept on and not enough speed for good control. All the damage was received when the plane dropped on hard after planing off a swell, except in the landing of 20 January when it is believed the damage was caused principally because a ten foot sea caught one wing tip float and flap. This suggests the desirability of devising some sort of air or water break or forward firing jet, or propeller capable of instant change from forward to reverse pitch or back again with a small pitch either way, in order that the seaplane landing run can be cut very short. Because the landing speed and the length of the landing run are for the present conventional aircraft directly proportional to the load, it is most important now that open sea or rough water landings be made at the lowest gross weight possible. The intelligent use of droppable tanks allows a pilot considerable flexibility in his plans, and for a difficult mission he should burn fuel from his integral tanks until the fuel remaining in these tanks is only enough to make his rescue and get home or to the nearest refueling point with a comfortable margin of safety, before shifting suction to the droppable tanks. He should jettison his droppable tanks early enough to permit a careful check of his longitudinal balance before landing.

Another desirable improvement in a seaplane for rescue work is a means of turning with positive control from up wind to down wind at very slow speed. This could probably be accomplished by a simple water rudder.

During these tests, take-offs were made on all headings with regard to wind and swell just as the landings were. The only damage encountered in the take-off was attributed solely to pilot error; however, on a number of occasions only the use of JATO prevented serious damage. On all take-offs it was found most important to get as much way on the aircraft as possible without planing off, before the pilot committed himself to the take-off, and that great advantage was gained on either a down swell or up swell take-off by applying take-off power at the top of a large swell and easing the nose down to race down the front or back of the swell. This technique gave very fast acceleration, and often the aircraft could be dragged off from the top of the next swell or with only one substantial bounce.

The problem of taxiing is very intimately connected with the take-off problem. It was found that difficulty in maneuvering on the water was more of a wave problem than a wind problem and that in some conditions of swell or sea steering was very difficult even with winds of only five to seven knots, that on other occasions with winds of fifteen to twenty knots steering was no more difficult than in the same wind condition in a harbor. When the sea is rough due to a local wind, streaming of sea anchors to assist in maneuvering is very likely to result in taking considerable water aboard when the hatches are opened. Some improvement in the low speed steering qualities of the PBM on the water is desirable. It was noted that the PBM aircraft with its engines dead drifts very fast in a fresh wind, approximately one knot faster than a life raft without a drogue. Because of this characteristic it is believed more desirable to cut the engines and drift down to leeward of a raft than to attempt to bull the airplane around in a rough sea to taxi down wind.

In winds of less than twenty knots, the best take-off heading was found to be parallel to the swell and getting a component of the wind ahead if possible. It is usually impossible to start the PBM-3 airplane on this heading from rest because of its quick weather cocking. Attempts were made carrying take-off power on the weather engine alone, but in some cases even this wasn't enough to hold the course and the airplane could not be got up to good steerable speed on one engine anyway; so usually as soon as power was increased on the leeward engine, the airplane would come right around into the wind. The best solution to this problem was found to be heading the plane down wind, which can be accomplished safely if the sea is not too tumbled and irregular, by the usual technique of deliberately laying the wind on the port bow and holding it there by port throttle and then suddenly starting a turn to port with the port throttle cut back, the starboard throttle advanced and the rudder hard left to get the airplane swinging left very fast. Some judgment must be exhibited by the pilot in this maneuver lest the sea be too rough and he lose a wing tip float. Once headed down wind, the airplane will quickly pick up speed until steering control is good and can be eased cross wind very handily and the take-off run made with a minimum of difficulty. The run down wind is much preferable to accelerating into the wind because the pounding and the spray are much less and less throttling and speed are necessary to make the turn to cross wind. During down swell taxiing the pilot will feel some alarm when the fast Pacific swells overtake him, but these are not a serious hazard to this type airplane. The pilot should remember that his airplane is rising like a duck on each of these swells; and because it is relatively so light and the tail surfaces are high, he need have little fear of being pooped as a small ship may be pooped in a sea. The sea will appear strikingly smoother to the pilot taxiing down swell than to one taxiing up swell regardless of the direction of the wind. A pilot who is making his first open sea landing and take-off or is unfamiliar with the existing sea conditions, will probably make a much better take-off if he will taxi about a little on various headings at various speeds to feel out this particular sea. This should be a "must" with all pilots unless the sea or wind are increasing rapidly, or minutes are going to measure life or death for a rescued crash survivor aboard.

In a long fast Pacific swell the second best take-off heading in winds of less than twenty knots is directly down swell disregarding the wind. This take-off is made best by taxiing down swell at the highest possible speed that still won't cause the aircraft to plane off the tops of the swells, carefully studying the sea until the pilot finds that he has overtaken, or has been overtaken by, a large swell with relatively smaller swells ahead. The throttles are advanced smartly to take-off power at the crest of the swell, the nose is eased down and an effort is made to race down the front of the swell. The aircraft should accelerate very fast and with good luck and smart handling it can be held off the water when it planes off the top of the next swell overtaken. If it does bounce again, the bounces are easy. This type of take-off will seem all wrong to the pilot making it, but he will almost invariably be surprised and pleased with the ease with which it is accomplished.

Take-offs directly into the long fast Pacific swell are a very poor last choice, and should be undertaken only if the pilot feels that the wind is too strong to permit a safe take-off on any other heading. On a take-off into a long fast swell, the pilot is quickly struck by the impression, as his plane gathers speed, that the seas are very close together and very high and very ugly; and what appeared to be a long low swell while he was taxiing, now looks like a high roaring sea. Attempts to jockey the nose up or down in these seas are met with great difficulty because he is crossing the seas so fast while still far below flying speed.

The most difficult take-off conditions are encountered in a complex sea with a fresh wind, unless the wind happens to be parallel to the long Pacific swell, in which case the take-off should be made very handily into the wind.

During any take-off in a complex sea the pilot should keep ever in mind that when two wave systems are in phase, the height of the resultant wave is equal to the sum of the heights of the two which form it, and that if by chance there is a small chop caused by the wind on top of this very high wave, he may easily knock off a wing tip float or a flap if he hits it just right. For this type of sea it is very desirable that the pilot carefully weigh in his mind all the factors which are going to hazard or affect his take-off. By the time he has made the landing, he has already learned a great deal about this sea and he can now use that knowledge plus what he has gathered from taxiing in planning a take-off run which will (a) avoid running directly into the face of any large wave system, (b) bring as large a component of the wind ahead as possible, and (c) involve a minimum of difficult taxied turns out of the wind. Having decided on the take-off heading and being sure that the engines are ready for take-off, mixture rich, propellers in low pitch, flaps down (or juice checked up to the flap motors if the flaps are kept up until a final stage in the run), crew stationed and ready for take-off, and co-pilot instructed as to when he takes the throttles and when he fires the jets if they are to be used, the pilot starts his take-off using just as much power as he can without the airplane planing off the tops of the swells and advances over the sea using elevators and ailerons smartly to keep the plane well under control and simultaneously studying the sea ahead. At this stage the airplane is taking a considerable measure of abuse, but this speed on the plane is going to contribute materially to making a short take-off run in the most dangerous part of the take-off. The pilot should continue to run ahead, studying the sea ahead patiently, throttling back or increasing throttles as necessary to avoid planing off the waves and still keep the maximum way possible on the plane short of the planing off speed. Within, at the most, thirty seconds, a relatively smooth spot should appear ahead which is caused by the complex wave motions being for the moment in opposite phase; and at this instant the pilot should advance his throttles to take-off power and hammer his way across the relatively smooth spot and attempt to stay in the air when he planes off on the first large sea beyond this area. If jets are used, maximum jet power should be fired at the same instant the throttles are advanced to take-off power.

Pilots have noticed that there is one particular attitude at which a seaplane accelerates much faster than at any other; and because fast acceleration is very desirable, every effort should be made on a take-off run to stay very close to that attitude with respect to the water surface over which the plane is running at a given instant, always having due regard to the danger of smashing the nose of the seaplane into a wave front.

During the tests reported here, the great majority of pilots have agreed that the best take-off is made in the open sea using full flaps; but there is a difference of opinion as to whether the take-off run should be started with full flaps or half flaps or no flaps. A slight advantage in acceleration will be gained by starting the take-off run with the flaps up; but in a difficult take-off both pilot and co-pilot are very busy, are under considerable mental strain and are being shaken about in their seats pretty badly, so it is probably worth considering the possibility of the flap switch being fumbled or of some other necessary measure being overlooked in the co-pilot's concentration on the flaps. During the take-off run the co-pilot normally takes the throttles as soon as the pilot has pushed them to approximately take-off power or at an earlier point prearranged between pilot and co-pilot. Because during the early stages of the run the pilot has had to play his throttles freely to assist in steering, the throttle friction brake is probably off; and the co-pilot's first gesture on taking the throttles should be to set up the throttle friction brake firmly. He should then be alert to handle flaps, windshield wipers, and jets, as prearranged or on the pilot's signal. He should attempt simultaneously to check the engine gauge readings for indications of trouble and the plane itself, especially the wing tip floats and flaps, for indications of damage on take-off.

In case the airplane receives serious damage during the take-off, the co-pilot should not cut the throttles back without the pilot's signal. The decision whether to stop or continue a take-off when a wing tip float or flap or possibly a jet unit has been damaged or torn loose must, or course, be made quickly, and the pilot should have considered such possibilities before the take-off and be prepared to make a quick decision. The pilot's decision as to whether to throttle back or continue the take-off if he has already reached a speed with good aileron control should be based on (a) can repairs be effected locally with the means at hand, (b) if a wing tip float is badly damaged or lost, the airplane will probably roll over and sink rather fast unless a life raft can be got under that wing tip very quickly which is at best a difficult trick, (c) will the crash survivors just picked up survive longer exposure, (d) does the expected weather indicate that surface vessels can be guided to the spot in a reasonable time, (e) has the damage to the plane created the probability that it cannot be kept safely under control during a flight to the nearest protected waters or shipping, (f) could a wing tip float if torn loose and dangling below the wing and endangering the wing structure, be shot away by gun fire, and (g) other considerations special to that situation.

During these tests JATO gear was carried on nearly all the flights whether it was used or not, and was considered a safety factor in case the aircraft got into trouble from which it could be saved by a sudden application of power. On several occasions it was so saved. Fifteen jet take-offs were made in the open sea on various headings and under various sea conditions. On one occasion one jet failed to fire due to an electrical ground. Possibly because the take-off doctrine using jets here had been to get good way on the airplane before firing the jets, the failure of one jet to fire did not in any sense jeopardize either the stability or the controllability of the aircraft, the only result felt in the cockpit was less thrust than had been expected.

Two theories on best doctrine for open sea take-offs with jets have been advanced here. The other one is that the jets should both be fired before the throttles are advanced, one jet being fired ahead of the other to correct for the winds effect on the aircraft. The theory in favor of that doctrine is that the pilot now has the thrust of the jets and all of the throttle power left for steering effect. Several objections to it are (a) the jets have a very limited period of burning in contrast to practically unlimited time of power from the engines, (b) if one of the jets, by chance, fails to fire, a sudden turning effect may be felt at low speed, and (c) in the case of solid jets the pilot commits himself to this increment of thrust and cannot turn it off until it has burned out.

All the pilots flying in these tests have been very enthusiastic about the merit of the jets, and a number of take-offs have been made with the jets which the pilots feel certain could not have been accomplished without them. At first the pilots were worried over the possibility that the jet thrust imposed on the airplane during the rough take-off involving radical flight attitudes might introduce prohibitive stick forces, but tests indicated that the thrust of these jets is felt only as additional power and the airplane is definitely more controllable with the jets on than in the same take-off without them probably due to going more rapidly through the take-off run.

Requests have been made by this station for the provision of jets on all patrol aircraft operated here to be used to protect the aircraft in situations where additional power is emergently necessary, such as planing high in a radical attitude from a very rough sea.

The shortcomings of the jets as presently available are (a) the great weight of the liquid units and (b) the lack of flexibility of the solid units which cannot be turned on and off like the liquid units. It is understood that a new jet propellant which will very radically reduce the weight of the liquid units is almost ready for use. Until this improvement is available, the solid units are considered much more desirable for rough water operations than the liquid because of the contrast in weight, eight hundred pounds for the solid as against over seventeen hundred pounds for the liquid.

Though the pilots taking part in these tests were of varying opinions as to the over-all merit of the PBM-3 airplane, they agreed that (a) the airplane has very fine landing characteristics, (b) it has a very rugged hull and wing structure and engine mount structure, (c) it is probably at least as controllable through all stages of a rough water landing and take-off as any other airplane presently available and adaptable to this work--and possibly a little better than any other, and (d) it has easy stick forces and is not tiring to fly on a long search. The objections to the airplane as a rescue plane are: (a) The engines have to be continually babied, and at the best will probably throw engine parts into the cowling sooner or later. No one has complete confidence in these engines. (b) It requires three times as long to get away on a rescue call as the Catalina--again mainly because of these engines. (c) It does not have the flexibility of the land cat in being able to go to an alternate field if the first choice is shut in. The choice of sea dromes is much more limited.

The data forwarded with this report may appear at some points not to be in support of the conclusions and some discrepancies will be noted between its various sections. This data was taken from readings of instruments, from observers' estimates, and some of the weather data was from the recorded observations of the Institute of Oceanography at La Jolla. Sometimes the observations of the oceanographers were made at a different time of the day from the tests and varied considerably from the actual conditions existing at the time of the tests. Sometimes the estimates of two observers differed widely, and a few of the memoranda records were lost or destroyed in handling and had to be reconstructed from memory, and one or two film records were lost in the photo lab. Lest individuals feel that their opinions were being influenced, no efforts have been made to make all the data consistent except that requests were made for the correction of glaring errors. It is believed that the weather data appearing on the recapitulation sheet (Section VI) is generally the most reliable.

Throughout this study a continuous effort has been made to keep the approach objective. All parties to this study have been constantly urged not to try to prove anything; but rather to question everything for validity, including all their own beliefs and earlier conclusions on the matters at issue. Readers are urged to study this report with the same challenging attitude.

SECTION IV

WIND, WAVES AND SWELL

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WIND, WAVES AND SWELL

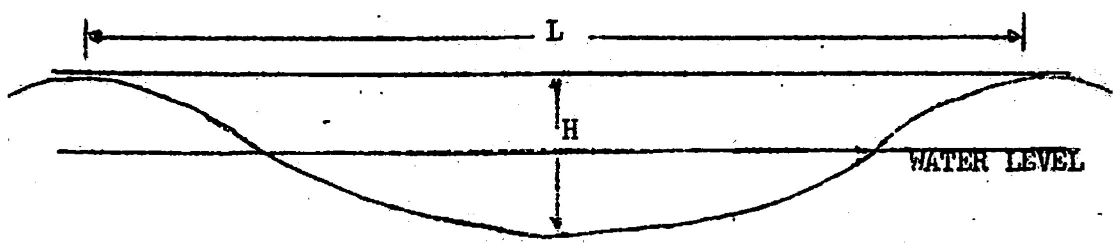
INTRODUCTION.

Some information on waves and swell was obtained from oceanographers of the Scripps Institute, University of California, and checks of the practical results of their formulae against carefully observed data suggest that they are, within the limitations specified by the oceanographer, very reliable. The oceanographers approach to this subject was very detailed and thorough and much of it is believed unnecessary and unsuitable to this discussion. It is emphasized that the data and the formulae given below are empirical; that some of these vary moderately in conclusion between authorities, and that all of this matter is based on limited observation.

DEFINITIONS.

A wave is described by its <u>length</u>, <u>L</u>, representing the horizontal distance from crest to crest or trough to trough (see Fig. 1A.), and by its <u>height</u>, <u>H</u>, representing the vertical distance from trough to crest. A wave is furthermore characterized by its <u>period</u>, <u>T</u>, representing the time interval which in one given locality elapses between the appearance of two consecutive crests.

Figure 1A.



Wind waves are waves which are growing in height under the influence of the wind.

Swells are waves generated by winds far away and which have advanced into regions of weaker winds or calms and are decreasing in height.

For a given velocity, the wave height becomes greater, the greater the stretch of water over which the wind has blown. This stretch is called the <u>fetch</u> of the wind and is represented by the letter, <u>F</u>.

By <u>energy of the wave</u> is always understood the average energy over one wave length. The energy is in part <u>potential</u>, E_p, associated with the displacement of the water particles above or below the level of equilibrium, and in part it is <u>kinetic</u>, E_k, associated with the motion of the particles. In surface waves half the energy is present as kinetic and half as potential. The <u>total</u> energy is $E = 1/8\ g\rho\ H^2$ where ρ is the density of the water, and g is the acceleration of gravity. For a 10 foot high wave the total energy is 800 foot-pounds per square foot.

During one wave period, T, the wave crest advances one wave length, DEFINITIONS. (Cont.)

L, and the velocity of the wave, C, is therefore defined as $C = \frac{L}{T}$.

A normal, well-formed ocean swell exhibits very consistent relationships between C in Knots, L in feet, and T in seconds. These can be described by the formulae $C = 3.03\,T$, $L = 5.12\,T^2$, $T = 0.33\,C$. It is unfortunate that no simple relationship exists between the foregoing factors and the height of a wave, however a general rule is that the ratio $\frac{H}{L}$ always remains less than $\frac{1}{7}$.

DISCUSSION.

Waves of relatively small heights can be represented by a sine curve. These are the waves with which we are here concerned. This discussion will deal with waves which appear as rhythmic and regular deformations of the surface.

As the height of a wave increases, the profile departs from the true sine curve to an approach to a trochoid. In the trochoid the troughs are flatter and the wave crests are narrower than in a sine wave. When waves of different heights and lengths are present simultaneously, the appearance of the free surface becomes very complicated because in some areas the waves may be opposite in phase and therefore eliminate each other; whereas in other regions they may coincide in phase and the wave heights may be added.

The wave pattern formed by interference shows groups of waves which reach the double height of the waves in the two trains and which are separated by regions in which the waves disappear completely. These groups advance with the velocity which is nearly equal to one half of the average velocity of the two wave systems.

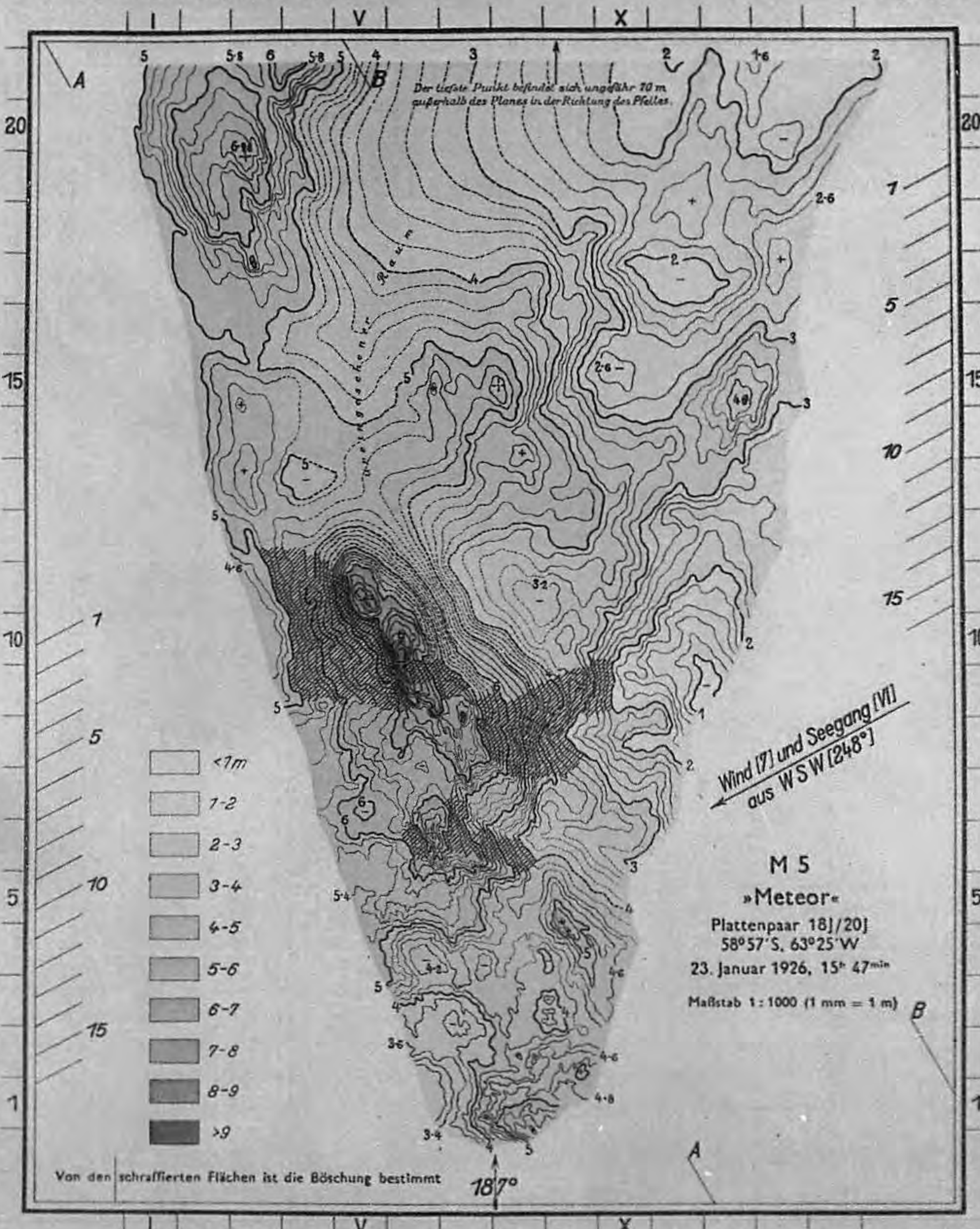
Because of interference, formation of short crested waves and breaking of waves, there is little regularity in the appearance of the sea surface, particularly when a strong wind blows.

Where short, high wind waves occur simultaneously with the long, low swell, the shorter, higher waves dominate to such an extent that the presence of the long swell is obscured.

White caps are formed by the breaking of relatively short waves usually appearing as riders on longer waves. Waves break when their steepness reaches the critical value $\frac{H}{L} = \frac{1}{7}$. Large waves may attain this steepness and may break if they are formed by interference. As a result of these processes--interference, formation of short-crested waves, and the breaking of waves--the instantaneous appearance of the sea's surface presents a highly complicated picture.

There appears to be a very definite relationship between the steepness of a wave and the ratio between the wave velocity and the wind velocity. Waves are steepest when the local wind is twice the velocity of the local swell or waves, and as the wave velocity increases or the wind decreases, the steepness of the waves lessens rapidly. When wind velocity and swell velocity are the same, the steepness of the wave, $\frac{H}{L}$, is approximately half as great as when the swell velocity is only half the wind velocity.

The pictures listed, following this sheet, illustrate the actual complexity of apparently normal seas. The German chart (Plates 18j/20j) was taken from a volume by Schumaker on the METEOR Expedition, 1925-27. The plates taken from the Japanese, marked 8A, 9A, 8B and 9B, are pairs of simultaneous single camera pictures and photogrammetric studies of the same seas and illustrate very well that a sea cannot be shown in its true character by a single camera. The Japanese pictures are from the REPORT OF THE OCEANOGRAPHICAL OBSERVATIONS MADE ON BOARD R.M.S. SYUNPU MARU IN THE KUROSIO REGIONS IN THE SUMMER OF 1933, 1934, 1935.



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Ausmessung: Photogrammetrie G.m.b.H., München

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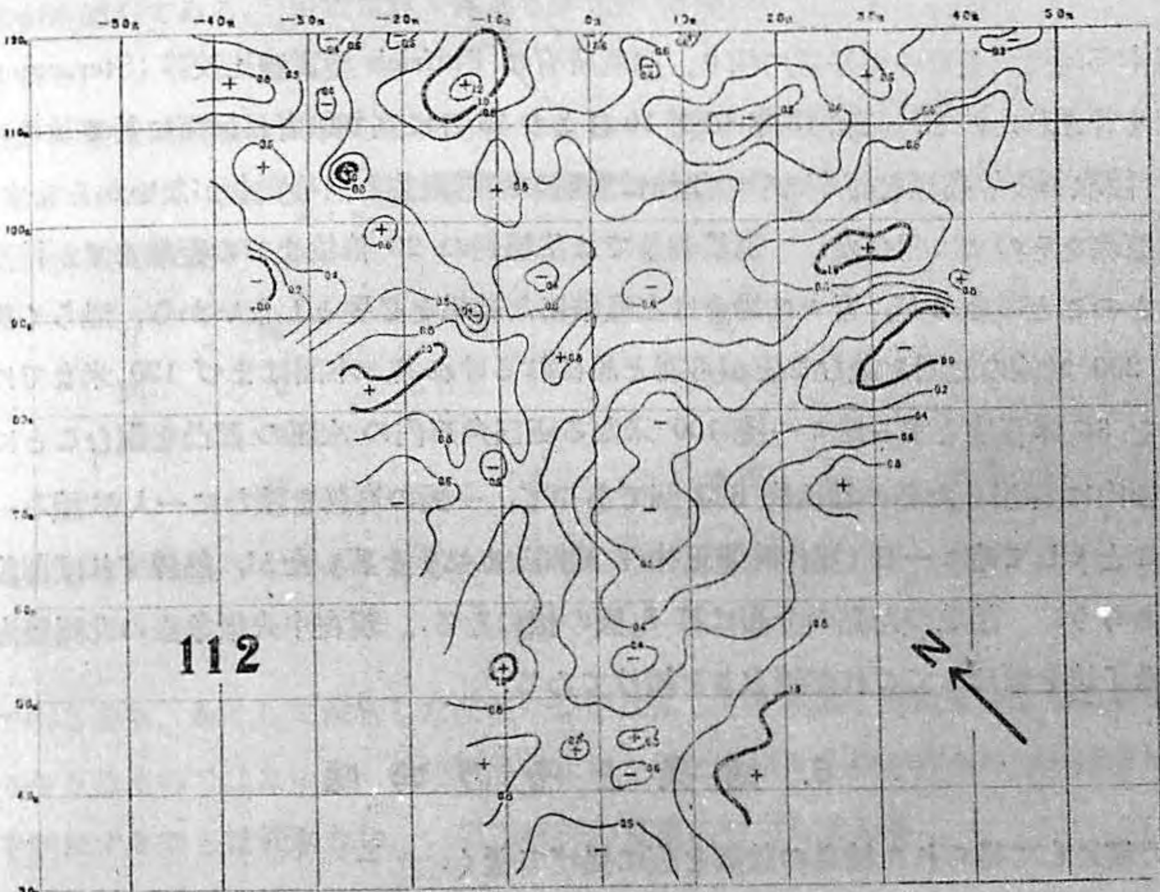
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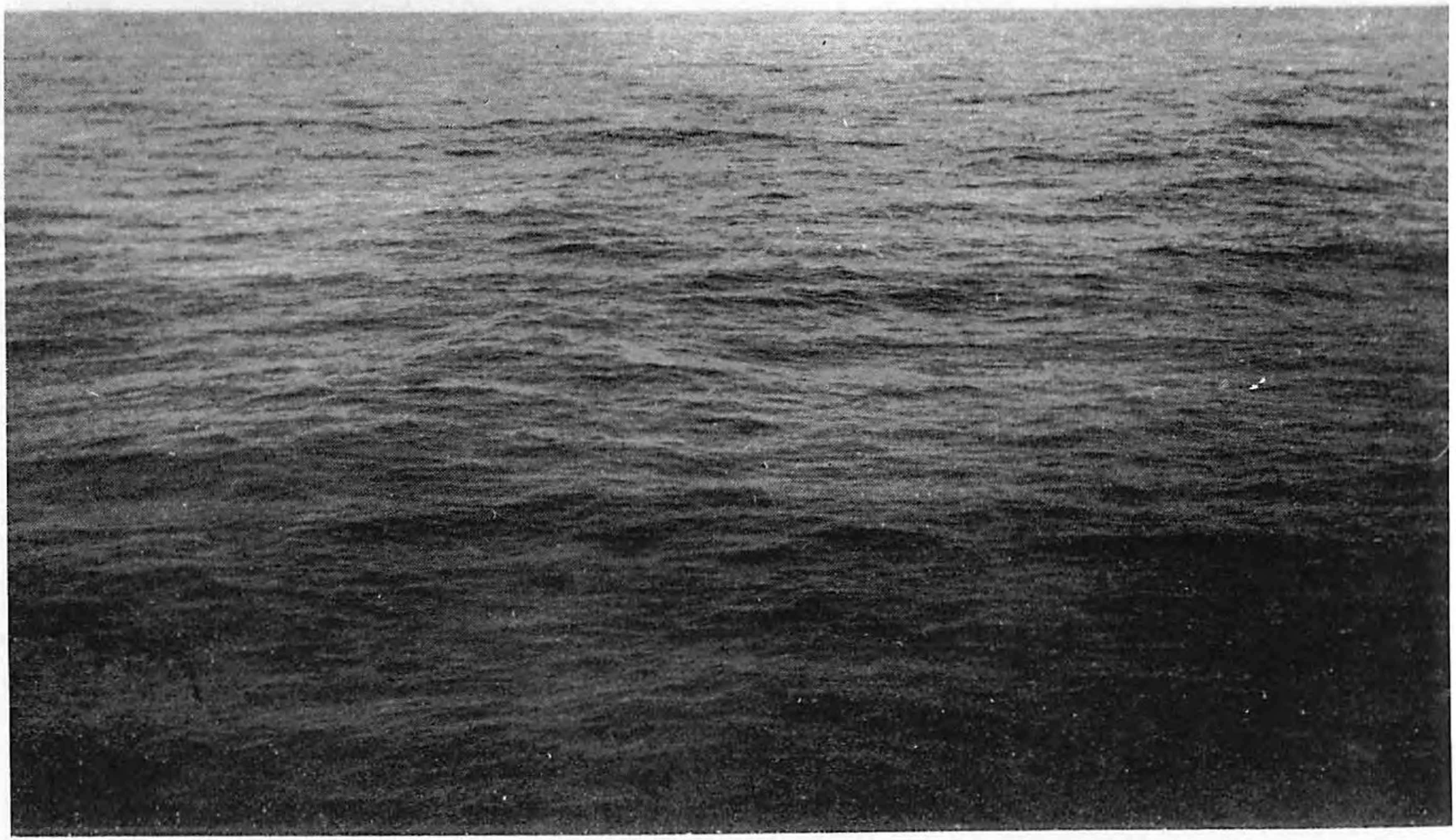
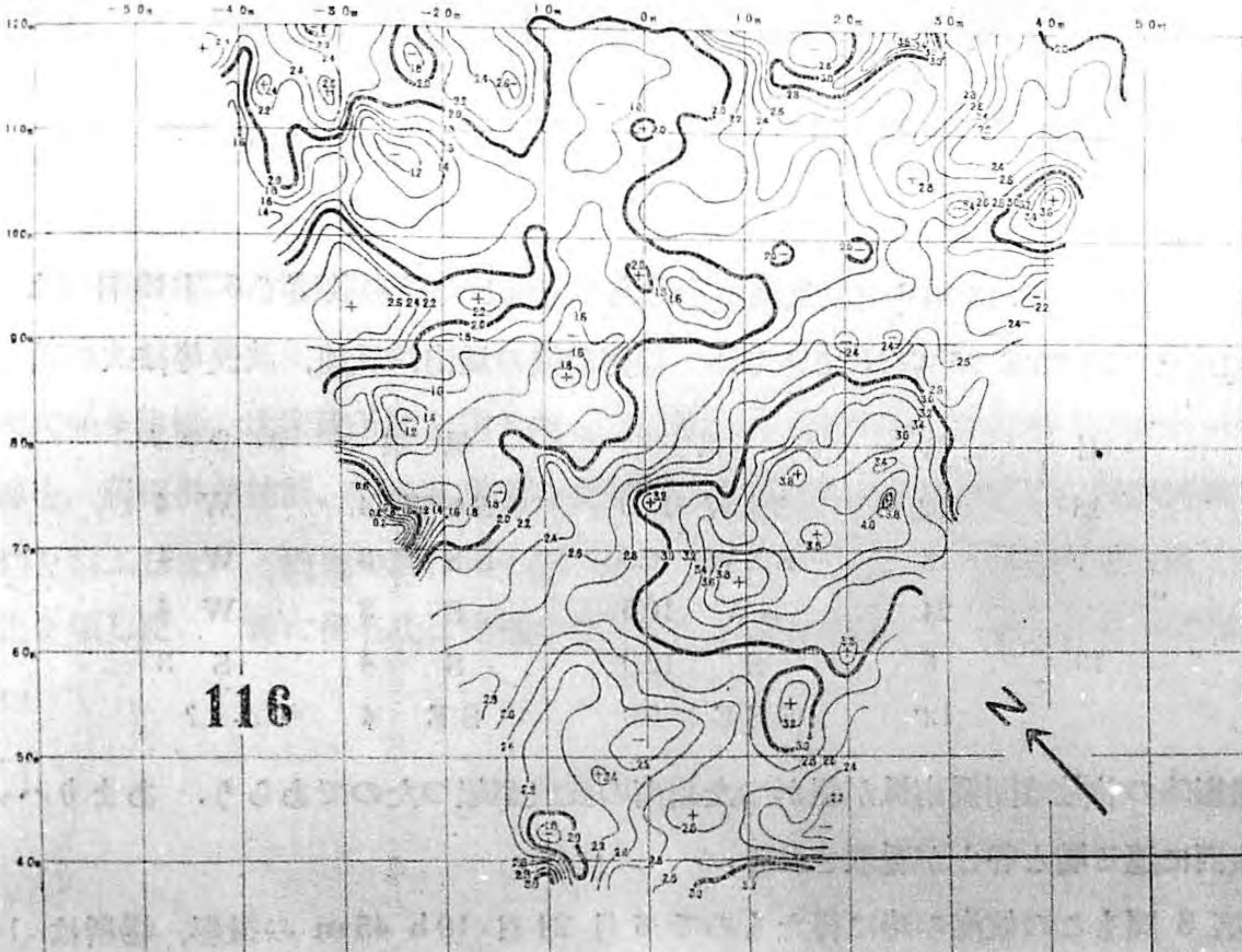
第 8 圖 A



第 8 圖 B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第 9 圖 A

第　9　圖　B

DISCUSSION. (Cont.)

The lengths of most waves and the heights of low waves are apt to be underestimated, while the heights of big waves are generally overestimated. Experienced and careful observers conclude that waves above 55' high are extremely rare, though literature contains many reports of waves exceeding 80' in height.

A strong wind can raise high waves in a short time. As an example, a wind of 32 knots may produce 20' high waves in 40 hours. A wave velocity has been observed to have doubled during 18 hours under a wind velocity of 22 knots. The effect of increasing wind velocity on wave steepness is obscure. Authorities are at issue on this subject. The steepness of a wave is governed rather by the stage of development of the wave than by the immediate wind velocity affecting it.

The height of the swell decreases as the swell advances.
Some authors claim that the period of the swell remains unaltered when the swell advances, whereas others claim that the period increases. The greater amount of evidence appears to favor the latter opinion.

In the type of waves under discussion here, the water particles move in vertical circles which may be likened to one of a great number of hoops advancing side by side with the upper profile of the swell forming the upper half of the hoop. Their radius is very roughly $\frac{H}{2}$. The particles complete one revolution in time, T. In an average ocean swell travelling at 30 knots, the velocity of the water particles in this rotation should nowhere exceed 2 knots, and consequently becomes a very small factor except that the vertical component will possibly change an airplane's rate of descent when flown on at say 200' per minute to a relative 300' per minute at the instant of contact. It should be noted, however, that this effect is present at only one instant when riding over a swell, and at all other times the vertical component of the force of these rotating water particles is changing through zero to a negative value so rapidly that it is unlikely to have much practical effect on an aircraft landing or taking off.

Plates 1 to 5 appended show certain relationships between wind velocity and fetch; wave height and period for a long and short fetch; the relationship between wave height and period, and wind velocity and duration; the decay of waves as affected by distance; and the effect of opposing or following winds on the height of a swell.

APPLICATION OF WAVE KNOWLEDGE BY THE PILOT.

There are many ways in which a knowledge of sea formation may be used by a pilot who is contemplating an open sea landing or take-off. To begin with, the final election for a landing direction in any sea, other than a smooth one completely without swell, is a compromise. The pilot desires to get on and stay on with the minimum of damage or to get off and stay off the same way. Where the wind is plainly very light, he should make his election independent of wind direction; but when the wind becomes fresh or strong, the problem grows complicated. Then it is rare that the sea conditions are due to only one simple wave system, and as indicated on the discussion on waves, frequent groups of waves will appear which are much greater than the average wave and similarly frequent other groups will appear which are much smaller than the average wave. This occurs because the heights of the waves when two wave systems are in phase are equal to the sum of the heights of the two systems and when two wave systems are in opposite phase, the crests of one system fill the troughs of the other system and the sea looks relatively smooth. A pilot can take advantage of this and if it isn't important for him to land at a particular point, he may be able to drag over the sea at a speed just above stall until such a smooth spot develops ahead of him and then drop on and run most of his way out before he hits a very hard wave.

A pilot contemplating a landing, who remembers that a locally formed moderate sea may almost completely conceal a large ocean swell beneath it, will save himself great embarrassment if in planning his landing he will also remember that the concealed ocean swell may be advancing at 30 or 40 knots, and that if he strikes such a swell at high speed very far from parallel to the advancing swell front, he may find himself planing off 20 or 30 feet into the air with no flying speed or control.

Pilots should remember that the lengths of waves and the heights of low waves are usually underestimated. A pilot should always assume that the sea beneath him is going to be much rougher than it appears from the air. Many pilots fear landings cross wind or parallel to the swell because they imagine that they are likely to waterloop or drag a wing tip float under or slide down the face of the swell out of control. The last image is no hazard at all. The first two are small hazards compared to that of slamming into the front of a 30 knot ocean swell out of control. So if a pilot will very carefully check the direction of the ocean swell while he is high enough so that he can see it (1,500 feet plus) and remember that if the wind is blowing he won't see this swell in his landing approach, he may still consider it and avoid serious trouble.

Every pilot knows the value of a lee. Some do not realize that a lee may be of considerable advantage up to 10 miles off. Here it should be remembered that ocean swells will often walk completely around small islands with very little apparent diminution.

Remembering that wind waves are growing in height, that a strong wind will raise high waves in a short time and that a wave velocity may double in less than 24 hours, and that the steepness of a wave is greatest when the wind velocity is twice that of a swell and decreases as the ratio decreases, a pilot may make a more intelligent decision as to whether to attempt a rescue immediately or possibly wait the arrival of a more seaworthy plane or surface ship.

Most pilots estimate surface winds on the sea with reasonable accuracy. To estimate the length of a swell and the speed with which that swell is advancing is much more difficult and generally very poorly done. By the use of the oceanographer's formula, length and speed of swells may be determined very well. A pilot may drop a Mark 4 smoke float, circle the smoke, call "Mark" as the smoke rises on a swell, count 5 or 6 times as swells pass under the smoke, and finally call "Mark" again as it rises on the crest. The co-pilot or radioman can give him the elapsed seconds. Dividing by the number of swells will give the period of the swell, T. C, the velocity of the swell in knots, equals 3.03 T in seconds. If T is 10 seconds, the velocity of the swell is approximately 30 knots. Also L, the distance between swells in feet, equals $5.12\ T^2$ or in this case approximately 500 feet. Without the use of the formula, the pilot will probably estimate the speed of the swell at 10 knots and the distance between swells at 100 feet.

Knowing that the swell is travelling 30 knots and that the wind is from the same direction at 10 knots, we may quickly calculate that a landing into wind and swell if stalled on at 65 knots will give us a relative speed over the swells of 85 knots. In contrast, a landing down wind and down swell under the same conditions will give us a landing speed over the swells of 45 knots. Manifestly, in the down swell landing we are going to tend to plane off on swells much less than on the up swell landing.

After careful study here of the factors in a rough sea which endanger an aircraft landing or taking off, it has been concluded, though without mathematical proof, that almost the entire force from a moving sea that throws the aircraft into the air against the wishes of the pilot is caused by the planing effect of the aircraft running up the front or back of the swell, and tending to continue in that direction from the top of the swell until pulled down by gravity. This effect is analogous to that which causes a land plane to be thrown into the air when it rolls down a smooth landing strip and strikes a long dip or bump in the strip.

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The material presented above was prepared in the main from a manuscript on "Principles in Forecasting Wind, Waves and Swell", prepared for the Hydrographic Office, U. S. Navy, by The U. S. Navy Project, at The Scripps Institution of Oceanography, University of California, La Jolla, California. That institution did not proof read the material presented above and is not responsible for errors. Anyone interested in further study of this subject is referred to the publication mentioned above and the following additional references:

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Ocean waves and kindred geophysical phenomena. Cambridge, England, Cambridge University Press. 1934.
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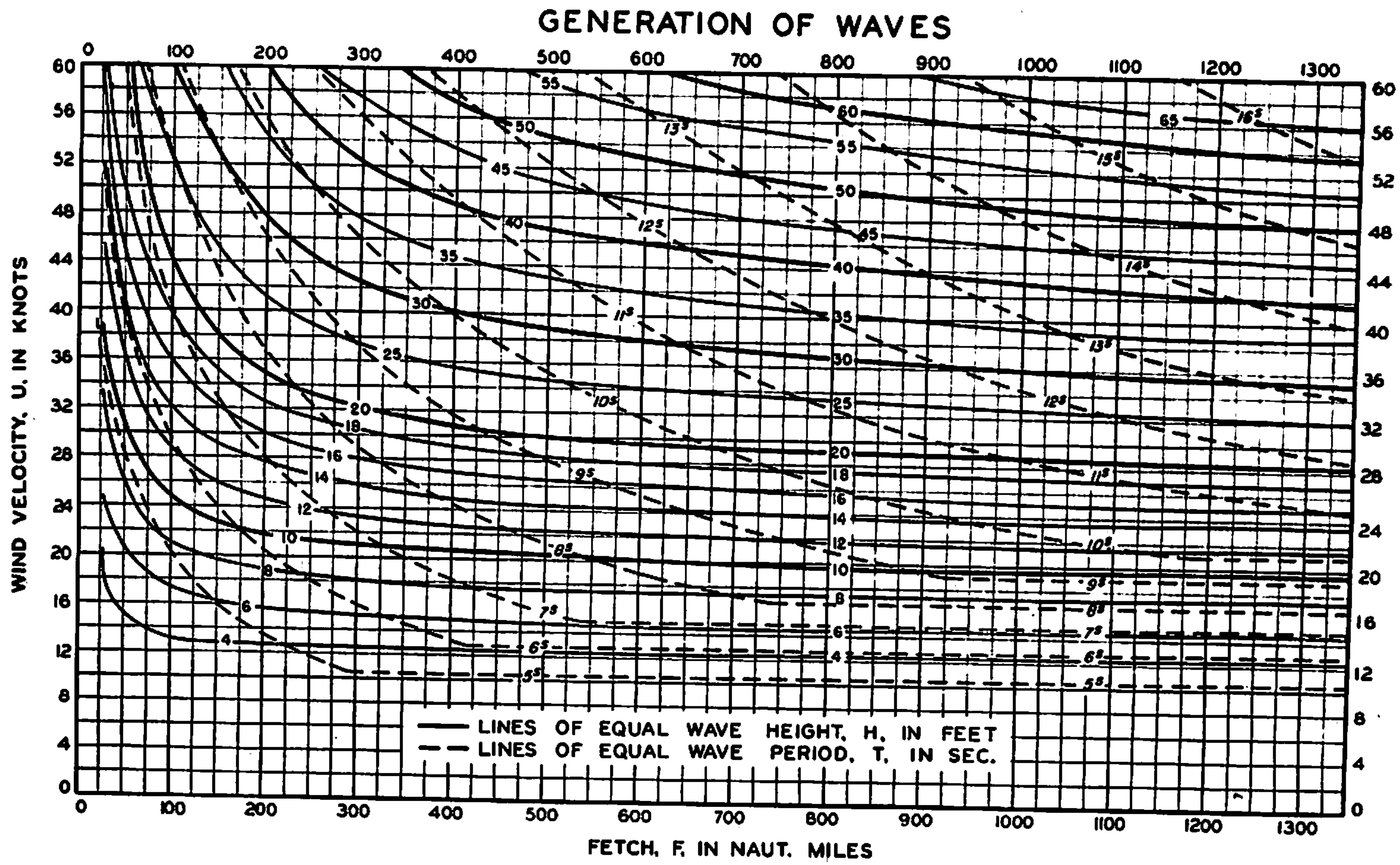


Plate I. Growth of wind waves. Wave height and wave period as functions of wind velocity and fetch.

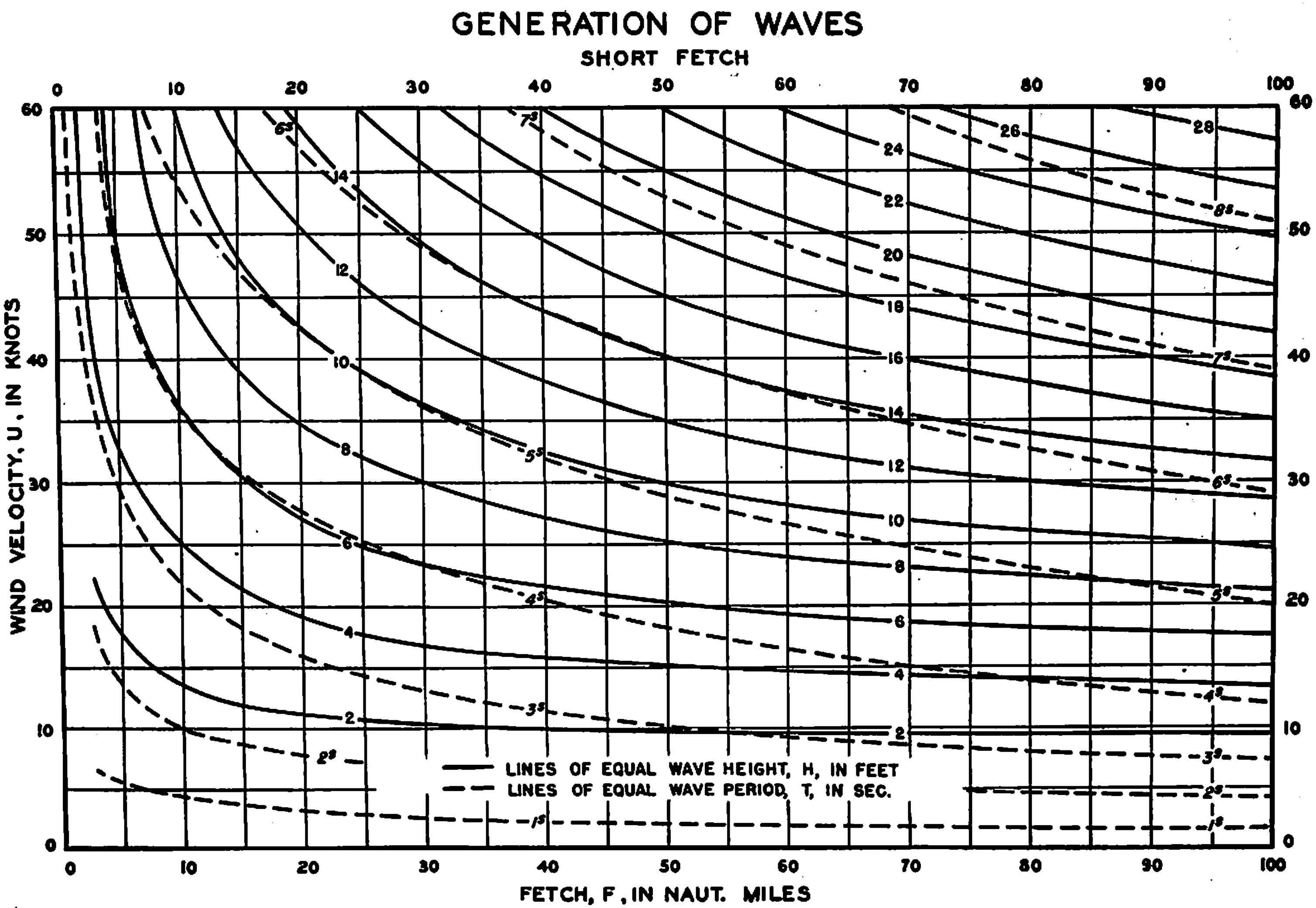


Plate 2. Growth of wind waves. Wave height and wave period as functions of wind velocity and short fetch.

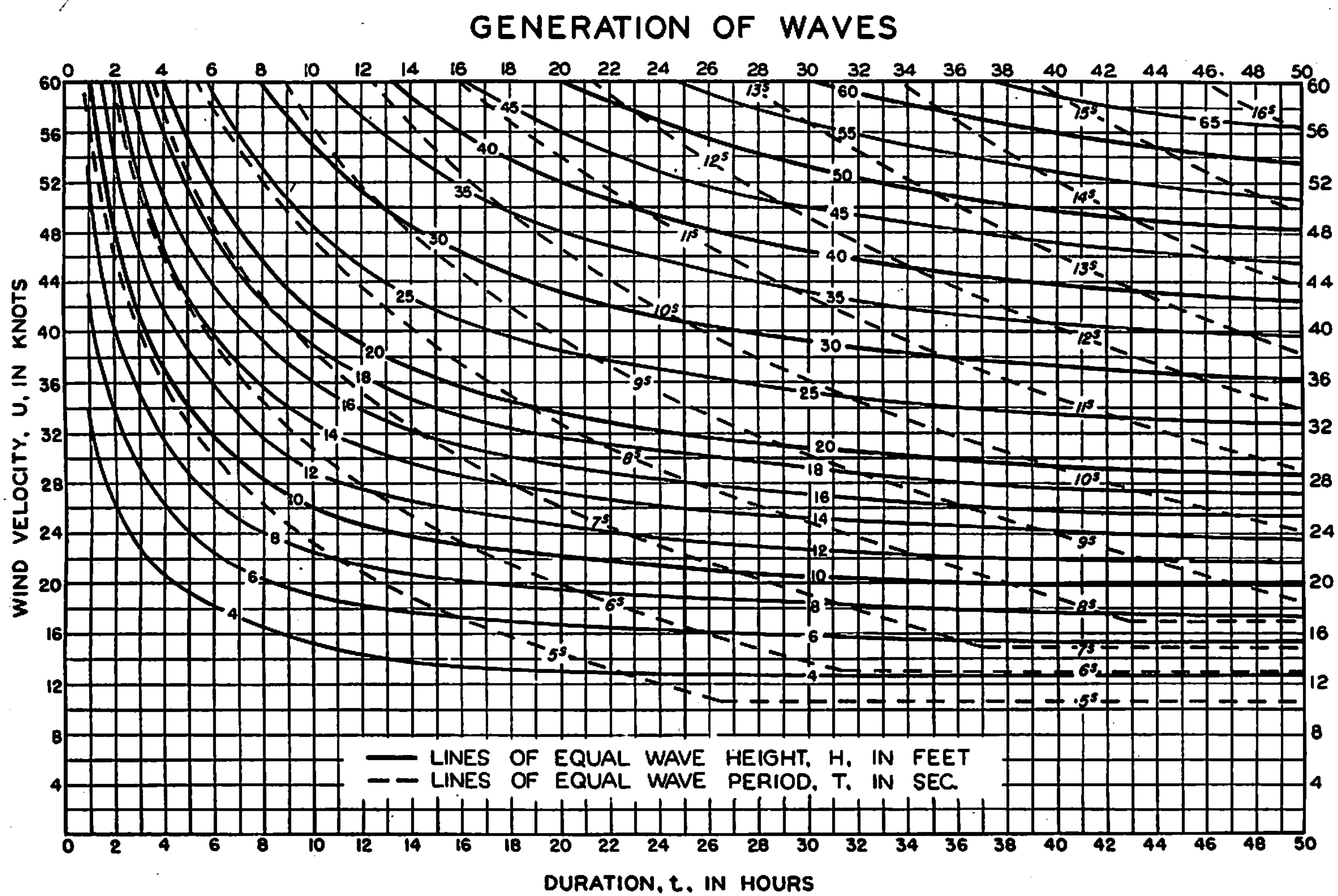


Plate 3. Growth of wind waves. Wave height and wave period as functions of wind velocity and duration of wind.

DECAY OF WAVES

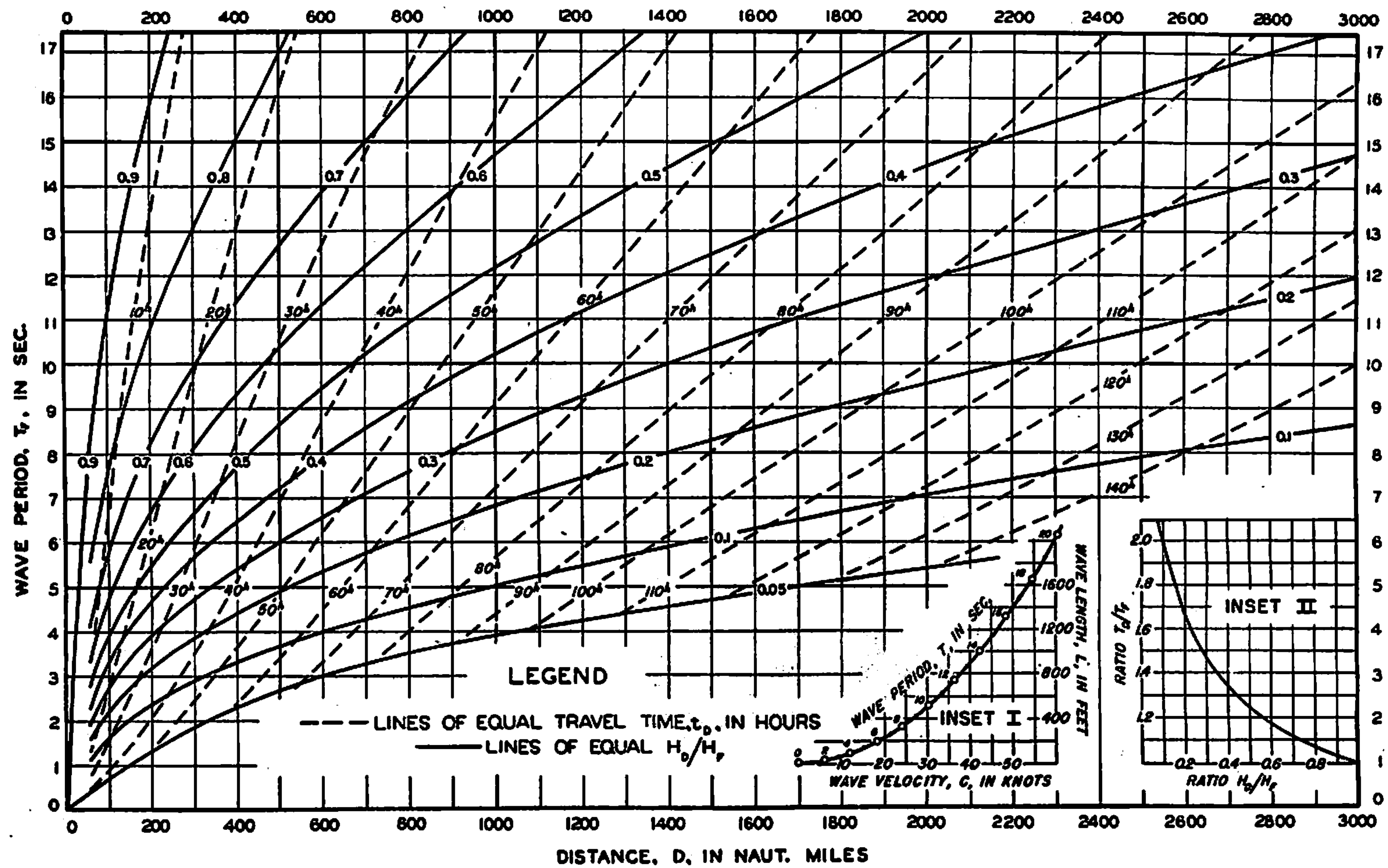


Plate 4. Decay of waves. Ratio between wave height at end of distance and decay, H_D, and at end of fetch as functions of wave period at end of fetch and distance of decay.

Inset I. Wave velocity and length for different periods.

Inset II. Ratio between period at end of distance of distance of decay, T_D, and period at end of fetch, T_F, as function of ratio H_D/H_F.

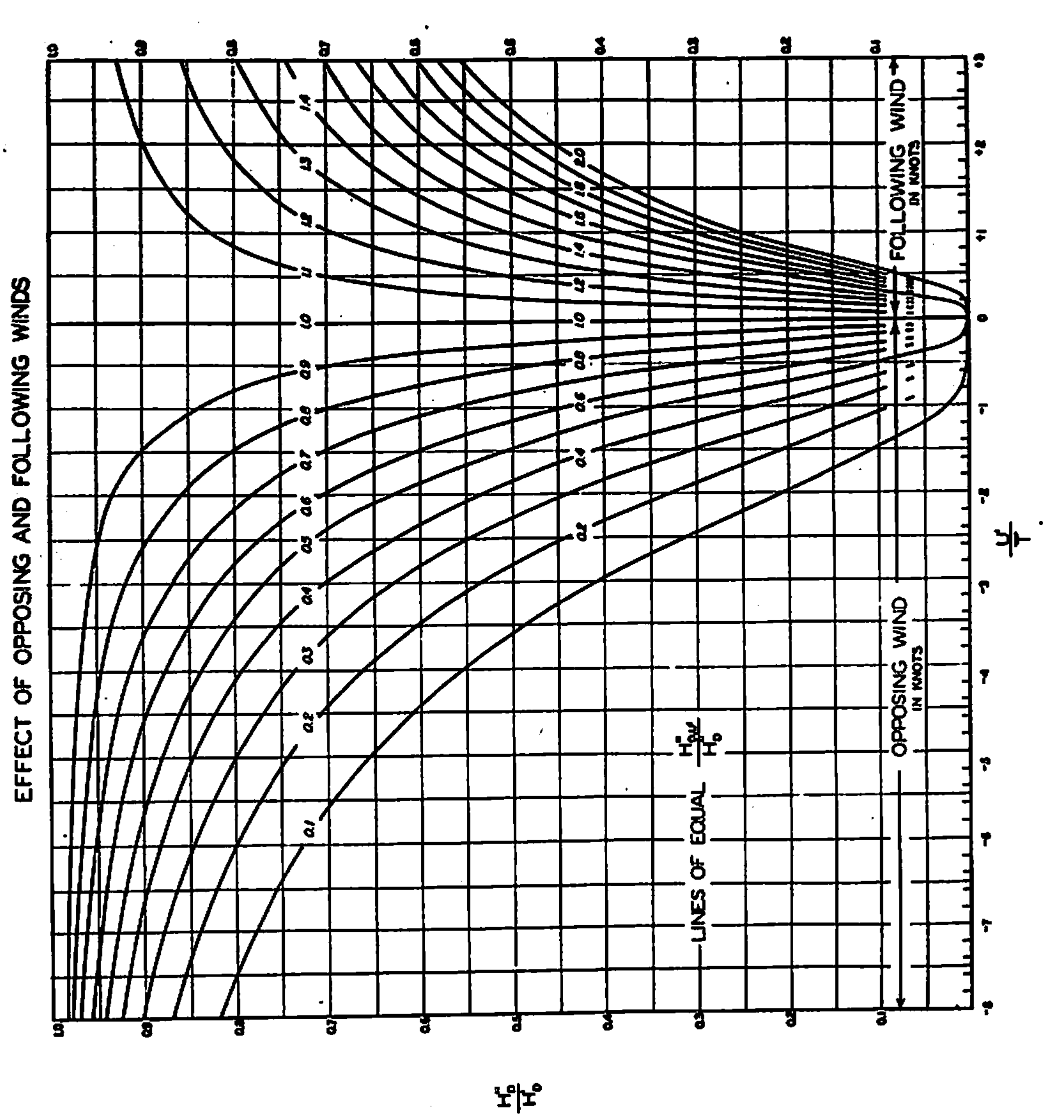


Plate 5. Change in height of swell due to opposing or following winds.

SECTION V

DAMAGES ENCOUNTERED

INCLUDING PILOT'S STATEMENTS

SECTION V

Take-Off, 2 December, 1944

Pilot's Statement

Pictures of Damages

No. 489-A Wrinkling of skin at hull station #239, top, aft of radar hut, outside view.

No. 489-C Wrinkling of skin at hull station #239, top, aft of radar hut, inside view.

No. 489-F Wrinkles in leading edge wing to hull facing left side of hull, top view.

PILOT'S REPORT OF TAKE-OFF WHICH DAMAGED PBM-3C, BUNO 6586,

2 DECEMBER, 1944, OFF POINT LOMA, CALIFORNIA

The local sea was between 5 and 8 feet from the West travelling at 25 knots. The Pacific swell beneath was estimated at 3 feet travelling at 30 knots, also from the West. The wind force was 15 knots from the West. The take-off was planned to be made down wind down swell using jets if necessary. The gross weight of the airplane was 43,000 pounds. The center of gravity was at 31.9% M.A.C. The take-off run was started by first taxiing fast on an easterly heading, holding the nose high and throttling back as necessary to avoid planing off on a swell. At the top of one swell, the throttles were advanced to 43 inches. The flaps were already down full. The local sea was too short to drag the airplane off on the first bounce. She fell back on hard on the back of a swell. The pilot called for the jets. The co-pilot threw the jet switches, but the back of his hand hit the switch again inadvertently the next instant and cut the jets off. Due to a misunderstanding between pilot and co-pilot as to when the co-pilot took the throttles, the co-pilot did not check the throttle setting and the pilot was at this point giving his entire attention to the yoke and rudder and the sea which was quite difficult. The airplane struck 3 or more successive swells before the pilot was able to drag it off at very low air speed. The airplane then staggered along just off the water barely holding its own for approximately 20 seconds before it fell on again. About 3 seconds before it fell on the last time, the pilot observed that the manifold pressures were back to 37 inches and promptly advanced them to 43 inches. The airplane still struck very hard on the back of this swell and then flew away very handily.

One jet was torn loose from its fitting in this pounding take-off which took a total of 70 seconds, and during the long run overtook the sea where the 5 to 8 foot local waves were in phase with the 3 foot Pacific swell underneath, resulting in a very rough sea.

Lateral and longitudinal controllability were good throughout this take-off, but required radical use of elevators and ailerons.

The accelerometers registered $8\frac{1}{2}$ g. The plane suffered oil canning in the wing root fillet and a crack in the crown skin just aft of the radome. The plane was flown into the harbor and landed with one jet unit dangling, but without difficulty.

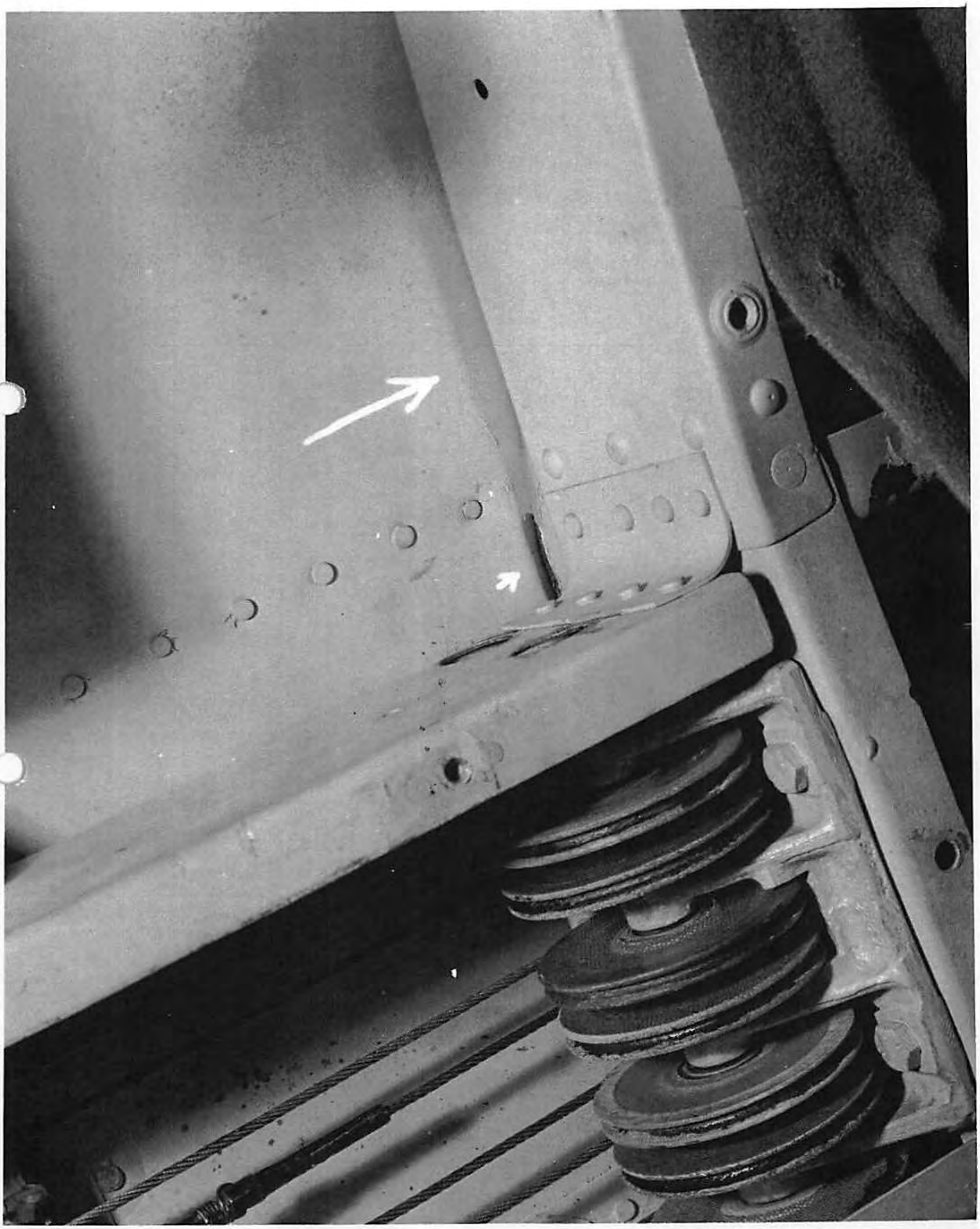
It is believed the entire trouble assessment on this take-off should be assigned to pilot error.

D. B. MACDIARMID
Comdr., USCG

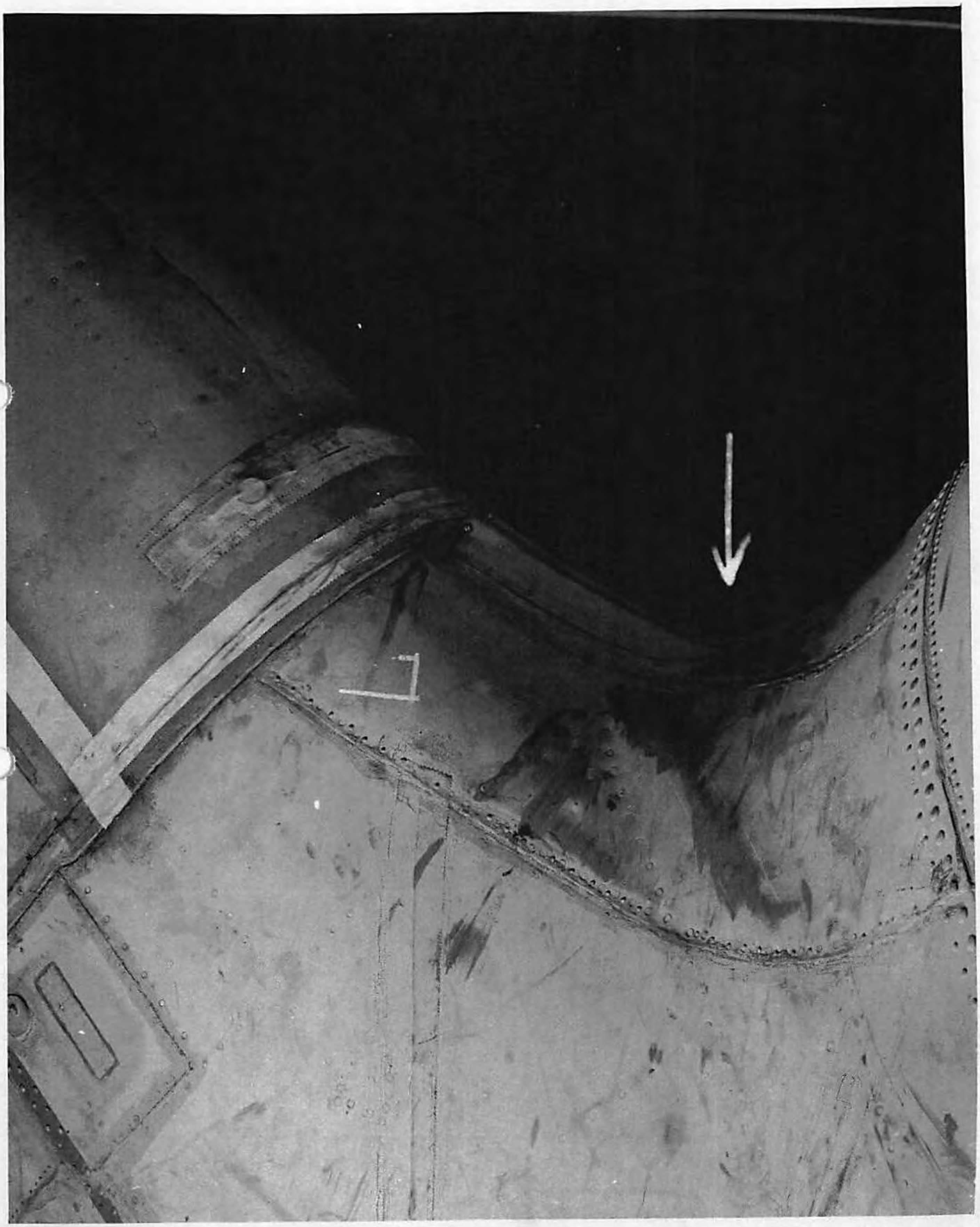
No. 489-A Wrinkling of skin at hull station #239, top, aft of radar hut, outside view.

139.

No. 489-C Wrinkling of skin at hull station #239, top, aft of radar hut, inside view.



No. 489-F Wrinkles in leading edge wing to hull facing left side of hull, top view.



Landing, 14 December, 1944

Pilot's Statement

Pictures of Damages

No. 486-D Outboard side of left bomb bay-fore and aft diagonal compression member of support assembly, engine mount part #162 C 12496, showing damage (in mirror) spreading between units.

No. 486-E Outboard side of right bomb bay-fore and aft diagonal compression member of support assembly, engine mount part #162 C 12495, showing "no damage" (in mirror).

No. 517-A Outboard side of left bomb bay fore and aft diagonal compression member of support assembly, engine part #162 C 12495 showing spreading at upper end between rivets.

PILOT'S REPORT OF LANDING WHICH DAMAGED PBM-3C, BUNO 6586,

14 DECEMBER, 1944, OFF POINT ARGUELLO, CALIFORNIA

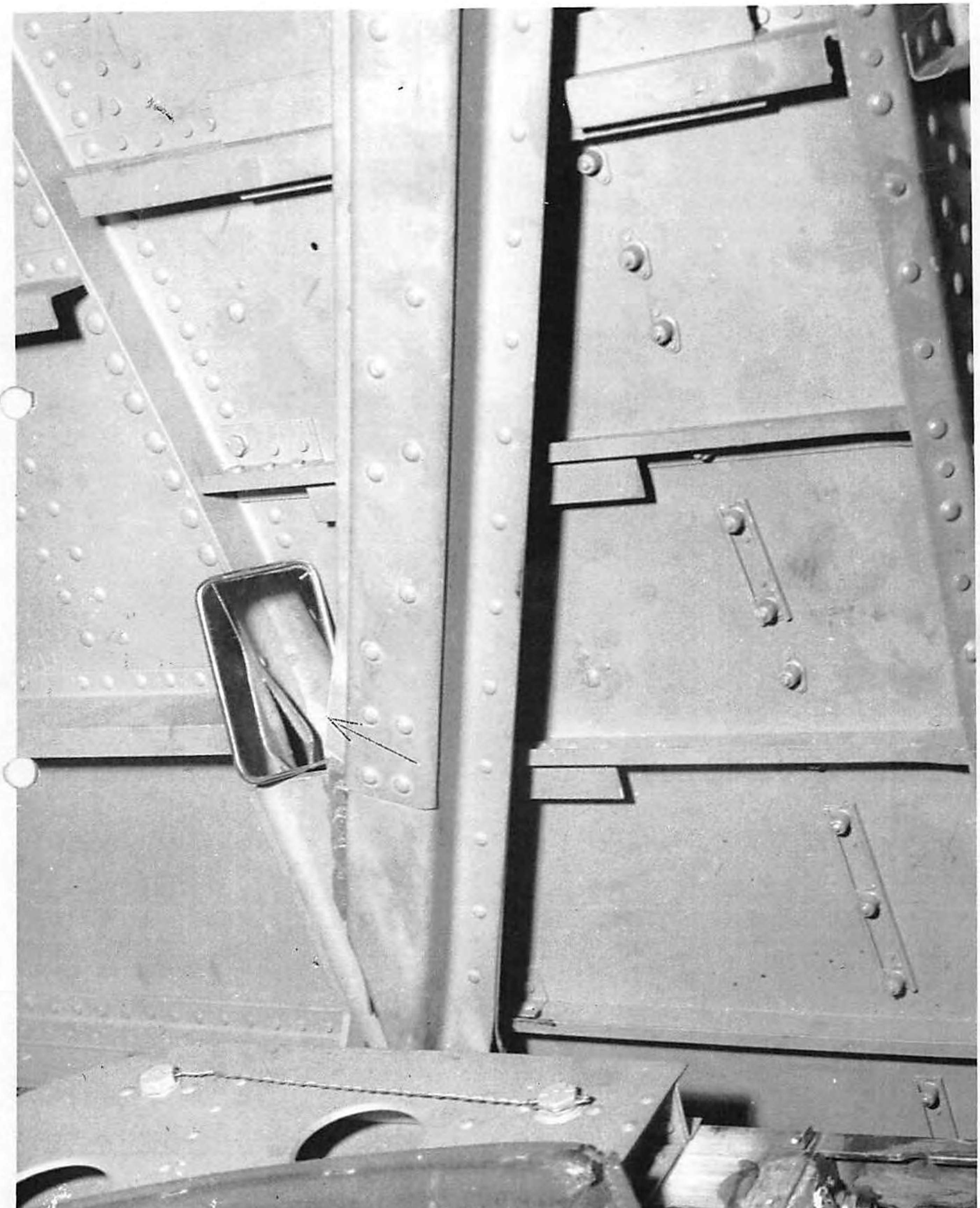
The local sea consisted of a 6 foot, 25 knot swell from the Northwest overriding a 4 foot, 48 knot Pacific ground swell from the West. The landing was made into the slower swell with a 4 knot wind at about 195° relative. The distance between crests of the shorter swell was 320 feet and between the crests of the longer swell, 1,280 feet. The landing was dragged in and the airplane was stalled on about 20 feet past the crest of a swell. The swells appeared to be coming at the plane at a very fast rate which gave the illusion that they were very close together. Because of the pilot's fear of thrusting the plane's nose against the face of one of these swells, the nose was held high throughout the landing. The plane showed no tendency to drop either wing or nose, but bounced about four times. Two of these bounces were very hard. The bow accelerometer registered 5½ g. The gross weight of the airplane was 43,300 pounds, and the center of gravity was at 31.5% M.A.C. Post flight inspection of the airplane disclosed that the aluminum alloy hat section flanges which stiffen the wing at the engine mount had been deformed by compression.

Two attempts were made to take off from this sea on this same heading and given up because the plane was thrown about so at low speed that the pilot could not control it. A take-off was then made down swell without jets and was accomplished very easily.

The damage to this aircraft is believed attributable half to the sea conditions and half to pilot technique. If the nose had been held lower at each instant when the aircraft planed off a swell, it would have had less tendency to plane high and consequently would not have fallen so far coming back on. The nose low landing technique had not been tried at this stage.

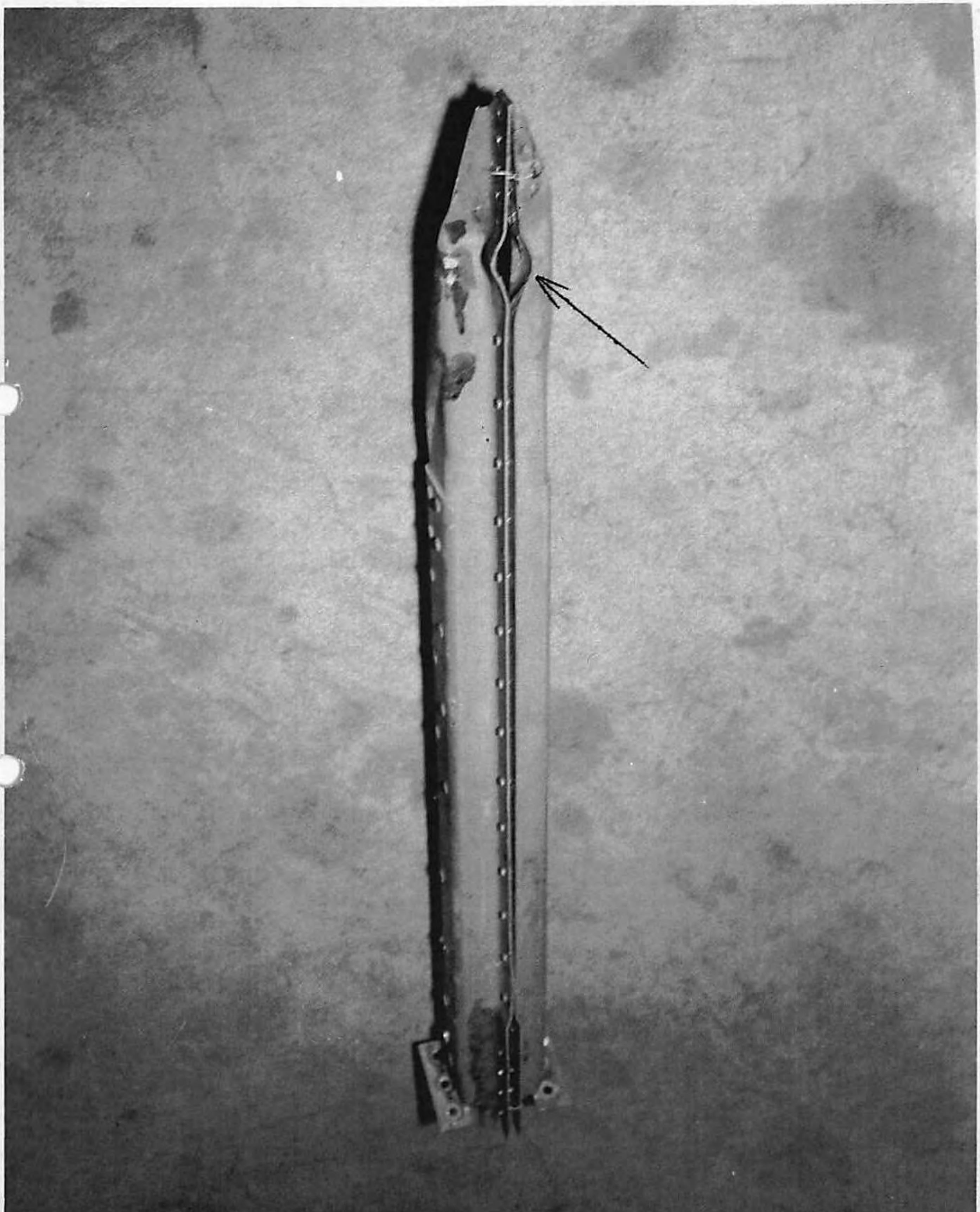
D. B. MACDIARMID
Comdr., USCG

No. 486-D Outboard side of left bomb bay fore and aft diagonal compression member of support assembly, engine mount part #162 C 12496, showing damage (in mirror) spreading between units.



No. 486-E Outboard side of right bomb bay fore and aft diagonal compression member of support assembly, engine mount part #162 C 12495, showing "no damage" (in mirror).

No. 517-A Outboard side of left bomb bay fore and aft diagonal compression member of support assembly, engine part #162 C 12495 showing spreading at upper end between rivets.



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Landing, 6 January, 1945

Pilot's Statement

Pictures of Damages

No. 527-B Forward "A" frame suspension showing damage. This JATO bottle remained suspended by this support.

No. 527-D Part of forward "A" frame suspension, that remained in mount after JATO bottle was lost.

No. 530 Left side chine wrinkled for a distance of 7' 9" forward from main step.

PILOT'S REPORT OF LANDING WHICH DAMAGED PBM-3C, BUNO 6586,

6 JANUARY, 1945, OFF SANTA CRUZ, CALIFORNIA

The ceiling was too low to permit a study of the ground swell. The local sea was short and relatively high. These seas were curving from the West around Point Carrington, and appeared to be more like rips than like a true deep water sea. The sea was 7 feet high, advancing at 19 knots from the West. The wind was from the West, 4 knots. This landing was made down swell down wind. The plane was dropped on full stall at 60 knots about 10 feet past the crest of a swell. The plane made one easy skip and then rode along on the water for a considerable way when it planed off about 6 feet high. When the airplane settled on again, it hit the back of a small swell very hard and planed off again as high or higher than before. The airplane fell on the third time very hard at a speed of about 47 knots and stayed on. The landing was made with the nose held high throughout. On either the next to the last or the last touch down, the port jet unit was torn completely out of its fittings and lost. The starboard unit was torn loose at one end and swung below the beaver tail like a pendulum. The plane was taxied to sheltered water where the swinging unit was removed and the plane was inspected. There were no signs of failure in the engine mount supports or wing attachment fitting or the hull generally, so it was flown home. Post flight inspection disclosed that the hull was damaged along the chine which was wrinkled on the port side a distance of 7 feet, 9 inches from the main step forward. 24 rivets were weeping. Three stringers on the left side of the keel forward of the step were slightly bent.

Both the NACA landing analyzer and one accelerometer indicated over 11 g. for this landing.

The gross weight of the airplane was 43,400 pounds, and the center of gravity was at 30.8% M.A.C.

The airplane appeared controllable practically throughout this landing. Similar landings made in the past had been very easy, and the pilot could not understand why this airplane kept planing up. The damage received on this landing is believed attributable to the presence of a ground swell underneath the local sea which could not be detected at low altitude.

D. B. MACDIARMID
Comdr., USCG

No. 527-B Forward "A" frame suspension showing damage. This JATO bottle remained suspended by this support.

No. 527-D Part of forward "A" frame suspension, that remained in mount after JATO bottle was lost.

No. 530 Left side chine wrinkled for a distance of 7' 9"
forward from main step.

Landing, 20 January, 1945

Pilot's Statement

Pictures of Damages

No. 539-C Damage to right inboard flap showing damage to trailing edge, inboard end, from striking hull after outboard hinge damage.

No. 539-D Damage to chine and bottom, right side of right float forward of step.

No. 545-A Outboard (Movable) hinge of right inboard flap showing bend. Center line shown to indicate amount of bend.

No. 545-B Torque tube (View #1) right inboard flap showing spread of torque tube lever arm. Collar due to rivet shear.

No. 545-C Outboard (Fixed) hinge of right inboard flap, showing bend in bearing end. Center line shown to indicate amount of bend.

No. 545-D Torque tube (View #2) right inboard flap showing missing rivet and spread torque tube lever arm collar.

No. 545-E Damage to flap control rod, right inboard flap, showing failures.

PILOT'S REPORT OF LANDING WHICH DAMAGED PBM-3C, BUNO 6586,

20 JANUARY, 1945, OFF POINT LOMA, CALIFORNIA

The local sea was a relatively short 10 foot sea moving from the West at 24 knots. The wind was blowing 16 knots from about 20° to the right of the sea and was causing a cross chop about 2 feet high with occasional breaks on the crests. The landing was made parallel to the swell with the wind on the port bow.

The gross weight of the airplane was 43,000 pounds, the center of gravity was at 30.8% M.A.C.

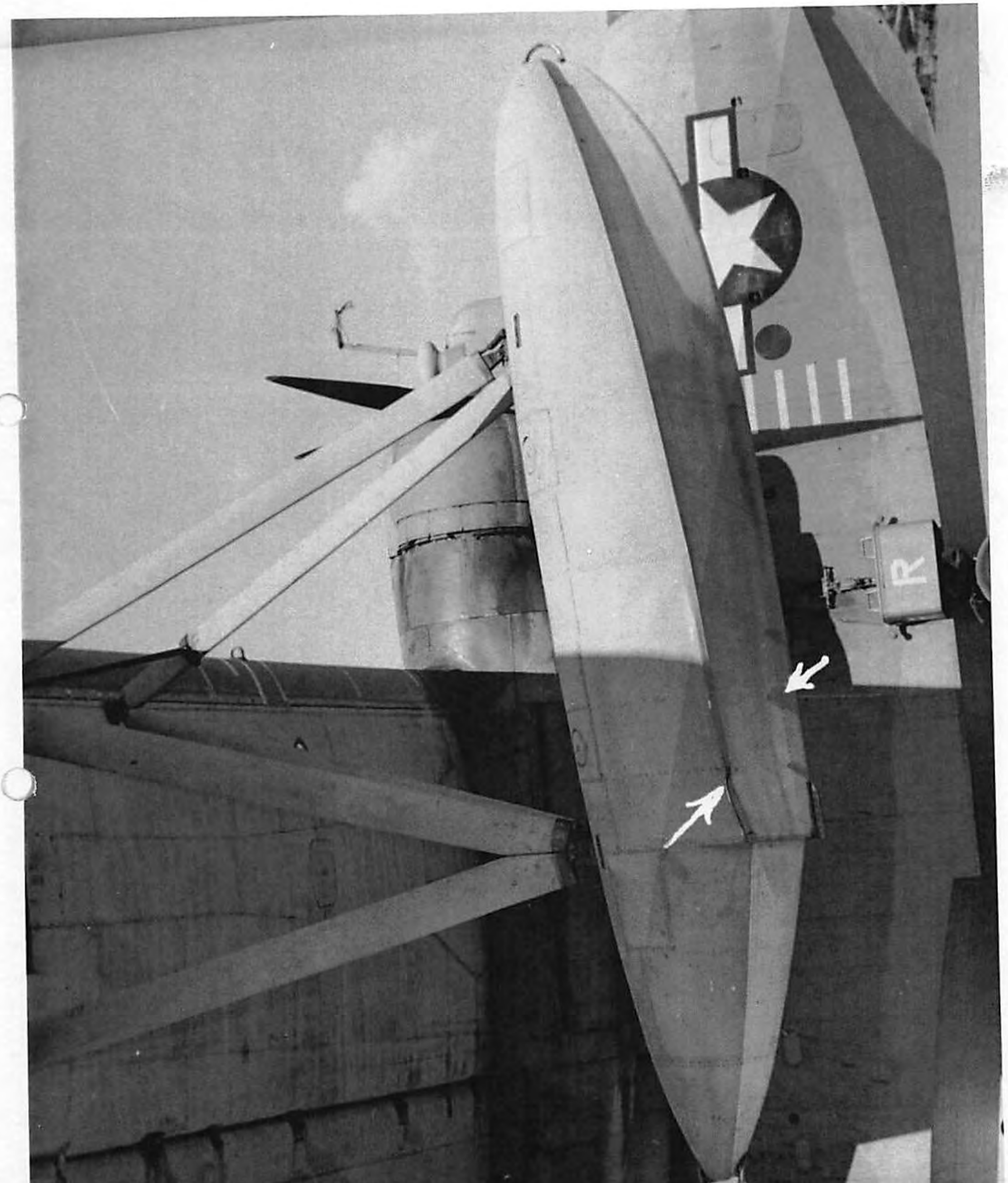
A full stall landing was made at 63 knots. The plane stayed on for a short time before planing off to about 3 feet. While in the air, the plane drifted to the right slowly, but not as fast as the sea, and settled on again falling into the trough at such an attitude that the 10 foot sea with the 2 foot chop on top of it was able to reach up and strike the right flap and wing tip float. At the instant of this contact, the right wing was slightly lower. The low right wing could have been due to the left float planing a bit as the plane went off, or it could have been due to slow pilot reaction. Lateral control at the time was as good as could be expected under the circumstances. The plane hit with a jolting shock which wasn't felt in the cockpit as especially severe, but which registered 9.3 g. in the bow, 6 g. at the center of gravity, and 5 and 4 g. respectively at the step and tail. The starboard jet unit was torn loose from its fastenings at one end. The plane was taxied home. Turning and running quartering down this sea was very difficult and it is possible that the starboard float was damaged in this maneuver.

Post flight inspection revealed that the right wing float was dished in on the outboard side, buckling three frames. The right flap was bent and pushed inboard, damaging the skin and two frames. This type of sea is believed very nearly the practical limitation for the airplane, and the damage would very likely be worse on any other type of landing.

D. B. MACDIARMID
Comdr., USCG

No. 539-C Damage to right inboard flap showing damage to trailing edge, inboard end, from striking hull after outboard hinge damage.

No. 539-D Damage to chine and bottom, right side of right float forward of step.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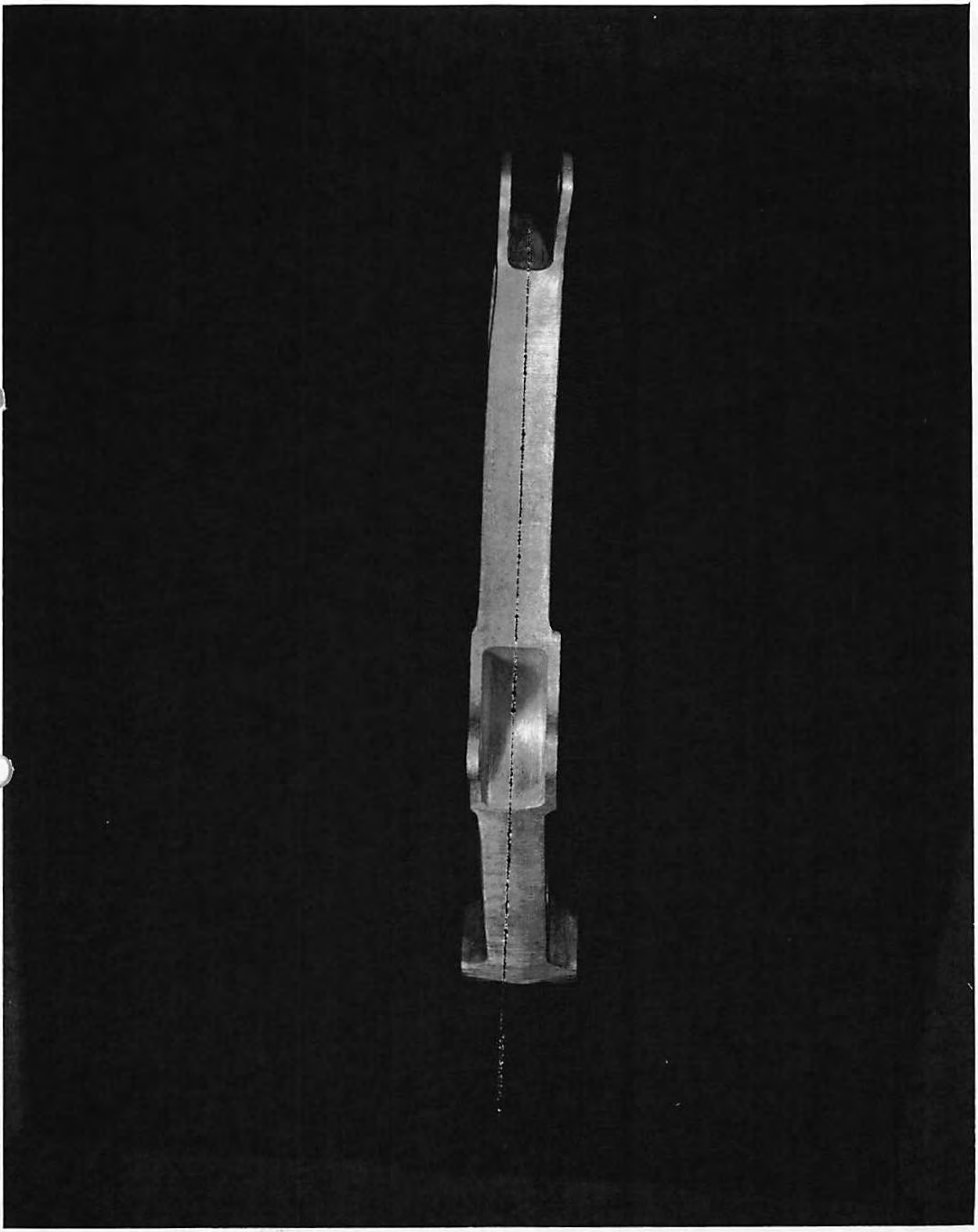
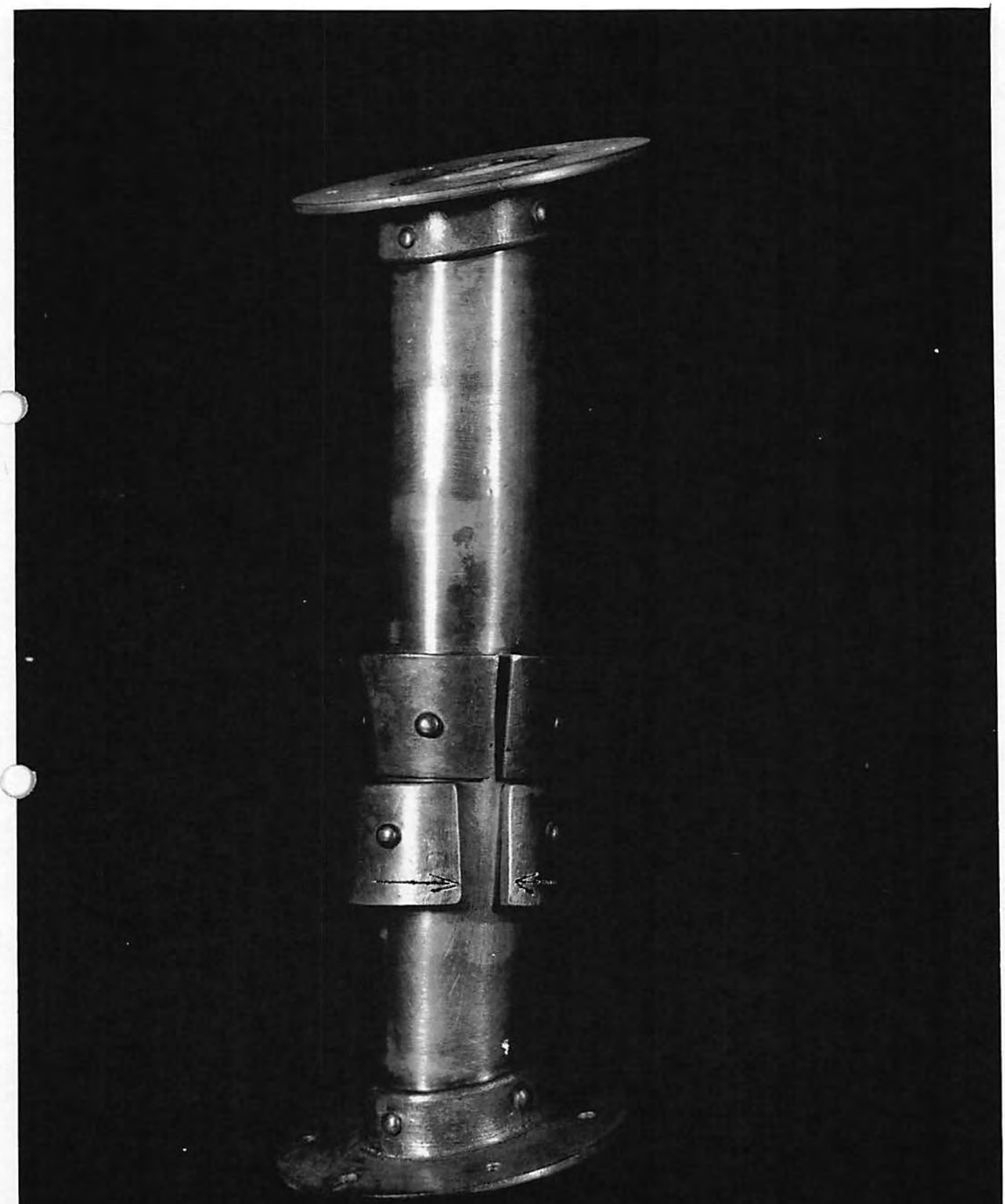
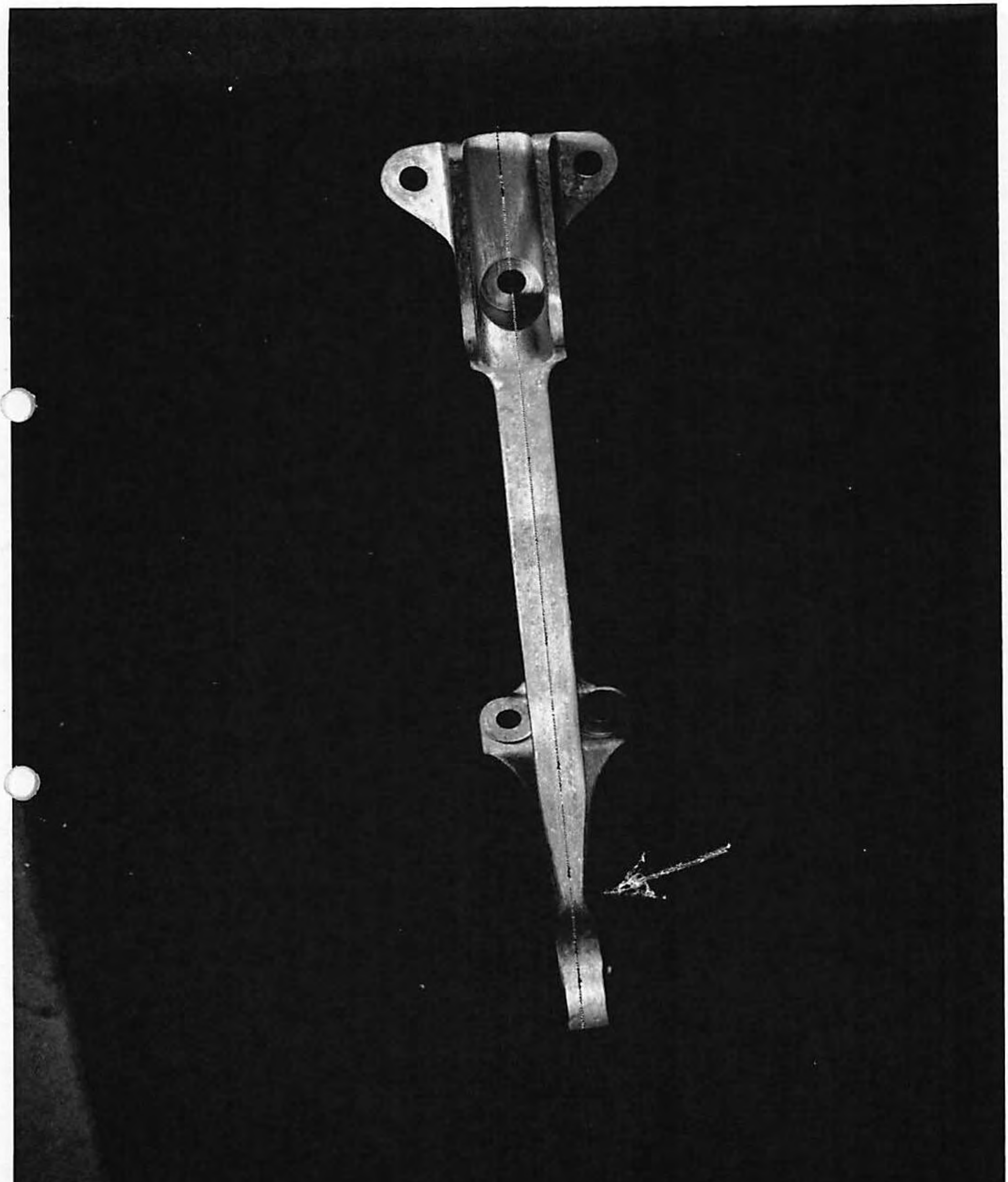
No. 545-A Outboard (Movable) hinge of right inboard flap showing bend. Center line shown to indicate amount of bend.



No. 545-B Torque tube (View #1) right inboard flap showing spread of torque tube lever arm. Collar due to rivet shear.



No. 545-C Outboard (Fixed) hinge of right inboard flap, showing bend in bearing end. Center line shown to indicate amount of bend.



No. 545-D Torque tube (View #2) right inboard flap showing missing rivet and spread torque tube lever arm collar.

No. 545-E Damage to flap control rod, right inboard flap, showing failures.

No. 571 JATO bottle showing reinforced "A" frame and added rod to prevent spreading of suspension points.

No. 572 After suspension hooks of JATO mount showing holes drilled for bolting unit in place. (Unit not droppable when bolted.)

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SECTION VI
RECAPITULATION OF OPEN SEA LANDING TESTS

DATE	SWELL DIR. SPEED & HT.	WIND DIR. & VEL.	GROSS WEIGHT	C. of G. % M.A.C.	PILOT	CO-PILOT	PLACE	NO. OF LANDINGS	JET TAKE-OFFS
17 Nov.	W 5 Kn 8'	NW 5 Kn	42,300	28.8	MACDIARMID	WALL	Pt. Loma	2	
18 Nov.	W 15 Kn 10'	W 10 Kn	43,000	30.1	MACDIARMID	WEED	Pt. Loma	3	
19 Nov.	W 15 Kn 11'	W 10 Kn	43,000	30.1	MACDIARMID	SUTTON	Pt. Loma	3	
24 Nov.	W 20 Kn 8'	W 5 Kn	43,000	30.0	WEED	MACDIARMID	Pt. Loma	2	
25 Nov.	W 30 Kn 3'	W 10 Kn	43,200	30.1	MACDIARMID	GOULD	Pt. Loma	1	1
28 Nov.	W 30 Kn 3'	W 5 Kn	43,000	30.0	WEED	DAVIS	Pt. Loma	4	
1 Dec.	W 20 Kn 6'	W 14 Kn	43,200	30.3	WEED	NOOTEBOOM	Pt. Loma	3	3
2 Dec.	W 25 Kn 8' sea on 3' swell	W 15 Kn	43,000	31.9	MACDIARMID	WEED	Pt. Loma	2*	1
11 Dec.	W 25 Kn 5'	W 5 Kn	43,500	31.0	MACDIARMID	GOULD	Pt. Loma	1	1
12 Dec.	W 10 Kn 1'	Calm	43,800	30.0	MACDIARMID	BENDER	San Clemente	7	4
14 Dec.	W 25/48Kn6'/4'	E 5 Kn	43,300	31.5	MACDIARMID	GOULD	Pt. Arguello	5*	1
6 Jan.	W 19 Kn 7'	W 4 Kn	43,400	30.8	MACDIARMID	DAVIS	Santa Cruz	2*	
12 Jan.	7' sea NxW swell W 30 Kn 6'	NxW 18 Kn	42,100	30.0	MACDIARMID	VUKIC	500 Miles West of San Diego	1	1
20 Jan.	NW 24 Kn 10'	NNW 16 Kn	44,000	30.6	MACDIARMID	MC MULLAN	Pt. Loma	1*	
30 Jan.	W 39 Kn 3'	W 5 Kn	43,800	31.5	MACDIARMID	MC MULLAN	Pt. Loma	4	
6 Feb.	NW 39 Kn 5'	NW 15 Kn	44,000	30.1	MC MULLAN	MACDIARMID	Pt. Loma	2	1
9 Feb.	WNW 24 Kn 8'	W 20 Kn	43,000	29.6	DAVIS	MACDIARMID	Pt. Loma	1	
10 Feb.	W 30 Kn 4'	W 7 Kn	43,200	29.9	MACDIARMID	DAVIS	Pt. Loma	5	1
15 Feb.	WNW 15 Kn 6'	W 7 Kn	44,500	30.6	MACDIARMID	TRUBEY & STORM	Pt. Loma	3	
20 Feb.	W 30 Kn 5'	Calm	43,000	30.8	DAVIS	DE JOY & HARRIS	Pt. Loma	2	1
							Totals	54	15

* Plane was damaged.

Pilot experience in these tests: Comdr. D. B. MacDiarmid 42, Lt. Comdr. O. D. Weed 14, Lt. Comdr. L. L. Davis 14, Lt. Comdr. I. H. McMullan 7, Lieut. R. C. Gould 7, Lt. Comdr. C. R. Bender 7, Lieut. R. P. Trubey 3, Ensign V. W. Sutton 4, Ensign P. Nooteboom 3, Lieut. A. W. Wall 2, Ensign J. Vukic 1, Comdr. A. J. DeJoy 1, Comdr. T. J. Harris 1.