FOURTH EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

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SEA BEHAVIOUR PREDICTION OF HELICOPTERS THROUGH FREE MODEL TESTS

R.A. Verbrugge - P. Gythiel

Institut de Mécanique des Fluides de Lille

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Associazione Industrie Aerospaziali

1 - INTRODUCTION.-

The diversity of tasks entrusted to helicopters lead them often to manoeuvre above water and sometimes to alight (ditch).

However we usually distinguish two categories of helicopters : those specifically "Marine" and those fitted with emergency floats.

The "Marine" crafts have to be used afloat in various situations and therefore particular research on their hydrodynamic behaviour have to be made. The bottom of the fuselage is generally watertight and they are fitted with fixed floats.

Those fitted with emergency floats are basically "land" versions for which safety has to be guaranteed in case of damage, excluding any manoeuvres on the water.

Sea behaviour prediction of helicopters particularly in the case of dynamic manoeuvres such as ditching generally requires an experimental rather than analytic approach due to difficulties in modelling such phenomena.

The main goals aimed at in sea behaviour prediction are to :

- allow the choice of the hull shape by the design office
- specify the loads on the structure during manoeuvres
- give handling instructions and determine safety margins.

Since its founding in 1930, l'Institut de Mécanique des Fluides de Lille (France) develops test methods based on free models. These methods initially applied to wind-tunnel spin studies on aircraft have been in the last twenty years extended to catapulted models in order to establish a well adapted experimental base to study complex phenomena such as : response of aircraft to vertical or lateral gusts, landing in calm or disturbed air, crash, ditching of aircraft or helicopters and sea behaviour.

The Main interest in developping such an original experimental method lies in the following points :

- Direct representation of impact characteristics
- Evolution in a well-known surrounding and control of inputs such as swell, wind ...
- Precise knowledge of mass,inertia and structural characteristics of the models
- Wide complementarity with others methods.

This paper presents the facilities and methods for sea behaviour prediction of helicopters for various situations and manoeuvres and gives a scope of the different kinds of tests illustrated by some results and specifies the impact of these experimental methods. The studies concern dynamic and static stability, ditching, towing and hydroplaning.

2 - GENERAL ASPECTS OF THE EXPERIMENTAL METHOD.-

2.1 - Basic principle - Physical similitude.

The similar representation of dynamic phenomena (trajectory and movements) concerning half immersed bodies requires the identity of Froude number (expressing the ratio of inertia to gravity forces) between model and full scale.

The variables of the problem can be expressed as a function of independant fundamental quantities that are : reference length L , density of medium ρ and gravity g .

So if λ is the geometric scale of the model the similarity ratios of the main physical quantities are defined in the following table

Fundamental Quantities

Tests conducted in Froude similitude most often lead to results directly applicable to full scale helicopters as far as hydrodynamic behaviour is concerned.

Quantities	Dimension	Ratio
Length	L	λ
Mass	M	λ^3
Time	T	$\lambda^{1/2}$
Surface	L^2	λ^2
Volume	L^3	λ^3
Inertia	ML^2	λ^5
Speed	LT^{-1}	$\lambda^{1/2}$
Force	MLT^{-2}	λ^3
Moment	ML^2T^{-2}	λ^4
Pressure	$ML^{-1}T^{-2}$	λ
Frequency	T^{-1}	$\lambda^{-1/2}$
Linear Acceleration	LT^{-1}	1

2.2 - Direct and indirect similitude.

Froude similitude mentionned above can be defined as a "direct similitude" giving answers to the problem during the experiments.

Another way possible is "indirect similitude".

In this case tests on models can be used to validate a representative model of physical phenomena concerning simple manoeuvres (Determination of hydrodynamic coefficients force, moment and derivatives). The modelling can then be transposed to the full scale helicopter taking into account its own characteristics.

The two types of similitude are most often associated (fig. 1).

2.3 - Models and equipments.

2.3.1 - Model building

Depending on the goals, two types of model are considered :

- On the one hand models for complete studies of sea behaviour. They are large (1,5 m) scale λ between 1/5 and 1/8. They can carry important instrumentation.Similitude requirements especially concerning mass and inertia lead us to choose a construction combining lightness, structural stiffness (impact) and watertightness. Basic material is balsa wood covered with coated silk pongee. The models entirely fitted for the dynamic tests have a mean mass of 10 Kg. Most often floats are interchangeable in order to allow the study of size and shape effect.

- On the other hand models meant for stability tests on swelling sea alone and equipped with emergency floats. In this case the geometrical scale of the model is determined by the imposed swell characteristics (λ between 1/25 and 1/30e), mass and inertia constraints are then decisive and require a very light structure (mean mass 0,05 to 0,1 Kg). The models are vacuum moulded. Nó instrumentation is required only visualisations are made. For this kind of model the top rotors are schematically represented : shape, blade flexibility and motion, freedom in rotation. Floats on these models are also interchangeable.

2.3.2 - Mass and inertia identification

Precision on mass and inertia characteristics for free or half-free models is fundamental for quantitative test results analysis.

The identification methods of these characteristics have been suited to this necessity.

- Mass of the models is obtained by weighing on high quality balance : precision is $\pm$ 0,5 %o

- Center of gravity location in X, Y , Z direction is obtained by fixing the model at one end of a beam resting on a knife edge balanced by marked mass.

X , Y , Z model axis are successively oriented parallel to the axis of the beam (fig. 2). Precision is 0,5 mm.

Inertia around body axis is obtained by means of a dynamic set up made up of a torsion rod embaded at one end and equiped on the other end with a plate holding the model. The model can be mounted in three positions body axis successively parallel to the torsion rod.

This set up constitutes a pendulum which is electro-dynamically excited. The measurements are made at phase resonance controlled on a scope (Lissajoux Method) for an amplitude equal to that of the calibration.

The global precision of the method is better than 10^{-2}.

The inertial identification for small size models is made by the composite pendulum method.

2.3.3 - On board instrumentation

The usual equipment of free or half-free models is made of accelerometers and gyrometers sets intended to determine dynamic behaviour at the impact and motion on water. The chosen frequency band-width is 250 Hz per channel, precision class of the transducers is 10^{-5} .

For impact studies instrumentation is completed by straingauges to determine local efforts on separated elements such as floats. The evolution in time of the wetted surface during impact is obtained by fitting under the fuselage and floats a net of multi-contacts. Most often pressure transducers are used to mesure the unsteady pressures under the fuselage. Fifteen channels are available for this purpose.

Telemetry is composed of a coder-transmitter P C M unit having 30 entrance channels. The word format is 12 bits and the bit frequency is adjustable to 250 Kb.

Geometric references are materialized on the model for optical trajectography.

The model is equiped with a set of photoelectric cells. This system has as two functions : the starting of the information through the coder on board, setting the time base of the system (1,28 ms), and the determination of the releasing moment.

2.4 - Ground facilities.

These means include test facility and the observation device on ground and the transmitted data processing system.

2.4.1 - Test facility

The dimensions of the test basin is 40 x 6 x 1 m (fig. 3). It is equiped with a longitudinal + transversal swell generators. The wave length + trough of the swell are adjustable and measured during the test by emerged electrical probes. The ratio : trough over wavelength can reach 0,15, adjustable according to the following parameters : water depth, frequency + amplitude of beaters. Winds corresponding to a full scale velocity of up to 100 Km/h can be represented on water surface by the orientable wind generator. The basin can be equiped with the necessary device for the different tests : hydroplanning, towing, turning, dynamic + static stability as well as alighting. Examples of specific installations are shown on fig. 4 + 5.

2.4.2 - Ground observations

A series of cameras taking 60 images/sec. covers all the test field which contains geometric references.

They permit a direct restitution of the movements of the models during the test : trajectory + attitudes - as well as an observation of the subsidiary phenomena : hights of the sprays of water, visualisation of the wetted surface, rotor clearance etc...

2.4.3 - Teletransmission - Data acquisition - Soft ware

The organisation of the telemeasuring system is found in fig. 6. It is a general purpose device well adapted to measurements of rapidly varying phenomena such as those met during impact tests. Moreover this system gives the possibility to elaborate simple command loops in real time or to monitor chosen parameters.

The global precision of the telemetric system is better than 10^{-3}. The command loops can be realised in pure digital mode or convertor. The soft ware used to analyse the test data includes a program for trajectography and a program for the dynamic recording.

The trajectography program processes the spatial traces of the model references obtained after the analysis of the optical records. A root mean square linearisation of each spatial trace is realized. We thus obtain the centre of gravity coordinates during movement, the Euler angles ψ , θ , φ + the coordinates of the flight path angle.

The program for the dynamic recording processes the telemeasured values $\vec{\Gamma}_G$ et $\vec{\Omega}$. It allows for each P C M subcycle (1,28 ms), the restitution of the totality of the test parameters : attitude relative to ground, angular velocities, load factor, side-slip etc...

The analysis of specific measurements such as pressures, evolution of wetted surface, localised strains etc..., can also be realized through specific routines.

The results obtained from these two independant sources may be used in the data validation test. It permits, for instance in the case of alighting, an adjustement of the dynamic conditions by establishing a correlation between the trajectography + the integrated dynamic informations. These general purpose programs are usually used at I.M.F.Lille for free flight tests of airplane models. Their application to the hydrodynamic tests is direct.

3 - GENERAL VIEW OF THE EXPERIMENTAL STUDIES OF SEA BEHAVIOUR.-

3.1 - General characteristics of the test.

The global prevision of sea behaviour of a helicopter necessitates a great number of various tests associated to numerous parameters corresponding either to the definition of the model or to the environmental conditions.

The main types of tests generally made, lead to the definition : static + dynamic stabilities specially in roll + yaw.

- The stability on a wavy sea , rotors stopped, with or without wind
- Behaviour during towing and during hydroplanning in a straight line or in a turn
- The characteristics of alighting for a wide domain of glide path angle.

The usual parameters to be considered are on the model :

- Mass, C.G. location and inertia
- Rotor thrust
- Destructibility, shapes, overrunning, etc...

and in the environment

- swell (trough, wave length)
- wind (speed + direction).

We find in fig. 7 for each type of test, the most influent parameters, as well as a review of measurement + observations made during the test.

3.2 - Roll stability test.

Before proceeding to particular tests, water lines are obtained for different loadings + different floats.

Roll stability must be considered with special care taking into account the fact that it constitutes one of the very first limitation to the use afloat of the helicopter and that moreover in the past several years commontype crafts are known to have capsized rotor stopped in the U.S.

The diagram of the test facility is shown on fig. 8. Tests are made with or without simulation of the rotor lift. Characteristic results are shown in fig. 9 for rotor stopped tests. The stability features obtained are very much influenced by the weight of the helicopter, and by the shape + the disposition of the floats (for these examples the ratio of the volume in liters of the various elements giving buoyancy and the mass of the craft is close to 1,5).

The influence acts not only on the maximum capsizing torque but also, specially for small amplitudes of lateral attitude on the moment derivative ($C_{L\varphi}$).

These tests are particularly indicated for the preliminary determination of the form on a model meant to be used in an ulterior dynamic test program.

Generally tests in roll oscillations take place on calm water. They lead to the definition of the model damping coefficients and provide useful data to an analytical step according to the method of indirect similitude.

The pitch stability is definitely more high than the roll stability. The return to equilibrium generally occurs in a quasi-aperiodic manner.

3.3 - Dynamic hydroplaning yaw stability tests.

The test installation diagram is given in fig. 10. The model is half-free.

The longitudinal attitude is fixed as that of free hydroplaning.

The lateral attitude and side-slip, as well as the speed, can be ajusted.

Pumping is free, and the rotor traction can be represented by removing weight from the model. A torque meter with strain gauge measures the moment of yaw.

In general the hull is unstable for yaw when the traction is applied at the rotor focus.

In particular, fig. 11 shows that the yaw moment coefficient varies in function of the hydroplaning speed when the side-slip is constant. This variation is due to a sucking phenomenon that pulls the hull down as the speed increases (0.2 m at 5 m/s).

The yaw moment coefficient does not however increase in a linear fashion with the side-slip, this being due to swell various interactions between fuselage and floats, etc... and to the complex characteristics of the flow on the bottom of the fuselage that can be observed by visualization (see fig. 12).

Such results are difficult to predict by direct calculations.

Furthermore, the influence of side-slip is a determining factor for all floating manoeuvres ; in the past, "marine" models have had to be equiped with a water side-slip detector under the fuselage.

The visualizations above also enable the appropriate detector localization to be defined for the side-slip to be considered.

3.4 - Stability on sea with swell.

These tests were designed to define the limit floating stability conditions of a helicopter with rotor stopped, when faced with weather conditions combining wind and swell (sea conditions force 0 to 7, see fig. 13), and to evaluate the possibility of evacuating the aircraft.

The parameters usually considered are :

- for the aircraft : mass, position and dimensions of the stabilizers
- wind : variable in force and direction
- initial heading relative to the wind and the swell.

The only observations taken were concerned with the motion of the aircraft.

In most of the cases, simple suggestions concerning the floats enabled a configuration to be defined capable of resisting to the most severe operating conditions.

3.5 - Towage afloat.

For the towage tests, the model is pulled by the fore or aft rings usually provided to this effect on some crafts. Towage can be done straight or in a curve (see fig. 14). The parameters most often taken into consideration are ; mass of the helicopter stabilizers shape and dimensions, towing speed, waves, curve radius, towing cable length.

The pulling force is constant during each test.

The results obtained relate to the pulling force, towing speed, the longitudinal attitude, and observing the secondary phenomena such as any roll and yaw motion, visualizing the flow on the stabilizers, the free height under the rotors.

The first limit to the manoeuvre is most often the result of the maximum pull that can be withstood by the bow towing ring.

In general, towing can be carried out with no problem (see fig. 15), up to speeds of 5 or 6 m/s. Waves have little effect on the behaviour. The cable length should be taken into consideration for high speeds where combined roll-yaw oscillations can result in sudden overturning.

When towing from the rear, the results are poor, since the submerged surfaces are not designed for this application.

In order to evaluate the stability of phenomena near zero side-slip for this type of manoeuvre, towing is performed after having off-centered the towing ring, in order to impose a ——— side-slip when pulling in a straight line. The force and moment coefficients can also be determined in function of the longitudinal and transverse attitudes relative to the ground, and in function of the side-slip.

3.6 - Hydroplaning.

Hydroplaning is a floating evolution of the helicopter by its own means. The movement in a straight line and in a curve is considered.

The basic test assembly is shown in fig. 16.

The horizontal traction component is applied at the focus height taking into account in particular the resulting force to be represented and the rotation speed.

In order to ensure an artificial yaw stability, a triangulation at right angles with the pull is used. The hull is otherwise unstable for yaw when the pulling force is centered at the focus. The vertical thrust component is achieved by lightening the model. The phenomena here are permanent or very slowly variable ; the distorsion of this representation due to center of gravity accelerations do not have a significant effect.

Amongst the very influencial parameters affecting this manoeuvre, one should note the side-slip relative to the water. A precise indication of the side-slip, in real time, proves necessary in order to carry out the manoeuvre.

The longitudinal attitude (fig. 17) remains quite level, thanks to the good pitch stability even when the longitudinal pulling component of the rotor is high.

Along with the usual suggestions, one should note that a symmetrical main rotor thrust should be maintained.

Consequently, hydroplaning in a curve is most often a delicate operation, requiring a wide margin of rol stability. This evolution is studied on a special set-up.

3.7 - Hydroplaning in a curve.

These tests are carried out on a round about (see fig. 18). The model is free for pumping, pitching and rolling. The curve radius and trajectory speed are predetermined.

The yaw is established for each test, and the moment of yaw is obtained from gauge measurements taken in the lateral connecting rods.

The three resulting rotor thrust components are applied at the focus.

The vertical and lateral components are established for each test. The longitudinal component is measure by a gauge in the vertical beam passing through the focus.

With all these measurements, the complete movement can be plotted, and the main components of the hydrodynamic forces and motion can be determined.

Here again, the side-slip has a determining effect on the roll stability related to the lateral attitude and the yaw stability requiring a particularly sensitive control of the rear rotor when side-slipping with the nos outside the curve.

Once again, the side-slip relative to the water must be known to the pilot in this manoeuvre. A side-sli indicator is necessary since the pilot cannot estimate its value correctly.

The advice most often given for performing this manoeuvre is to side-slip with the nose inside the curve in proportion with the tightness of the curve ; in this case the lateral forces are balanced resulting in a level transverse attitude.

High displacement speeds must be avoided for piloting reasons.

The curve radius is often of secondary importance.

3.8 - Ditching tests.

The aim here is to propose advice for ditching even in critical cases where the vertical descent speed is high, the range or impact slopes is wide, and the sea and wind conditions are variable.

Two installations are used to represent slopes from 0 to 90° (fig. 20 and 21) and a range of vertical speeds from 0 to 5 m/s.

The models in this case are fully equiped with instruments to measure the evolution of the acceleration vector and instantaneous rotation, the pressure to be sustained by the bottom of the hull, the free height of the rear rotor during the manoeuvre and the stresses to which the float or wing float connections are subjected. A trajectography using land-based optical equipment is established.

The sea surface is smooth or with swell with frontal, lateral or cross waves.

The wind is represented by combining the wind speed vector relative to the water with the speed vector relative to the air. This disposition requires a new slope and trajectory speed to be determined and gives a side-slip relative to the water at impact. Only the aerodynamic factors are not represented, but they are of secondary importance relative to the hydrodynamic components of this manoeuvre.

The other parameters usually taken into consideration are : longitudinal and transverse attitude at impact, helicopter mass, rotor thrust, stabilizer shape and dimensions, overrunning ...

One of the conclusions of these tests is that, taking into account the type of helicopter ditchings should be performed at a medium slope to reduce the load factor at impact, increase the free height under the rear rotor, associated with nose up longitudinal attitude. In this case, the mean pressures under the hull tend to be reduced (fig. 22 - 23).

The influence of the nature, shape and disposition of the stabilizers, i.e. the configuration of the helicopter is nevertheless a determining factor in the ditching characteristics.

Although a moderate swell has little effect on a ditching, but scatters the results, the effect of the wind is very important (see fig. 24). Side-slip relative to the water must be kept in a very narrow fork, on account of the helicopter's roll stability.

When ditching, values such as wind speed cross-wind, and side-slip relative to the water are unknown to the pilot. An estimate, however, of the transverse speed relative to the water can on its own define the practical domain of ditching, and hence take into account the important effect of the wind.

4 - CONCLUSION.-

The experimental methods and the various means used enable a very satisfactory prediction of helicopter behaviour afloat.

Previous experience in this domain and the results obtained especially for ditching and floating stability are based on a varied range of about 10 helicopters studied mostly for the SNIAS - Helicopter division.

The method goes beyond simple observation of the characteristics during different manoeuvres, to guide the definition of the floating components of an helicopter and the characteristics of the structure concerned.

For each manoeuvre, simple concluding advice is given for the pilots' use.

In order to perform extensive marine behaviour studies, the I.M.F.L. has under taken a feasibility study for carrying out these tests using completely free self-propelled models with instrumentation (R.P.V.). These methods can also be applied to the problems of crash already studied by the I.M.F.L. for several years.

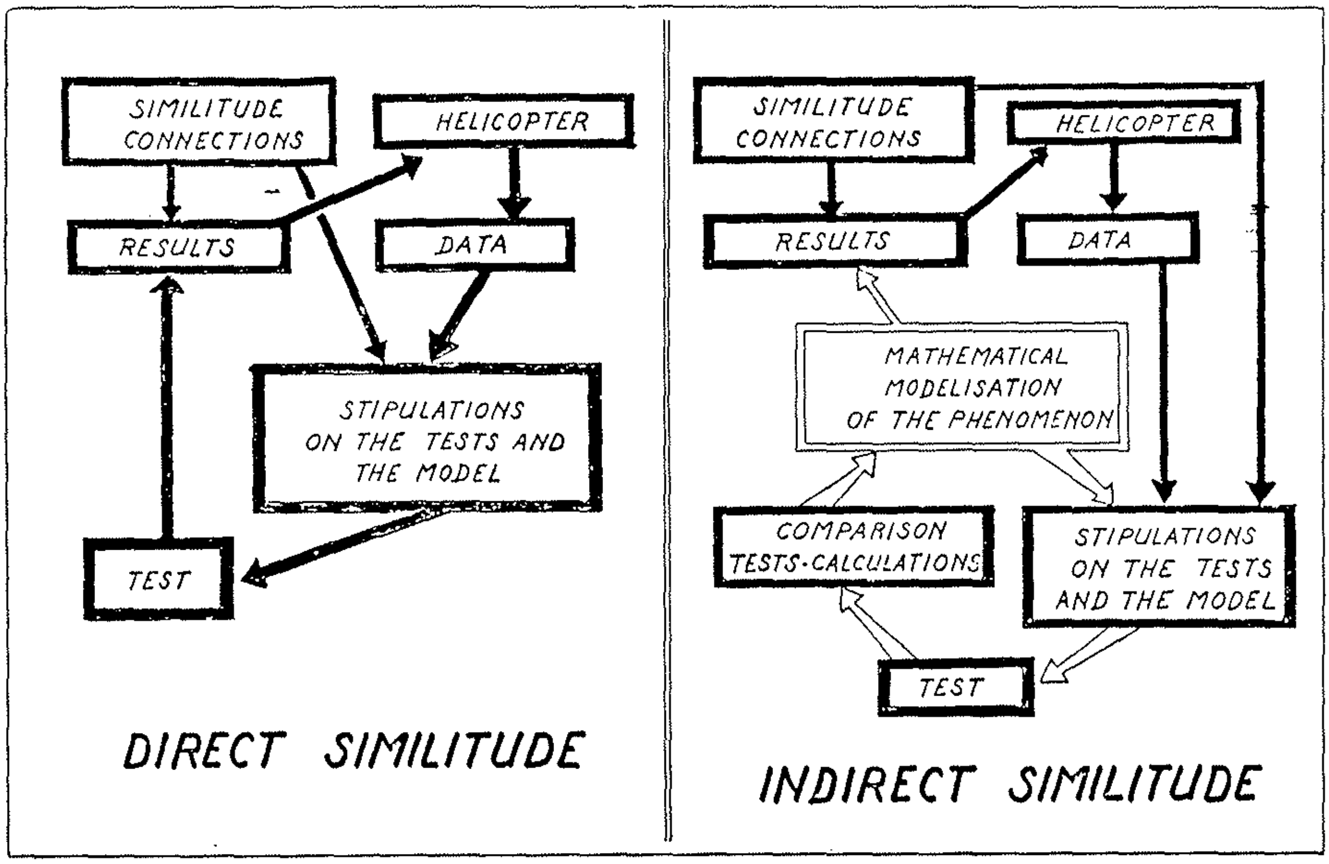

SIMILITUDE CONNECTIONS
HELICOPTER
RESULTS
DATA
STIPULATIONS ON THE TESTS AND THE MODEL
TEST
DIRECT SIMILITUDE
SIMILITUDE CONNECTIONS
HELICOPTER
RESULTS
DATA
MATHEMATICAL MODELISATION OF THE PHENOMENON
COMPARISON TESTS-CALCULATIONS
STIPULATIONS ON THE TESTS AND THE MODEL
TEST
INDIRECT SIMILITUDE

Fig. 1

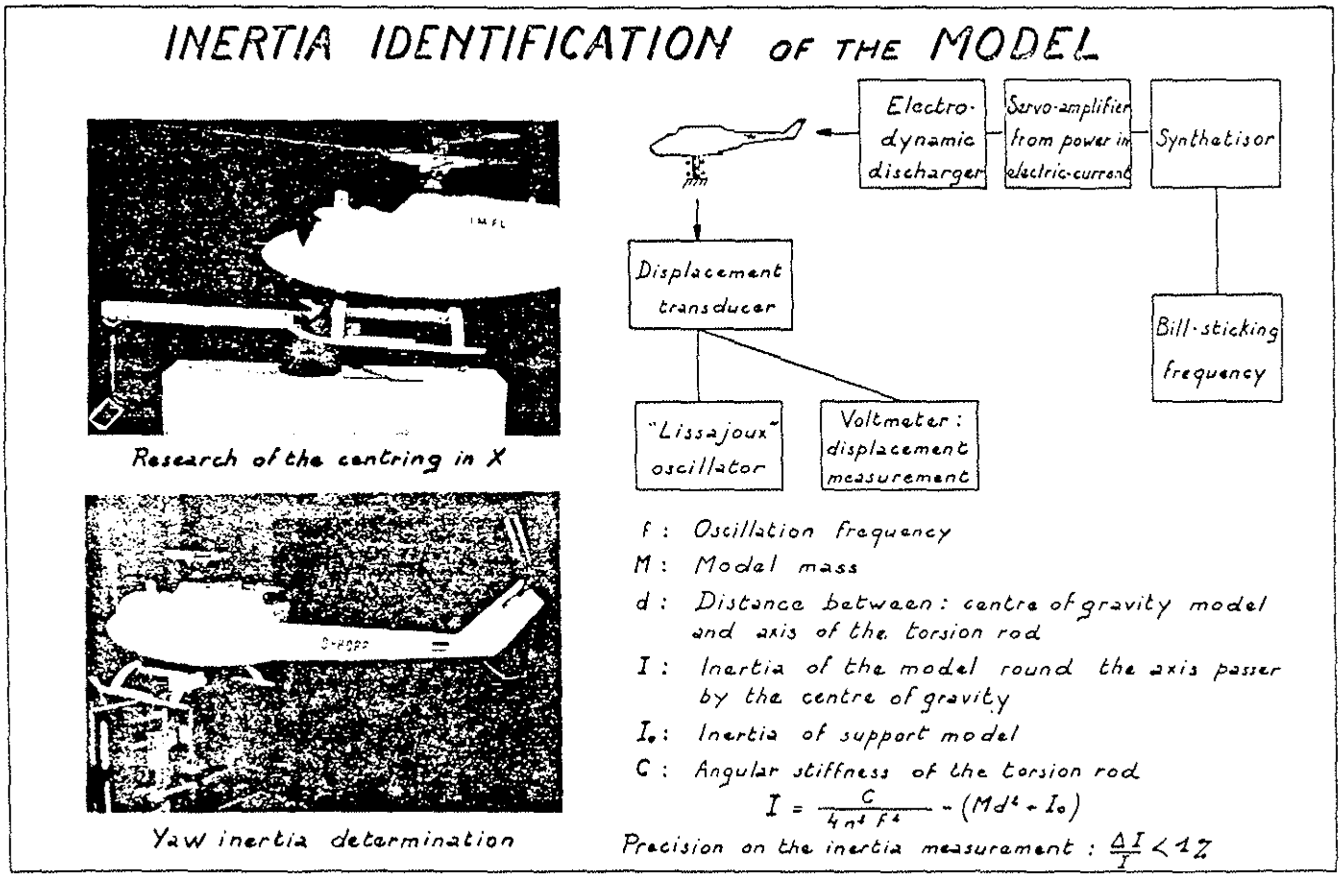

INERTIA IDENTIFICATION OF THE MODEL
Electro-dynamic discharger
Servo-amplifier from power in electric-current
Synthetisor
Displacement transducer
Bill-sticking frequency
"Lissajoux" oscillator
Voltmeter : displacement measurement
Research of the centring in X
Yaw inertia determination
f : Oscillation frequency
M : Model mass
d : Distance between : centre of gravity model and axis of the torsion rod
I : Inertia of the model round the axis passer by the centre of gravity
I₀ : Inertia of support model
C : Angular stiffness of the torsion rod
I = C / 4π² f² - (Md² + I₀)
Precision on the inertia measurement : ΔI/I < 1%

Fig. 2

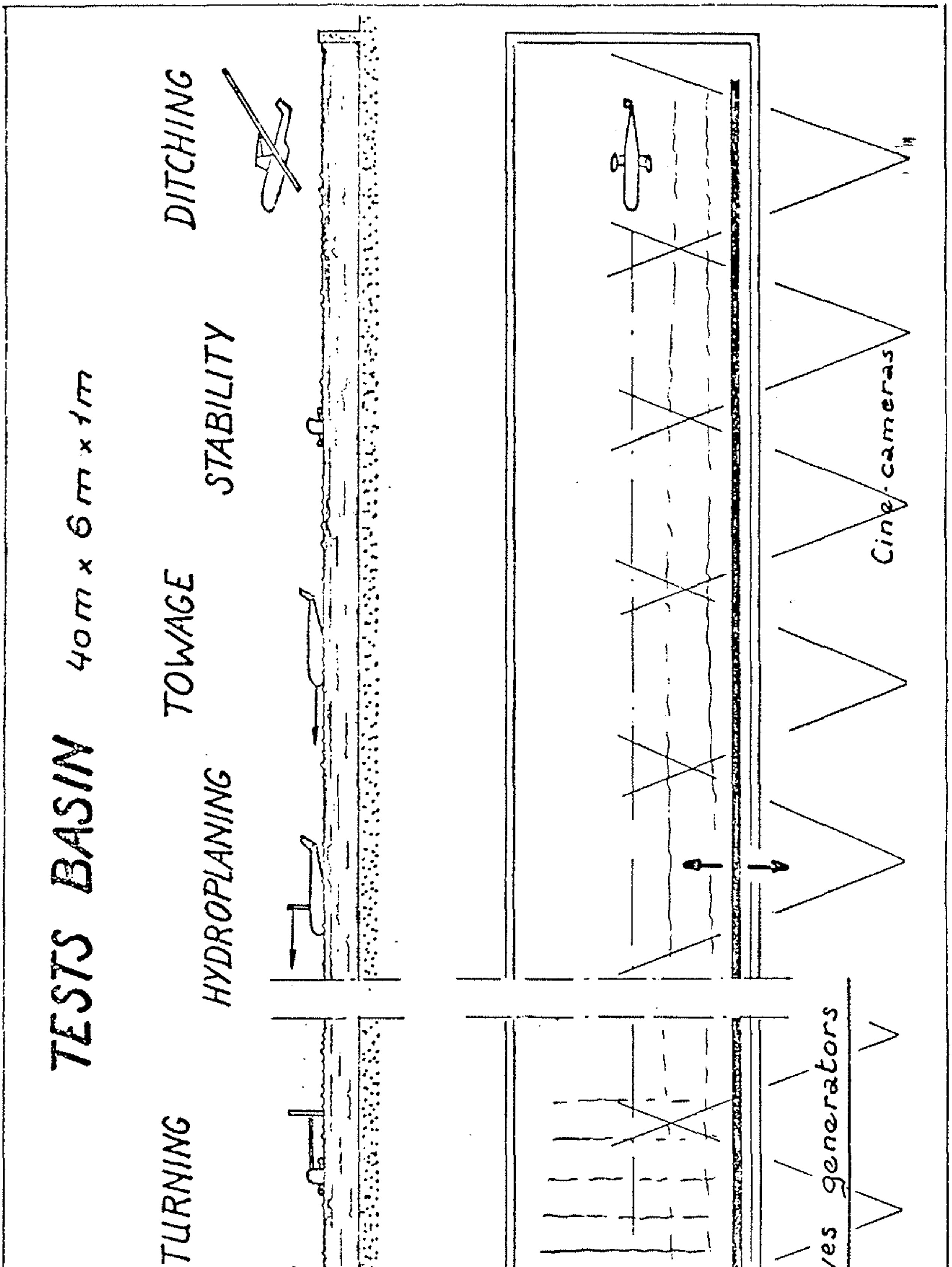

TESTS BASIN 40m x 6m x 1m
TURNING
HYDROPLANING
TOWAGE
STABILITY
DITCHING
Waves generators
Cine-cameras

Fig. 3

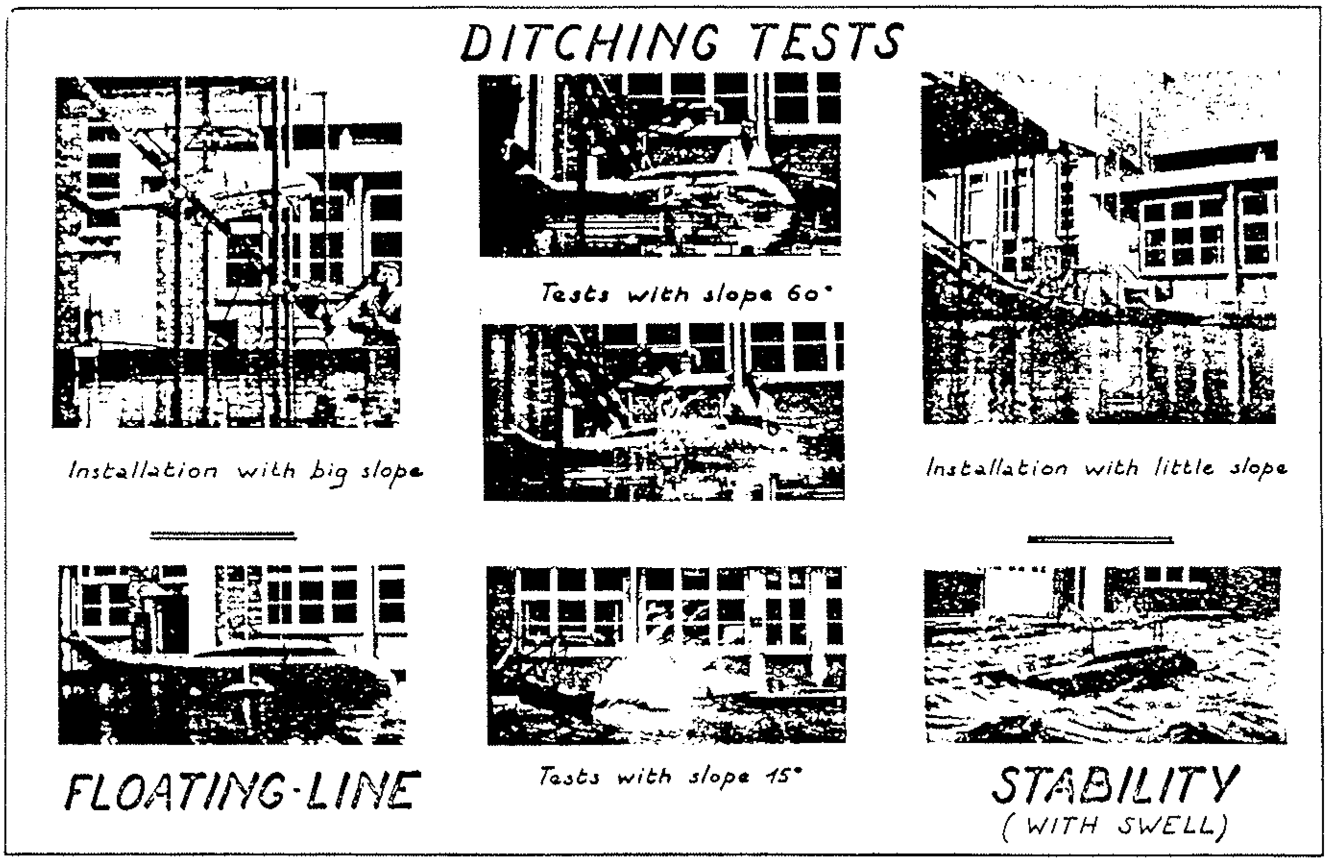

DITCHING TESTS
Tests with slope 60°
Installation with big slope
Installation with little slope
FLOATING-LINE
Tests with slope 15°
STABILITY
(WITH SWELL)

Fig. 4

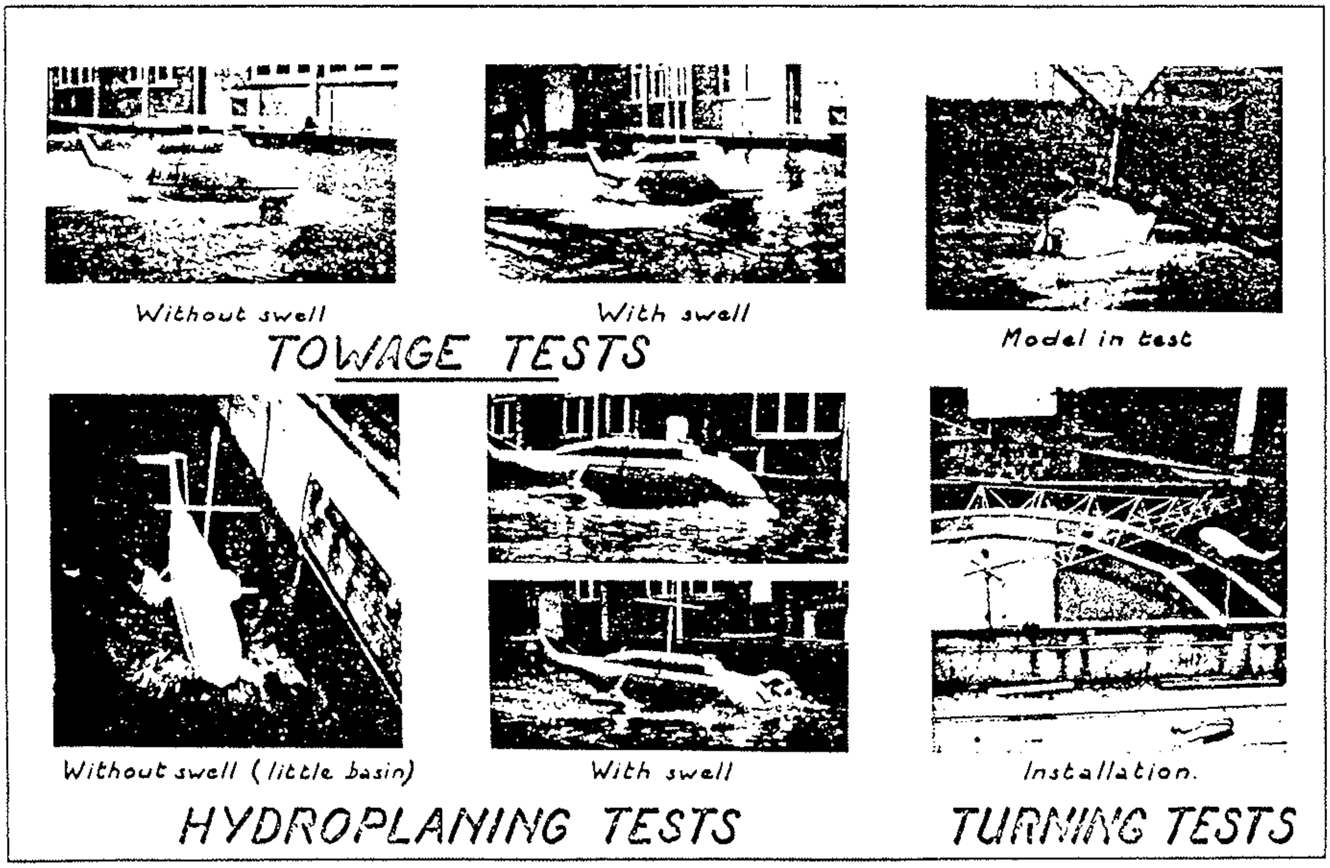

Without swell
With swell
Model in test
TOWAGE TESTS
Without swell (little basin)
With swell
Installation.
HYDROPLANING TESTS
TURNING TESTS

Fig. 5

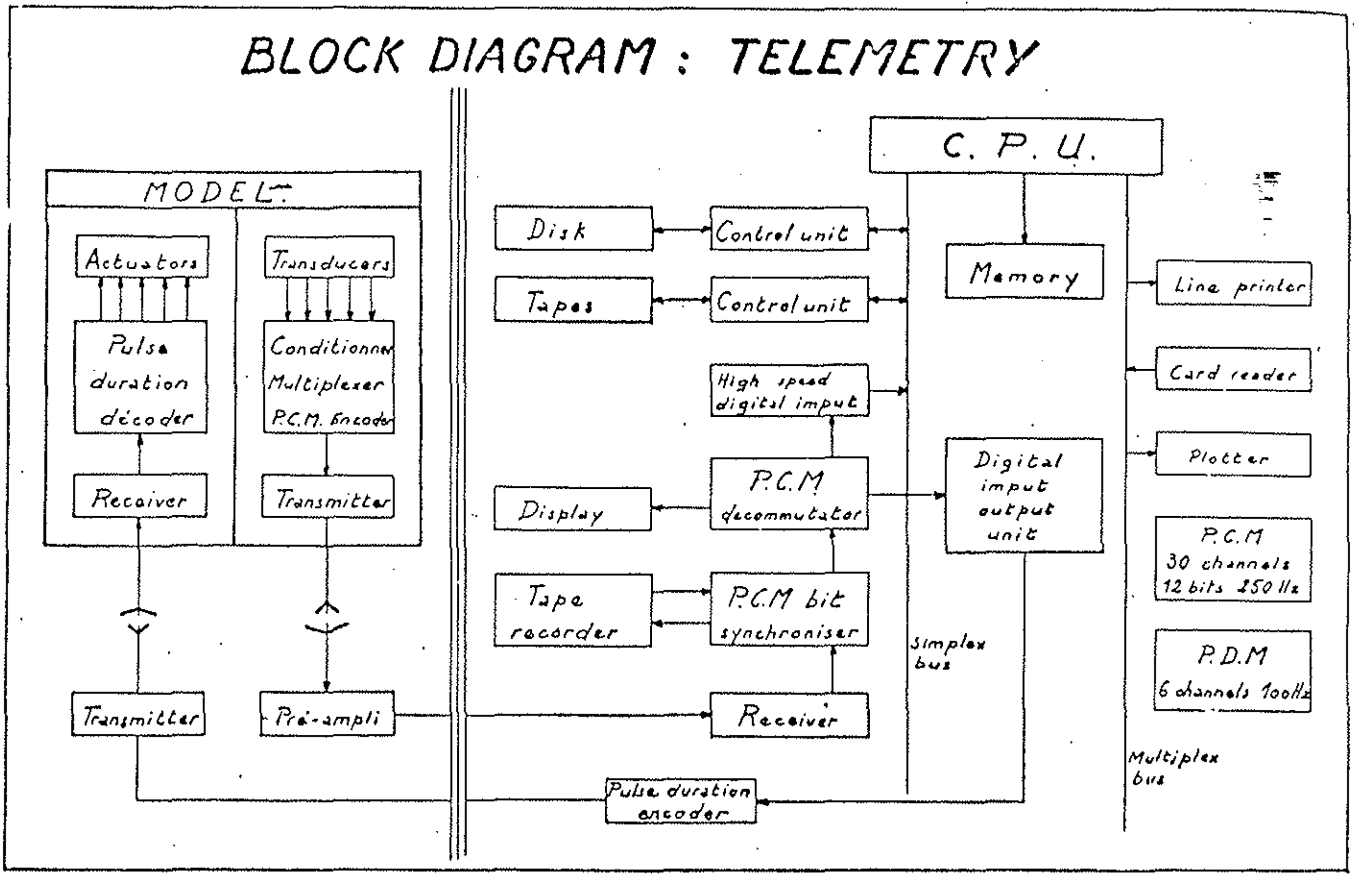

BLOCK DIAGRAM : TELEMETRY
MODEL
Actuators
Pulse duration décoder
Receiver
Transducers
Conditionner Multiplexer P.C.M. Encoder
Transmitter
Transmitter
Pré-ampli
C. P. U.
Disk
Control unit
Tapes
Control unit
Memory
High speed digital imput
Display
P.C.M decommutator
Digital imput output unit
Tape recorder
P.C.M bit synchroniser
Receiver
Simplex bus
Line printer
Card reader
Plotter
P.C.M 30 channels 12 bits 250 Hz
P.D.M 6 channels 100Hz
Multiplex bus
Pulse duration encoder

Fig. 6

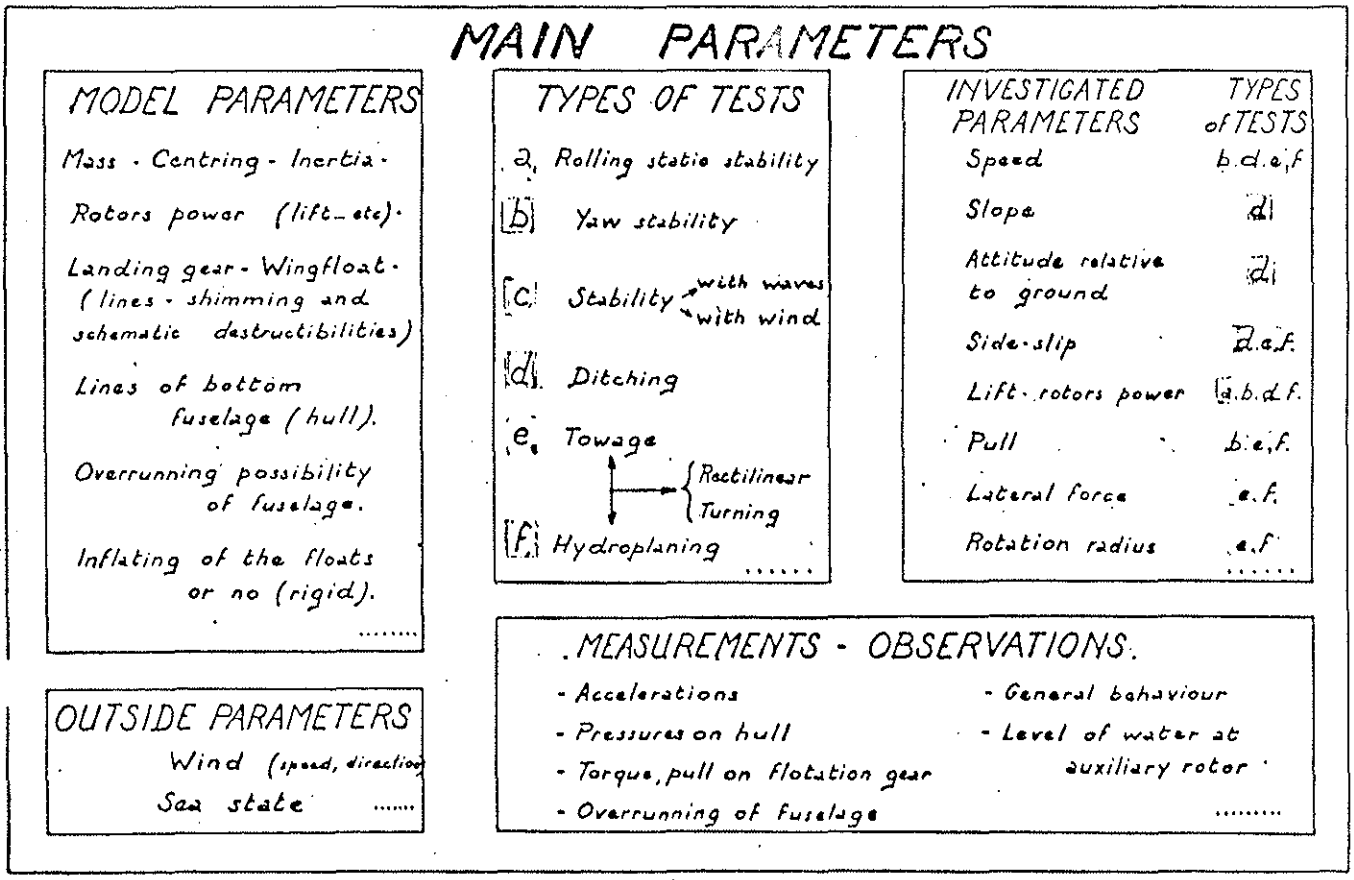

MAIN PARAMETERS
MODEL PARAMETERS
Mass - Centring - Inertia -
Rotors power (lift - etc) -
Landing gear - Wingfloat - (lines - shimming and schematic destructibilities)
Lines of bottom fuselage (hull).
Overrunning possibility of fuselage.
Inflating of the floats or no (rigid).
....
TYPES OF TESTS
a Rolling static stability
b Yaw stability
c Stability with waves / with wind
d Ditching
e Towage
Rectilinear
Turning
f Hydroplaning
......
INVESTIGATED PARAMETERS
TYPES of TESTS
Speed b.d.e.f
Slope d
Attitude relative to ground d
Side-slip a.e.f.
Lift - rotors power a.b.d.f.
Pull b.e.f.
Lateral force e.f.
Rotation radius e.f
......
OUTSIDE PARAMETERS
Wind (speed, direction)
Sea state ......
MEASUREMENTS - OBSERVATIONS.
- Accelerations
- Pressures on hull
- Torque, pull on flotation gear
- Overrunning of fuselage
- General behaviour
- Level of water at auxiliary rotor
....

Fig. 7

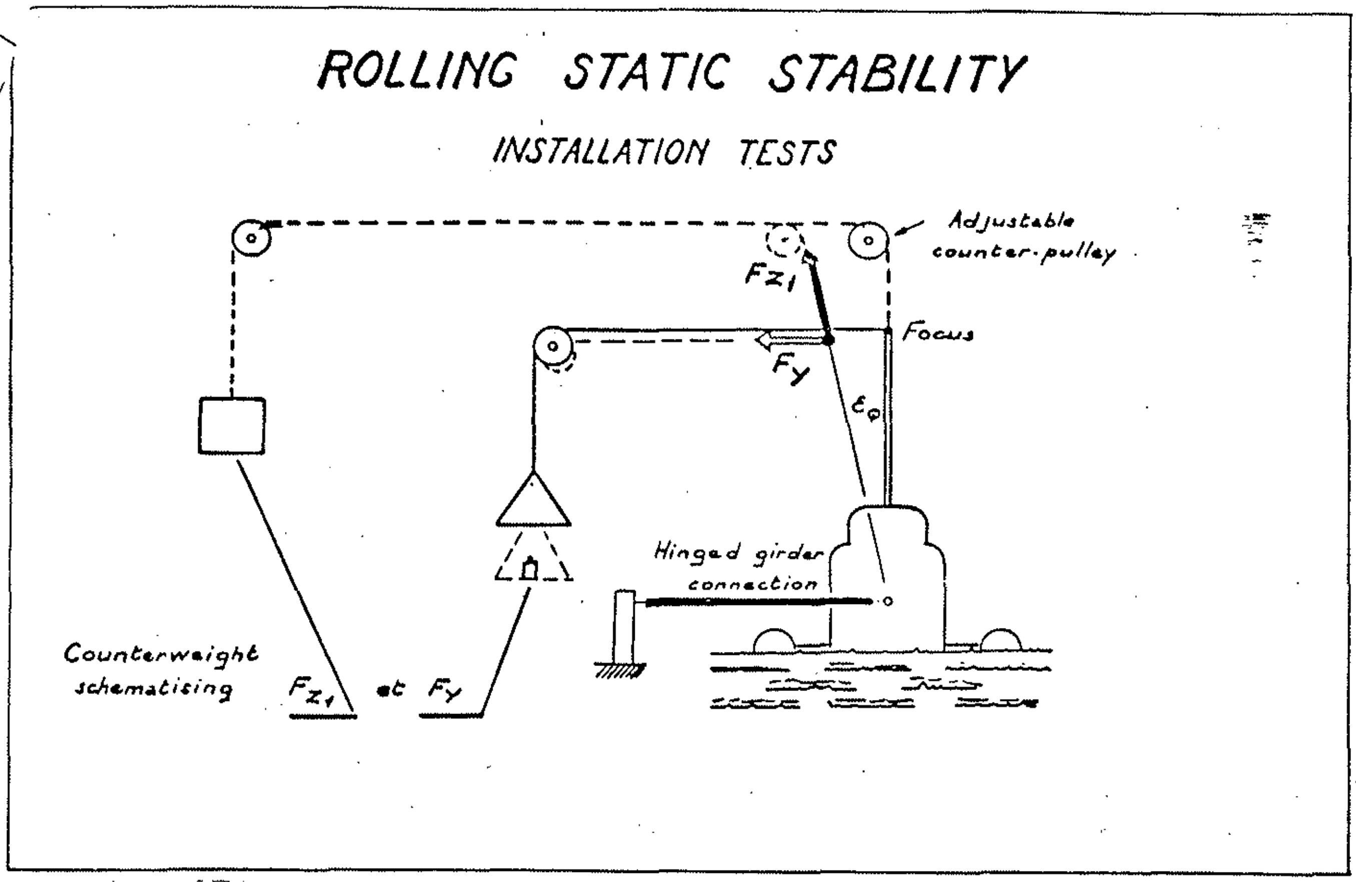

ROLLING STATIC STABILITY
INSTALLATION TESTS
Adjustable counter-pulley
Fz1
Focus
Fy
Hinged girder connection
Counterweight schematising Fz1 et Fy

Fig. 8

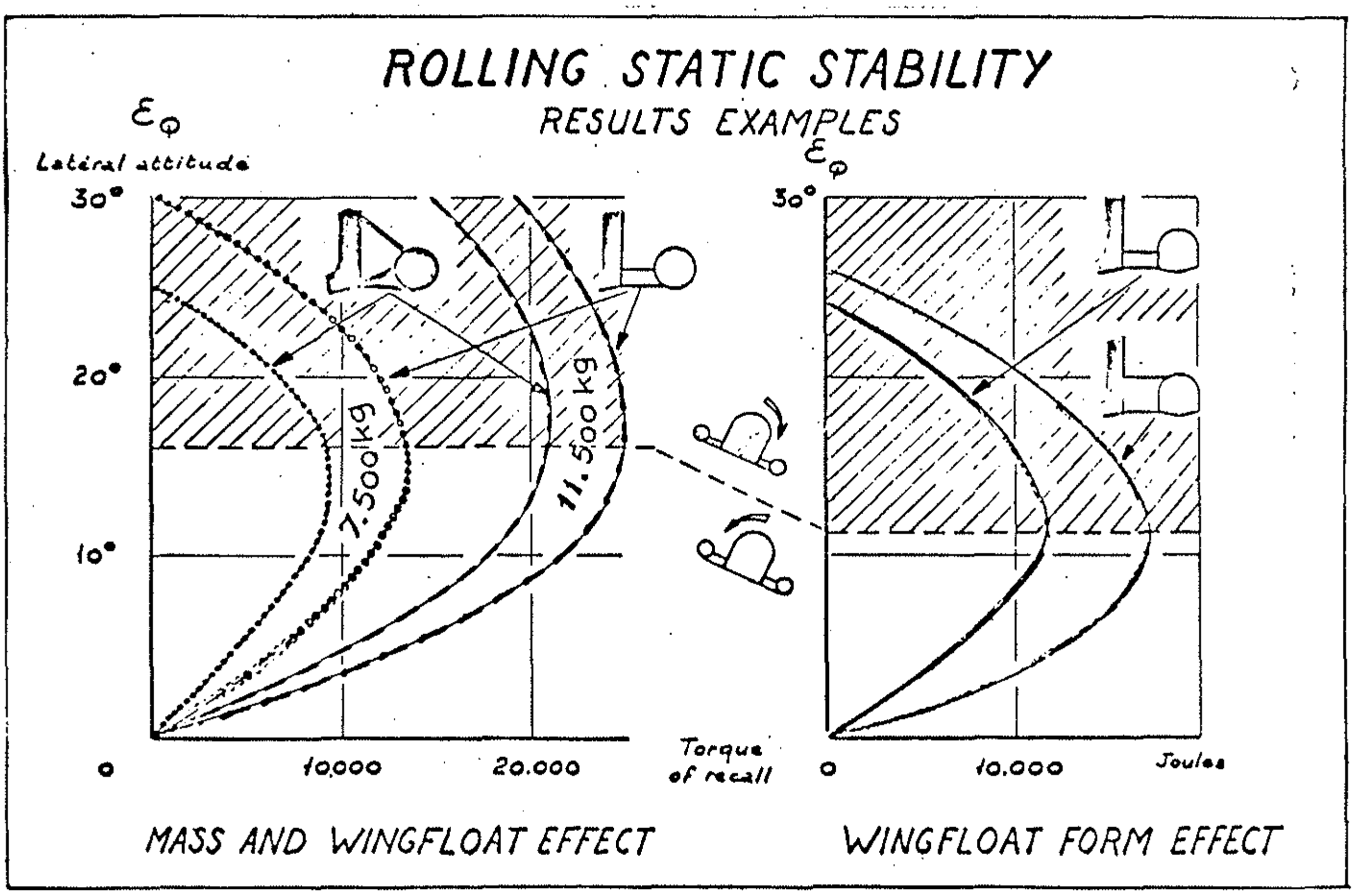

ROLLING STATIC STABILITY
RESULTS EXAMPLES
Lateral attitude
30°
20°
10°
0
7.500 kg
11.500 kg
10,000
20.000
Torque of recall
10.000
Joules
MASS AND WINGFLOAT EFFECT
WINGFLOAT FORM EFFECT

Fig. 9

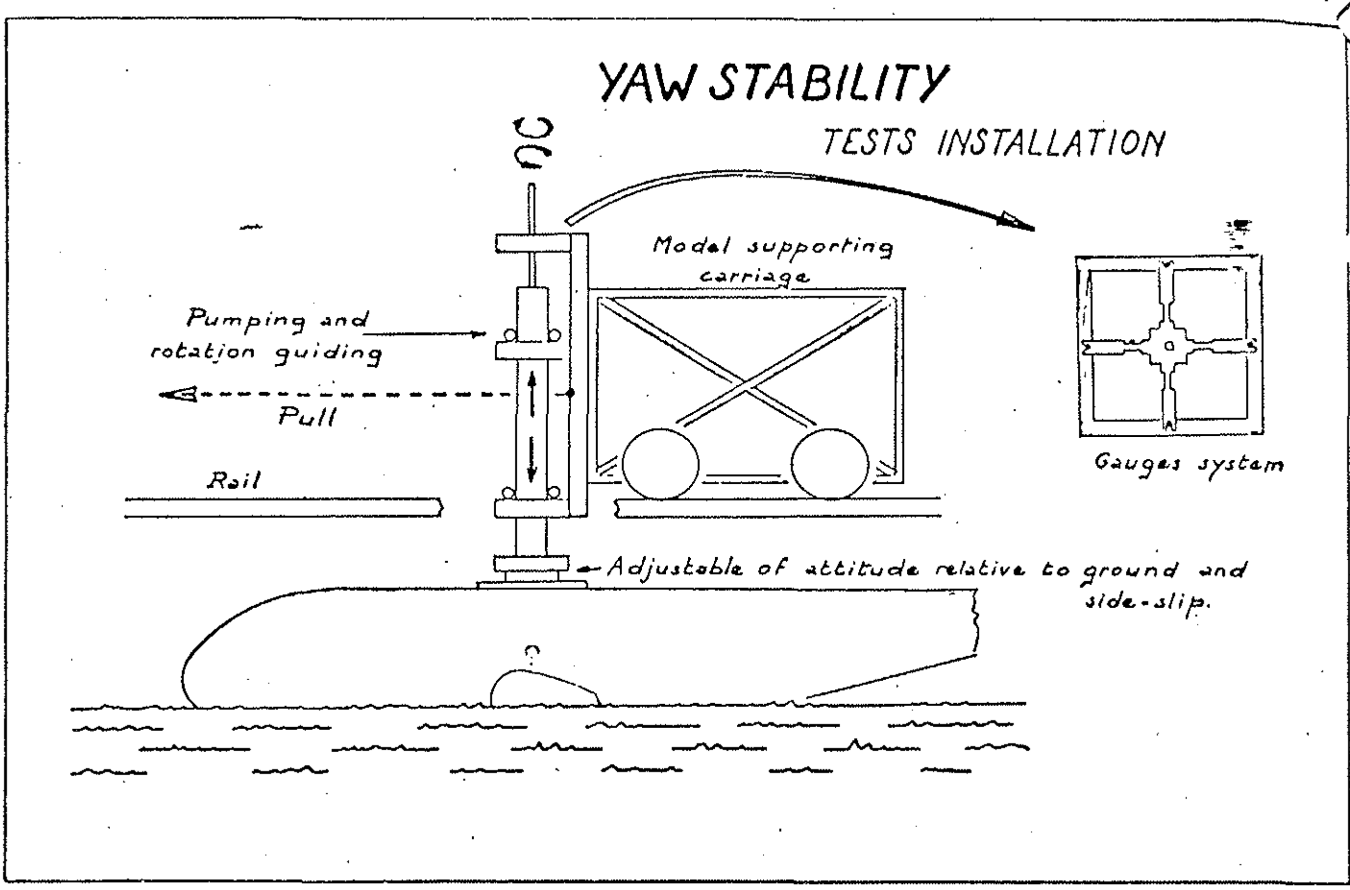

YAW STABILITY
TESTS INSTALLATION
Model supporting carriage
Pumping and rotation guiding
Pull
Rail
Gauges system
Adjustable of attitude relative to ground and side-slip.

Fig. 10

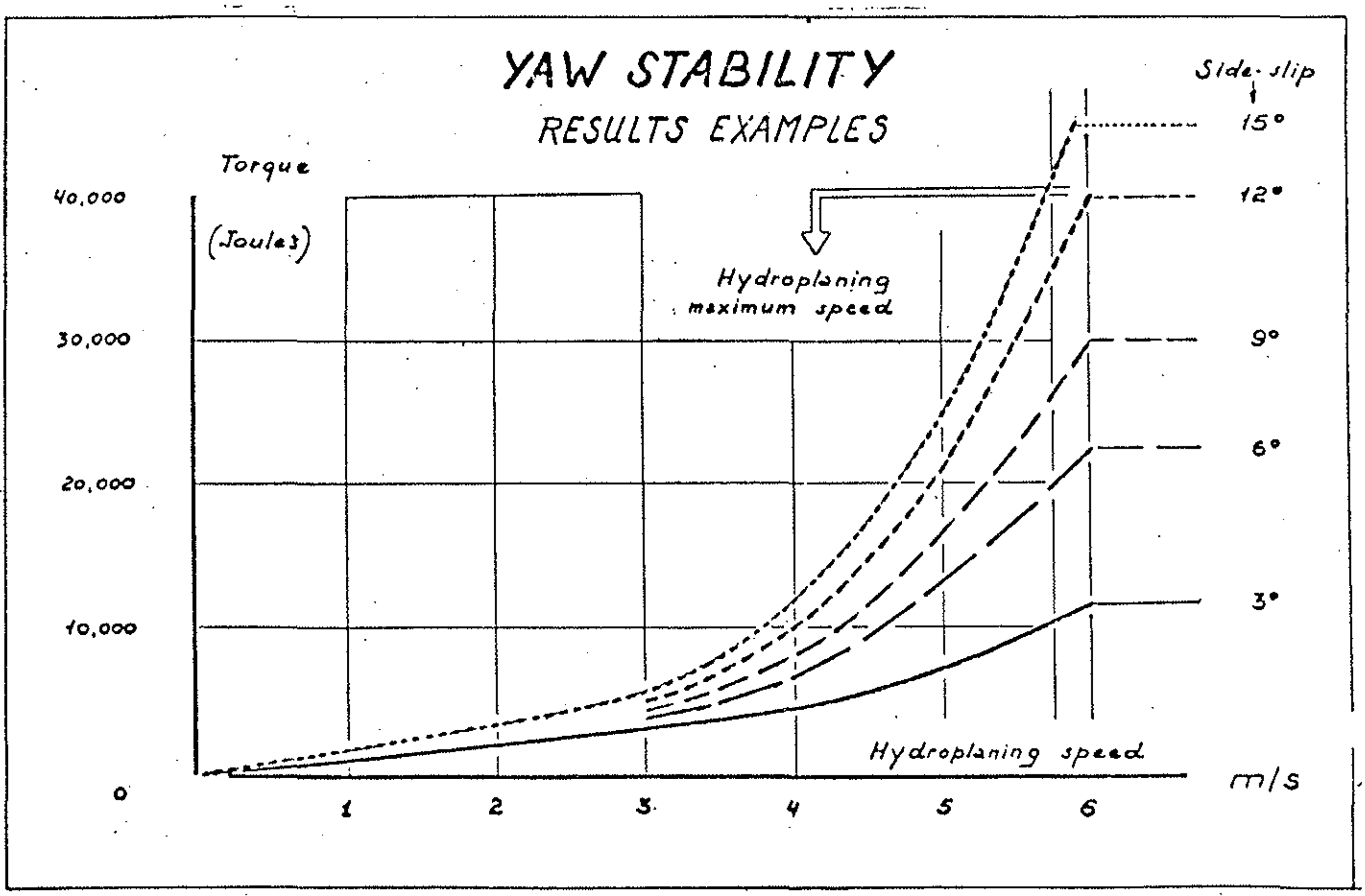

YAW STABILITY
RESULTS EXAMPLES
Side-slip
15°
12°
9°
6°
3°
Torque
(Joules)
40,000
30,000
20,000
10,000
0
Hydroplaning maximum speed
Hydroplaning speed
1
2
3
4
5
6
m/s

Fig. 11

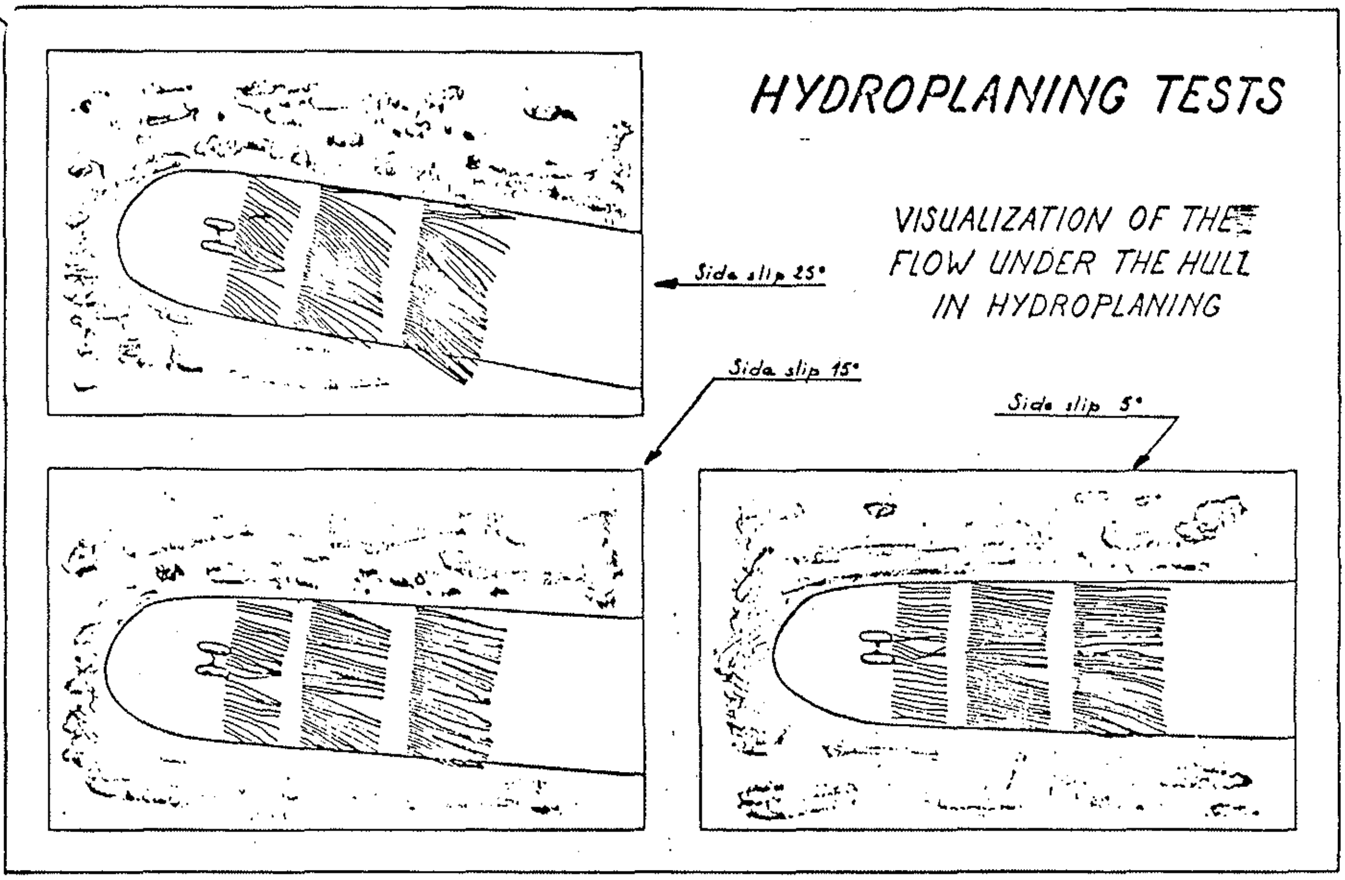

HYDROPLANING TESTS
VISUALIZATION OF THE FLOW UNDER THE HULL IN HYDROPLANING
Side slip 25°
Side slip 15°
Side slip 5°

Fig. 12

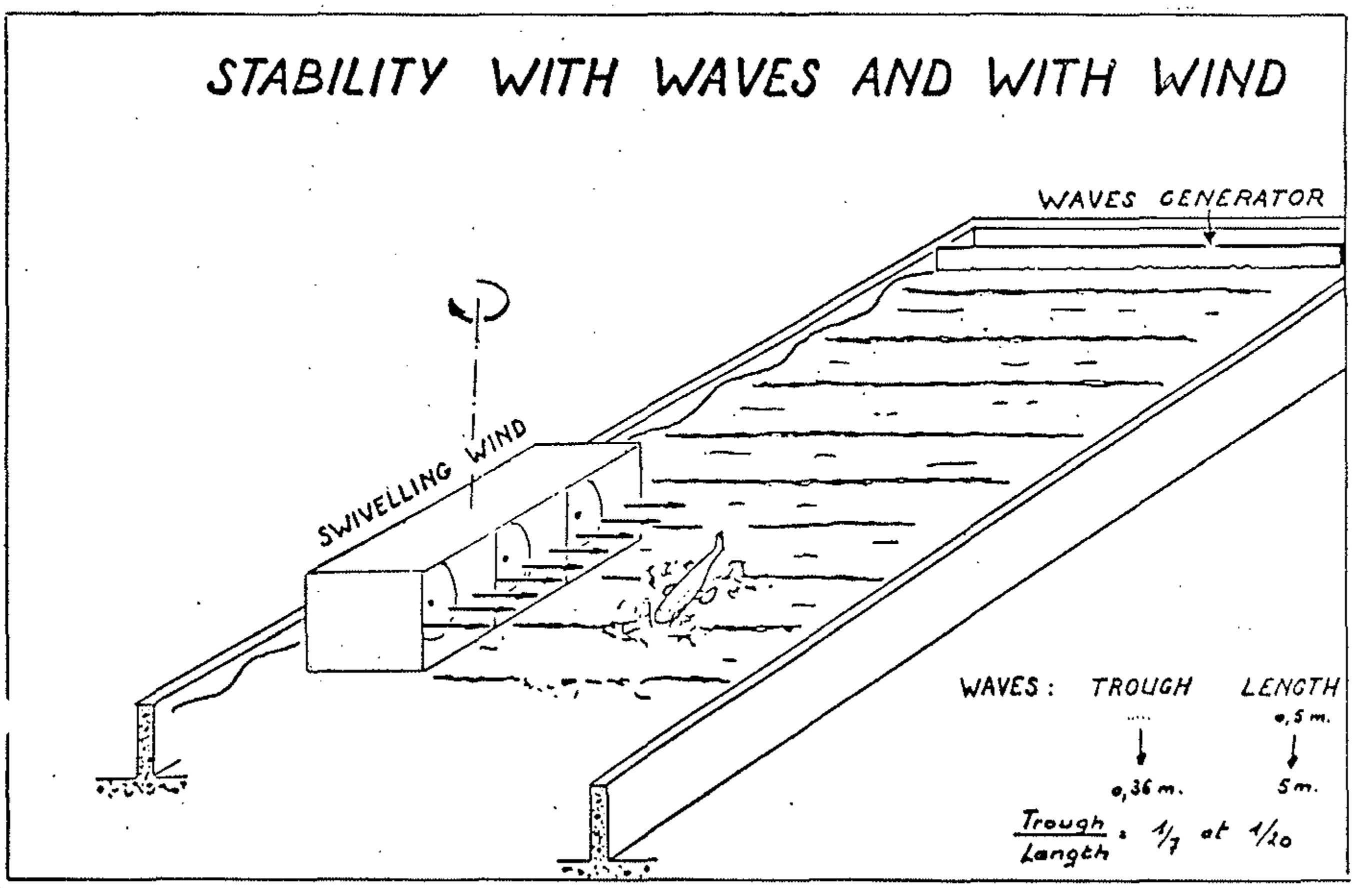

STABILITY WITH WAVES AND WITH WIND
WAVES GENERATOR
SWIVELLING WIND
WAVES : TROUGH LENGTH
0,5 m.
0,36 m. 5 m.
Trough / Length : 1/7 at 1/20

Fig. 13

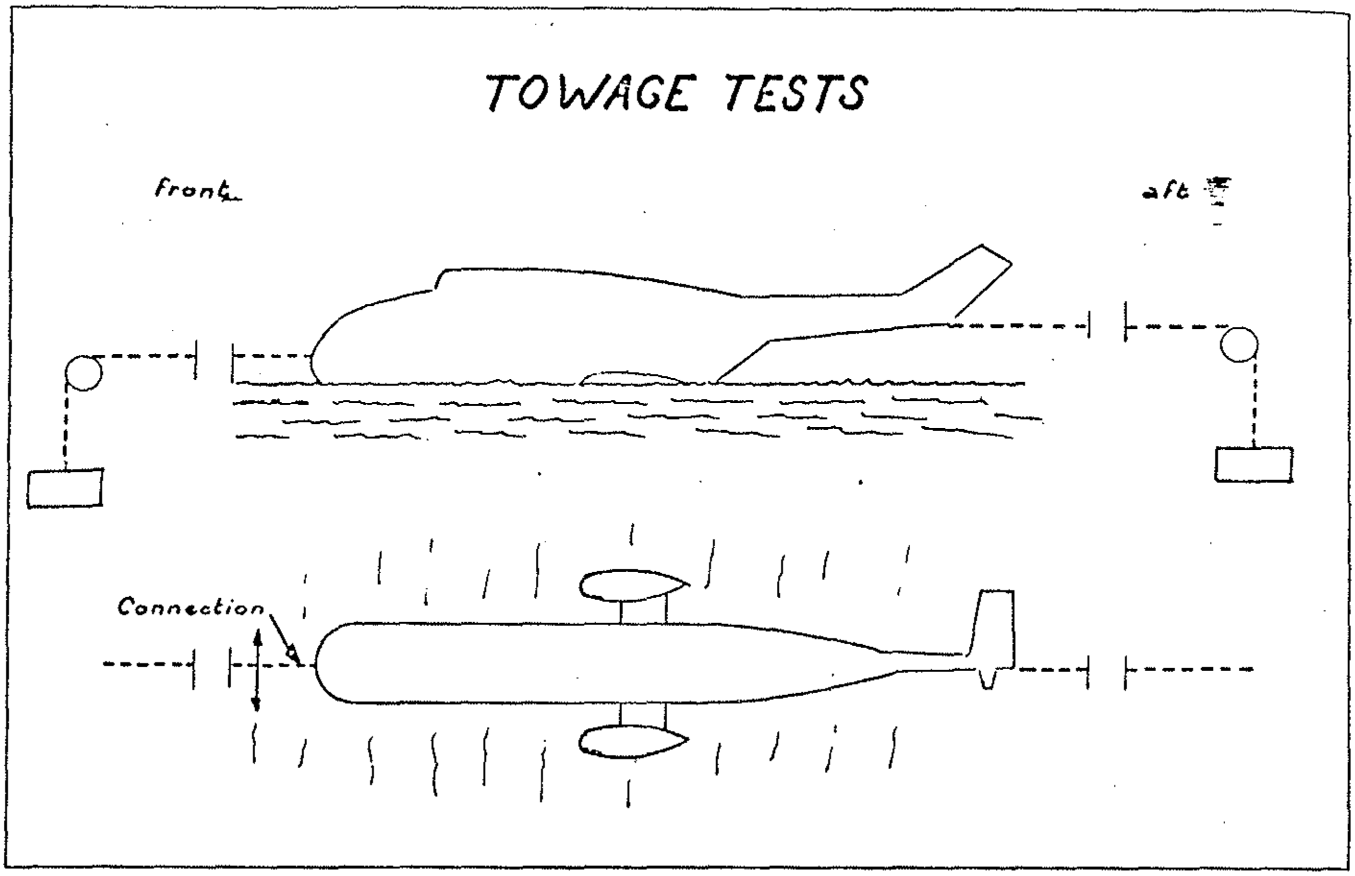

TOWAGE TESTS
front
aft
Connection

Fig. 14

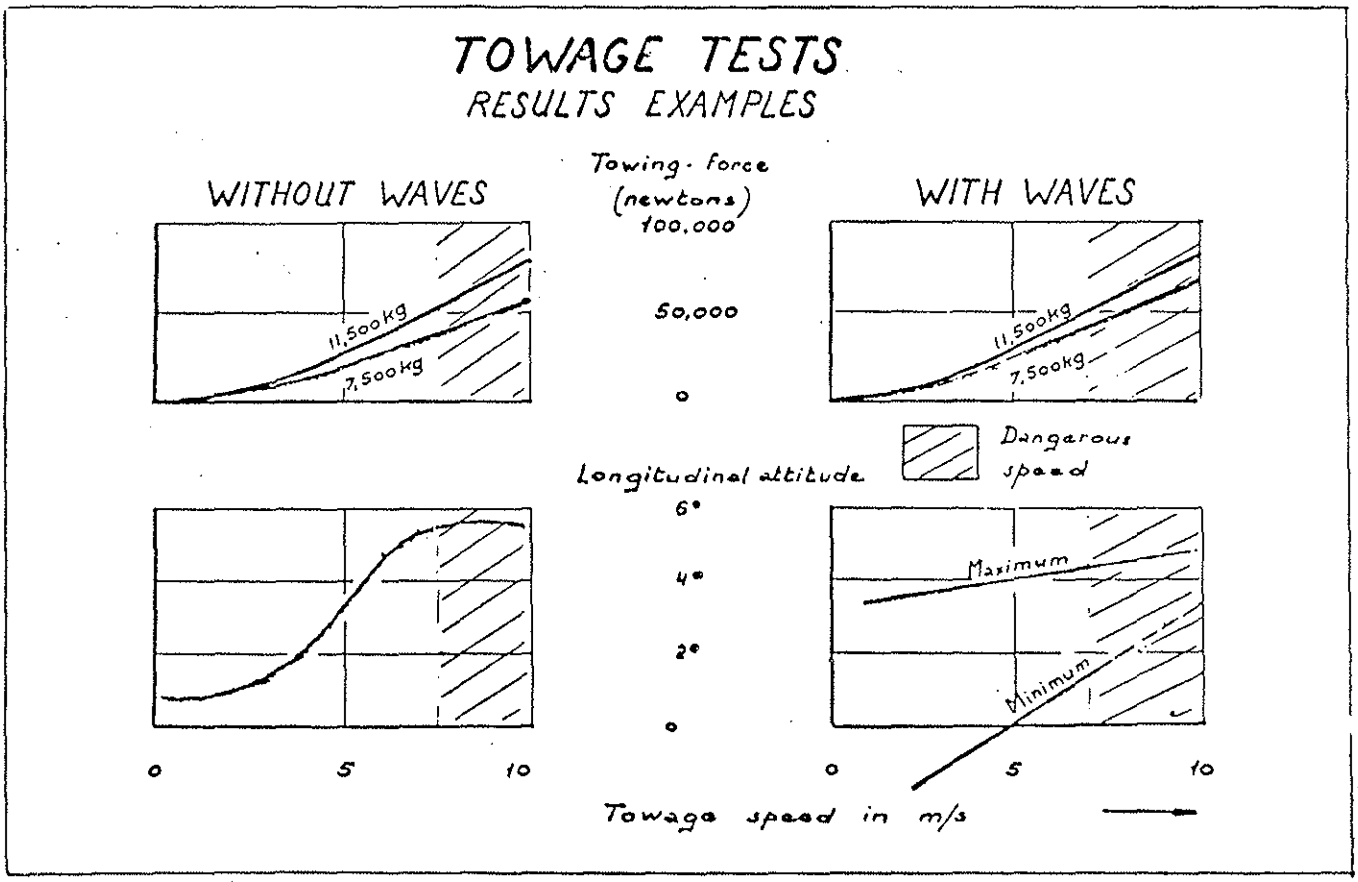
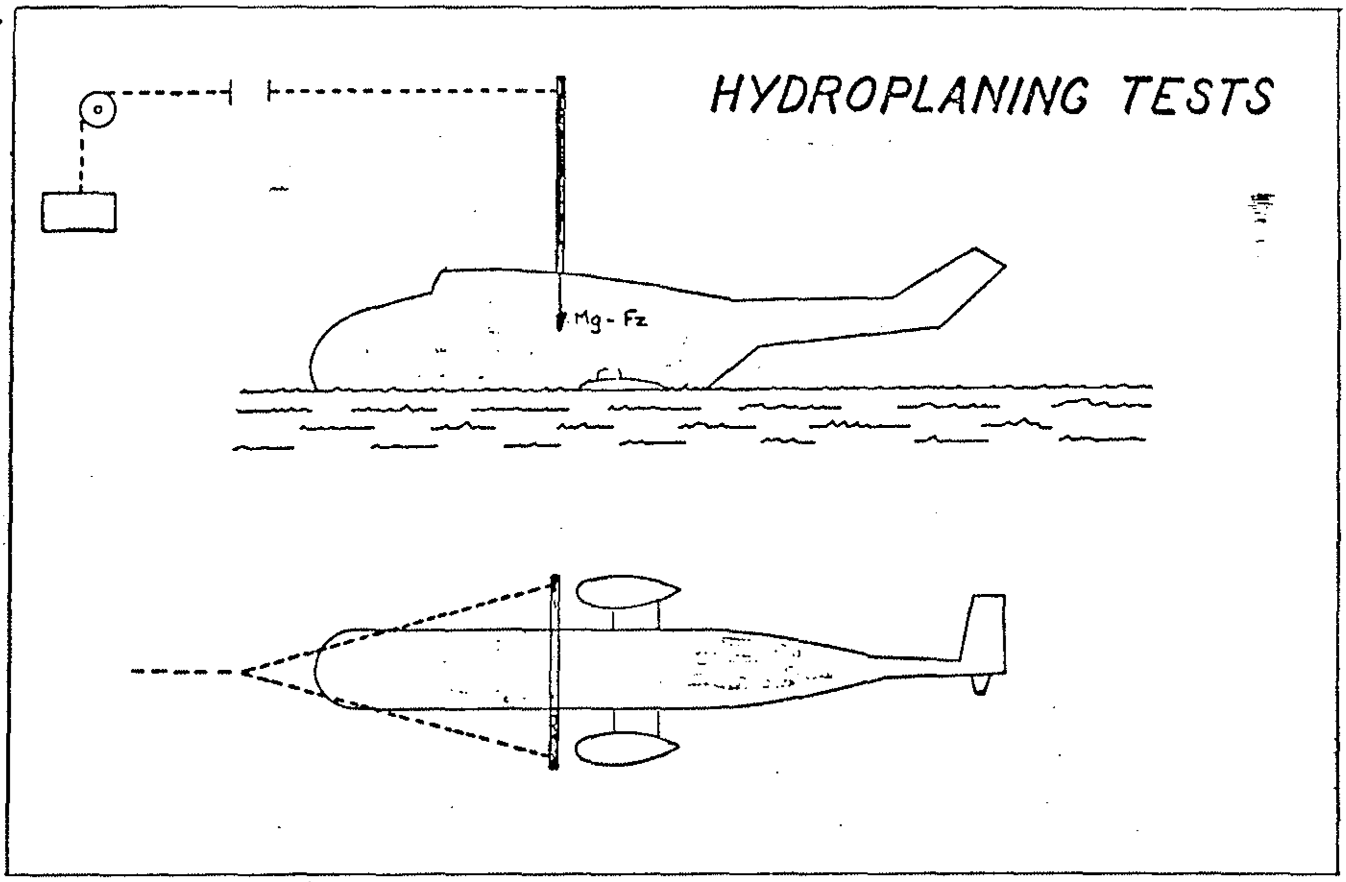
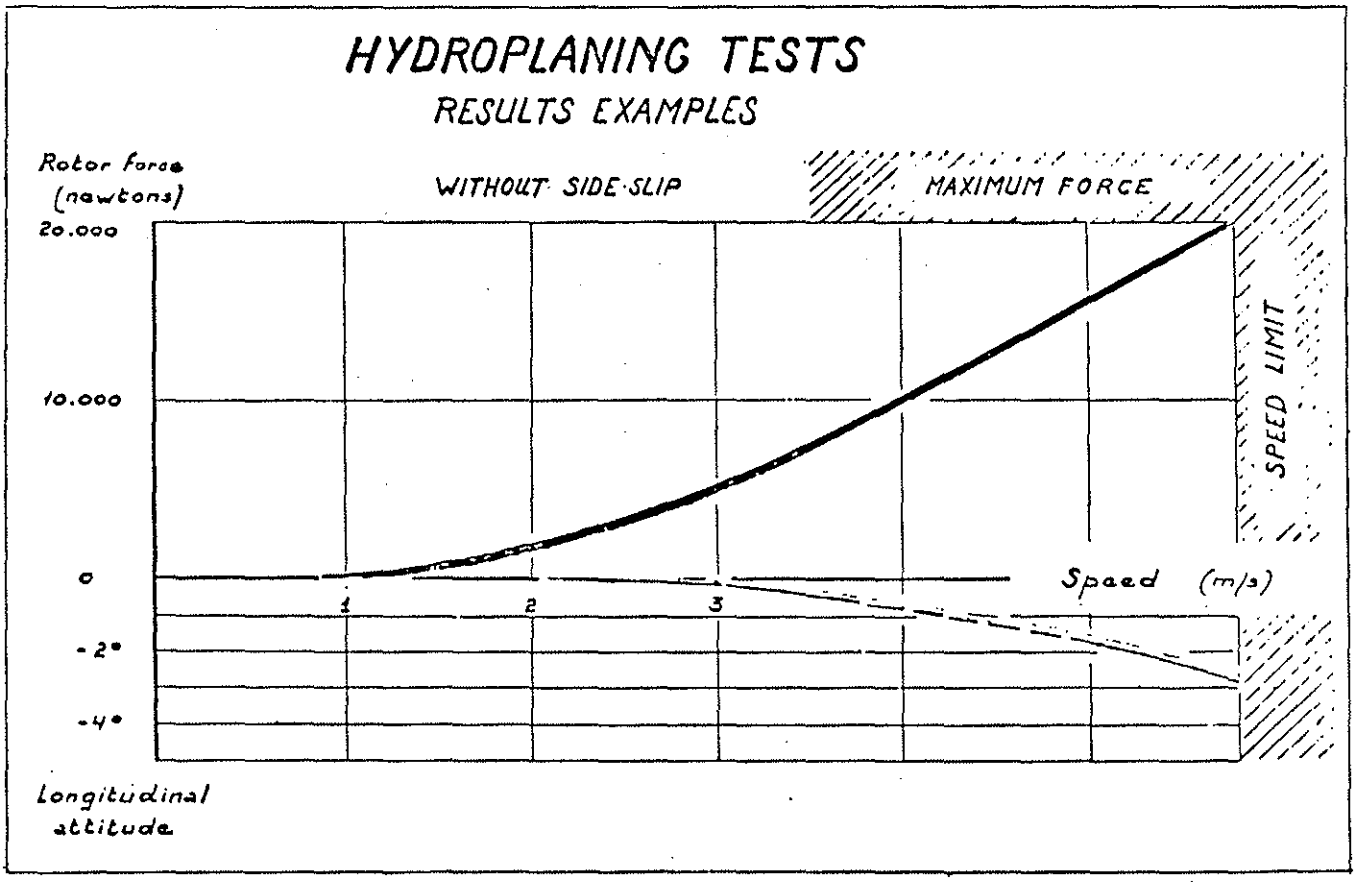

TOWAGE TESTS
RESULTS EXAMPLES
WITHOUT WAVES
WITH WAVES
Towing - force
(newtons)
100,000
50,000
0
11,500 kg
7,500 kg
11,500 kg
7,500 kg
Dangerous speed
Longitudinal attitude
6°
4°
2°
0
Maximum
Minimum
0
5
10
0
5
10
Towage speed in m/s

Fig. 15



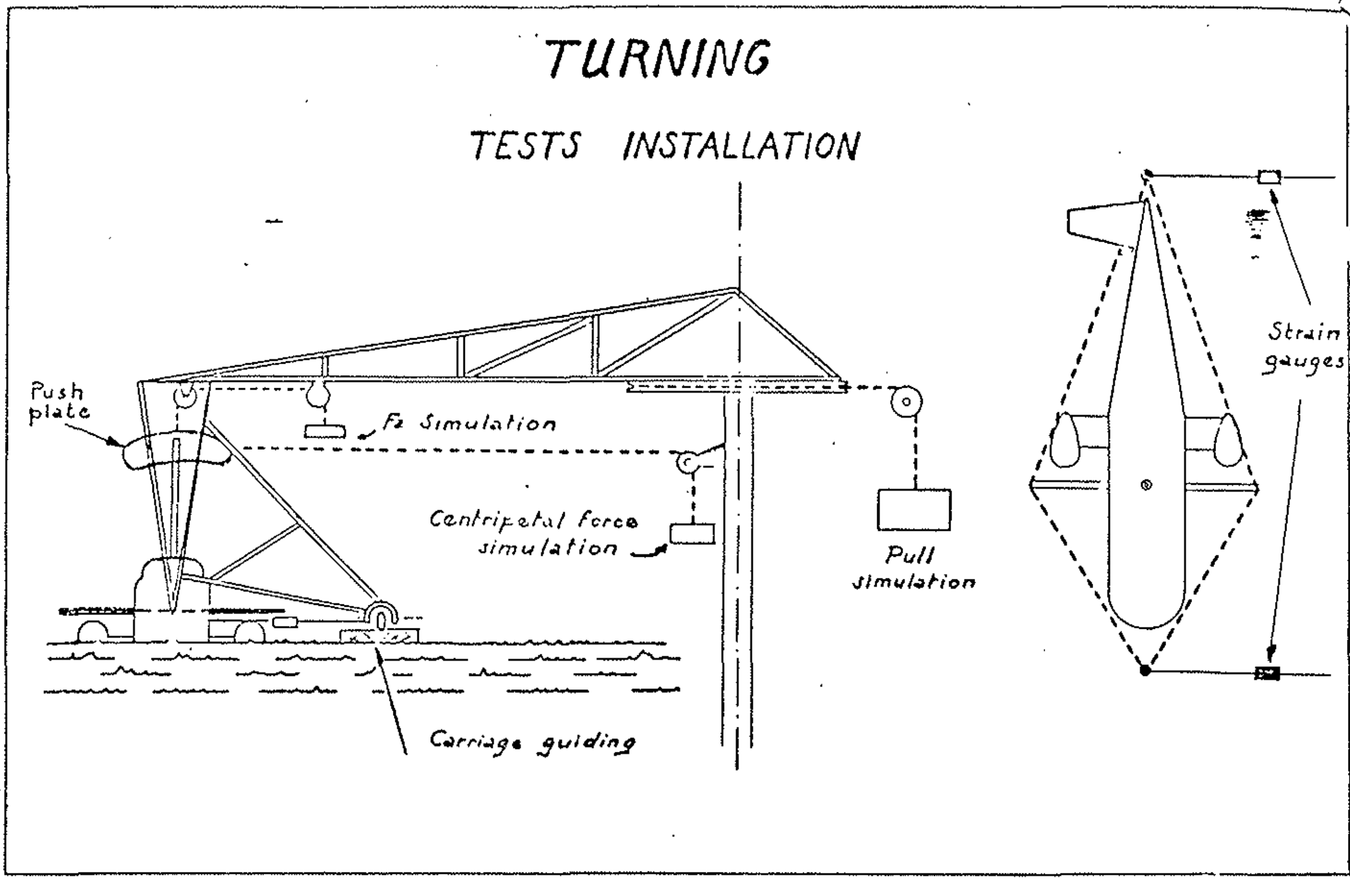
HYDROPLANING TESTS
Mg - Fz

Fig. 16



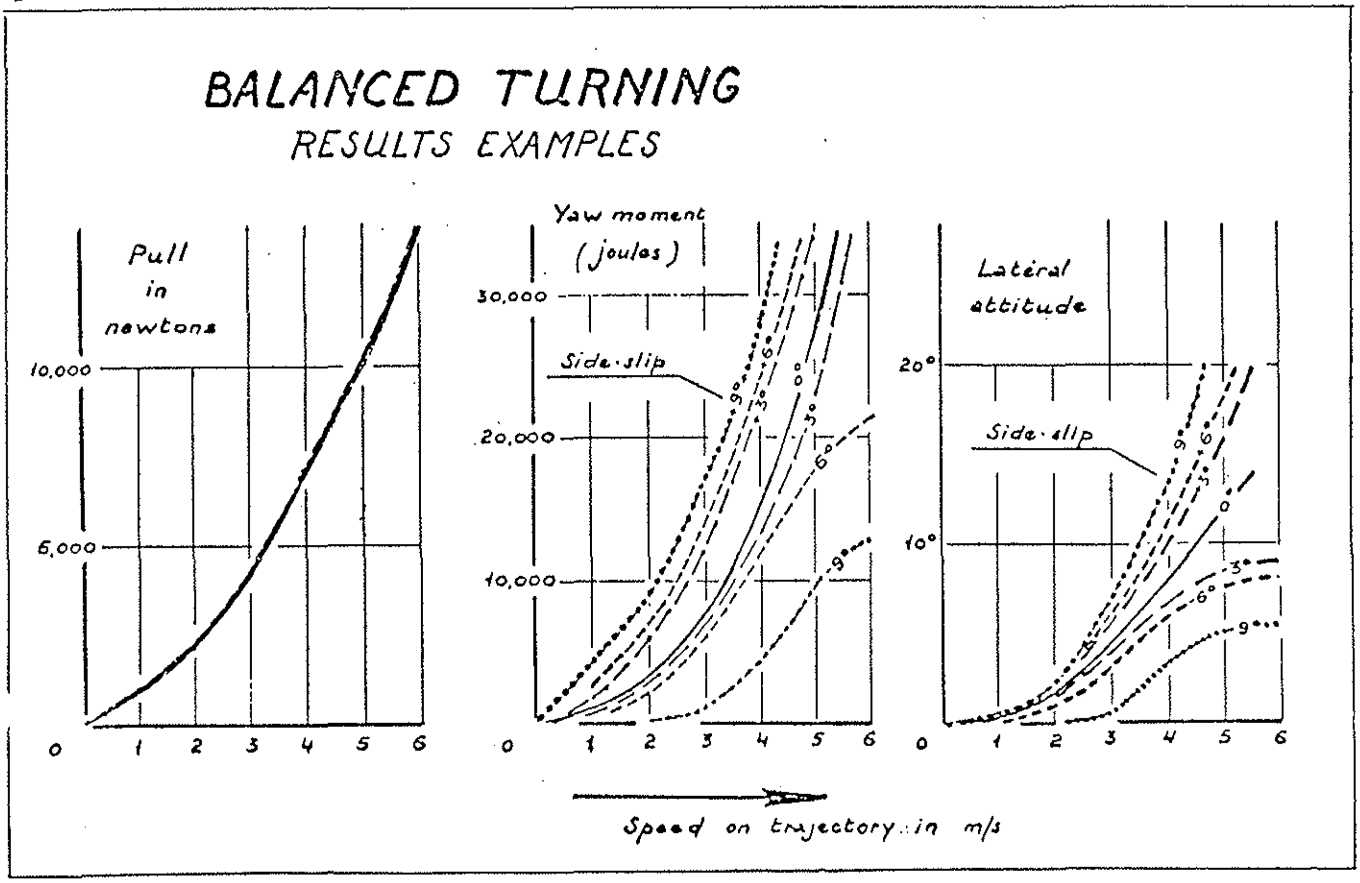
HYDROPLANING TESTS
RESULTS EXAMPLES
Rotor force (newtons)
WITHOUT SIDE SLIP
MAXIMUM FORCE
20.000
10.000
0
SPEED LIMIT
Speed (m/s)
1
2
3
- 2°
- 4°
Longitudinal attitude

Fig. 17



TURNING
TESTS INSTALLATION
Push plate
Fz Simulation
Centripetal force simulation
Pull simulation
Carriage guiding
Strain gauges

Fig. 18



BALANCED TURNING
RESULTS EXAMPLES
Pull in newtons
10,000
6,000
Yaw moment (joules)
30,000
20,000
10,000
Side-slip
Lateral attitude
20°
10°
Side-slip
Speed on trajectory in m/s

Fig. 19

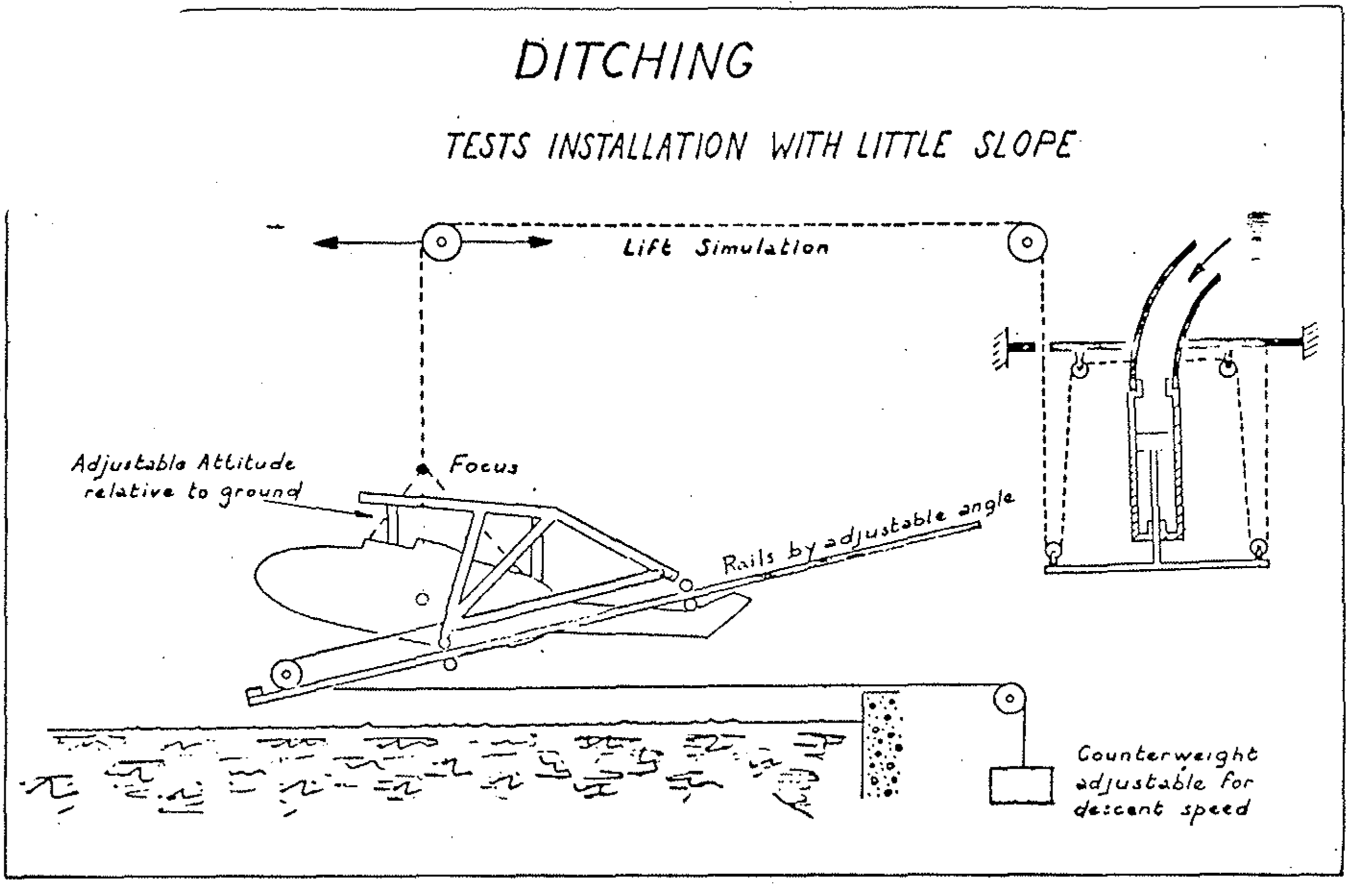

DITCHING
TESTS INSTALLATION WITH LITTLE SLOPE
Lift Simulation
Adjustable Attitude relative to ground
Focus
Rails by adjustable angle
Counterweight adjustable for descent speed

Fig. 20

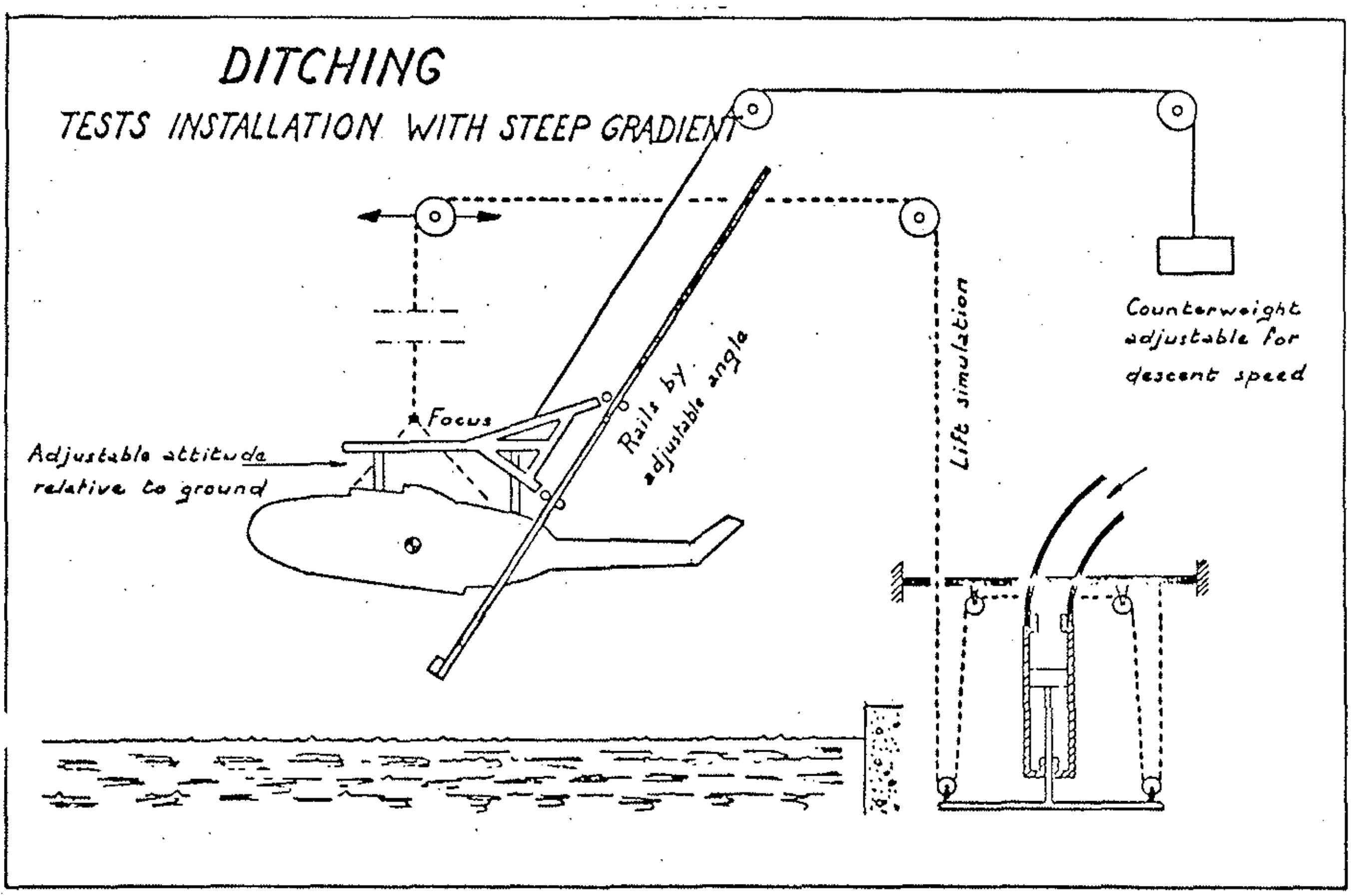
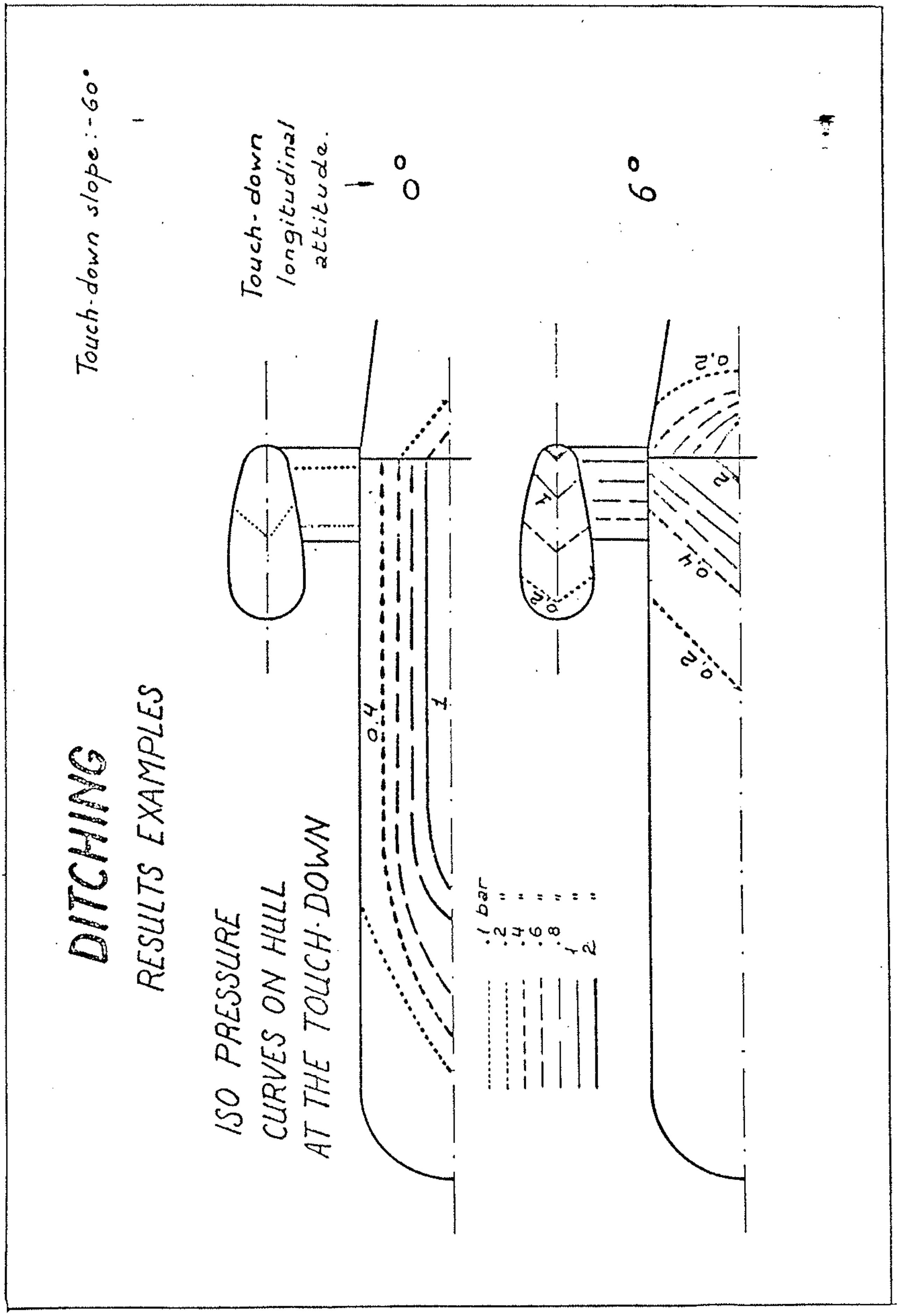

DITCHING
TESTS INSTALLATION WITH STEEP GRADIENT
Focus
Adjustable attitude relative to ground
Rails by adjustable angle
Lift simulation
Counterweight adjustable for descent speed

Fig. 21



Touch-down slope : -6°
Touch-down longitudinal attitude.
0°
6°
DITCHING
RESULTS EXAMPLES
ISO PRESSURE
CURVES ON HULL
AT THE TOUCH-DOWN
.1 bar
.2
.4
.6
.8
1
2
0.4
1
0.2
0.4
2
0.2

Fig. 22

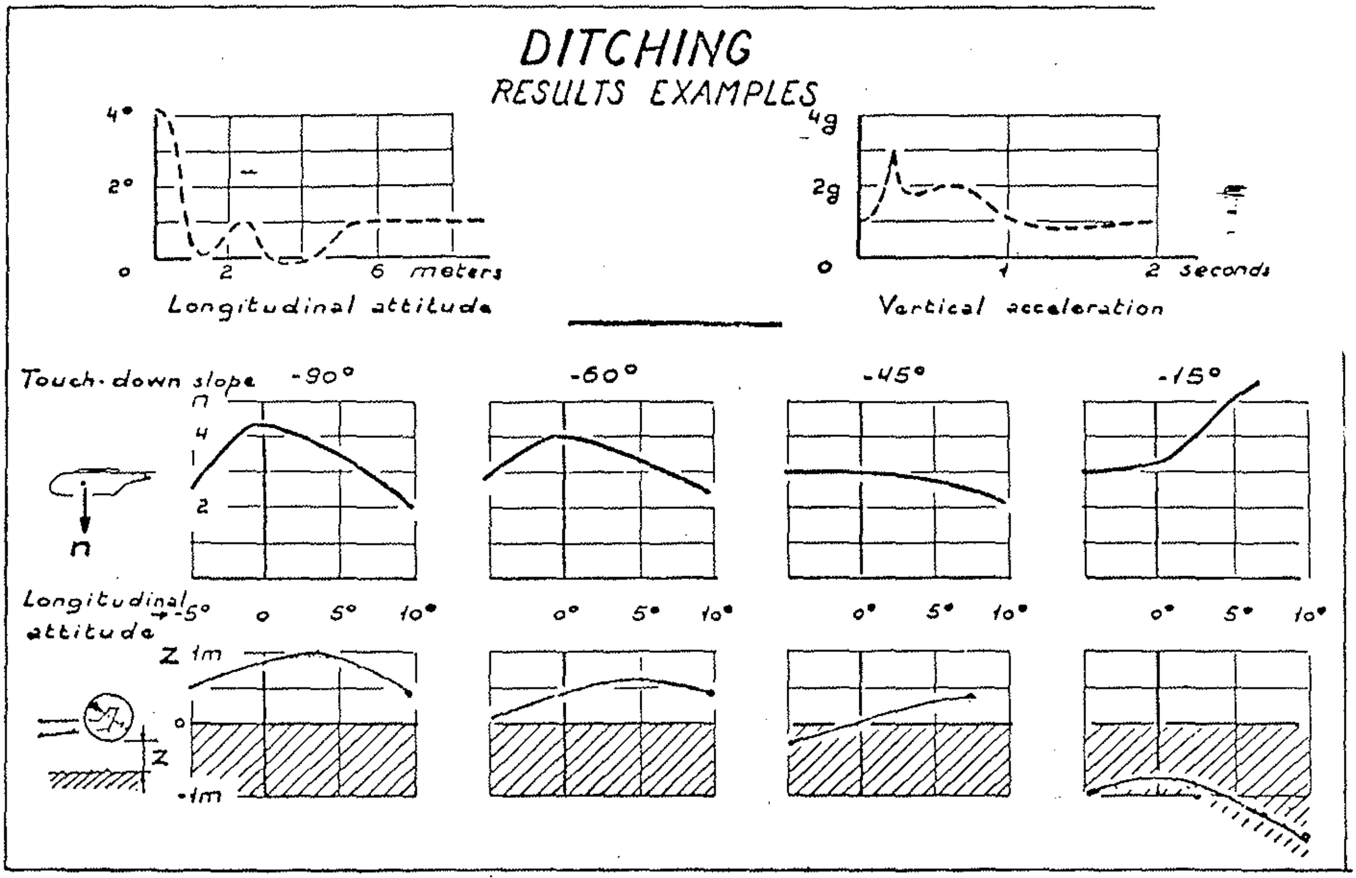

DITCHING
RESULTS EXAMPLES
Longitudinal attitude
6 meters
Vertical acceleration
2 seconds
Touch-down slope
-90°
-60°
-45°
-15°
Longitudinal attitude
Z 1m
-1m

Fig. 23

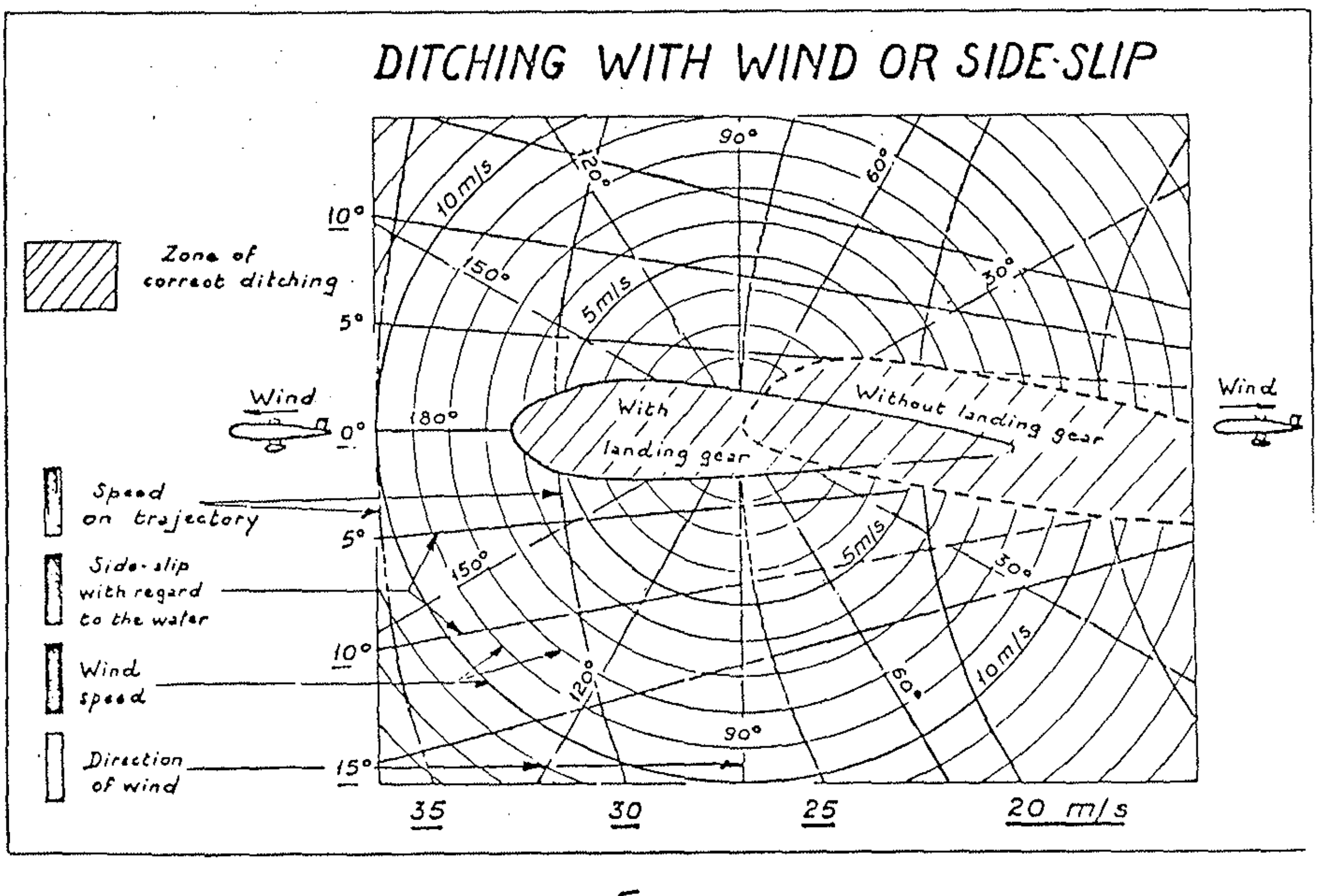

DITCHING WITH WIND OR SIDE-SLIP
Zone of correct ditching
Wind
With landing gear
Without landing gear
Speed on trajectory
Side-slip with regard to the water
Wind speed
Direction of wind
10 m/s
5 m/s
35
30
25
20 m/s

Fig. 24