STATEMENT OF A YEAR'S INVESTIGATION OF THE A. V. ROE CANADA V.T.O. PROJECT AND OUTLOOK ON ITS DEVELOPMENT

May 12, 1953.
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To - Prof. D. L. Mordell

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Malton, Ont.

Aerodynamic Design and Performance Prediction of the Engine

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SECRET

(SPARE SHEET)

On Fig. 11 the increases in thrust and consumption with reheat are plotted, and it is suggested that if these are used with Fig. 8 a good first approximation to the true performance will be obtained.

When the design is finally agreed on a more detailed set of calculations, taking account of variation of specific heats, using more data, and a calculating machine, should be made to produce a final performance prediction.

GENERAL CONCLUSIONS

(1) With the exception of the height of the last stage compressor blade, the present design appears to be aerodynamically satisfactory. The turbine as drawn would be improved by lengthening the blades some 15%.

(2) To get the proposed thrust, the mass flow must be increased by some 10% (spec. thrust 51/lbs/lb/sec) In part this may require lengthened blades, but it is believed that probably half of the increase can be accomodated by an increase in Mach number on to the first stage compressor blade.

(3) The performance at high flight speeds is good. In the tropopause reheat is effective.

D. L. Mordell.

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STATEMENT OF A YEAR'S INVESTIGATION OF THE A. V. ROE CANADA V.T.O. PROJECT AND OUTLOOK ON ITS DEVELOPMENT

1. INTRODUCTION

This project is essentially a simple proposal to make a very large gas turbine engine a suitable shape to fly by a redisposition of its functional parts.

The "flying wing" formed by covering the engine is then said to be the minimum aeroplane that can be designed round a turbo-jet engine.

At its inception it was said that the arrangement could result in a S.L.S. thrust/frontal area ratio of about 850 lb./sq. ft. for the whole aircraft and a S.L.S. thrust/weight ratio of about 2.0 lb./lb. so that vertical take-off and landing and supersonic flight would be possible in the same aeroplane. It was implied that these figures could be obtained by using this layout with a gas-turbine engine of very ordinary efficiency by present day standards, without reheat.

The engine essentially involves a large diameter rotor flying edge on to the wind instead of axially with a polar inertia about $\frac{1}{4}$ of that of the whole aircraft. It was also suggested that this rotor would provide heavy gyroscopic stabilization and permit the centre of gravity to be in the middle of the all-wing aircraft even for subsonic flight, that is to say permit what would be a hopelessly unstable condition in the absence of the gyroscope.

After some considerable study it is still said that it will be possible to provide a S.L.S. thrust/frontal area ratio of about 750 lb./sq. ft. and a S.L.S. thrust/weight ratio of about 1.60 lb./lb. with an engine of very ordinary efficiency and to boost these figures to 950 lb./sq. ft. and 1.9 lb./lb. with development of the engine. By using a simple fixed nozzle reheat scheme, reheating to a very moderate temperature, further increases will be possible.

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3 TECHNICAL EVALUATION

3.4 STABILITY AND CONTROL (continued)

In the first (S.&C. 1) complete equations of motion are set up and the method of attacking the problem is outlined and in the second (S.&C. 2) numerical solutions are presented. Approximate derivatives are used and varied over a wide range to study their effects. Mach numbers of 0.75 and 1.5 have been considered at S.I. and [illegible],000 ft.

In the third (S.&C. 4) a simplified approach is adopted aimed at studying the various modes independently of one another. Numerical solutions are compared with numerical solutions by the full equations of motion developed in the first report and agreement is good. The solutions show various modes.

(a) A nutation, a gyroscopic oscillation which is reasonably damped at ordinary or high forward speeds and of very small amplitude at slow speed.

(b) A snaking, showing normal damping reinforced by the dashpot effect of the engine rotor.

(c) A quite rapid subsidence in the vertical velocity perturbation.

(d) Two very slow subsidences, one very slow divergence. The slow divergence is so very slow that it is immaterial.

A fourth report (S.&C. 3) deals exclusively with the gyroscopic oscillation or nutation and shows that it is impossible to excite a nutation of appreciable magnitude in the static case.

Finally a report by Dr. G. Bull showing the response to step input functions evaluated on an analog computer is presented. These results were obtained with an independently estimated set of derivatives and show good agreement with the conclusions of the second report. The principal derivatives are again varied over a wide range, and their effects confirmed.

Two notes on control are also available (S.&C. 5 and 6). The first is a brief examination of rates of roll at supersonic speed and in the second control angles for turns to various 'g' are evaluated. The response to fully crossed controls with various amounts of negative static margin has also been examined for some cases. At high subsonic speed at S.I. "cross back" angles (counter-action of induced roll due to negative margin when pitching) become quite large but this is thought to be acceptable.

A memorandum on the position at March 1, 1953 summarizes the situation.

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3. TECHNICAL EVALUATION

3.5 STRESS ANALYSIS

The main emphasis in stressing has been placed on the rotor assembly and main body structure as being the components having the greatest bearing on accurate wiehgt estimation and effect on engine performance. The rotor is dealt with in a comprehensive report (Stress 1) which evaluates the stresses and radial deflections due to centrigugal forces and assumed temperature gradient. It also includes a theoretical analysis and numerical calculations to determine the deflections, out of the plane of rotation, due to manoeuvre. A rate of manoeuvre of one radian per second has been assumed in the numerical calculations. A detailed study (Stress 3) of the rotor bearings and bearing rail stresses has been carried out and endorsed by the Barden Corporation (makers of precision ball bearings). It has been shown that an average bearing life in excess of 6500 hours is obtainable.

The main body structure report (Stress 2) shows the deflection of the ribs at critical engine stations and stresses under maximum engine pressures. Work is being carried on at present on the effect of air loads on rib and skin stresses. However, since these loads are, at the most, only about 10% of the engine bursting loads, it is anticipated that they will have little effect on the strength of the structure. A preliminary investigation showed that the air load distribution followed very closely the weight distribution so the large bending moments found in conventional wing structures are not present in this aircraft.

Preliminary work has also been done on the turbine and compressor blading, and the stresses and deflection of the undercarriage due to flight and landing loads.

4. TESTING

4.1 FREE FLIGHT MODEL

A 1/10 scale representative near-free flight remote-control model with all degrees of freedom excepting sideslip and forward velocity has been made; and qualitative assessments of the control response and characteristic have been carried out on a rig, mounting the model in front of a motor car. It proved easily controllable with a large negative margin. The controls were crossed through 90° and a representative gyro was rotated by means of two small electric motors in the model. This model can easily be put in a slow speed wind tunnel on a modified mounting which may cater for freedom in sideslip. Photographs are included with this note.

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4. TESTING

4.2 WIND TUNNEL MODELS

Three wind tunnel models have been designed:

1. A 1/14 scale model omitting the air intake but simulating the peripheral jet flow with air from a static tank; with representative control surfaces. A preliminary plan for static tests with this model is contained in a formal report (W/T 1). This model is just finished and ready for testing. Photographs are included with the report.

2. A 1/10 scale ½ plane model simulating both intake and jet flows is covered by a second report (W/T 3) with drawings. This model is part finished. Provision is made for sucking or energizing the boundary layer in front of the intake and the model will also be fitted up to make surface pressure recordings.

3. A 1/40 scale ½ plane model with the jet flow simulated has been designed for a 10" x 10" supersonic suck-through tunnel. The jet flow is simulated by an air flow and again the intake is omitted. At such small scale it is not felt to be worthwhile in any case. A plan for tests with this model is covered by a third report (W/T 2) with drawings.

4.3 ENGINE DETAILS

Two simple tests which are important to the engine design are under way on a combination rig. The rig consists of a 3 ft. diameter steel disk spun at 3600 rpm by an electric motor.

The outer rim of the disk runs at the same speed as the track supporting the rotor and is used as a runner for a test roller; which is loaded against it with similar loads as on the full scale rotor. To represent still more closely the true working conditions of a roller, the whole disk plus roller will be put in an insulated chamber, which can be controlled at the temperatures at which the roller will work in different flight conditions.

The front face of the disc is used for testing the shroud seals of the engine compressor. This seal consists of a thin metal plate having a feather edge which maintains a small gap with the shrouding, and deflects with the rotor. A special chamber to which the test seal rings are attached can be pressurized and the rate of leak as well as mechanical friction (as a function of deflection) will be measured. Photographs of this rig with the seals assembled are included with this note.

4.4 RESEARCH TESTING

In the proposed aircraft the final nozzle may be considered as a slot some 50 ft. long. It is well known that a jet issuing from a slot can be deflected through very large angles simply by a curved surface [illegible]

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4. TESTING

4.4 RESEARCH TESTING (continued)

with the edge of the jet on one side. (The so-called Coanda effect). Since control of thrust forces is a cardinal feature of this design tests are being carried out to investigate this extremely simple method of control. Depending on the results the possible application to this project will be considered.

It seems likely that no such suitable application of this principle has arisen before and there is not as far as is known any systematic body of tests of its efficiency nor on whether the deflections so produced can be readily controlled.

Some very preliminary small scale testing has been carried out using an air jet issuing from a slot around a 6" diameter disk and deflected around a 0.3' radius. Photographs of a balance rig (which demonstrates a large ground effect) and a rotating arm rig are included with a brief note of the interesting but mostly qualitative results so far obtained. It seems well worthwhile to expand and increase the scale of these tests.

5. ENGINE COST FORECAST

It is naturally assumed by most people making a first examination of this project that because of the physical size of the engine rotor it involves an enormous engineering effort taking years and costing millions of dollars (or pounds). In an attempt to put things in perspective and to emphasize the basic simplicity which is achieved - and which must be reflected in cost - an estimate of the cost of the latest designed engine has been prepared in great detail.

This cost estimate is necessarily very limited in scope since it has not yet been possible to get a realistic idea of the cost of the whole aeroplane nor of the test house and facilities necessary nor of course will it be possible to estimate the inevitable development cost. Nevertheless it covers the whole unit as designed and because it is largely made up of contractor's quotations to engineering drawings, its probity makes a considerable impact.

One such quotation (the J. Brockhouse Engineering Co. (Canada Limited) gives the striking figure for compressor blading strip rolled finish at $2.50 per 100 ft. length, which is less than 2¢ a blade.

The engine of the present design produces as much power as is provided by seven of today's current engines in the 6000 lb. class. Seven of these may be expected to cost say $400,000 or £150,000 on production.

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5. ENGINE COST FORECAST (continued)

This sort of production figure is contrasted with a firm estimate of $325,000 for the proposed engine as a one-off job of which only $120,000 is labour and material cost and $100,000 is a heavy contingency allowance. More than anything else this proposal represents an effort to cut down on the rising costs which are coming to be inevitably associated with top-level performance.

6. SIMPLICITY OF THE DESIGN

In advocating this project the basic simplicity is put forward as its most important feature. An exploded view of the aircraft has been drawn to illustrate the main component breakdown except for the appendages outside the engine, and is included with this note. To assemble the engine the upper and lower rings are simply bolted together around the rotor. It is envisaged that this breakdown can be made a relatively simple servicing operation. The engine and fuel cell doughnut is thus a separate unit and in the middle the crew compartment is fitted. The intake shell and undercarriage complete the assembly out to the turbine ring.

A further sketch is also included which illustrates a satisfactory light undercarriage consisting of a quadriped gear (the legs retracting back onto a central longitudinal beam, leaving the wing tips free for fin and rudder in the jet stream). The most recent schemes for intake and controls are also available.

7. OUTLOOK

The engine as designed has two main advantages:

1. Its specific cost in thrust per dollar or £ sterling looks very good.

2. It is a suitable shape to fly and dovetails into the simple aeroplane which has been designed, giving it vertical take-off and landing, gyro stabilization and exceptional performance.

The next step is to build and prove this engine. Little virtue is seen in attempts to test it at small scale; it is questionable whether much would be saved by building at say ½ scale instead of in the required size where all is accounted for: certainly nothing would be gained.

Rig testing is another matter and tests have been proposed for developing exhaust system and controls using the blast of some suitable jet engine; but these do not affect the building of the basic engine. Rig testing of the combustion system, which does, is the earliest necessity. The compressor blading may also be tested at small diameter in a high altitude tunnel.

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7. OUTLOOK (continued)

At the same time the best arrangements for controls, undercarriage and intake and exhaust systems - which are about all that is left of the aeroplane - should be further studied, and the various tests arranged carried on with as quickly as possible.

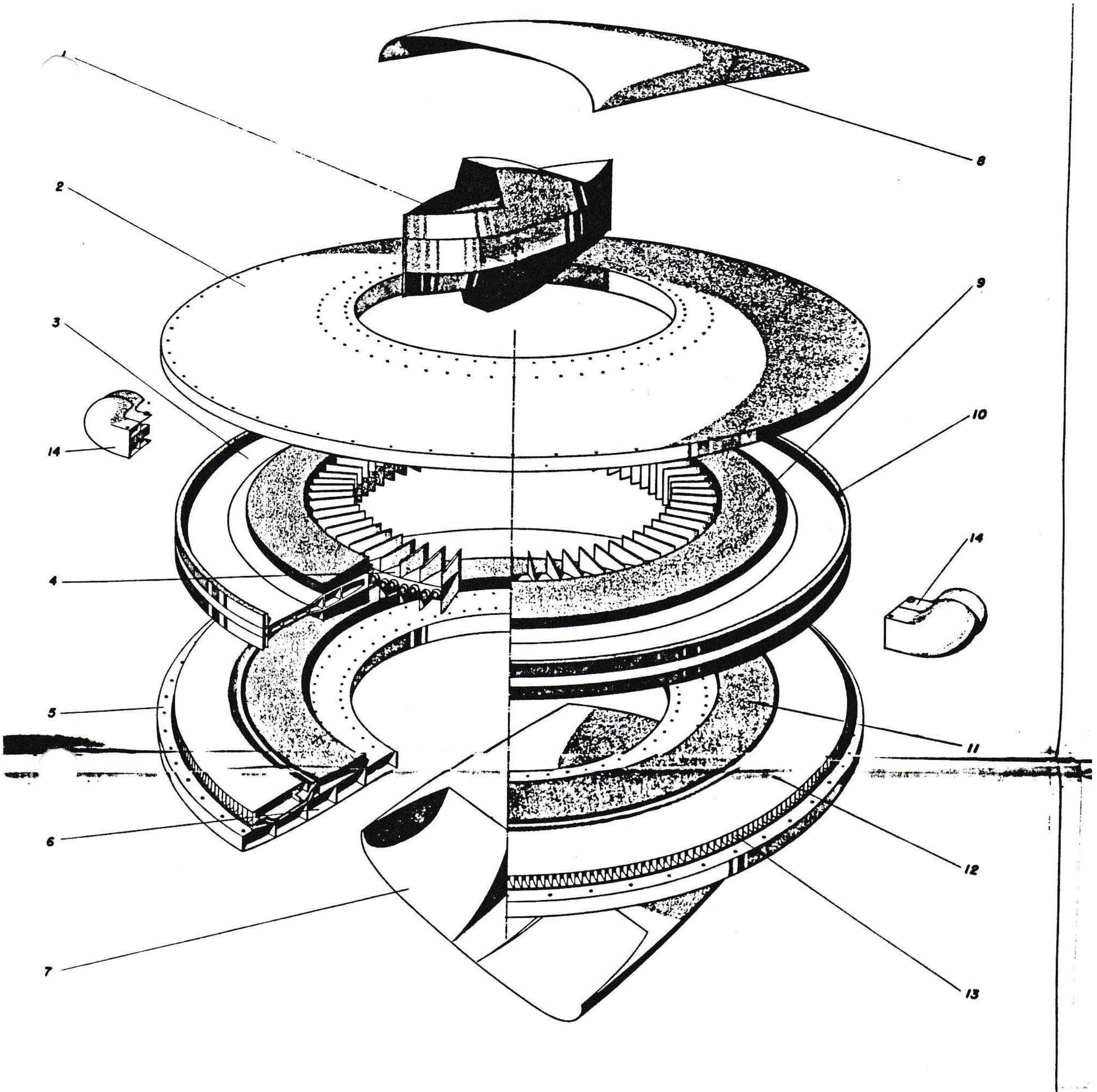
It seems right to design the first aircraft of such a novel form as this as a research job. It has deliberately been kept small with this in mind although the size of the compressor blading indicates that in this size the engine is smaller than the optimum for the layout. Again it is pointed out in the engine report that in a larger size the engine may be less cramped for compression ratio - that is it may be possible to increase the principal flow area dimension (thickness) more than the radial length of the engine. Fuel capacity will increase as the cube of the linear dimension but overall thrust/weight ratio need by no means be expected to fall linearly. The military role which the type of aircraft can accomplish must not however be lost sight of and the suitability of the layout for armament and radar installation ought to be considered.

The proposed aircraft could without difficulty and with little effect on performance be armed with four of the latest U.S. h.v. 20 mm. cannon. with gun laying radar, and a large salvo (200) of 1.5" NAKA air-to-air rockets. With an armament like this (the installation should weigh less than 1700 lb.)(guns are 130 lb. each. rockets 3.5 lb. each) it appears that what we have considered a minimum size is a happy one from the fighter viewpoint. Alternatively, it is suggested that guided missiles (for instance Falcons) can possibly be stowed in the large space given up to ammunition boxes and rockets. Drawings showing the suggested installations are available. As a transonic-supersonic fighter of only 15 ft. maximum dimension; and having vertical landing and take-off ability; this aircraft should have an exceptional utility, and could be operated from almost anywhere. It could, it is suggested, even be carried on or in a submarine. Furthermore. (for good measure) in a defensive role it might be held that an aircraft that can put down almost anywhere can expect its return journey fuel to be brought along in a bowser after a "forced" landing. For ferrying, external tanks are not excluded, or external drop tanks for increased combat range.

Finally, it is obvious that it would be very nice to make a craft that would take-off flat. It is clearly possible to achieve this by making use of the so-called Coanda effect; the large ground effect associated with it reinforces this claim. The potentialities and means for controlling such an aircraft remain to be worked out. It seems that the "unsticking" of the jet by introducing air at its low pressure side is a servo-mechanism which may have considerable possibilities.

Without prejudice to the construction of the high performance aircraft now almost designed, here is a sideline which should be followed up with great care.

May 4, 1953.
T. D. Earl - cs



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2· TOP STRUCTURAL UNIT
3· ROTOR UNIT
4· BEARING RING
5· BOTTOM STRUCTURAL UNIT
6· INTEGRAL FUEL TANK
7· BOTTOM INTAKE SHELL
8· TOP INTAKE SHELL
9· COMPRESSOR ROTOR BLADES
10· TURBINE BLADES
11· COMPRESSOR STATOR BLADES
12· BOTTOM COMBUSTOR
13· NOZZLE GUIDE VANES
14· EXHAUST NOZZLE

—A.V. ROE CANADA LTD.— MALTON ONTARIO		
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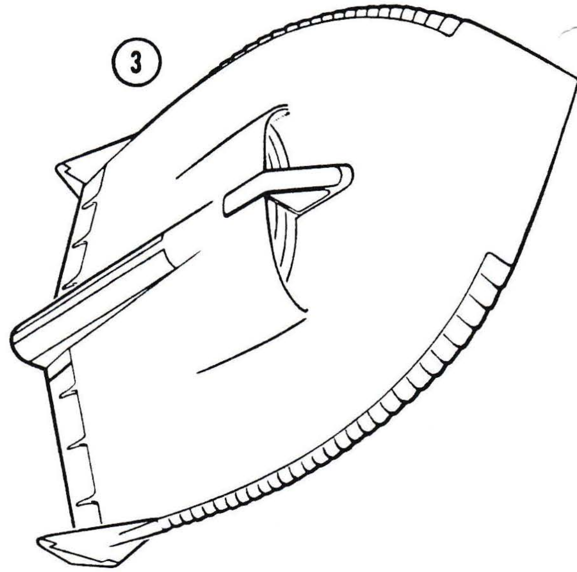
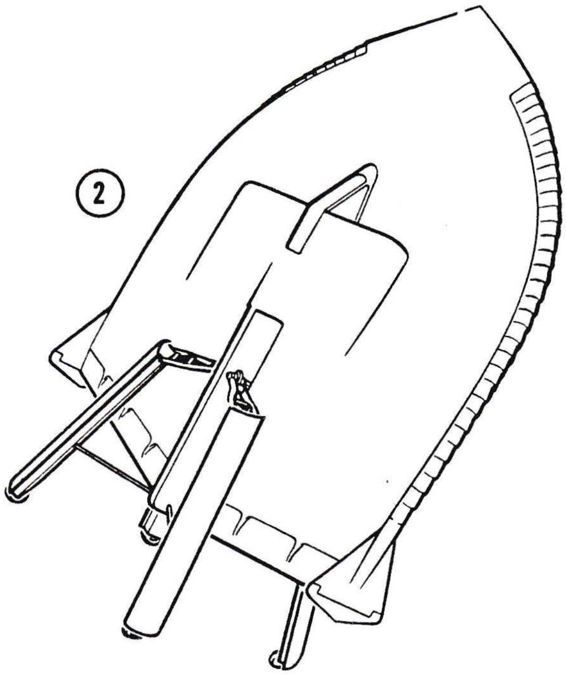
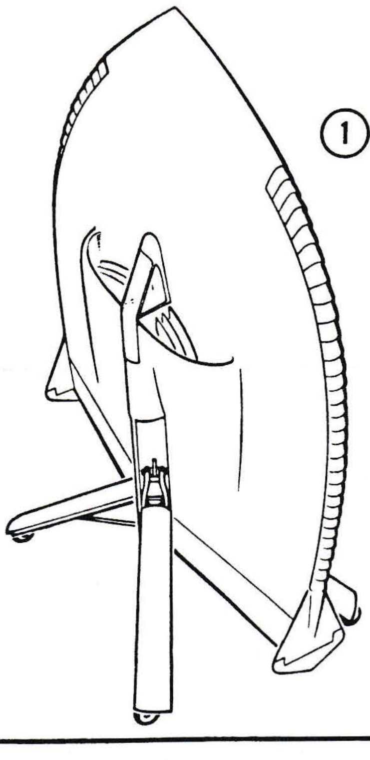


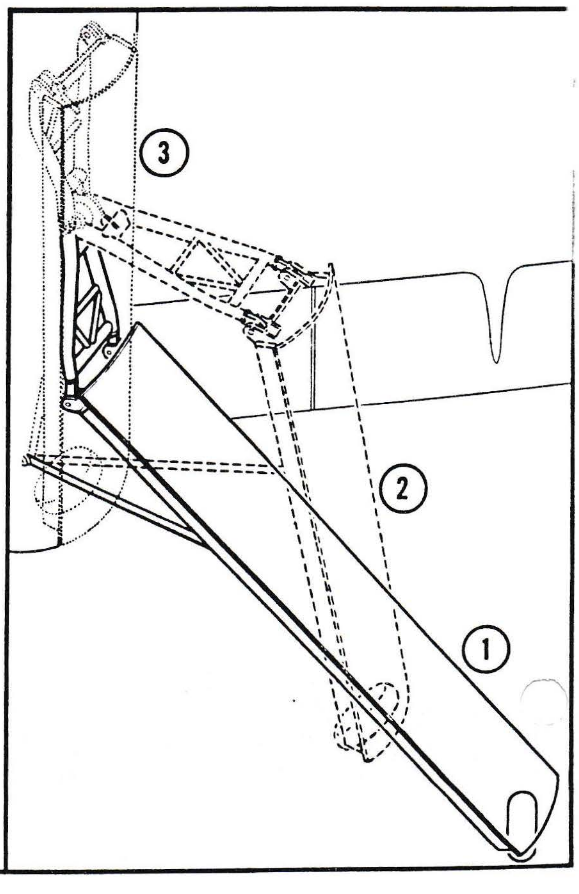




(1) UNDERCARRIAGE IN EXTENDED POSITION

(2) UNDERCARRIAGE IN PROCESS OF RETRACTION

(3) UNDERCARRIAGE RETRACTED

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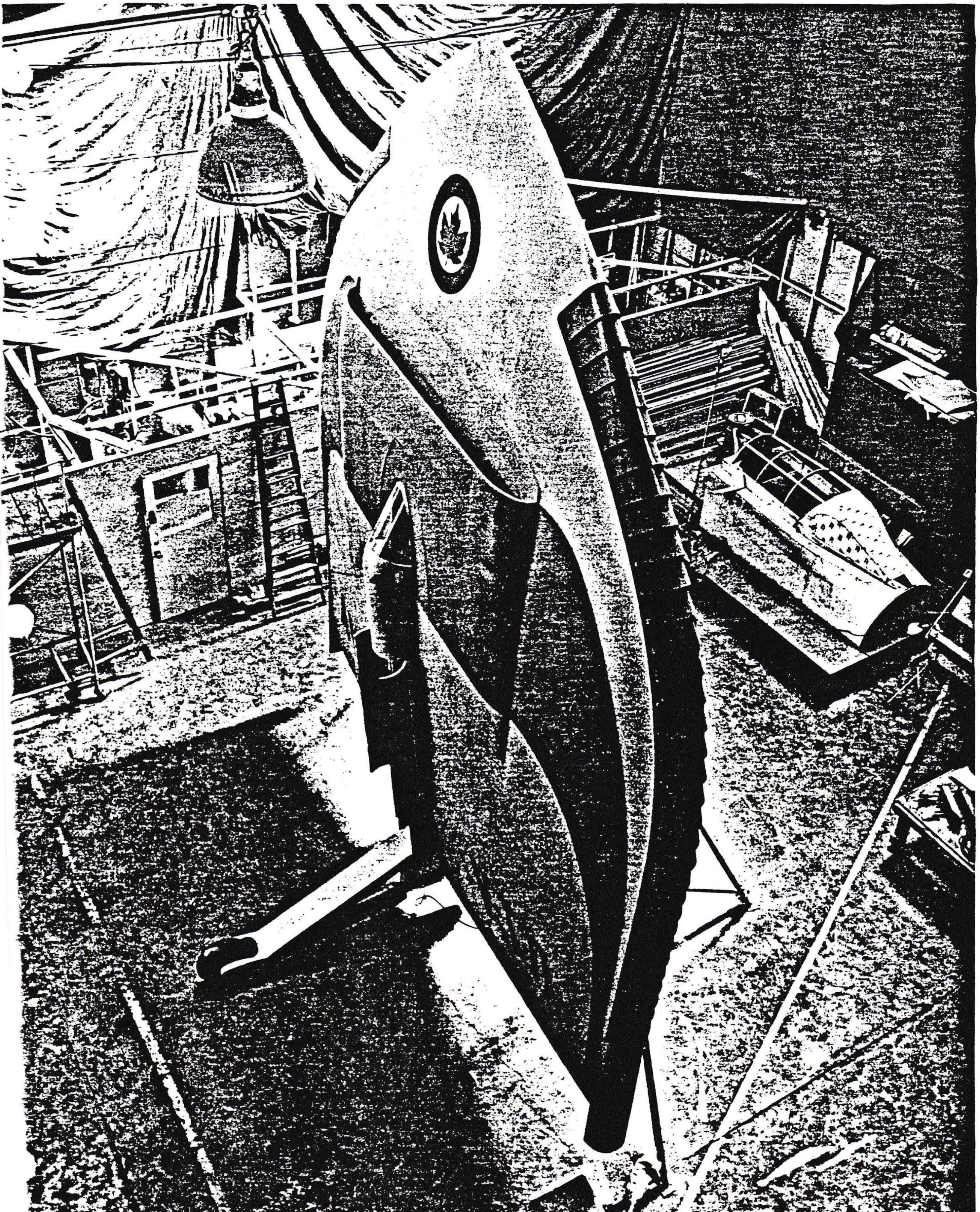

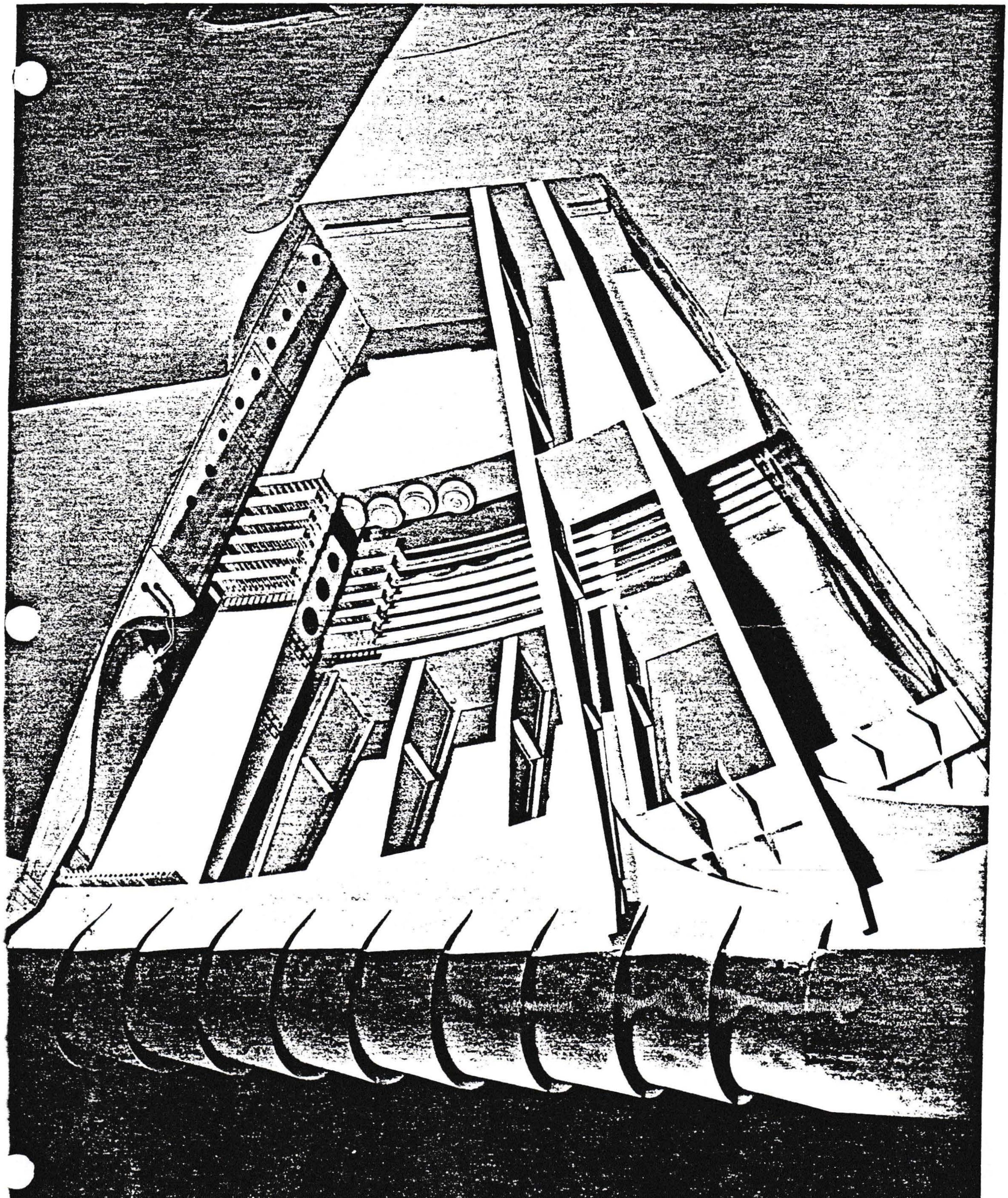

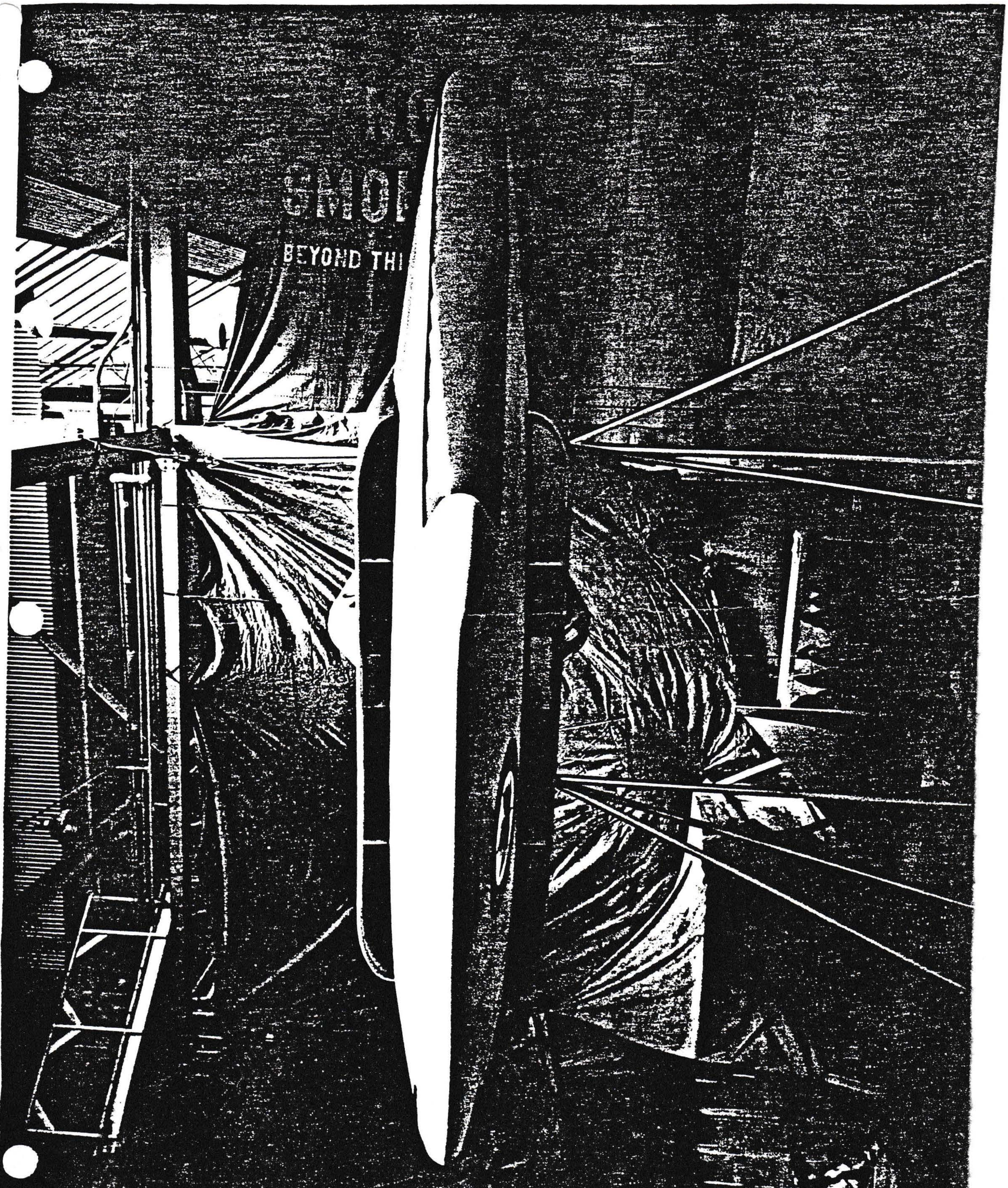
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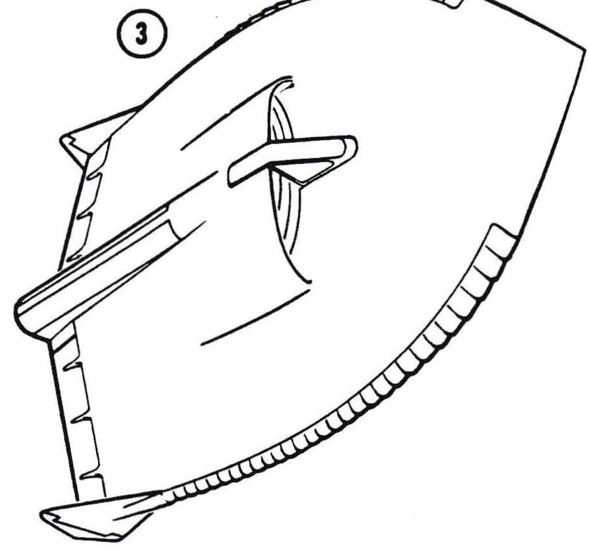

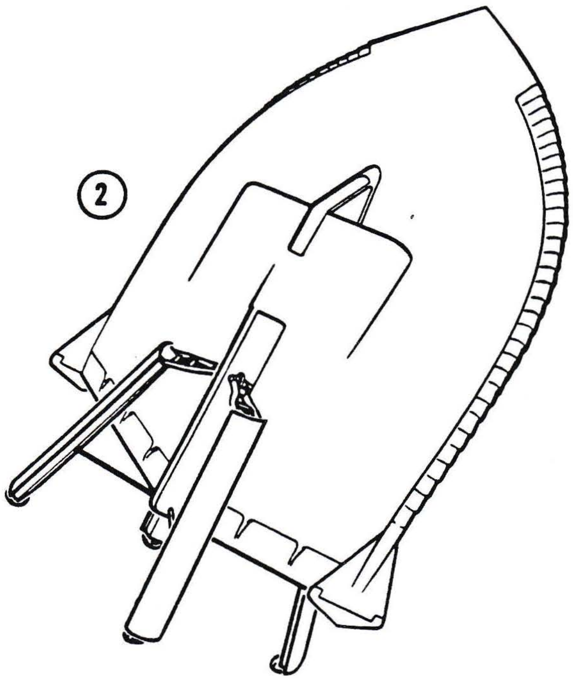

1) UNDERCARRIAGE IN EXTENDED POSITION

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