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ENVIRONMENTAL RELIABILITY TESTING OF HELICOPTER SYSTEMS

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SUMMARY

This paper describes the techniques employed in and the results obtained by the environmental reliability testing of the Westland WG.13, Lynx Helicopter, during both Development and Production phases.

In the first part of the paper, the basic philosophy behind the type of testing carried out is discussed. Details of previous reliability tests undertaken on various aircraft at Westland Helicopters are given, in order to show the development of testing techniques within the company. Difficulties in providing a reasonable representation of the helicopter environment, within the confines of a static test rig, are discussed, with particular reference to the factors governing the choice of test variables e.g. temperature ranges and vibration levels.

The second section of the paper deals mainly with descriptions of the Lynx Reliability Rig and associated test facilities, and details of the duration and method of test. Brief details are given of the aircraft systems fitted to the rig for assessment. Various problems arising in the instrumentation and automation of the rig under representative aircraft conditions are discussed.

The final section of the paper covers the findings of the trial. The types of defect experienced on the rig are classified and main areas of failure discussed. It is attempted to show the relationship between results obtained from rig reliability testing and those obtained from various Development aircraft, thereby emphasising the value of this method of total system testing in addition to the type testing of individual system components. An analysis of the cost-effectiveness of a rig of this nature is made, not only in the light of the advantages of being able to carry out assessments on the performance of aircraft equipments under accelerated environmental test conditions, but also with respect to the problems encountered in determining actual rig costs. These problems include the importance of early availability of aircraft equipment to ensure adequate rig running in advance of the aircraft programme.

The paper also briefly describes possible future trends in helicopter systems and the implications these are likely to have on the environmental testing of aircraft at Westland Helicopters.

1. WHY RELIABILITY TRIALS?

1.1 Purpose of a Reliability Trial

One of the major complaints levelled at aircraft manufacturers by the Military Services is the cost of equipment unreliability in service. Unreliable systems mean loss of operational use of an aircraft and high costs incurred in the repair of faulty units, obtaining of replacements and stocking of adequate spares. This has resulted in stringent reliability requirements being included in aircraft specifications; these requirements often, in the case of helicopters, being given priority over all others including even those of performance and manoeuvrability.

A helicopter specification may ask for a particular reliability target, which could sometimes be in the form of a guaranteed level, and it is obviously necessary for the manufacturer to be able to achieve these reliability requirements. Demonstration of the ability of a particular aircraft to meet the requirements will usually consist of results obtained during its development both from flight and rig testing. The Reliability Trial forms part of this Development programme and aims particularly at improving overall reliability by the detection and elimination of problem areas and the introduction of relevant modifications at an early stage.

The Reliability Trial should be a closely controlled test wherever possible on a production standard system, in the correct aircraft environment (e.g. aircraft electrical supplies) with temperature, vibration and humidity levels representative of those occurring on the aircraft in service. Equipments should be subjected as far as possible to duty cycles representative of typical aircraft operation.

A strong argument exists that such testing is, to some extent, already carried out by sub-contractors in the standard type-test for delivery of equipment. However, experience on all previous Reliability Trials at Westland Helicopters has shown that some equipments which have passed a formal type-test have repeatedly failed during environmental reliability testing. It might also be agreed that the equipment manufacturers should carry out reliability testing of their own products. It is considered, however, that reliability testing should be carried out as far as possible on a representative aircraft system ideally, putting equipment into an airframe and supplying it from actual aircraft electrical systems. Practical limitations of this ideal situation are discussed in section 1.2.

In addition, a system will often consist of equipment supplied by several different manufacturers which have all been tested separately, but are interfaced for the first time on a Reliability Rig. There is obviously a strong case for proving or developing the reliability of the total system in a representative aircraft environment, as any interaction between sub-systems will be shown, a condition not apparent in individual type tests.

1.2 Choice of Test Rig Framework

There are two methods of mounting equipments for reliability testing, either on a specially constructed framework (bench rig) or utilising an actual helicopter fuselage. Both methods have been used for Westland Reliability Trials.

The bench-type rig is normally designed so that aircraft equipments and connecting wiring looms can be mounted in a manner similar to the actual helicopter installation. with the rig being vibrated to the reliability specification. The alternative is to use the whole or part of a helicopter fuselage, in which case the equipment will be mounted in its normal aircraft position and experience local environmental conditions.

The obvious advantage of the bench rig is that it is relatively cheap to manufacture in comparison with an aircraft fuselage and if correctly designed, is extremely flexible and can be easily adapted to suit other requirements.

The fuselage has an advantage over the bench rig with respect to vibration, as a framework can never truly represent helicopter conditions but can only provide nominal levels of vibration at given frequencies. Vibration of a fuselage could be more representative, as it could be induced in the most realistic way i.e. through a rotor head attachment.

During the Development phase Lynx Reliability Trial, criticism was made of the low vibration levels experienced by some equipments fitted to the test rig in the light of vibration problems encountered on the aircraft with the same equipments. It is felt, however, that this problem can be overcome by the addition to the rig, of small vibration platforms with separate exciters on which the suspect equipments can be mounted and subjected to more representative conditions.

The choice of the type of rig is, therefore, obviously dependent on the "trade-off" between truly representative conditions at high cost and limited representation at a much lower cost.

1.3 Choice of Environmental Conditions

The temperature levels and ranges to which equipments are subjected during a Reliability Trial must obviously be representative of the world-wide helicopter operating conditions as laid down in the various military and commercial specifications. However, the choice must be made whether these conditions will be applied in steady-state or cyclic modes. If the latter is chosen, a further decision on the duration of the cycles has to be taken. Various combinations of environmental conditions have been tried during the Westland Reliability Trials and these are discussed in section 1.5.

1.4 Choice of Systems under Test

The choice of systems to be included in a Reliability Trial depends on a number of factors including system complexity, system test requirements and cost. Our approach has been to test systems for which the company is directly responsible i.e. those which it procures and technically defines. Among systems which fall into this category, emphasis has been placed on those primarily affecting aircraft performance.

Notable exceptions are the mechanical systems such as engines, transmission and rotor blades which are subjected to many hours of testing on development and individual type-test rigs. These systems form the major part of the Rotor Rig on which rigorous and extensive development testing is carried out. Complete fuel and hydraulic systems are also extensively tested on other development rigs but only the electro-mechanical and electro-hydraulic components of these systems are included in Environmental Reliability Trials, where they interface with Avionic systems.

It is considered that the greatest benefit will be gained by the reliability testing of the aircraft Avionic and allied systems i.e. generation, automatic flight control (A.F.C.S.) and compass systems, as these use large numbers of electrical, electronic and electromechanical devices.

1.5 Previous Reliability Trials

(a) Wasp H.A.S. MK.1 (1964-1967)

This was the first Reliability Trial to be conducted by Westland Helicopters, being carried out to on the generation and autopilot/autostabiliser systems only.

The trials was split into two parts, the first period of 1079 hours (including 193 hours "burn-in") being carried out in accordance with the American A.G.R.E.E. procedure. This laid down a set of environmental conditions consisting of rapid cycling between maximum and minimum working temperatures (see Figure 1). It was found, however, that this method tended to be more severe than actual service conditions, and the procedure was changed for the second period of 854 hours to cycling over a narrower temperature range with short soaking intervals at the extremes of the temperature range (see Figure 2). Vibration levels were also changed for the second period of the trial, again to provide a more truly representative aircraft environment.

The test facility consisted of a bench-type test rig on which systems under test were mounted, and also limited automatic control and sequencing equipment to control the operating cycle. The latter consisted of pneumatic actuators and an electrical system controlling actuator operation. Testing, however, required virtually 100% manual supervision, the rig being left in a soak condition with power-off when unattended at night and week-ends. Simulated engine starts, initial system engagement and chamber temperature cycling were all manually controlled.

The trial resulted in a total of 113 incidents and although the Wasp aircraft had been in service for approximately three years before the trial was begun, it showed that modifications and improvements were necessary to the equipments. It is interesting to note that, on the strength of the reliability testing carried out on the Wasp, it was the first British aircraft to be sold to a foreign customer with a guaranteed level of reliability.

(b) Sea King (1969-1970)

The test rig in this case consisted of a section of aircraft fuselage including all pilots controls, situated inside an environmental chamber. Vibration levels of ± 0,254 m.m. at 8,5 Hz (0,07 g) in the power-off condition and ± 0,44 m.m. at 17 Hz (0,5 g) during switching periods were applied by means of a two speed motor and adjustable rotating weights.

As a result of experience gained during the Wasp trial, a narrow band temperature cycling procedure was adopted consisting of 100 hour periods alternating between temperate, tropical and arctic cyclic conditions (see Figure 3).

The systems under test during the 1000 hour trial comprised the complete A.F.C.S., including the compass system and electro-hydraulic valves on the auxiliary servo pack. Electrical supplies were derived from an aircraft alternator feeding a distribution panel supporting all A.C. and D.C. equipment associated with the aircraft generation system.

Once again, although a number of stimulators and simulators were introduced to facilitate rig operation, system running was conducted manually either from the Control Console or actual rig Pilots Controls.

The trial resulted in a total of 56 incidents over the 1000 hour period, respective incident rates for the first 600 hours and final 400 hours being 0,0685/hour and 0,0375/hour. This showed a substantial improvement in equipment reliability over the trial period. As with the previous environmental trial, a significant number of modifications and changes to equipments were carried out on the basis of test results.

(c) Gazelle SA341 (1970-1972)

The Reliability Trial of the Gazelle SA341 was a joint Anglo-French venture, the design of the bench-type rig being carried out by Sud Aviation and manufacture and tests by Westland Helicopters. Testing was carried out on the aircraft electrical and A.F.C.S. systems including compass, fuel system elements and external lighting.

The duration of the trial was 2579 hours, the first 630 hours on pre-production standard equipments and the remainder on production standard. Environmental conditions were based on those followed during the two previous trials, with 100 hour periods alternating between temperature, tropical and arctic cyclic conditions. With the exception of the alternator and generator, the total system was subjected to a basic vibration of ± 0,23 m.m. at 20 Hz (0,33 g).

The major difference between this trial and those preceding, was the extent of automation which, in the case of the Gazelle, allowed automatic rig running to be carried out overnight without operator supervision. This was achieved by means of pneumatic jacks operated by signals from programmers in the Control Console and enabled rig running for 21 hours in 24.

A total of 42 incidents was recorded over the 2579 hours of the trial.

From the brief descriptions of earlier Reliability Trials conducted at Westland Helicopters it can be seen that considerable experience and benefits were gained. Testing techniques were developed to enable major improvements in aircraft systems to be carried out quite early in the aircraft programme. The results of all these trials were analysed, wherever possible, to make initial predictions of the Mean Time Between Failures (M.T.B.F.) and Mean Time Between Defects (M.T.B.D.) for the particular aircraft concerned.

2. DESCRIPTION OF LYNX RELIABILITY TRIALS

In contrast to previous trials, the object of the Lynx Reliability Trials is not to predict statistics (M.T.B.F. and M.T.B.D.) but to detect likely areas of unreliability in the systems under test. The emphasis is placed on immediate reporting of any failures leading to remedial action being carried out by the appropriate equipment manufacturers.

2.1 Development Phase (1972-1974)

An initial Reliability Trial was carried out during the Lynx Development Programme on development standard equipments. The various equipments and systems under test were mounted on the Lynx Reliability Rig, a bench-type structure situated within an environmental chamber, and subjected to various environmental conditions and two types of vibration. Where applicable, electrical inputs were fed into the systems by means of simulators and mechanical inputs introduced by means of stimulators.

All systems were run off aircraft supplies, powered by aircraft A.C. and D.C. generators positioned external to the environmental chamber in sound-proofed housings. The generators were not subjected to either environmental conditions or induced vibration.

Wherever possible, the rig was run in an automatic mode, utilising pneumatic jacks although manual running could be implemented if required. Control of the running cycle was achieved by means of two programme readers using photo-electric cells. This type of programmer had previously been used on the Gazelle trial and had been retained on account of proven reliability and ease of alteration of the programme bands in the event of changes to the basic programme being required. Approximately 75% of rig running was automatic and it was again possible to achieve an average of up to 21 hours running per day.

Essential parameters were monitored by means of a U.V. trace recorder, various meters and a Central Warning Panel situated in the Control Console. A closed-circuit television system was used to survey the correct functioning of the Pilots instruments on the rig during relevant simulations and some setting-up procedures. The built-in test facilities on some of the equipments were used during daily checks to highlight any faults.

Equipments under test were subjected to two levels of vibration - aircraft or ship. Aircraft vibration was applied during periods of rig running with power on the systems, ship vibration was applied during periods when the rig was not running.

The hours completed in each vibration conditions were as follows:

Ship - ± 0,31 m.m. at 10,3 Hz (0,13 g) 2023 hours (power off)
Aircraft - ± 0,33 m.m. at 20 Hz (0,6 g) 1110 hours (power on)

The procedures regarding changes of environment on the Lynx Reliability Trial differed from those used on previous trials, in that a "steady-state" type of testing was adopted as opposed to cyclic modes. Figure 4 shows the pattern of environmental conditions over the whole trial running period (excluding "soak" conditions). During the Development Trial, equipments were subjected to the following environments (with power on):

+20°C	416 hours
-5°C	213 hours
-26°C	214 hours
+30°C 90% relative humidity (r.h.)	218 hours
+55°C	282 hours
Total trial running time	1343 hours

In addition, equipments were also subjected to a total of 2023 hours (power off) covering the following "soak" conditions: -5°C, -26°C, -35°C, +20°C, +30°C 90% r.h., +55°C and +70°C.

These "soak" conditions were mainly carried out at weekends throughout the trial.

The trial was conducted to determine the reliability of all Avionic systems, excluding Government furnished items, fitted to the Lynx aircraft. A list of the systems tested, together with brief descriptions of component parts, is given in Appendix 1 of this paper.

Several difficulties were encountered during the trial with environmental and automatic control. It was found absolutely essential to have an environmental plant which could cope with rig running at the low end of the temperature range. Towards the latter part of the trial it was found extremely difficult to maintain the specified arctic conditions with the refrigeration installation available.

With reference to the rig automation, it had been found during both the Wasp and Gazelle trials that the air used to supply the pneumatic actuators had to be absolutely dry. This proved to be a considerable problem on the Lynx trial, owing to the high percentage of automatic operations and also the prolonged periods of running at low temperatures. In spite of attempts at filtering compressed air supplies to the chamber and wrapping air lines and pneumatic jacks with heating tape, there was sufficient moisture present in the comprssed air to enable the formation of ice pellets, which succeeded in blocking the air lines and stopping rig running.

These problems were obviously taken into consideration during preparation for the second phase trial.

2.2 Production Phase (1976-

As a result of the useful experience gained from the initial 1000 hour Lynx Reliability Trial and also the differences in equipments between Development and Production aircraft, it was decided to run a second Reliability Trial on the Lynx Reliability

Rig. Numerous modifications and wiring changes have been made to the rig in order to accept production standard equipments wherever these equipments were available for fitting within the trial timescale.

In addition, modifications to the chamber and associated rig facilities have been carried out, not only as a result of problems encountered during the last phase of the trial but also to accommodate changes to the environmental specification and to cope with the need for increased automation, resulting from the additional equipment fit.

A new environmental plant has been installed to overcome the failure to meet the lower temperature range, the new installation having the capacity to maintain a temperature of -40°C with a total rig dissipation of 10 KW (at present total rig dissipation, including chamber lighting, is approximately 2 KW). It was also found during installation that the method previously used to provide relative humidity i.e. steam injection, was not adequate for coping with rapid changes in temperature. This has now been replaced by a cold water atomiser system. In addition, environmental conditions, whether "steady-state" or cyclic modes are required, are now fully programmable, leaving the operator free to concentrate on the behaviour of the aircraft equipments.

Additional automation in the form of two more programmers has been added to the rig in order to cater for the additional equipment fit, and also to increase the number of operations of certain units which were felt to have been inadequately operated on the last trial. These additional tests have led to increasing the duration of the simulated aircraft sortie from 30 minutes on the previous trial to 1 hour. The layout of the programme bands is shown in Figures 5 and 6 (all programmes being controlled by the master programme on reader A). Rig operation during this second trial will be 95% automatic. In order to overcome the problem of ice forming in the pneumatic jacks and air lines, a new air filtration and de-hydration system has been incorporated. It is hoped that this will enable longer periods of equipment testing at low temperatures to be conducted without rig failure.

Certain changes have also been made to the environmental test procedure. During the 1000 hour trial, the rig will be subjected to each of the environmental running conditions of the previous Lynx Trial (see 2.1), in blocks of 200 hours at each temperature excluding temperate conditions (20°C). The latter will be divided into 50 hour runs between each temperature condition. A 50 hour exploratory run at -35°C will be carried out at the end of the trial in compliance with the specification laid down in reference (1). The intended running programme is shown in Figure 7. At weekends, equipments will be subjected to either tropical or arctic cyclic soak conditions as shown in Figure 8.

Monitoring of equipments and essential parameters has also been increased with the introduction of an aircraft Warning Panel to the rig and the addition of a 100 channel Data Logger external to the chamber for recording parameters during continuous night running.

The commissioning and "burn-in" periods of the trial have been completed and the trial proper has commenced. Several incidents have already occurred during the initial stages and are at present being pursued with the manufacturers. It is hoped to complete this second Lynx trial by June 1977.

3. RESULTS OBTAINED FROM THE DEVELOPMENT LYNX TRIAL

The initial Lynx Reliability Trial resulted in a total of 99 recorded incidents, including 12 incidents raised after completion of the trial as a result of equipment checks to the Acceptance Test Schedules. Of these 99 incidents, one is still outstanding and two have been discounted for statistical purposes, leaving a total of 96 incidents which have been resolved. 33 of the 96 resolved incidents have resulted in a positive action being taken i.e. design change or quality improvement, either by the equipment manufacturers or by Westland Helicopters.

The recorded incidents arising during and after the Lynx Reliability Trial can be divided into four main categories for ease of failure classification. The categories are defined as follows:

Electronic - Any failure caused by an electronic component e.g. resistor, capacitor, semi-conductor etc.

Electrical - Failure mainly concerning power supplies, filaments and electro-mechanical devices

Mechanical - Pure mechanical failure

Unclassified - Unconfirmed defects

The categories are shown graphically in Figure 9, with the outstanding incident omitted.

The main incident areas on the Lynx Reliability Trial are shown in Figure 10. It should be noted that, although there appear to be relatively few incidents involving the Compass System, the Compass Computer was off the Reliability Rig for a total of approximately 300 hours, during which time the Compass System was inoperable. Incidents arising on the major system fitted, the A.F.C.S., are further broken down in Figure 11.

It is interesting to note that, during the trial, there was a marked increase in the number of incidents occurring immediately following a period when the rig had not been run for some time.

In addition to detecting system failures, the Lynx Reliability Rig was successfully used to conduct special tests in the assessment of the performance of particular equipments, with a view to their inclusion on Production aircraft.

Having listed and discussed the results obtained from the initial Lynx Reliability Trial, it is now necessary to make some comparison with results obtained from the various Development aircraft. A comparison table of defects is given in Figure 12. Bearing in mind the relatively small sample size of Reliability Rig equipments, the trend of defects is very similar to aircraft results (the apparent anomaly in the results of the Hydraulic and Fuel Systems can be explained by the fact previously mentioned in section 1.4, that only the electro-mechanical and electro-hydraulic components of these systems are fitted to the Reliability Rig).

From this, it is evident that a great deal of useful information can be obtained from a closely controlled Environmental Reliability Trial, the obvious advantage being to subject the aircraft systems to representative world wide aircraft flying conditions in an accelerated time-scale, with comparatively few staff necessary to maintain the trial. If correctly programmed into the aircraft Development time-scale, a trial of this nature can provide reliability data sufficiently early in the aircraft programme to enable the necessary modifications to be made to equipments before final production begins.

This leads to the obvious question - when is the most effective time to conduct an Environmental Reliability Trial within an aircraft Development/Production programme? An important factor in the determination of the best time to start a trial of this nature is consideration of the type of project involved. In the case of a long-term new airframe project, e.g. the Lynx, there is justification for conducting the reliability testing on the basis of results obtained from other early Development trials. This means running a Reliability Trial towards the end of the Development period so that any information obtained can be of direct use to planning the Production phase of the programme.

In the case of modifications to an existing airframe the Development/Production programme will be compressed into a much shorter time-scale. This leads to the need for a Reliability Trial to be run slightly in advance of the Development phase.

Coupled with deciding on the most beneficial Reliability Trial time-scale, is the all important financial decision of how far in advance of the aircraft the trial can afford to be. The reason for asking this question is that the cost of manufacture and delivery of a set of equipments for reliability testing too far in advance of aircraft production deliveries will, possibly, outweigh any of the advantages of accelerated environmental testing and minimal technical staff support. To be of maximum usefulness, therefore, it is important that a trial of this nature be initiated at the latest possible period in an aircraft Development programme, so that costs can be minimised yet results are available in time to influence production items.

4. WHERE DO WE GO FROM HERE?

The future of environmental reliability testing at Westland Helicopters is obviously dependent on the type of projects to be undertaken and an assessment of likely problem areas, based on our past experiences. It is felt that, in order to improve overall aircraft system reliability, the inclusion of equipments other than those for which Westland Helicopters is directly responsible, must be considered.

Another factor now being evaluated is the handling of equipments on the aircraft. To this end, it is felt necessary to incorporate an "awkwardness" factor into future rig designs. This need not be a costly excercise and can be achieved by the addition of simplified aircraft structures and equipment bays to the basic bench rig, enabling units to be mounted in representative aircraft positions.

With current trends towards digital Avionic Systems, it will be essential to re-consider the methods of input simulation, system response monitoring and data handling and analysis. The complexity of such systems may demand the use of digital monitoring computers to carry out first-line data reduction.

REFERENCES

1. Av.P.970 - Design requirements for Service Aircraft (Vol. 3 - Rotorcraft Design Requirements)
Ministry of Technology Aviation Publication

APPENDIX 1

Equipment Fit on Lynx Development Reliability Trial

D.C. Power Supplies -	Battery, starter generator, regulator, all aircraft relays, contactors etc.
A.C. Power Supplies -	Alternator, static inverter, protection unit, phase detector
A.F.C.S. -	A.F.C.S. computer, all A.F.C.S. controllers, acceleration control computer, gyros (yaw rate and vertical), all aircraft actuators (pitch, yaw, roll, collective)
Compass -	Computer, controller, flux valve, directional gyro
Visual Readout -	All pilot's aircraft instruments (barometric altimeters, radio altimeters, engine instruments etc.)
Hydraulic System -	Aircraft manifold, pressure transducers, main servo jack, tail servo jack
Fuel System -	Tank probes, fuel pumps, float switches, fuel cocks
Miscellaneous -	All aircraft external lighting (navigation, landing etc.) engine bay vent fan, starter solenoid switch, any other miscellaneous electrical equipment.

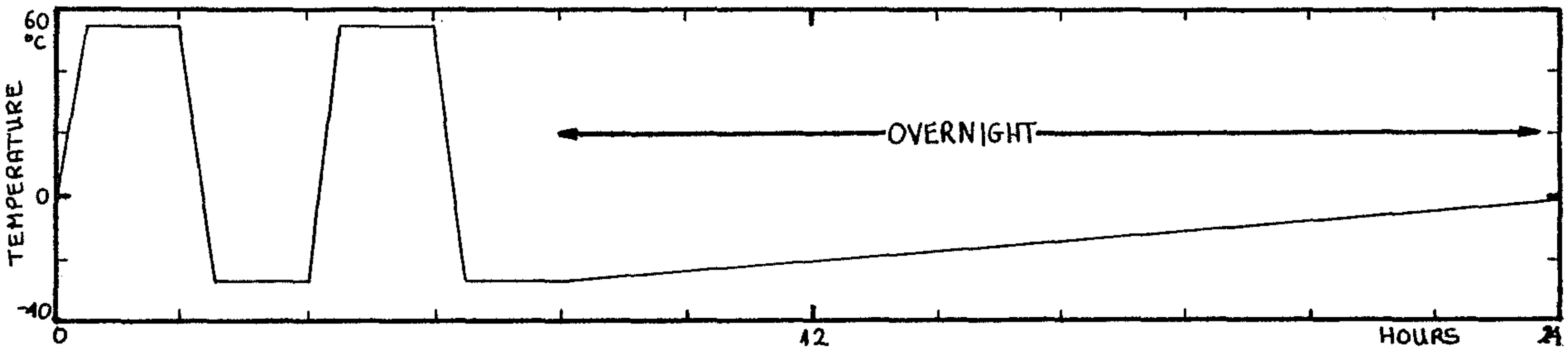


FIG. 1 TEMPERATURE CYCLE - 1ST. WASP TRIAL

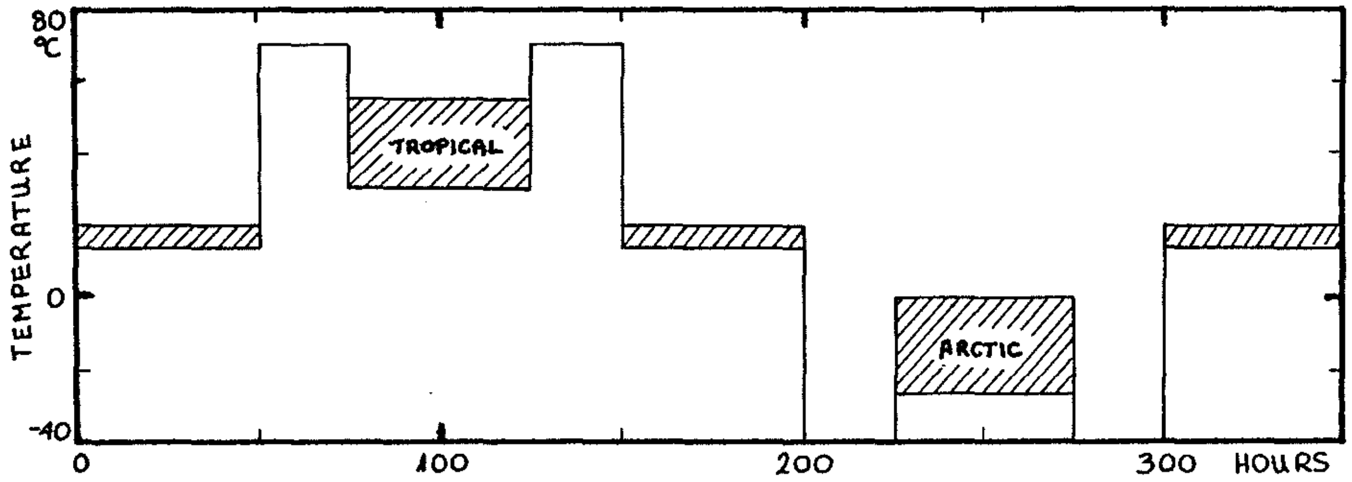
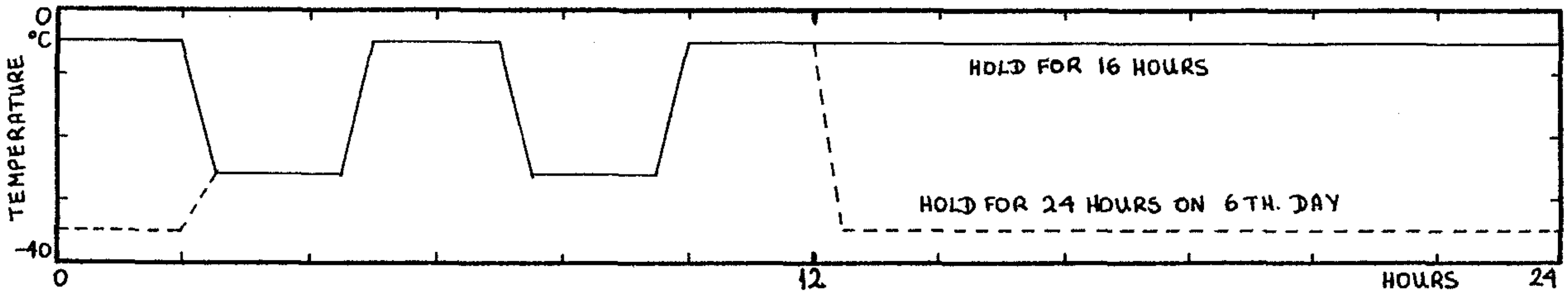
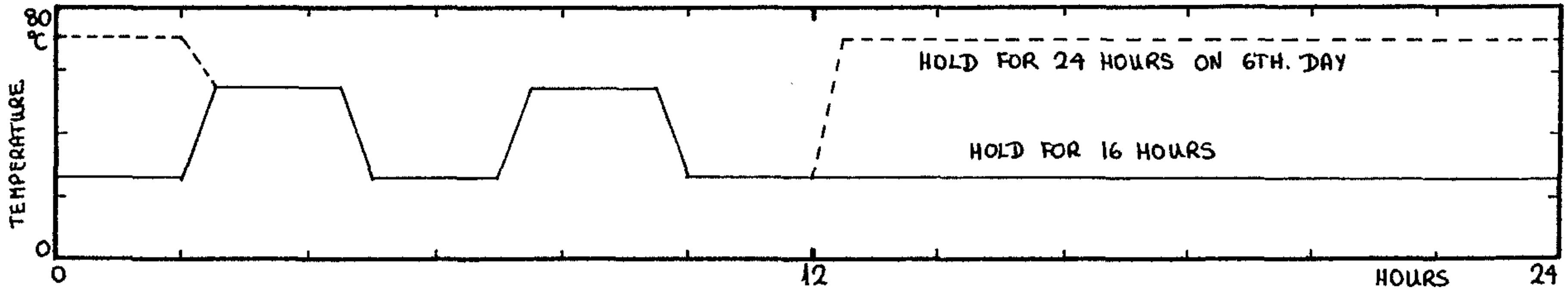


FIG. 2 TEMPERATURE CYCLE - 2ND. WASP TRIAL



(a) ARCTIC CYCLING



(b) TROPICAL CYCLING

FIG. 3 TEMPERATURE CYCLES - SEA KING TRIAL

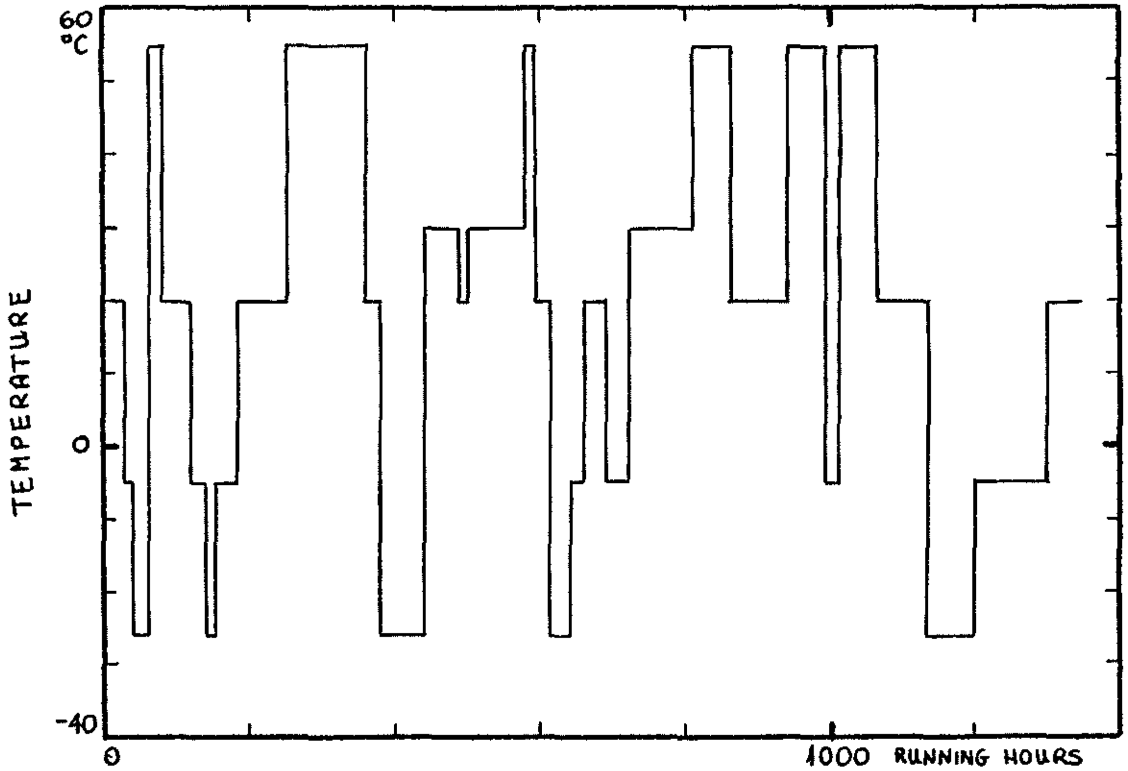
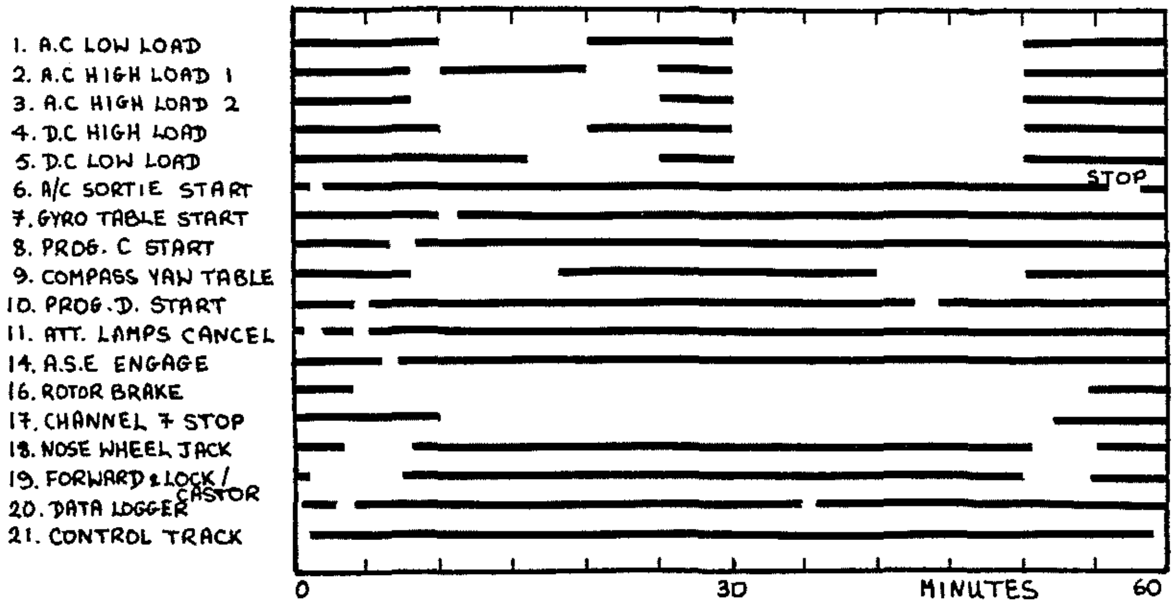
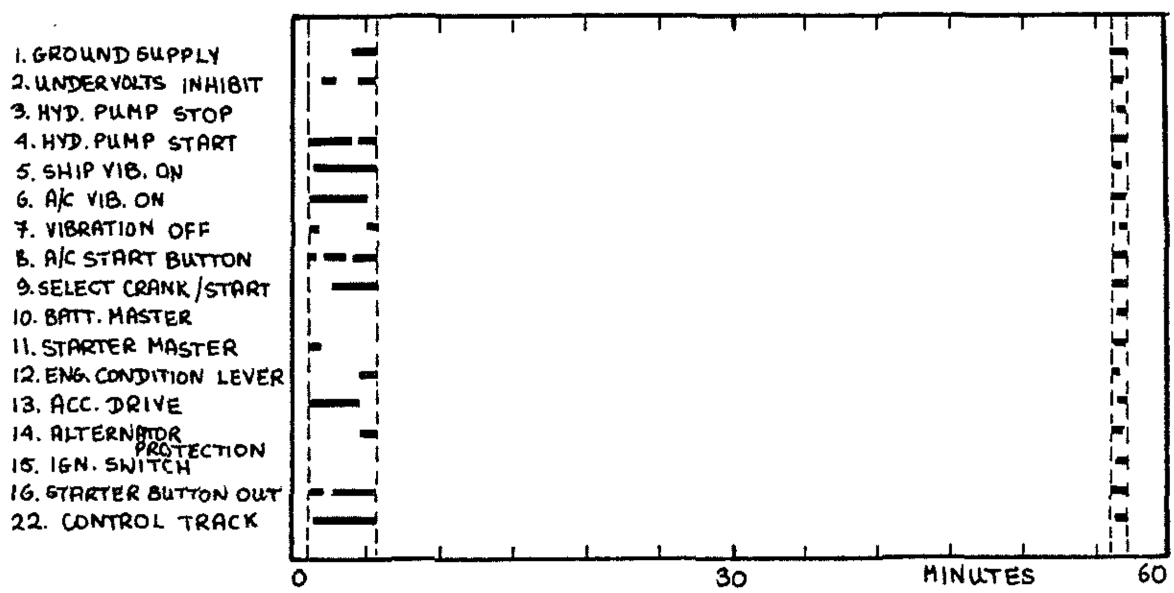


FIG. 4 ENVIRONMENTAL CONDITIONS - LYNX DEVELOPMENT TRIAL

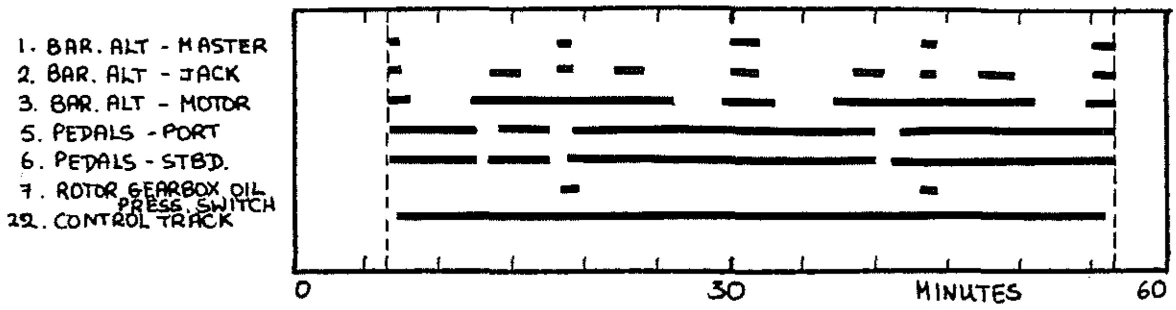


PROGRAMME A

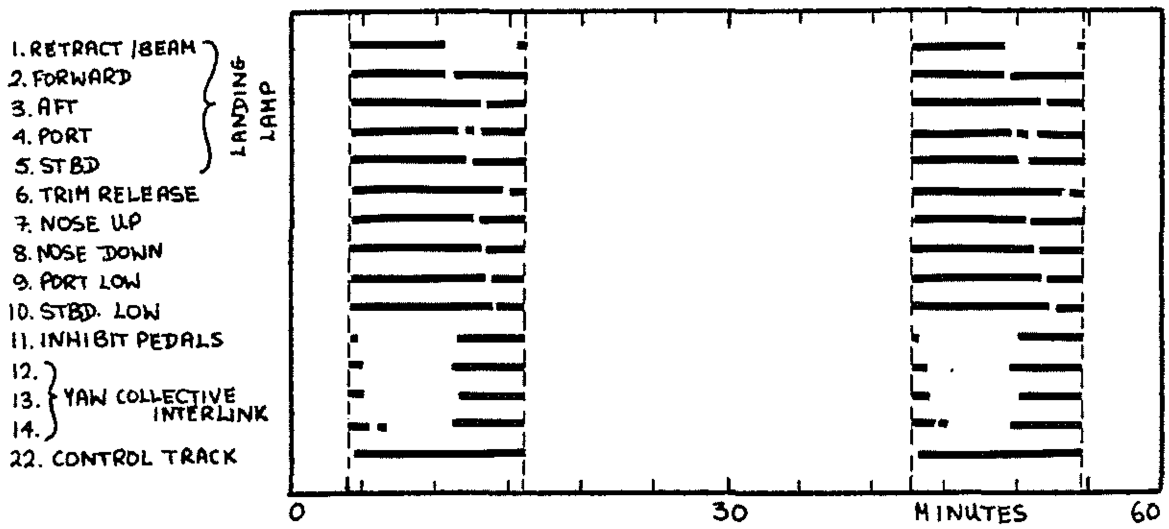


PROGRAMME B

FIG. 5 RIG CONTROL PROGRAMMES - LYNX PRODUCTION TRIAL



PROGRAMME C



PROGRAMME D

FIG. 6 RIG CONTROL PROGRAMMES - LYNX PRODUCTION TRIAL

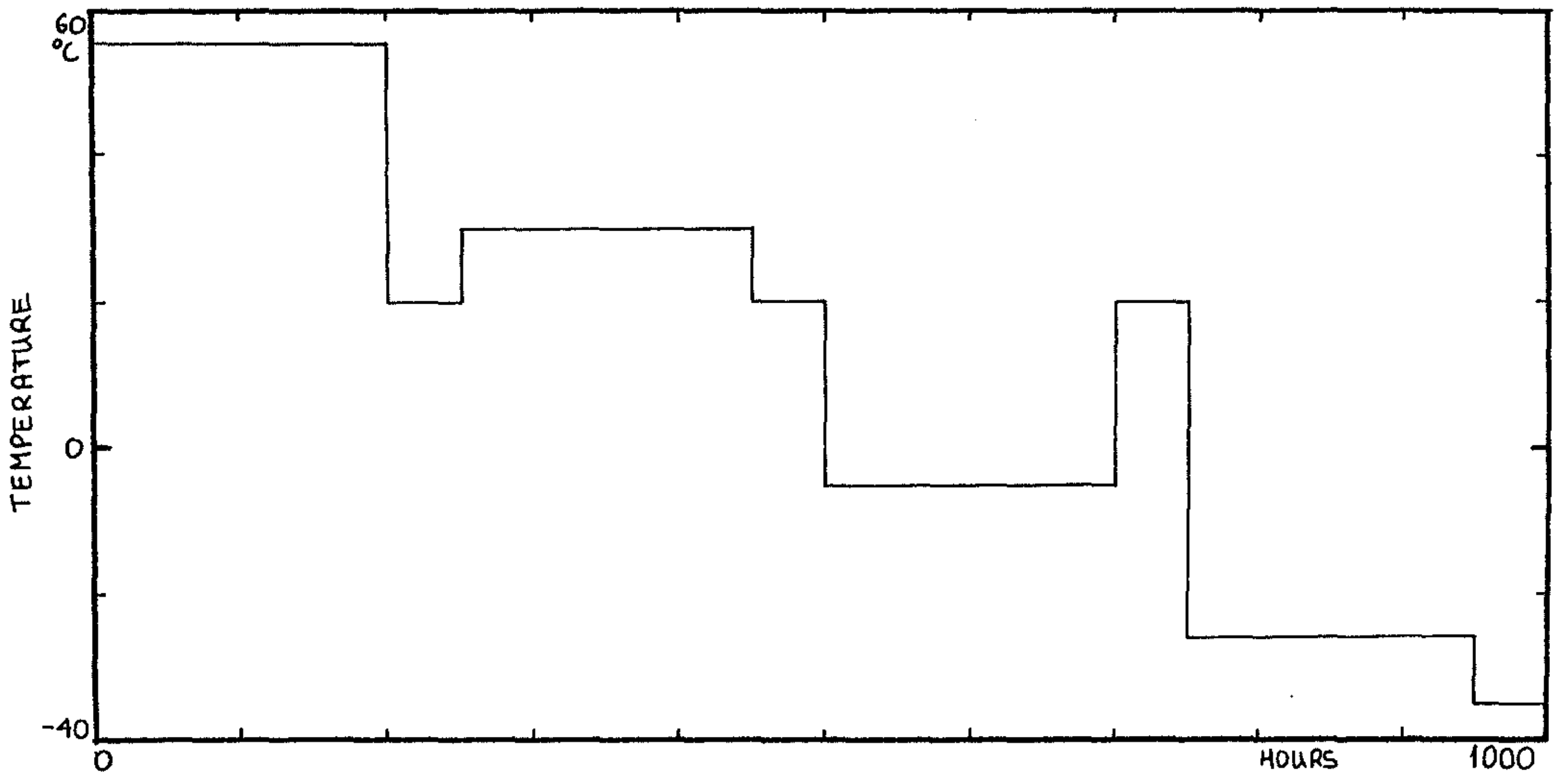


FIG. 7 ENVIRONMENTAL RUNNING CONDITIONS - LYNX PRODUCTION TRIAL

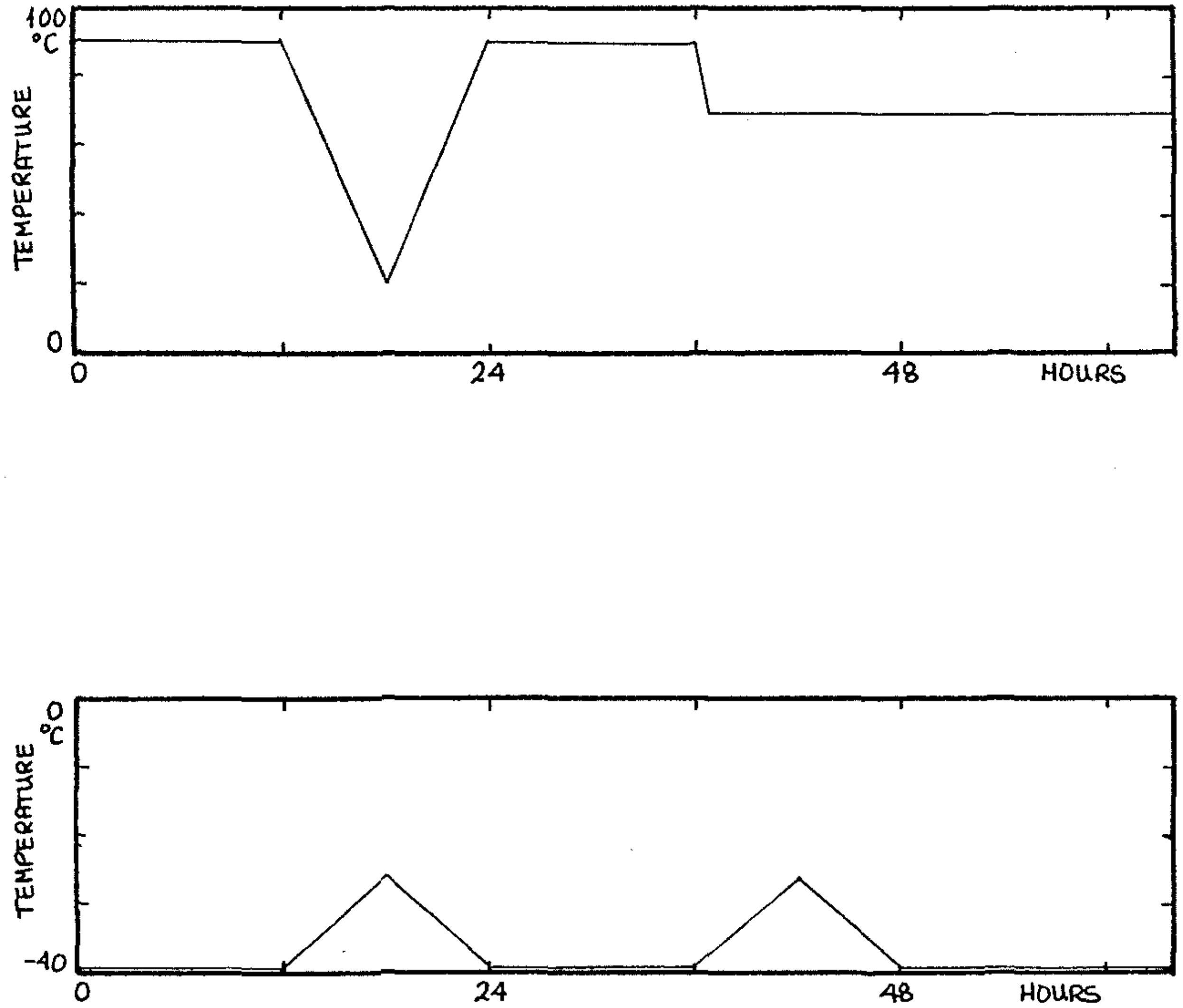


FIG. 8 ENVIRONMENTAL SOAK CONDITIONS - LYNX PRODUCTION TRIAL

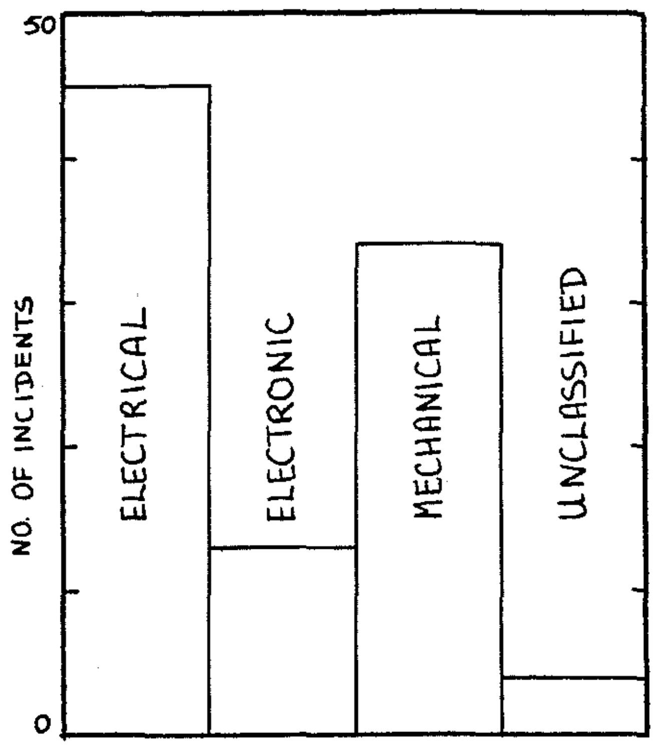


FIG. 9 TYPES OF FAILURE - LYNX DEVELOPMENT TRIAL

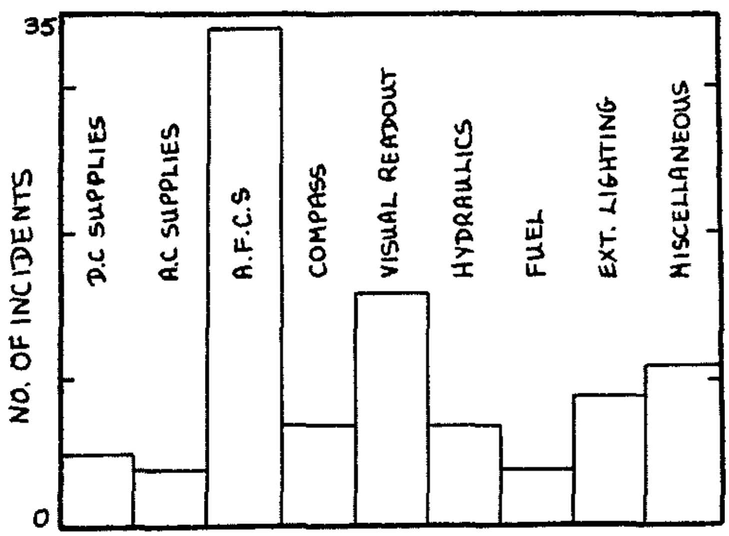


FIG. 10 MAIN INCIDENT AREAS - LYNX DEVELOPMENT TRIAL

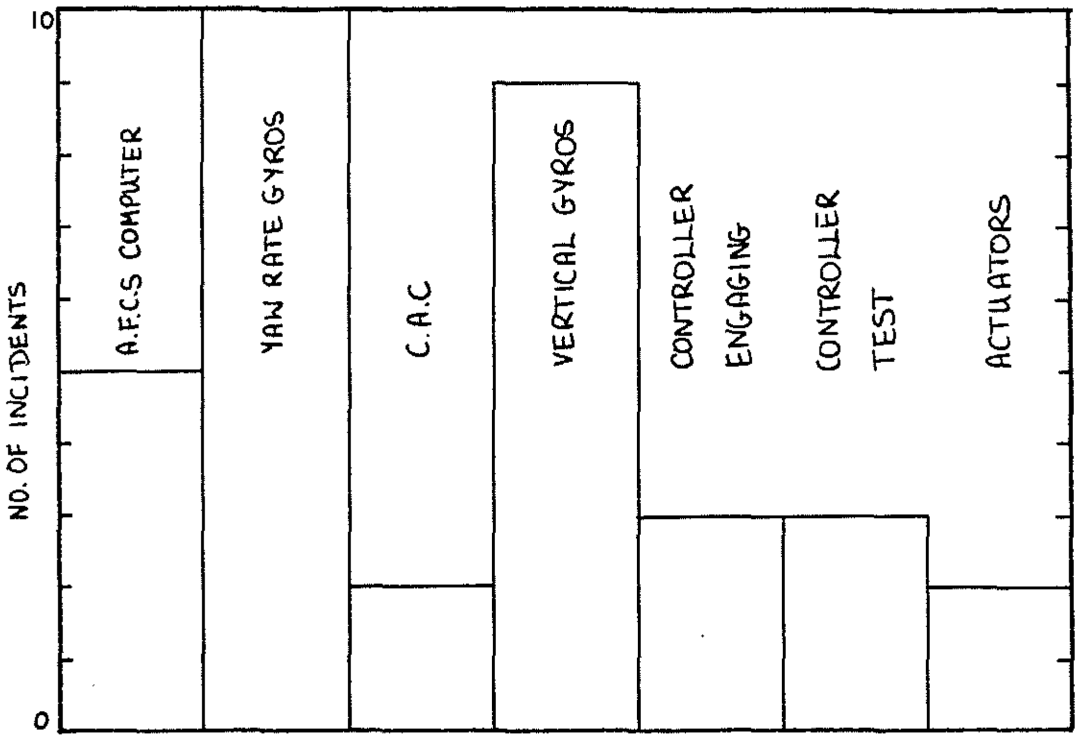


FIG. 11 A.F.C.S. FAILURES - LYNX DEVELOPMENT TRIAL

SYSTEM	RIG DEFECTS	AIRCRAFT DEFECTS
ELECTRICAL	20	117
A.F.C.S	34	157
NAV. & COMPASS	7 (NAV. SYSTEM NOT FITTED)	61
INSTRUMENTS	16	70
HYDRAULICS	7	197
FUEL	4	68
LIGHTING	9	25

FIG. 12 COMPARISON OF RIG AND AIRCRAFT DEFECTS