Reliability Testing and Demonstration of Radar PS-46/A

Utdrag ur Ericson Review 1985 nr 2

Denna digitala version omfattar enbart sidorna 52 till 59

Tidningen i sin helhet finns här:

Ericsson Review 1985 nr 2

Reliability Testing and Demonstration of Radar PS-46/A

Göran Holmberg and Gösta Steen

The fighter version of the Swedish Air Force's aircraft Viggen, JA37, is equipped with a sophisticated pulse Doppler radar. This radar, designated PS-46/A, has been developed by Ericsson Radio Systems AB in Mölndal, Sweden. Among the many demands made on a modern fighter radar, high reliability is in the forefront. A reliability qualification test has therefore been carried out on a number of PS-46/A systems in service with Air Force units, in order to demonstrate the radar's reliability performance.
The authors describe the practical aspects of the testing, the tests results and the experience gained. They also describe the methods used at Ericsson during design, development and production to assure fulfilment of the contractual reliability requirements.

UDC 621.396.962.33.001.42
radar systems
reliability
testing
doppler effect

Ericsson has developed, manufactured and delivered airborne radar systems for three generations of aircraft for the Swedish Defence Establishment. During the 1950s radar units were supplied for the Lansen aircraft and in the 1960s approximately 500 radar systems for the Draken aircraft.

Then came aircraft 37, or Viggen, a multi-purpose aircraft which was planned at the end of the 1950s and which, with different types of equipment, was to be able to serve in several different roles. The attack version, AJ37, came first, quickly followed by the reconnaissance version, SH37, both equipped with radar systems developed and manufactured by Ericsson Radio Systems.

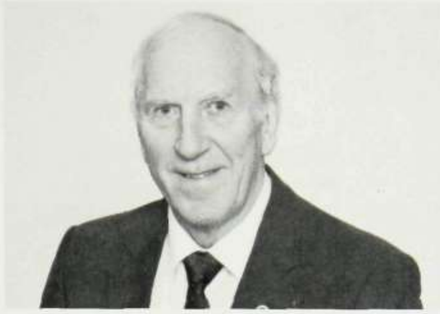
At the end of the 1960s the studies for the fighter version, JA37, started. The radar for JA37 was developed by Ericsson Radio Systems during the period 1970–1978. The development comprised three prototype generations for different stages of testing on the ground and in the air. The first series production system was delivered in the spring of 1978.

The radar for JA37 is designated PS-46/A. It is technically the most advanced radar system Ericsson Radio Systems has delivered hitherto. It is built up of almost 10 000 parts or components, with 3 200 microcircuits, 900 semiconductors, nearly 5 000 resistors and capacitors and a large number of waveguide components, hydraulic details and mechanical parts.

The usefulness of a modern fighter aircraft is greatly reduced if the radar should fail. Consequently, for strategic reasons and also to ensure low maintenance costs the radar must have high reliability and short repair time.

As military systems become more complex and technically advanced, specifications and contracts make more stringent demands on the reliability performance of the equipment.

Fig. 1
Radar PS-46/A installed in the nose cone of aircraft JA37



GÖRAN HOLMBERG
GÖSTA STEEN
Ericsson Radio Systems AB

In the specification for PS-46/A the MTBF (Mean Time Between Failures) is set to 100 hours for in-flight operation. In the series contract it is specified that, in order to demonstrate fulfilment of the reliability requirements, Ericsson Radio Systems must follow up and evaluate the results obtained from reliability predictions, fault records etc. and the results of a reliability qualification test.

Design and construction

PS-46/A is a modern airborne pulse Doppler radar. A detailed description of the radar, its function and design has been published in a previous issue of Ericsson Review[1].

PS-46/A is secured in the nose of the aircraft by means of four bolts, fig. 2. The radar consists of ten replaceable units mounted in a rack, which in itself is a replaceable unit. The system also includes a power divider and two reference antennas placed elsewhere in the aircraft. All units are easy to replace in the field. Fig. 3 shows the designations and positions of the different units.

The electrical power, cooling air and hydraulic power for the radar are provided from the aircraft. Indirect cooling is used wherever possible. The two-axis antenna is operated by two hydraulic motors. The data and signal processors are digital with flat-pack circuits mounted on multi-layer printed circuit boards. This construction makes the units light and compact. The radar is equipped with a 50 kW transmitter with an air-cooled travelling wave tube. The total weight of PS-46/A is 298 kg.

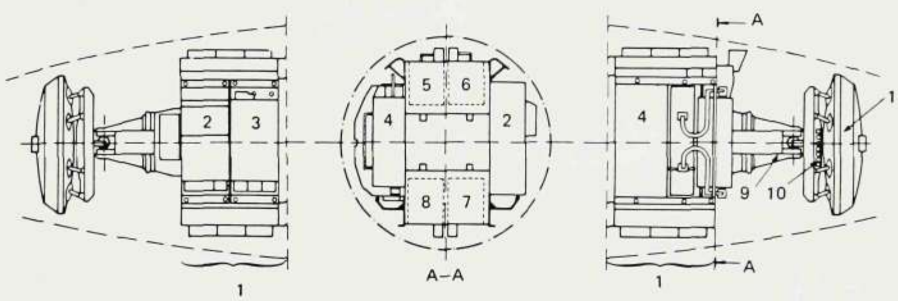


Fig. 3
PS-46/A with the units mounted in their rack in the nose cone of the aircraft

1. Rack
2. Illuminator
3. Exciter
4. Power amplifier
5. Radar signal processor
6. Receiver
7. Power unit
8. Radar data processor
9. Pedestal unit
10. Microwave unit
11. Reflector

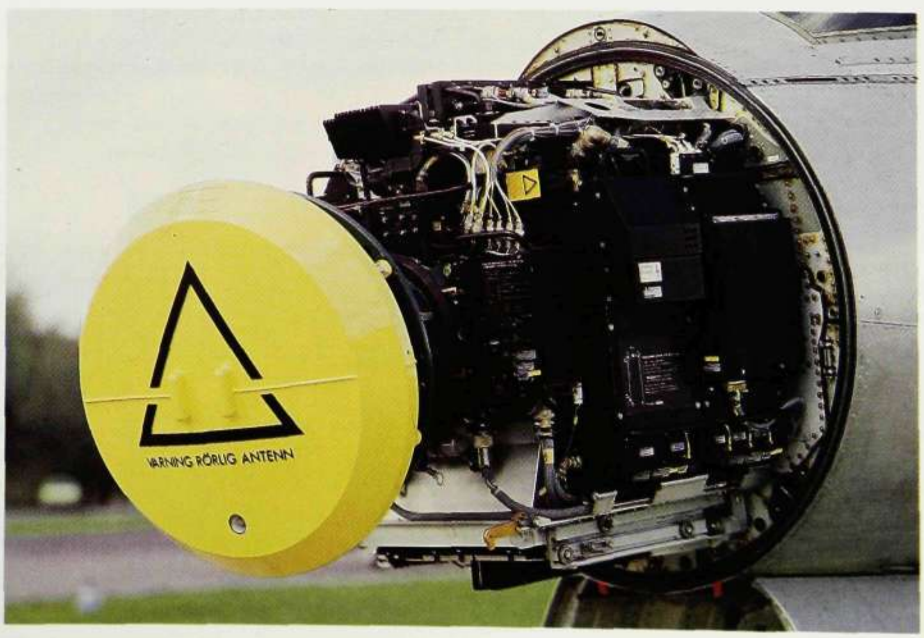


Fig. 2
Detail from fig. 1

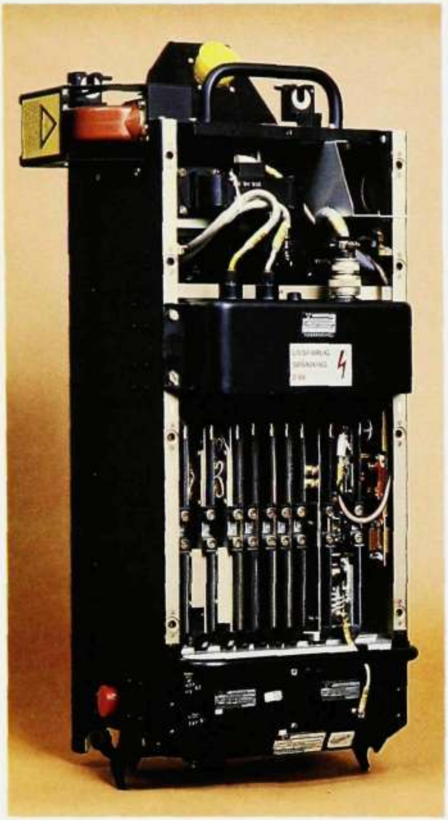
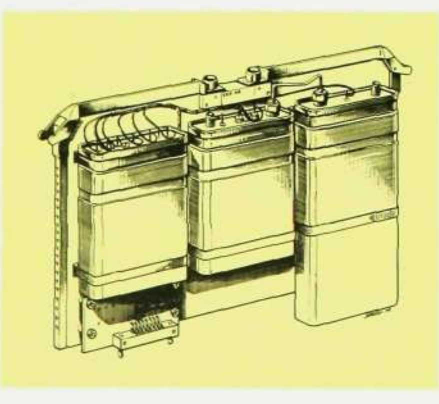
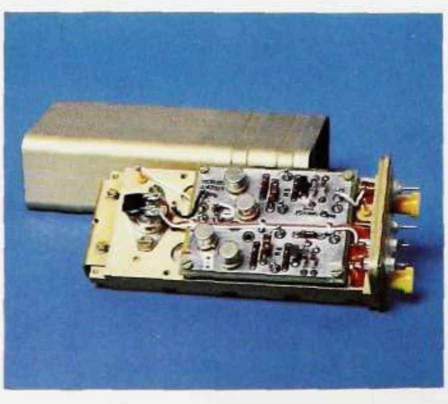


Fig. 4a
The illuminator with the cover removed. The klystron is placed at the top, with the high-voltage parts and electronic circuits on printed boards below

Fig. 4b
A module for microwave technology circuits. The microwave circuits are mounted in hermetically sealed cans mounted on a heat exchanger





Equipment intended for modern military aircraft is subject to rigorous demands as regards weight, volume and performane, and of course reliability performance. Fault localization and repair must be simple. As a result the design and construction requirements are very stringent, not least because of the tough environment.

Figs. 4a and b illustrate the robust design of the units and the easy maintenance.

A built-in supervision system, which does not affect the operation of the radar system, keeps the pilot informed continuously about the condition of the system. If a fault occurs, alarms are given via the head-down display or indicator lamps. Repair usually entails replacement of a unit. A built-in test system with automatic failure localization greatly facilitates maintenance in the field.

Reliability and maintainability activities at Ericsson Radio Systems

In order to be able to meet the high demands of both military and civil customers, Ericsson Radio Systems at Mölndal, Sweden, has gradually built up expertise in the field of reliability and maintainability. A system for failure data collection and failure analysis was introduced as early as the end of the 1950s, when the company moved to Mölndal. This system has been improved and further developed over the years and now covers type development, receiving inspection, manufacture and testing as well as the period after delivery.

Special efforts are made to collect data on delivered equipment and then to feed back the experience thus gained into new designs. This prevents faults from being repeated and utilizes the positive experience gained.

The results from failure data collection and analysis are also used to predict failure rate and MTBF for products being developed.

Computer-based models and systems are used for prediction and analysis of reliability performance, maintenance resources etc.

Individual reliability and maintainability programs are prepared for large projects. Such programs are adapted to and integrated with the other project activities and are controlled by a reliability and maintainability engineer specially appointed for each project.

Reliability and maintainability program for PS-46/A

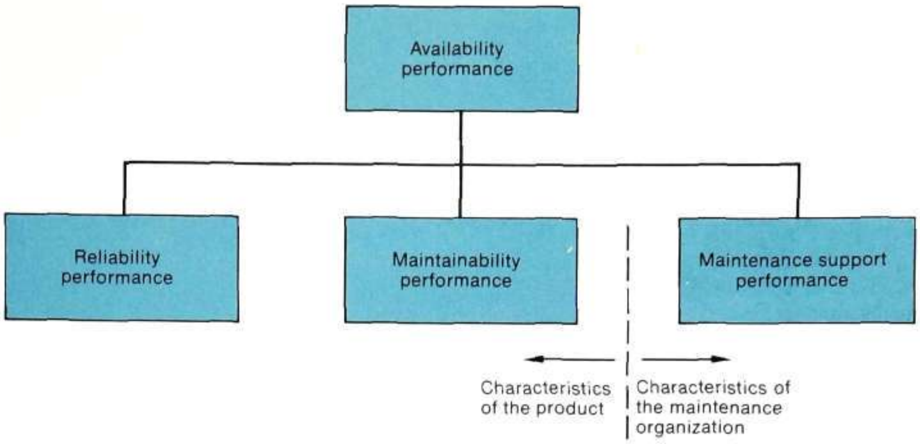
When the development of PS-46/A was started, guidelines were also laid down for the reliability and maintainability activities.

A special reliability and maintainability program was planned and carried out within the framework of the project in order to ensure that the specified MTBF would be met. The program comprised such activities as studies of similar projects, predictions and analyses, follow-up and evaluation of the results of development of prototypes, and at a later stage follow-up of series production and delivered equipment. Special measures were taken to increase the reliability of PS-46/A when the program results indicated that this was necessary.

Designs, constructions, component quality etc. have been chosen bearing in mind the reliability requirements. The manufacturing methods have also been adapted to suit these requirements. For example, before delivery each series produced equipment undergoes a burning-in test with the whole system in operation.

The specified MTBF, which is 100 hours for in-flight operation, refers to the con-

Fig. 5
Reliability and the associated concepts. Reliability is often given as the mean time between failures, MTBF, and is thus defined as the ability of a unit to carry out specified tasks without any failures that reduce its performance



stant failure rate period. Experience shows that for a flight radar of the type referred to, this period starts about 3 years after initial delivery and after a few hundred hours of operation for each individual radar system. These periods are approximate and can vary considerably from one type of equipment to another.

During the product development work the reliability was determined regularly by means of predictions and analyses.

Early predictions indicated that it would be difficult to meet the specified MTBF with the set prerequisites. Analyses showed that an economically suitable way of increasing the MTBF to the required level would be to raise the quality level originally chosen for microcircuits and certain semiconductors. The raising was decided on and introduced in the series.

Predictions made during later development stages indicated that there was a high probability that the specified reliability would be met. The latest prediction, made in 1979, gave an MTBF of 161 hours.

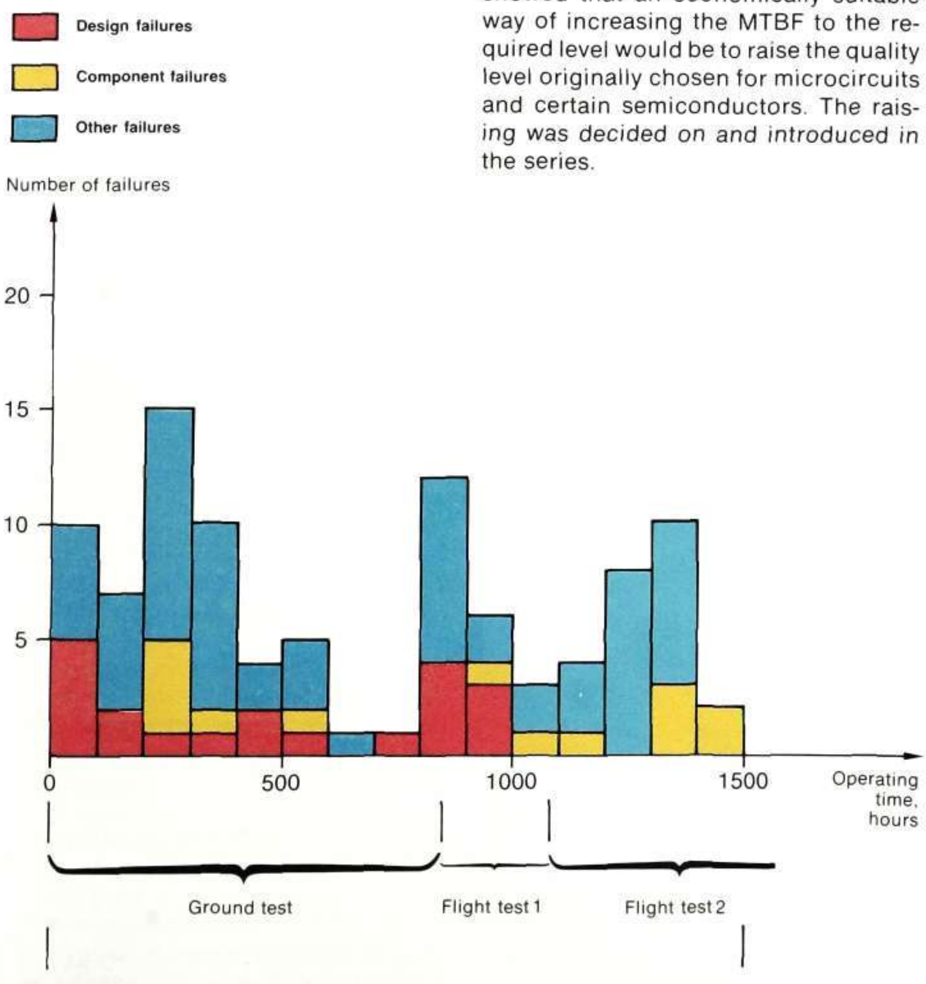
A series of prototypes were developed as a part of the development program. The first ones were used to test the function of the radar and its interworking with other systems in the aircraft. The later prototypes were more like series production units as regards construction, component choice and manufacturing methods, and they were useful for testing such features as reliability performance. The results of the tests were followed up and evaluated from many aspects, including the reporting and analysing of every failure and deviation detected.

Fig. 6 shows the failure spectrum for one of the later prototypes, and the figure shows how the design failures decrease with time.

Regular meetings have been held with, among others, the project manager, quality engineer, reliability engineer, senior design engineer and senior production engineer, where all failure reports from system tests, including burn-in, have been reviewed in order to ensure that adequate actions have been taken to prevent repetition of detected failures and weaknesses. Further analyses and measures have sometimes been decided upon, and the participants in the meetings have seen to it that decisions have been carried out with the effect intended.

Summaries of the failure reports from different stages indicated that the probability of reaching the specified MTBF was high. One prerequisite for this was of course that the work of correcting detected failures and weaknesses continued. Fig. 7 shows the situation for all delivered radar systems two years after

Fig. 6
Failure spectrum for one of the later prototypes. In this case the study has concentrated on the distribution of design and component failures with time. Note the decreasing trend in the overall failure picture, and the increase as the flight testing of the prototype started



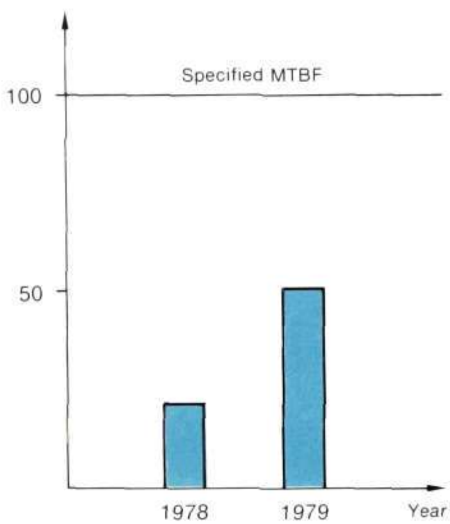


Fig. 7
The figure shows the measured MTBF at test start for all radar systems delivered during 1978 and 1979

the first delivery. It should be noted that the figure includes all early failures for each unit. If this fact is taken into consideration the development is more or less as expected.

Purpose and scope of the reliability qualification test

In accordance with the contract and at the request of the Defence Materiel Administration a reliability qualification test for PS-46/A was carried out. The test took place in connection with special priority flights at Norrköping by four JA37s. The purpose of these flights was to accumulate the maximum possible flight time over a limited period during the early part of the series and thereby facilitate early detection of wear-out and design weaknesses in the aircraft and its parts.

The purpose of the reliability qualification test was to measure the MTBF for four radar systems during normal operation, and on the basis of the results to assess whether or not PS-46/A met the specified requirements.

Participation in the special flights made it possible to carry out the measurements under controlled conditions and to obtain reliable results at a reasonable cost.

Five radar systems were used in the test: four installed in the four aircraft and the fifth used as a spare set for maintenance purposes.

The qualification test started on August 1, 1980. Originally the test was intended to finish in August 1982. A flight stoppage in 1981 extended the test time to September 10, 1983.

A preliminary test was carried out during a forced service test at SAAB, Linköping.

Test procedure

The qualification test was carried out in close collaboration between Ericsson Radio Systems at Möndal, the Materiel Administration of the Swedish Armed Forces (FMV), the Maintenance Department of the Swedish National Industries Corporation (FFV:U) and the Bråvalla Air Wing at Norrköping (F13).

F13 was responsible for the flights, the operational use and normal maintenance. FFV:U assisted in, for example, failure localization and analysis at operational level. Ericsson Radio Systems participated at operational level and also carried out failure analysis and repair of faulty units.

Follow-up meetings were held regularly with participants from Ericsson Radio Systems, FMV, FFV:U and F13. At these meetings practical matters concerning the test process were discussed, as well as events that had occurred, measures that had been taken and the various types of problems that had arisen. Failure classification was also carried out.

The qualification test was based on a test specification, which was prepared by Ericsson Radio Systems and accepted by FMV before the test started. The specification included rules and routines for the test, decision criteria, areas of responsibility, and rules for failure classification.

During the test period the radar systems were mounted in the four JA37s used for the priority flights. The operation and maintenance routines that applied to other equipment were also used for PS-46/A.

When a failure was detected and localized to a radar unit, this unit was immediately replaced. The replacements consisted primarily of units from the special replacement set. Units that had not been selected for the test were used only in special cases. The faulty units were sent to Ericsson Radio Systems for failure analysis and repair. The repair was always carried out down to such a level that the failure could be analyzed and classified with a satisfactory degree of certainty. Particular importance has been attached to the recording of any observations that could be useful in subsequent failure analysis and classification.

A maximum repair time of 20 working days was aimed at by Ericsson Radio Systems in order not to have to use spare units that had not been chosen for the test. The repairs were normally made within the set time.

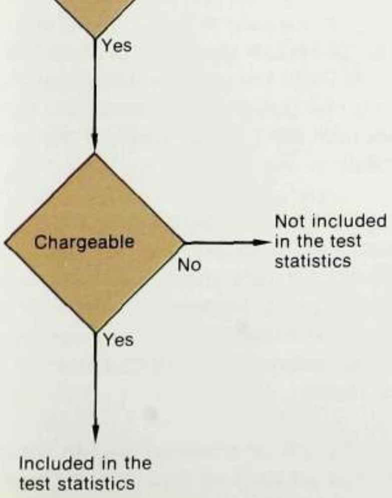
Fig. 8
Maintenance of the radar at Air Wing F13.
Photo: Rune Rydh

Fig. 9
Rules for failure classification

Verified failures are considered relevant unless caused by
- accidents
- faulty handling
- environmental limits etc. being exceeded.

Unverified failures and intermittent failures are also regarded as relevant.

Chargeable failures are: design, production and component failures and software errors that have not been cleared.
Secondary failures and failures caused by component life being exceeded or preventive maintenance not being carried out are non-chargeable failures.



All units used in the test, including those in the spare set, were marked with special labels for easy identification and to avoid mix-ups.

Before the start of the test, temperature indicators in the form of thermotape were placed at selected spots on the test objects. The indicators made it possible to check whether specified temperature limits had been exceeded and to record any occurrence of too high temperature within the units. The thermotapes were read off by Ericsson Radio Systems during checks and when faulty units were in for repair.

Tape recorders were used during the flights to record events that could affect the test results. The recordings were also used in the failure localization and analysis work. On certain occasions special recording apparatus, which registered all important signals in the radar during flight, was used to help locate failures.

Reporting and failure classification

Failures detected in the field were reported through the Air Force's normal system for failure data collection, DIDAS. Each failure was analyzed at Ericsson Radio Systems and then examined in order to determine its cause; for example design, manufacture, component or handling.

During the follow-up meetings the failures were classified as chargeable or non-chargeable to the test results. The fault classification was carried out in accordance with the rules given in the test specification, which in their turn are basically in accordance with the US standard MIL-STD-781C[2].

The failure classification comprised two stages. The failures were first classified as relevant or non-relevant. Non-relevant failures were, for example, those caused by external damage. The relevant failures were then divided into chargeable and non-chargeable failures.

The types of failures classified as chargeable were intermittent and unverified failures, and all design, manufacture and component failures. Software errors were also regarded as chargeable with the exception of those for which the necessary corrective measures were considered to have been taken, fig. 9.

Methods for calculating MTBF

The specified MTBF refers to the time the radar is in operation during flight.

Table 1
Accumulated operating and inoperative time during the test period. Aircraft no. 309 has a total of 683 flight hours. The corresponding times for aircraft nos. 310, 316 and 317 are 590, 687 and 585 hours respectively

Sub-period	Accumulated time, hours Real flight operating time	Ground time	Equivalent flight operating time
1	608	16 090	930
2	1 937	70 437	3 346
Total	2 545	86 527	4 276

Aircraft number		Sub-period 1		Sub-period 2		Whole test period
	N	MTBF	N	MTBF	N	MTBF
309	5	70	2	388	7	161
310	1	351	3	208	4	244
316	0	–	6	168	6	192
317	0	–	7	135	7	147
Total	6	155	18	186	24	178

Table 2
The number of detected and verified chargeable failures, N, and the measured MTBF in hours for in-flight operation during the test period, broken down in terms of aircraft and periods

Unit	MTBF, operation during flight N	Measured	Predicted
Rack unit			2 538
Rack	–	–	–
Waveguide unit	2	2 138	–
Exciter	3	1 425	1 414
Power amplifier	7	611	703
Illuminator	2	2 138	1 681
Microwave unit	1	4 276	2 320
Pedestal unit	–	–	1 996
Reflector	–	–	55 556
Receiver	4	1 096	1 441
Radar signal processor	1	4 276	1 110
Radar data processor	3	1 425	2 410
Power unit	1	4 276	9 434
Power divider	–	–	200 000
Reference antenna	–	–	166 667
The whole PS-46/A	24	178	161

Table 3
The number of relevant and chargeable failures, N, and the measured and predicted MTBF for each type of replaceable unit in PS-46/A

Table 4
The failures classified as chargeable, divided up according to cause. There were no software errors among those considered as contributory. The reason for this was that the necessary measures to clear the failure were considered to have been taken for all software errors detected during the test. According to the failure classification rules, such failures should then not be considered as chargeable

Cause of failure	Number of failures
Design failures	2
Manufacturing failures	3
Component failures	12
Failures that could not be detected during checks by Ericsson Radio Systems	4
Failures of uncertain cause	3
Total	24

Failures also occur at other times, for example during test runs on the ground, when the aircraft is being transported on the ground with the radar switched off or when the aircraft is immobilised.

It is often difficult to determine the stage at which a failure has actually occurred. This problem was circumvented by including all failures that were detected during the test period and which were classified as chargeable in the statistics, and at the same time including the time the radar was on test runs or switched off during the test. The conversion to the equivalent flight operation time was made by adding 0.02 of the ground time to the actual flight operation time. The MTBF was calculated as follows:

$$\text{MTBF} = \frac{\text{Total equivalent flight operation time}}{\text{Total number of chargeable failures}}$$

MTBF was determined for the overall test time and also for the period before and after the flight stoppage, sub-periods 1 and 2. Sub-period 1 comprises the period August 1, 1980, to April 6, 1981, and sub-period 2 April 7, 1981, to September 10, 1983. The stoppage period has thus been included in sub-period 2.

Measured reliability

The total number of flight hours during the test period was 2545. The inoperative time and time for operation on the ground was 86 527 hours. The total equivalent flight operation time was 4 276 hours. Table 1 shows how the times are distributed between sub-periods 1 and 2.

During the test period 79 failure reports were received that concerned the test objects. Of these, 44 led to a unit being replaced. 24 failures were considered to be relevant and chargeable. Thus not all failure reports resulted in units being replaced. The reason for this is discussed later in the article.

The above-mentioned operating times and failure numbers give a measured MTBF for the whole test period of 178 hours. With a confidence interval of 90% the confidence limits are 126 and 259 hours, i.e. the probability that the real MTBF for flight is between 126 and 259 hours is very high.

Table 2 gives the measured MTBF for the different aircraft and periods.

Fig. 10 shows that the specified MTBF was reached during sub-period 1 and the predicted value during sub-period 2.

In table 3 the measured MTBF for operation during flight is given for the different units of PS-46/A. The MTBF value given in the specification is for a complete radar system. There are no similar values for sub-units. Nevertheless, in order to get an idea of the measured MTBF level for the individual units the predicted values are used as a reference. It should be noted that the predicted MTBF is 1.61 times higher than the specified MTBF. The table shows that most units meet the predicted values satisfactorily. However, the test time was rather short for a reliable assessment of the MTBF values for units. For example, a single failure in the power unit meant that the measured MTBF for this unit was only about half the predicted value.

All failures have been divided into categories according to their actual cause. Table 4 shows how the failures classified as chargeable are distributed between these categories.

Failure alarms that did not result in unit replacement

During the verification period the pilots reported 79 failures in the test objects. In 44 of these cases the failure was verified during a test on the ground, and the indicated unit was replaced. In the remaining 35 cases it was not possible to detect the failure during a ground test after the flight period. An investigation was carried out to try to establish the causes of the 35 unverified failure alarms.

The basic data for the investigation included tape recordings of each flight period, which were studied with respect to radar alarms. Information regarding function deterioration that did not give rise to an alarm was obtained from the pilots' notes.

The investigation showed that in most cases the unverified alarm had been

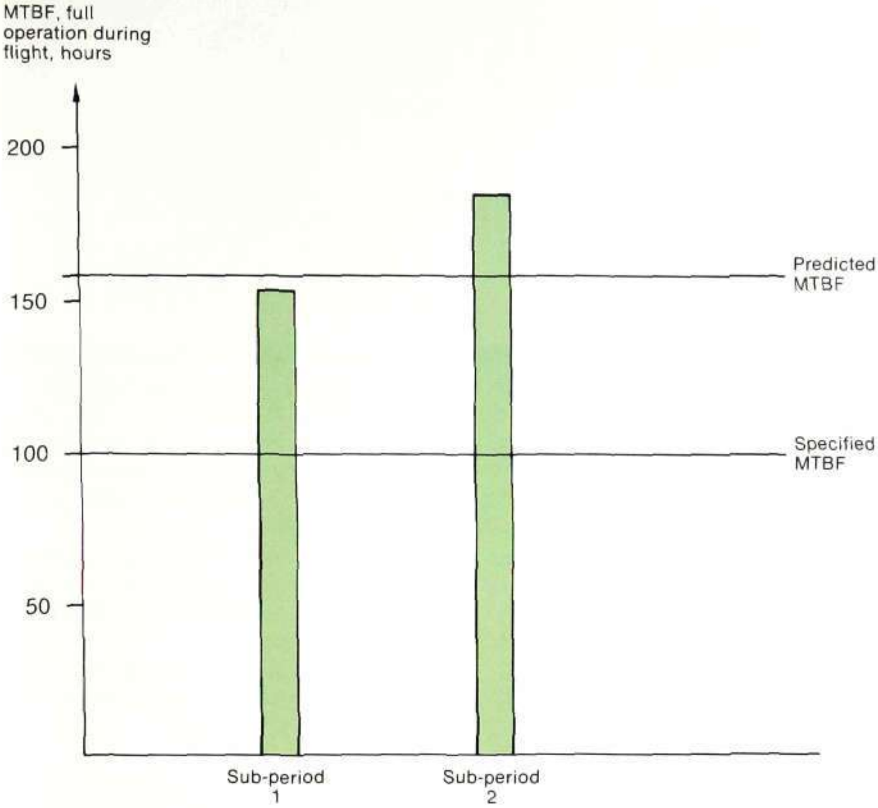


Fig. 10
The bar diagram shows the measured reliability for sub-periods 1 and 2. The specified and predicted MTBF values are shown for comparison purposes

caused by a faulty unit which had later been replaced because of that particular failure. It was therefore a case of "a fault building up", which at the early stages only caused sporadic alarms.

The fact that a unit that had been indicated as faulty was not replaced until the fault was fully developed simplified the failure classification work.

A small number of unverified complaints were caused by faults that were cleared by means of modifications made in the software for the radar data processor.

Only a few flights showed disturbances the cause of which could not be determined by the end of the test. However, there are reasons for assuming that these were also caused by developing faults.

Summary

The MTBF specified for radar PS-46/A is 100 hours for in-flight operation. The predicted MTBF is 161 hours.

The MTBF for operation during flight measured during the reliability qualification test was 178 hours. With a confidence inverval of 90% the real MTBF is between 126 and 259 hours.

The result obtained for the first part of the test period was 155 hours, and 186 hours for the second part.

The reliability qualification test shows that the specified MTBF is met with a high degree of probability.

The predicted MTBF was also reached during the test period.

The result must be considered wholly satisfactory and means that an accept decision has been reached.

FMV has declared itself very satisfied, not only with the good result but also with the positive and constructive atmosphere of the reliability qualification test. FMV has also pointed out that from the point of view of economy there are considerable advantages in carrying out a test of this type by following up the operation in the field rather than by carrying out supervised laboratory tests.

Finally Ericsson Radio System wishes to express its gratitude to all those who contributed to the excellent result, especially Jan Falk and Benny Olsson at F13, Sören Janeheden, Claes Wennerlund and Ingemar Selberg at FFV:U, and Lars-Erik Lindqvist, Gunnar Ericsson and Karl-Erik Klarby at FMV.

References

1. Andersson, B. et al.: *Radar PS-46/A for Aircraft JA37.* Ericsson Rev. *60* (1983):2, pp. 46–57.
2. MIL-STD-781C. *Reliability design qualification and production acceptance tests: Exponential distribution.*