



ICAO

Doc 8071

Manual on Testing of Radio Navigation Aids

Volume I — Testing of Ground-based Radio Navigation Systems
Fifth Edition, 2018



Approved by and published under the authority of the Secretary General

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AMENDMENTS

Amendments are announced in the supplements to the *Products and Services Catalogue*; the Catalogue and its supplements are available on the ICAO website at <http://www.icao.int>. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

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FOREWORD

The need for uniform navigational guidance signals and consistent system performance for radio navigation aids used in the international aeronautical services has been recognized as an important adjunct to safety and regularity in civil aviation. ICAO continuing air navigation policies, and associated practices of the Organization in their part concerning ground and flight testing of radio navigation aids, call attention to this need and encourage improvements in radio navigation ground equipment, including associated testing and monitoring facilities, with the view to minimizing, to the extent practicable, the more demanding requirements of flight testing. Annex 10 — *Aeronautical Telecommunications*, Volume I — *Radio Navigation Aids*, 2.2, provides an international Standard on the ground and flight testing of radio navigation aids.

This new edition of the *Manual on Testing of Radio Navigation Aids* (Doc 8071) comprises three volumes, as follows:

Volume I (fifth edition) — *Testing of Ground-based Radio Navigation Systems*

Volume II (fifth edition) — *Testing of Satellite-based Radio Navigation Systems* (update ongoing)

Volume III (first edition) — *Testing of Surveillance Radar Systems* (see Note)

The purpose of this document is to provide general guidance on the extent of testing and inspection normally carried out to ensure that radio navigation systems meet the Standards and Recommended Practices (SARPs) in Annex 10. The guidance is representative of practices existing in a number of States with considerable experience in the operation and maintenance of these systems.

This document describes the ground and flight testing to be accomplished for a specific radio navigation aid, and provides relevant information about special equipment required to carry out certain major tests. It is not intended to recommend certain models of equipment, but rather to provide general details relative to the systems under consideration.

Guidance on ground and flight validation of instrument flight procedures is published in the *Quality Assurance Manual for Flight Procedure Design* (Doc 9906), Volume 5 — *Validation of Instrument Flight Procedures*.

Throughout this document, measurements have been given in SI units and non-SI approximate equivalents; the accuracy of conversion depends upon the general requirements of each specific stage.

Comments on this volume would be appreciated from States and other parties outside ICAO concerned with radio navigation systems development and provision of services. Comments, if any, should be addressed to:

The Secretary General
International Civil Aviation Organization
999 Robert-Bourassa Boulevard
Montréal, Quebec
Canada H3C 5H7

Note.— A minor update of Volume III to remove some obsolete material is ongoing; however it will remain applicable mainly to older radar systems. For testing of modern surveillance systems, see the Aeronautical Surveillance Manual (Doc 9924).

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LIST OF ACRONYMS

ADF	Automatic direction finder
AFC	Automatic frequency control
AGC	Automatic gain control
AIP	Aeronautical Information Publication
AM	Amplitude modulation
ANSP	Air navigation service provider
ATC	Air traffic control
ATIS	Automatic terminal information service
CATV	Cable television
CVOR	Conventional VOR
CMN	Control motion noise
CW	Continuous wave
DDM	Difference in depth of modulation
DGNSS	Differential global navigation satellite system
DME	Distance measuring equipment
DVOR	Doppler VOR
EIRP	Equivalent isotropic radiated power
EMI/EMC	Electromagnetic interference/compatibility
FM	Frequency modulation
FMS	Flight management system
GNSS	Global navigation satellite system
GP	Glide path
IF	Intermediate frequency
IFR	Instrument flight rules
ILS	Instrument landing system
IM/MM/OM	Inner/middle/outer marker
INS	Inertial navigation system
ISM	Industrial scientific medical
ITE	Information technology equipment
ITU	International Telecommunication Union
LF/MF/HF	Low/medium/high frequency
LOC	Localizer
MDS	Minimum discernible signal
MHA	Minimum holding altitude
MLS	Microwave landing system
MSL	Mean sea level
MTBF	Mean time between failures
MTBO	Mean time between outages
NDB	Non directional beacon
NOTAM	Notice to Airmen
PAR	Precision approach radar
PBN	Performance-based navigation
PFE	Path following error
PFN	Path following noise
PLC	Power line carrier
PM	Phase modulation

POP	Proof of performance
pp/s	Pulse pairs per second
PRF	Pulse repetition frequency
RDH	Reference datum height
RF	Radio frequency
RMS	Root mean square
RNAV	Area navigation
RPAS	Remotely piloted aircraft systems
SARPs	Standards and recommended practices
SDM	Sum of depths of modulation
SID	Standard instrument departure
SRE	Surveillance radar element
UAV	Unmanned aerial vehicle
VFR	Visual flight rules
VOR	VHF omnidirectional radio range
VSWR	Voltage standing wave ratio

.....

Chapter 1

GENERAL

1.1 INTRODUCTION

1.1.1 Annex 10, Volume I, Chapter 2, 2.2 states, “Radio navigation aids of the types covered by the specifications in Chapter 3 and available for use by aircraft engaged in international air navigation shall be the subject of periodic ground and flight tests”.

1.1.2 Volume I of the *Manual on Testing of Radio Navigation Aids* (Doc 8071, Fifth Edition) addresses ground-based radio navigation systems. This document contains “guidance material” only. The texts and procedures outlined do not have the status of Standards and Recommended Practices (SARPs) except for identified quotations from Annex 10.

1.1.3 Guidance on ground and flight validation of instrument flight procedures is described in the *Quality Assurance Manual for Flight Procedure Design* (Doc 9906), Volume 5 — *Validation of Instrument Flight Procedures*.

1.2 PURPOSE OF THE DOCUMENT

This document is intended to provide general guidance on the extent of testing and inspection normally carried out to ensure that radio navigation systems meet the SARPs in Annex 10. The guidance is representative of practices existing in a number of States with considerable experience in the operation and maintenance of these systems.

1.3 SCOPE OF THE DOCUMENT

1.3.1 This document describes the ground and flight testing to be accomplished for a specific radio navigation aid, and provides relevant information about special equipment required to carry out certain major tests. It is not intended to recommend certain models of equipment, but rather to provide general details relative to the systems under consideration.

1.3.2 System testing is addressed in this document in general terms. System testing is normally done as part of design and development activities, prior to volume production and individual site installations. System testing includes design qualification testing, operational testing and evaluation, and “shakedown” tests.

1.3.3 In this document, the terms “testing” and “inspection” have the following meanings:

- *Testing*: A specific measurement or check of facility performance that may form a part of an inspection when integrated with other tests.
- *Inspection*: A series of tests carried out by a State authority or an organization as authorized by the State to establish the operational classification of the radio navigation aid.

1.4 GROUND VERSUS FLIGHT TESTING/INSPECTION

1.4.1 Ground tests are carried out by a trained specialist using appropriate test equipment at the facility or at a point on the ground remote from the site. Flight tests are those carried out in the air by a trained flight inspection crew using a suitably equipped platform. Serious consideration should be given to the relative merits of these two methods, taking into account both technical and economic factors.

1.4.2 Ground tests are usually more appropriate and less costly for accurate and quick evaluation of the facility performance. Flight tests are required to examine the signals-in-space as received at the aircraft after being influenced by external factors such as site conditions, ground conductivity, terrain irregularities, metallic structures, propagation effects, etc. Certain tests that may initially appear to be ground-based may be more appropriate as flight tests or vice versa.

1.4.3 Ground tests are normally carried out more frequently and can be used as indicators to determine when a flight test is required. It is often worthwhile to expend considerable effort in developing accurate and meaningful ground tests to minimize the costs and disruption of normal operations associated with flight tests. The demonstration of correlation between ground and flight test measurements will allow intelligent decisions to be made based on experience.

1.4.4 Flight testing will continue to be important in the proof of facility performance because it represents in-flight evaluation and provides a sampling of the radiated signals in the operating environment.

1.4.5 Where the small number of radio navigation aids in a State, or other reasons, make the establishment of a flight inspection unit uneconomical or impractical, it may be possible to obtain services through other States or a commercial company. Information regarding flight inspection service providers can usually be obtained from the appropriate ICAO Regional Office or online from the International Committee for Airspace Standards and Calibration (ICASC) at <http://www.icasc.co>.

1.5 CATEGORIES AND PRIORITIES OF TESTS AND INSPECTIONS

1.5.1 The establishment of appropriate intervals between various types of testing/inspections must take into account many associated factors specific to different States. Factors such as stability of equipment, extent of monitoring, weather, experience of maintenance crews, availability of standby equipment, etc., are all relevant. The intervals between tests/inspections of a new facility or type of facility may be shorter during early operation and may be extended as satisfactory experience is gained.

1.5.2 This document contains suggested schedules for each radio navigation aid, which should be considered (and modified, if necessary), based on the conditions relevant to each State and each site. The manufacturer's equipment manual may contain recommendations that are useful in this regard. Facility testing can be considered in the following general categories.

Ground testing/inspection

1.5.3 *Site proving:* Tests carried out at proposed sites for the ground element of radio navigation aids to prove suitability in cases where site surveys and simulations do not provide sufficient confidence. Portable ground installations are used for this purpose.

1.5.4 *Initial proof of performance:* A complete inspection of the facility after installation and prior to commissioning to determine whether the equipment meets the Standards and specifications.

1.5.5 *Periodic:* Regular or routine inspections carried out on a facility to determine whether the equipment continues to meet the Standards and specifications.

1.5.6 *Special:* Tests after a failure of the facility or other circumstances that indicate special testing is required. The results of special tests will often identify corrective maintenance work necessary to restore the facility. (In some cases, a special flight inspection is also required.)

Flight testing/inspection

1.5.7 *Site proving:* In the case where a portable ground installation is used, a flight test is conducted at the proposed site at the option of the responsible authority to determine the effects of the environment on the performance of the planned radio navigation aid.

1.5.8 *Commissioning:* An extensive flight inspection following ground proof-of-performance inspection to establish the validity of the signals-in-space. The results of this inspection should be correlated with the results of the ground inspection. Together they form the basis for certification of the facility.

1.5.9 *Periodic:* Flight inspections to confirm the validity of the signals-in-space on a regular basis or after major scheduled facility maintenance.

1.5.10 *Special:* Flight inspections required as a result of certain corrective maintenance activities, reported or suspected degradation of signal-in-space performance, aircraft accidents, etc. Typically, it is necessary to test only those parameters which have or might have an effect on facility performance. However, it may be economically advantageous in many cases to complete the requirements for a periodic inspection.

Priority of inspections

1.5.11 Flight inspections should be scheduled and conducted using a priority system. The following is a suggested grouping:

- a) *Priority 1:* accident investigation, restoration of established facilities after unscheduled outages that require a flight inspection and investigation of reported corruption of the signal-in-space;
- b) *Priority 2:* periodic inspections, commissioning of newly installed facilities; and
- c) *Priority 3:* evaluations of proposed sites for new installations and other investigations.

1.6 OPERATIONAL STATUS

Facility status can be identified as follows:

- a) *Usable:* Available for operational use.
 - 1) *Unrestricted:* Providing safe, accurate signals-in-space conforming to established Standards within the coverage area of the facility.
 - 2) *Restricted:* Providing signals-in-space not conforming to established Standards in all respects or in all sectors of the coverage area, but safe for use within the restrictions defined.

- b) *Unusable*: Not available for operational use as providing (potentially) unsafe or erroneous signals, or providing signals of an unknown quality.

1.7 AUTHORITY FOR FACILITY STATUS DETERMINATION

The responsibility for determining facility status rests with the appropriate State authority or the organization authorized by the State. The status determination should include all factors involved. This includes judgement (by the pilot) of the flyability of the signal-in-space, analysis of airborne measurements of the facility (by the flight inspection technician/engineer), and a statement of readiness (by ground maintenance personnel). The flyability of the instrument procedures is assessed as part of the validation activity conducted in accordance with the *Quality Assurance Manual for Flight Procedure Design* (Doc 9906), Volume 5 — *Validation of Instrument Flight Procedures*.

1.8 NOTIFICATION OF CHANGE OF STATUS

1.8.1 Notification of a permanent change of the facility status is to be done through the appropriate Aeronautical Information Publication (AIP); differences from Standards are to be notified to ICAO and in the AIP.

1.8.2 Notification of temporary changes in the status of facilities are to be promptly and efficiently advertised. A change in the status of a commissioned facility as a direct result of ground or flight inspection procedures, and resulting in a change of operational status (“unrestricted/restricted/unusable”) or “unusable” designation, should be advertised immediately by air traffic control (ATC) personnel, and promptly by a Notice to Airmen (NOTAM).

1.8.3 A facility having an “unusable” status is normally removed from service and can operate only for test or troubleshooting purposes.

1.8.4 Particular attention should be given to periodic or corrective maintenance procedures that involve false guidance signals being temporarily radiated. These conditions should be coordinated with ATC and promulgated to users by NOTAM, before the procedures commence. Additional guidance on special measures preventing the operational use of ILS-radiated test signals is given in Chapter 4, 4.1.

1.9 AIRBORNE AND GROUND TEST EQUIPMENT CALIBRATION

The selection and utilization of ground and flight inspection equipment used to determine the validity of navigation information should minimize the uncertainty of the measurement being performed. This equipment should be periodically calibrated to ensure traceability of measurements to appropriate standards.

1.10 COORDINATION BETWEEN GROUND AND FLIGHT TESTING/INSPECTION

1.10.1 Comparison of the results, obtained during successive tests on the ground and in the air, can determine the extent of degradation in the performance of the installation as monitored on the ground. These results can also be used to determine the choice of the periodicity of the flight test/inspection.

1.10.2 Flight test/inspection may involve a coordinated effort with ground specialists who may make adjustments or participate in the flight test/inspection. Efficient two-way communications should be established between ground and air. An additional communication means is often installed in the flight inspection aircraft and a portable unit is employed at the facility to provide these communications without interfering with the air traffic control communications.

1.11 FLIGHT INSPECTION UNIT

1.11.1 This document considers the flight inspection unit to be comprised of three parts: the flight inspection crew, the flight inspection aircraft and the position-reference system.

Flight inspection organization

1.11.2 The organization has a clearly defined management structure and is capable of showing the reporting lines up to the accountable manager, or board, as appropriate. Where the flight inspection operation is part of a larger organization, it is important to ensure that all contributing departments, divisions or other organizations (e.g. subcontractors) involved directly or indirectly with the flight inspection operation comply with the flight inspection organizations' exposition or quality management system as appropriate.

1.11.3 The organization ensures that all changes to the area of operation are assessed and recorded through a change management process. Changes would normally include, but are not limited to, organizational, system and procedural changes. Significant equipment modifications and renewal might need approval by the accountable entity within the organization or by the civil aviation authority before implementation.

1.11.4 The organization ensures that all personnel concerned with the flight inspection are competent to conduct their job functions. The organization establishes a written procedure for determining required job competencies and continued competence checking of all personnel through regular assessment. Competence should be recognized through certification or qualification as detailed within the organization's procedures.

1.11.5 The flight inspection crew normally consists of two pilots and one or two technicians or engineers. It is important that members of the flight inspection crew be experts in their individual fields, have sound knowledge and experience in flight testing/inspection procedures and requirements, and be capable of working as a team.

1.11.6 The State authority or flight inspection organization, as authorized by the State authority, should formally certify flight inspection personnel. The objectives are to:

- a) grant authority to the flight crew member who ensures the satisfactory operation of air navigation facilities;
- b) provide a uniform method for examining employee competence; and
- c) issue credentials that authenticate inspection authority.

1.11.7 The organization should establish a written procedure for determining required job competencies and continued competence checking of all personnel through regular assessment. The procedure should consider all personnel directly engaged in the flight inspection operation; this includes, but is not limited to, the pilot (in terms of flying the correct flight inspection procedure), flight inspector, surveyor, documentation controller and auditor.

Flight inspection aircraft

1.11.8 The flight inspection aircraft shall be airworthy and approved by the airworthiness authorities for the intended operation in the area it operates.

1.11.9 More guidance on the flight inspection aircraft instrumentation, antennas and other aspects is provided in Attachment A to this chapter.

Position-reference systems

1.11.10 Appropriate aircraft position reference information for all types of flight testing/inspection is required when the accuracy of the navigation signal is being determined.

1.11.11 The position-reference system is independent from the facility under testing/inspection. The position-reference system and the flight testing/inspection receiver contribute to the error budget. The overall error budget should be five times better than the performance standard of the navigation signal.

1.11.12 The position-reference system generates position reference information using the same system parameters as the navigation system under testing, e.g. a reference distance for a DME, a reference localizer deviation, or a reference glide path signal. A great variety of technical solutions have been developed, either using position-reference equipment, which provides information already in the correct coordinate system, or using computer systems, which calculate the reference information from one or more sensors.

Position-reference systems for approach and landing aids

1.11.13 Theodolites with electric readouts have traditionally been used as a position reference for ILS testing. If the output signal is transmitted to the flight inspection aircraft, this avoids the need for data to be recorded on the ground with later requirements for post-flight evaluation or transmitted to the flight inspection aircraft. ILS testing requires two different theodolite sites for azimuth and elevation data. The addition of ranging equipment allows ILS testing from a single site. The theodolite-based position referencing requires minimum visibility of 11 km (6 NM). A skilled theodolite operator is required to minimize manual tracking errors.

1.11.14 Manual theodolite tracking may result in significant contribution to the overall error budget of the flight inspection; therefore caution should be exercised when approach and landing aids, particularly Category III facilities, are evaluated using theodolite. Automatic tracking systems have been developed to optimize the error budget.

1.11.15 Alternative position-reference systems are based on inertial navigation systems (INSS) integrated with other sensors. Accuracy is aided by various sensor inputs such as global navigation satellite system (GNSS), laser trackers and on-board camera systems which provide independent reference update information. GNSS, augmented by differential corrections as required, also serve as a position-reference system. With these technologies, certain flight inspection operations can be conducted under limited visibility conditions.

1.11.16 Additional information on position-reference systems may be found in chapters specific to each navigation aid.

Position-reference systems for en-route navigation aids

1.11.17 The basic solution of a position-reference system for flight inspection of en-route navigation aids is the use of charts. Aeronautical charts should be used if possible. Large scale charts that provide the greatest possible amount of

detail are desirable so that ground position-reference points can be better defined. The charts are to be marked for preparation of the flight inspection mission. Typically, charts provide reference information only for some parts of the flight path. Information has to be evaluated manually by the flight crew.

1.11.18 The equipment described in 1.11.13 to 1.11.16 may be used for the inspection of en-route navigation aids if better accuracy or continuous reference data are required.

Position reference system integration

1.11.19 A more general approach is the use of a position reference system that provides information for all phases of the flight inspection. A state-of-the-art solution is the combination of different sensors for the testing, including INSS, barometric altimeters, tracking of several DME facilities, and GNSS augmented as necessary. A high degree of automation can be achieved for the flight inspection since continuous position reference information is available.

Human-machine interface aspects

1.11.20 The operator's console should be designed and located in such a way as to offer the proper interface between the flight inspection crew and test and data-processing equipment. The console location should be determined based on noise and vibration levels, lighting, outside visibility, proximity of the centre of gravity of the aircraft, air conditioning, and forward-facing orientation.

1.12 ORGANIZATION, SAFETY AND QUALITY

1.12.1 The management of organizational features that can cause a risk to safety should be conducted systematically. The effective management of safety should be achieved by the derivation of policy and application of principles and practices designed to prevent the occurrence of factors that could cause accidents or serious incidents.

1.12.2 The minimum requirements for the safety system should include written procedures that document all of the actions necessary to ensure the safe operation of the flight inspection aircraft and system.

1.12.3 The minimum requirements for the quality system should include written procedures that document all of the actions necessary to ensure the verification of the radio navigation aids. The ISO 9000 quality management model provides a useful framework, and particular note has to be made of the following features expected in the quality management system:

- a) *Organizational and individual accountability.* Accountability and responsibility should be documented, traceable, and verifiable from the point of action through to the accountable manager (in most cases the Chief Executive).
- b) *Management review.* The system for management review should be effective and should ensure that senior management is fully cognizant of the systems and features that affect quality.
- c) *Exposition or company documentation.* An exposition or company documentation should be provided to clearly describe the organizational structure, personnel, accountabilities, responsibilities, resources, facilities, capabilities, policies, and purposes of the organization.

- d) *Record keeping.* Records should be accurate, legible, and capable of independent analysis. The retention period for records should be defined. Commissioning records and those documenting system modifications (e.g. changes to ILS antenna configuration from sideband reference to capture effect) should be kept for the entire life cycle of the facility.
- e) *Customer satisfaction.* The organization should establish a procedure to request feedback from their customer(s) on the service provided. This information should be used to improve service.

Personnel training and qualification

1.12.4 The organization should establish methods for determining required job competencies:

- a) all personnel directly engaged in the flight inspection, maintenance, or installation of an aeronautical navigation aid should be adequately qualified and trained, as well as experienced in their job functions;
- b) the management system should include a written procedure for ensuring the continued competence of personnel through regular assessment; and
- c) initial and recurrent training programmes for aeronautical navigation aid specialists should include a detailed explanation of maintenance procedures and their effect on the integrity of the radiated signal.

Documentation control

1.12.5 Under the quality system all test/inspection procedures should be controlled so that the correct version of any procedure can be easily identified and used.

1.12.6 Retention of data is required in order to permit trend analysis of ground and airborne flight inspection equipment. Such analysis will assist in the identification of fault conditions or substandard performance before development of any safety hazard. Examples of items that might be identified in this way are: a decreasing mean time between outages (MTBO); a slow drift in one or more radiated parameters; or a specific component that may appear to have a high failure rate.

1.12.7 More guidance on documentation and data recording is provided in Attachment B to this chapter.

1.12.8 The organization shall ensure that all documents that support the flight inspection operation should be controlled so that the correct version of any document can be easily identified and used.

Design qualification of ground equipment

1.12.9 A new design of equipment is subject to design qualification tests. These tests ensure that the equipment meets its design requirements. These tests are normally made on the "first production equipment" or on the first batch of equipment. If no serious problems are encountered, those tests are not repeated for future installations of similar equipment. Items to be addressed during these tests include:

- a) *Environmental performance.* These tests show that the equipment meets the tolerances under the range of environmental conditions specified by the manufacturer and purchaser. Environmental tests include all parts of the equipment, both internal and external.

- b) *Mean time between failures (MTBF)*. Before commencing such tests, it is essential to define the test conditions; for example, what constitutes a failure, what confidence level will be used during the demonstration, will modifications be permitted during the tests. See Annex 10, Volume I, Attachment A; Attachment C, 2.8 (Integrity and continuity of service — ILS ground equipment); Attachment F and Attachment G, 11 (Integrity and continuity of service — MLS ground equipment) for additional guidance on reliability aspects.
- c) *Manufacturer's quality system*. The equipment is manufactured under an effective quality management system. There should be traceability from modules and components back through to system design requirements.
- d) *Integrity*. The manufacturer should have made an in-depth study of system integrity. Safety critical components of the system are to be identified and all components used in these areas are to be traceable to their source. The integrity analysis should also define the maintenance and test intervals for the safety critical components of the system. Where a system is claimed to have automatic integrity checks, it is important to fully understand the depth of tests made by the automatic procedure. See Annex 10, Volume I, Attachment A; Attachment C, 2.8 (Integrity and continuity of service — ILS ground equipment); Attachment F and Attachment G, 11 (Integrity and continuity of service — MLS ground equipment) for additional guidance on integrity aspects.
- e) *Monitor correlation tests*. Many systems use integral monitors or monitors in the near field area of the antenna array. Tests should show that simulated faults in the system produce the same response on monitors as in the far field. This investigation should concentrate mainly on simulated antenna faults, including individual elements and the signal distribution equipment.
- f) *Safety assessment*. A system safety assessment should be conducted by the manufacturer of a navigation system element to provide evidence that the system meets the safety requirements as part of the overall design qualification requirements. The safety assessment process includes specific assessments conducted and updated during system design and development, and interacts with the system development supporting processes. The requirements for conducting safety assessments may vary on a national or regional basis.
- g) *Hardware/software design assurance*. The roles of hardware and software in implementing the functional requirements of a system must be clearly specified and justified. The partitioning of functions between hardware and software should take into account safety criticality, testability, reliability, verification, validation, maintainability and life cycle costs. A system development assurance level (as defined in RTCA and EUROCAE documents) will be based upon the contribution of hardware/software to potential failure conditions as determined by the system safety assessment process. The hardware/software level of development implies that the level of effort required to show compliance with the safety requirements varies with the failure condition category.

1.12.10 Quality maintenance measurements of the ground transmitting equipment can help ensure that the radiating signal generation has not changed since the last periodic correlation. Restricting the adjustment of the safety critical parameters without a flight inspection, and the establishment of ground maintenance methods to verify that the equipment is operating within clearly defined specifications, should be considered as parts of a quality maintenance regime.

1.13 ELECTROMAGNETIC INTERFERENCE

1.13.1 Electromagnetic interference to a navigation aid is a rare occurrence, but the possibility of it happening should not be excluded. All reports of suspected interference should be investigated. During a flight inspection of a radio navigation aid following a report of suspected interference, the interference might affect the signals from the navigation aid being inspected or it might affect the signals used for some types of position-referencing, such as GNSS.

1.13.2 Attachment C to this chapter gives guidance on this subject, including types of interference, possible sources, methods of detection, and steps which can be taken to eliminate or mitigate the effects.

1.14 SIGNAL ANALYSIS

1.14.1 The use of a signal analyser (i.e. spectrum analyser or other capability which may be part of a multifunction device) on the flight inspection aircraft and on the ground at navigation aid sites can be an effective means of resolving problems with radio navigation aids. The following are some of the applications for signal analysis as it relates to testing of radio navigation systems.

1.14.2 Signal measurements at specific points in the service volume should be accomplished on a flight inspection aircraft. It is recommended that the signal analyser set-up information, aircraft antenna position, and measurement time be recorded with spectrum measurements. At remote sites, the signal analyser on a flight inspection aircraft may be used for verification of the radiated signal spectrum from the ground system when the required test equipment is not available at the site.

1.14.3 The signal analyser can be used to measure carrier frequency (Doppler shift should be taken into account), sideband modulation levels and spurious emission levels. Residual frequency or phase modulation components on ILS transmitters can be identified from the radiated spectrum components. If present, frequency or phase modulation may affect the AM sideband amplitudes as measured on the signal analyser. Care should be taken to account for the Doppler shift in signals as the aircraft moves at high speed toward or away from the transmitter. Computer-aided acquisition and set-up of the signal analyser will be of great advantage in the air.

1.14.4 The signal analyser can be used in the periodic flight inspection for dual frequency ILS to measure the power ratio between the course and clearance transmitters. The course and the clearance signal frequencies can be measured simultaneously and any error in frequency alignment of the ground facility can be detected. This technique greatly improves the effectiveness and accuracy of the measurement, eliminating the need to switch between the two transmitters on the ground and position the aircraft at exactly the same position in space for two sequential measurements. Course/clearance power ratio can be checked simultaneously with the normal clearance procedure using this technique.

1.14.5 The signal analyser can also be used to identify the frequency and relative power of the interfering source when interference has been detected through loss or erratic behaviour of the cross-pointer, audio or automatic gain control (AGC) signal. Information on the types of sources and testing techniques is provided in Attachment C to this chapter.

1.15 GROUND AND FLIGHT INSPECTION PERIODICITY

General

1.15.1 This document includes suggested periodicities for various ground and flight tests that should be considered in the light of conditions relevant to each State and each site.

1.15.2 The suggested periodicities are given as general guidance and may be modified based on the manufacturer's recommendation or operational experience. In some cases, it may be necessary to carry out more frequent inspections, e.g. following initial installation. It may also be reasonable to extend the inspection intervals in some circumstances, if the factors outlined in this section have been taken into account. It is recommended that States have a documented procedure for determining and changing the test/inspection interval.

1.15.3 The manufacturer's equipment manual usually contains recommendations which are also useful in this regard.

Determination of test/inspection intervals

1.15.4 Many factors influence the choice of appropriate intervals for both ground and flight tests. These include the reliability and stability of operation of the equipment, the extent of ground monitoring, the degree of correlation between ground and flight measurements, changes in the operating environment, manufacturer recommendations, and the quality of maintenance. The complete programme of ground and flight inspections should be considered when determining test intervals.

1.15.5 Reliability and stability of equipment is related to age, design technology, and the operational environment. Stability of operation may also be affected by excessive maintenance adjustments attributable to either human factors or variation in test equipment performance. This is particularly true with some older test equipment where the accuracy and stability of the test equipment is not significantly better than the equipment under test. A major contribution to the demonstration of stability of navigation aids is the design of modern flight inspection systems and ground facility test equipment, where the standard resolution and accuracy are very high.

1.15.6 Ground maintenance activity and its frequency is dependent upon the design, reliability and stability of a particular equipment and the quality of the ground test equipment employed as a transfer standard. It has been shown that equipment reliability may be adversely affected by frequently scheduled major maintenance activity. It is, therefore, desirable to limit such activity to essential testing only, particularly for tests that require the disconnection of cables. There is a requirement for additional supplementary flight inspection when some engineering activities, such as glide path antenna changes or adjustments are made. Further investigation may be initiated if the independent monitor calibration indicates any adjustments are required.

Example of criteria to be considered for the modification of ILS flight inspection intervals

1.15.7 The correlation of air and ground measurement records and historic demonstration of equipment stability have allowed some States to extend the intervals between flight inspections. This is supported by the use of routine monitor readings, strict environmental safeguarding and closer tolerances on flight inspection results to ensure operational stability is maintained. Example criteria for the extension of ILS flight inspection intervals are given in 1.15.8 and 1.15.9.

1.15.8 This section gives an example of criteria applied to extend the nominal interval between flight inspections of selected facilities. The procedure requires:

- a) an initial demonstration of stability over four consecutive periodic flight inspections with no transmitter adjustments;
- b) good correlation between concurrent ground and airborne results;

- c) a record of independent monitor test results;
- d) a record of equipment monitor readings taken at regular intervals not to exceed 50 per cent of the extended flight inspection interval;

Note.— A shorter interval between monitor readings is suggested for ILS Facility Performance Categories II and III.

- e) evidence that the quality of the maintenance is high and that the recorded test result and monitor readings of critical parameters indicate that the equipment consistently meets performance requirements;
- f) that the facility is adequately safeguarded against changes in the operational environment, e.g. building development; and
- g) a recommended decrease in tolerances applied to the flight inspection results for critical parameters to 75 per cent of the normal acceptance standards. Examples of critical parameter(s) include:
 - 1) localizer alignment and displacement sensitivity;
 - 2) glide path angle and displacement sensitivity; and
 - 3) VOR approach radial alignment and structure.

1.15.9 Examples of cases in which the flight inspection interval should be decreased include:

- a) if the above criteria are no longer met; or
- b) if a facility fails to meet the same performance requirement on successive inspections; or
- c) if several requirements are not met on any one inspection.

Correlation as the basis for extending periodicity

1.15.10 A typical basis for extending the interval between required measurements without degrading ILS integrity is correlation. Any individual measurement is normally expected to be repeatable over time without adjustments to the equipment. Correlation between ILS measurements made both on the ground and in the air at the same or nearly the same time is also expected. This places equal responsibility on ground and airborne personnel and helps identify common-mode measurement errors. An additional requirement to extend flight inspection intervals is the influence of near- and far-field environments on the signals. These effects can be determined with a flight inspection aircraft. The following paragraphs give illustrations of the correlation technique.

1.15.11 *Preliminary requirements.* Certain fundamental requirements should be met prior to any measurement activity if correlation between ground and airborne measurements over time can be expected. Typical requirements include functionally similar training for personnel, appropriate calibrated test equipment, completion of all prescribed ground maintenance tasks, availability of commissioning reports and recent periodic inspection reports, and frequent use of measurement skills by both ground and airborne personnel.

1.15.12 *Techniques.* Achieving good correlation places the same or similar weight on both ground and airborne testing, and demands that both be conducted with great care. Initial or commissioning-type flight measurements should

be made with special care, as the corresponding ground measurements will be used as references for ground maintenance personnel. The portable maintenance receiver is readily used in the far-field for localizer facilities, while glide path facilities may require measurements in the near- or mid-field with an auxiliary antenna placed near the transmitting antennas.

1.15.13 **Tolerances.** New tolerances may be developed to define acceptable correlation between measurements. A rigorous application of correlation principles might include the following types:

- a) Setting tolerance — defines the exact value for a parameter, which should be achieved (within the measurement uncertainty) when adjustment is required.
- b) Adjustment/maintenance tolerance — defines the limit within which a parameter may vary without requiring adjustment.
- c) Operational tolerance — defines the ICAO Standard for a parameter.
- d) Discrepancy tolerance — defines, for certain parameters only, the limits of divergence between various measurements:
 - 1) Ground/ground discrepancy — applies to a divergence over time, or between different methods of measuring the same parameter (e.g. alignment monitor, portable ILS receiver, and far-field monitor).
 - 2) Ground/air discrepancy — applies to a divergence between measurements of the same parameter at the same or nearly the same time by ground and airborne testing personnel.

1.15.14 **Activities during flight inspection.** Typical correlation activities begin with a confirmation that airborne and ground test equipment is operating within tolerances. This may be achieved by comparing ground and flight test generators and receivers. (If the tolerances are not met, the flight inspection is delayed until the cause of the problem is eliminated.) If the ground or airborne results are out of discrepancy tolerances during the flight inspection and the cause cannot be determined, then the ground monitor alarm limits should be tightened, the facility declassified appropriately or removed from service. The successful completion of the flight inspection (all tolerances are met) establishes that the ground maintenance activities are effective and the interval between inspections may be maintained at the optimum periodicity.

Expiration of nominal intervals

1.15.15 To account for operational restrictions, States may permit the completion of a recurrent test/inspection within a certain time window following the nominal recommended interval. This extension is not to be intended as a means to systematically extend the test/inspection interval.

1.15.16 If a test/inspection is not conducted prior to the expiration of the appropriate time window, various actions may be considered:

- a) extension of the expiration after engineering evaluation and/or ground maintenance reinforcement;
- b) degrading of the category of ILS (Category III down to Category I) in cases where intervals vary according to the category of ILS; and
- c) temporarily removing the navigation aid from service.

1.16 FLIGHT INSPECTION AT NIGHT

1.16.1 Certain areas have high densities of air traffic during daylight hours. Conducting flight inspections in these areas during daylight can cause delays to normal traffic if safety is not to be compromised. It is possible to make many of the flight inspections, described in this manual, during the night to avoid interfering with normal flight operations. Noise abatement considerations may inhibit this.

1.16.2 Several additional factors need to be considered for night-time flight inspection. These are detailed in the following paragraphs.

1.16.3 *Effect of the environment on the radiated signal.* The signals radiated by some types of radio navigation aids are affected by propagation which differs between day and night. For example, the level of background radio noise over a city may be different.

1.16.4 *Effect of environment on the navigation aid.* The ground facility maintenance engineer should inform the flight inspector of any equipment variations, such as field monitor performance which may change at night. The effect of the local environment, such as changes in the position of reflecting obstacles, should be considered.

1.16.5 *Position reference.* Flight inspection at night will normally use an independent reference system but the use of ground tracking equipment is not excluded.

1.16.6 *Evaluation of results.* The State authority or the organization authorized by the State should decide whether differences from measurements made during the daytime are due to night conditions, problems with the equipment or making the measurements at different positions.

1.16.7 *Flight inspection reports.* The flight inspection report should indicate whether the inspection was made at night.

1.16.8 *Types of flight.* The inspection flights should be made in accordance with the guidance given in this manual, with the exception of measurements that specifically need low-level flights. It is recommended that at specific intervals an inspection is made under the same conditions as prevailed at the time of commissioning.

1.16.9 *Safety of flight.* Flights should be conducted 300 m (1 000 ft) above the level normally used for daytime flight inspection in areas having obstructions. It will be necessary to change some horizontal distances in order to retain the same vertical angle from the navigation aid, where this is important to the measurements. Low-level below path (safety approach) glide path inspection flights should not be made during the night or when the level of natural light is low. Flights should normally be carried out in accordance with VFR. The probability of birdstrike during night flight should also be considered.

1.17 COMBINED FLIGHT INSPECTION OF COMPLEMENTARY FACILITIES

1.17.1 The combining of flight inspection activities for complementary or collocated facilities, where practical, may offer cost and schedule efficiencies for the flight inspection operation while reducing impacts to other air traffic operations.

1.17.2 Examples of opportunities for combined flight inspection activities include:

- a) simultaneous measurements of flight inspection parameters for collocated VOR/DME or ILS/DME facilities;

- b) inspection of associated position fixes based on other navigation aids during flight inspection of VOR facilities;
 - c) simultaneous measurements of selected flight inspection parameters for ILS localizer and glide path facilities; and
 - d) assessment of visual approach aids during flight inspection of ILS facilities.
- 1.17.3 The realization of benefits from combined flight inspection activities will depend upon the incorporation of appropriate provisions in flight inspection procedures and equipment.
- 1.17.4 While guidance relating to flight validation is contained in Volume 5 of Doc 9906, in some cases it may also be possible to combine flight inspection and flight validation activities.

1.18 USE OF REMOTELY PILOTED AIRCRAFT SYSTEMS

1.18.1 A basic principle of flight inspection to assess compliance with Annex 10 Standards is to use representative avionics at normal aircraft speeds. While flight inspection aircraft and their avionics are not representative of all aircraft and avionics, they nonetheless facilitate making judgements on the operational relevance of signal anomalies. This principle does not prevent the use of more advanced measurement capabilities both in ground and flight testing; however, it requires that good correlation (impact of filtering, etc.) needs to be established.

1.18.2 Remotely piloted aircraft systems (RPAS) or unmanned aerial vehicles (UAV) should be assessed to determine that they provide the payload capability, speed and range necessary to conduct a flight inspection for navigation aids as recommended herein in a cost-effective manner. RPAS can and have been used for special and advanced measurement applications which are difficult to achieve with traditional ground and flight measurement capabilities. Nothing in this manual is intended to prevent the development of such capabilities. Some States are studying how the use of RPAS can help in making more regular measurement checks with the aim to reduce the periodicity of a full flight inspection with a typical flight inspection aircraft. These studies should take into account the guidance in section 1.15.

Attachment A to Chapter 1

FLIGHT INSPECTION AIRCRAFT

Aircraft type-preference should be given to multi-engine turbine aircraft for their reliability and performance. Pressurization and air conditioning should be available as a means to reduce crew workload, increase safety and keep the flight inspection system equipment within the technical specification. Standard avionics must match the airspace requirements. Many factors should be considered when selecting an aircraft as a vehicle for flight inspection. The number of aircraft required will be determined by the qualities of the aircraft chosen and factors such as the number of facilities to be flight inspected, their relative geographical locations, periodicity of inspections, and other duties of the aircraft.

1. GENERAL CHARACTERISTICS

1.1 The following desirable characteristics should be found in a flight inspection aircraft:

- a) reliable, efficient type equipped and certified for IFR operations;
- b) sufficient carrying capacity for the flight crew, as well as all necessary electronic and recording equipment and spares. It may also be necessary to have additional capacity to transport ground personnel and equipment;
- c) sufficient range and endurance to complete a normal mission without reservicing;
- d) aerodynamically stable throughout its speed range, but particularly at speeds encountered during flight inspection;
- e) low noise and vibration levels;
- f) low electrical noise characteristics to minimize interference with received signals; e.g. propeller modulation of the received signal must be as low as possible;
- g) stable electrical system of adequate capacity to operate the required electronic equipment in addition to the aircraft equipment;
- h) reasonably wide speed and altitude range to enable flight inspection to be conducted, where possible, under the conditions encountered by users. Good low-speed characteristics are essential where theodolite tracking by ground observers is carried out;
- i) suitable for future modifications or expansion of equipment to allow for inspection of additional aids or to increase accuracy or processing speed on existing facilities;
- j) aircraft cabin environmental control equipment that minimizes the adverse effects of temperature and humidity on the sensitive test equipment used in flight inspection systems and maintains a comfortable environment for the crew; and
- k) equipped with an autopilot to reduce crew workload.

1.2 A variety of aircraft having the above characteristics have been successfully used for flight inspection work. Some States are using the smaller, more versatile jet aircraft, of the type usually referred to as “business jets”, for medium- and high-altitude inspection of radio navigation facilities.

2. AIRCRAFT INSTRUMENTATION

2.1 The flight inspection aircraft contains a full range of navigation equipment as required for instrument flying. Additional equipment must be provided for the monitoring and recording of the received navigation signals. The navigation receivers may be used for both navigation and flight inspection. Special flight inspection receivers installed in addition to those used for navigation are preferable because of their special accuracy requirements.

2.2 When navigation receivers are shared between the pilot and observer, the control of the receiver during flight inspection should be with the technician/engineer.

2.3 Inspection of PAR may require an on-board positioning system to record the azimuth, elevation and distance. The aircraft plays a passive role as a reflector of electromagnetic signals. Flight inspection procedures and Standards, particularly those relating to strength of signal return, are usually related to aircraft effective size as a reflector.

Flight Inspection System

Build state and modification control

2.4 The build state of all equipment, including test equipment, should be recorded and the records should be updated whenever modifications or changes are made. All modifications should be accurately documented and cross-referenced to modification strikes or numbers on the equipment. After making any modification, tests and analyses should ensure that the modification fulfils its intended purpose and that it has no undesired side effects.

Calibration of flight test equipment

2.5 All test equipment used for calibration, test or maintenance of an aeronautical navigation aid should be listed and subject to regular calibration checks. Each item of test equipment should have a documented calibration procedure and calibration records. Test equipment should be calibrated at the manufacturer's recommended intervals, unless otherwise indicated by objective evidence or operational conditions.

2.6 The conditions of use of individual items of test equipment should be fully considered and the manufacturer's recommended interval should be queried if the utilization profile may be outside of the specified environmental conditions.

2.7 Regular calibration of the flight inspection receivers and position-reference system is to be performed in order to ensure a back tracing of data to international or national standards. The calibration may be performed either on board the flight inspection aircraft or in a laboratory. In both cases, a test transmitter is connected to the radio frequency (RF) input of the receiver in order to input simulated signals. The receiver output is compared with the nominal signals; deviations are recorded either in a test protocol or by computer. Calibration data are applied either online by the computer or during offline data evaluation.

Control of spares

2.8 Equipment spares should be stored under suitable environmental conditions. Spares having a limited lifetime, or requiring regular maintenance or calibration, should be suitably identified to that effect. Procedures should exist for the control, repair, and return-to-service of equipment or modules. The procedures should show which modules may be repaired on-site and which should be returned to the manufacturer or recognized repair facility.

System block diagram and description

2.9 The flight inspection equipment as shown in Figure I-1-A-1 comprises:

- a) flight inspection receivers with associated antennas;
- b) position-reference system;
- c) equipment for data display and processing; and
- d) equipment for data recording.

2.10 Flight inspection receivers provide both navigation information as in standard aircraft equipment and flight inspection information. Special care has to be taken concerning the location of antennas of the flight inspection receivers in order to avoid interference problems and to minimize the error contribution of the test equipment.

2.11 The position-reference system provides reference position (navigation) information in order to determine the navigation accuracy of the facility. Parts of the position-reference system may be shared with standard aircraft equipment.

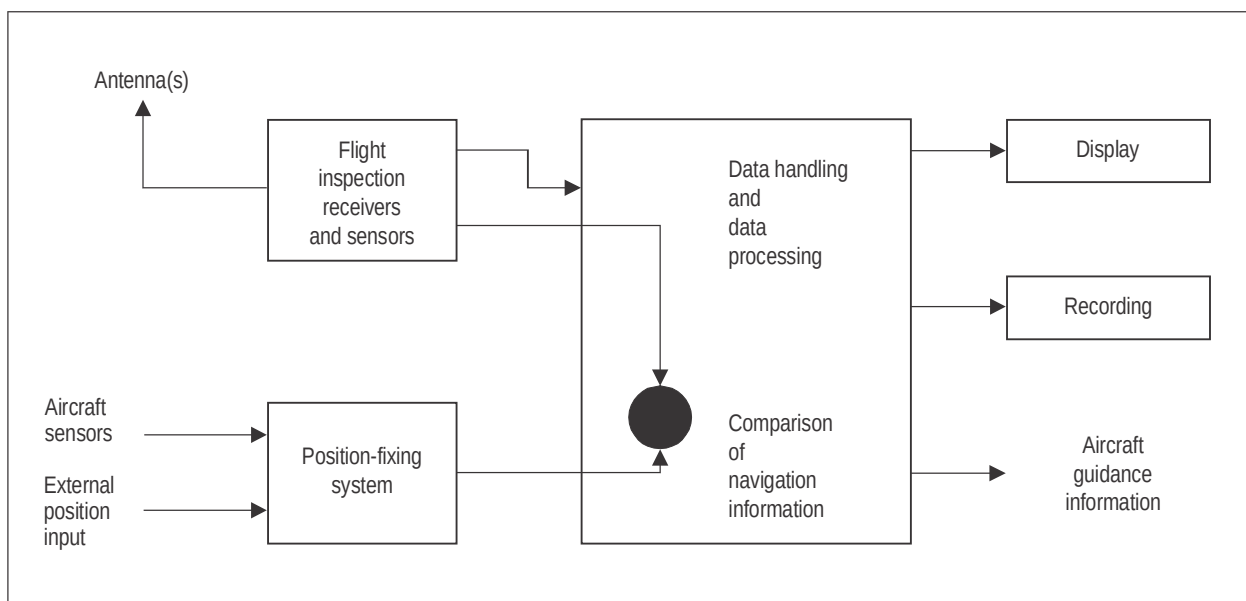


Figure I-1-A-1. Block diagram for flight inspection equipment

2.12 Data generated from the flight inspection receivers and the position-reference system are to be displayed and processed. The processing may be performed either online or after completion of an inspection. One important element of data processing is the comparison of ground facility navigation and reference position (navigation) information.

2.13 A recording medium is required for documentation of raw data and inspection results.

2.14 Calibration equipment may be connected to the flight inspection equipment.

3. ANTENNAS

3.1 Calibration and extensive testing to verify performance are normally required for antennas used to inspect navigation aid coverage.

3.2 Calibration of the antenna system gain is required for antennas used to measure field strength and should be considered early in the installation planning stage. Antenna system gain characteristics (including all feed cables, switches and power splitters) must be determined in order to measure the field strength with reasonable accuracy. The characteristics must be measured over the range of frequencies to be used and at the aircraft orientations experienced during the measurement procedures. These antenna gain characteristics must then be applied either in real-time as data is input and displayed, or post-processed to generate the final report data.

3.3 The above methods may be used to correct absolute or relative field strength measurements, however, there are some flight inspection applications for which gain errors cannot be corrected. These place additional constraints on the achieved airborne antenna patterns. An example is course structure measurements for localizer, glide path, and VOR, for which the contributing multipath errors may propagate to the aircraft from a widely different azimuth than the desired direct signal. In this case, variations in gain from an omnidirectional pattern will affect the measured amplitude of the course structure, with or without aircraft attitude variations, and flight measurements, by differing aircraft types, will vary. Flight inspection organizations should make every reasonable effort to achieve antenna patterns that represent the antennas used by the fleet operating on the airport — this is particularly important for Category II and III measurements.

Antenna measurement techniques

3.4 Many techniques, including mathematical modelling, reduced-scale modelling, full-scale ground testing and flight testing, are available for optimizing the location of antennas and characterizing their gain in a given location on an aircraft. The complexity and cost are generally proportional to the number of azimuth and elevation angles to be measured as well as the accuracy required of the measurements. The overall cost is reduced if a combination of modelling and ground testing is used to establish expected performance; flight testing would then be used as the final confirmation stage.

3.5 Flight test techniques capable of full azimuth or lower hemisphere characterization with high accuracy are now available through many flight test ranges, these should be the preferred methods used to provide confirmation of antenna patterns. Procedures that provide ongoing confirmation of antenna performance are still required and some form of ramp-based check should be established.

3.6 Consideration should also be given to characterizing the localizer antenna pattern over the FM broadcast band (88–107.9 MHz), if the aircraft is to be used in resolving electromagnetic compatibility (EMC) problems from FM broadcast stations. A separate broadband antenna may be fitted if the aircraft is to be used for general interference investigation.

Installation considerations

3.7 Antenna installation can affect the flight inspection measurements and the operational use of the aircraft in many ways. The following are a few examples:

- a) Propeller modulation effects can interfere with the received ILS localizer signal over a range of engine power settings. This can severely limit the use of the aircraft for flight inspection. Improving the antenna location is the best solution to this problem, followed by the modification of the propeller frequency. The formula below shows the propeller modulation frequency.

Propeller Modulation Frequency (Hz) = Shaft Rotation Speed (RPM) x Number of Propeller Blades/60

Examples:

3-blade propeller at 1800 RPM: $1800 \times 3 / 60 = 90 \text{ Hz}$ > BAD for ILS

4-blade propeller at 1800 RPM: $1800 \times 4 / 60 = 120 \text{ Hz}$ > OK for ILS

- b) Physical movement of other antennas, such as the weather radar, may affect the signal received from a glide path antenna located nearby. The weather radar may have to be parked in a known orientation to obtain stable glide path signals.
- c) Cross-coupling between aircraft transmitter antennas and receiving antennas can easily occur. Care must be taken to ensure adequate separation between potential interfering sources, such as VHF communications antennas and VOR/ILS localizer antennas.
- d) Aircraft structures must be taken into account when selecting antenna locations. The mounting of antennas near discontinuities in material types should be avoided if a good ground plane is required. Metallic support rods stowed inside a composite material nose cone can act as re-radiators affecting the performance of a nearby antenna.
- e) When one antenna is used to feed two or more receivers there is potential for receiver interaction resulting in an uncalibrated change to the antenna system gain. It is recommended that separate antennas be provided for the flight inspection receivers. Testing is recommended when a shared antenna must be used to ensure that tuning the second receiver over the band does not affect the signal level reaching the receiver used for coverage measurements.
- f) Changes in aircraft attitude will affect the relative positions of the antenna and tracking reference point if the aircraft measuring antennas are not located at the same point as the reference for the tracking system as seen from the ground. Certain flight inspection systems correct this by using software and inputs from the aircraft navigation sensors.
- g) The position of the phase centre for some types of antennas will vary according to the direction of arrival of the signals. Measurements have shown that the effective phase centre may move outside the physical area of the antenna. This change in position of the phase centre should be included in any correction algorithms which may be used.

4. FLIGHT INSPECTION RECEIVERS AND RADIO COMMUNICATION EQUIPMENT

4.1 Flight inspection receivers are to be of the highest quality in order to obtain the accuracy required for flight inspection purposes and should provide additional measurement outputs specific to flight inspection. A dual set of receivers is preferable to reduce statistical errors.

4.2 Flight inspection receivers include an AGC measurement. The AGC information allows the determination of the field strength if the receiver and antenna characteristic is taken into account. Further components have to be added like a temperature control for the receiver or a further dedicated receiver if the stability of the flight inspection receiver AGC output is not sufficient.

4.3 Flight inspection receivers used for the calibration of pulsed navigation facilities, such as DME and radars, provide the video signal of these facilities.

4.4 A radio is included in the flight inspection equipment in order to allow independent communication between the flight inspector and the ground crew, without affecting the pilot.

5. DATA PROCESSING, DISPLAY AND RECORDING

5.1 Modern flight inspection equipment includes a computer, which is used to read the data from the position-reference system and from the flight inspection receivers. The computer processes data in order to compare the facility navigation information and the position reference information. The computer has the capability of determining facility parameters, e.g. ILS localizer course width, alignment, etc.

5.2 The comparison of facility navigation information and position-reference point information may be performed with an analog solution, if the flight inspection system does not include a computer for calculating the results. The facility parameters have to be calculated manually in this case.

5.3 All relevant information like facility navigation information, reference information, facility error and additional receiver information, such as field strength, is displayed on board the flight inspection aircraft for the operator. Data may be displayed on analog or digital instruments as well as on computer screens.

5.4 Chart recorders or printers can be used for the documentation of flight inspection results. All data are annotated properly either by the operator or automatically by the data-processing system.

5.5 All raw data and computed data are recorded in electronic format on tapes or disks, if possible. This enables a later post-processing, if a specific investigation is required.

6. REGULATORY ASPECTS

6.1 Integration of the systems in the aircraft must not affect the Airworthiness Certificate of the aircraft. Every modification has to be recorded in the technical documentation of the aircraft, along with the approvals of the manufacturer and of the certification authority concerned.

6.2 Particular operating instructions should be registered in flight and exploitation manuals. If this integration entails any performance limitations or operational restrictions for the aircraft, they should appear clearly in the corresponding documents.

6.3 The integration of a flight inspection system results from the best compromise taking into account airworthiness constraints.

Attachment B to Chapter 1

DOCUMENTATION AND DATA RECORDING

1. FLIGHT INSPECTION REPORTS

1.1 The flight inspection report serves as the basic means of documentation and dissemination of the results of each flight inspection. The flight inspector in charge is responsible for initiating the report and ensuring that it clearly records the results of each parameter measured, along with an assessment of the conformance of the facility performance to the required standards. This assessment will normally involve an analysis of the data recordings and a review of the computer-aided analysis carried out on the data gathered during the inspection. Flight inspection reports should allow for “before” and “after” results to be entered into routine documentation of the adjustments made to the facilities.

1.2 Flight inspection reports typically include the following information:

- a) station name and facility designation;
- b) category of operation;
- c) date(s) of inspection;
- d) serial number of report/unique identifier;
- e) type of inspection, e.g. routine or annual;
- f) aircraft registration;
- g) manufacturer and type of system being inspected;
- h) wind conditions, to allow cross-wind to be established;
- i) names and functions of all personnel involved in the inspection;
- j) method of making each measurement (where alternatives are available); these may be referenced to the operating instructions;
- k) details of associated attachments, e.g. recordings;
- l) details of extra flights made necessary by system adjustments;
- m) an assessment by the flight crew of the navigation facility performance;
- n) comments by the flight inspector/equipment operator;
- o) details of any immediately notifiable deficiencies;

- p) results and tolerances;
 - q) statement of conformance/nonconformance; and
 - r) signatures of appropriate personnel.
- 1.3 A confirmation of the status of the inspection should be provided immediately after the inspection.

2. FLIGHT INSPECTION DATA RECORDINGS

The flight inspection data recordings serve as a record of the raw signal information used to assess ground facility performance. The recording medium may be a strip chart or electronic files of sampled data. Data recordings are normally archived and maintained on file with the flight inspection reports. This data should be made available to engineering and maintenance personnel for solving site problems and for assessing trends in facility or equipment performance.

3. FLIGHT INSPECTION SYSTEM CALIBRATION

Many of the components in a typical flight inspection system, as well as secondary or transfer standards, such as signal generators, must be calibrated on a periodic basis to ensure measurements are made with the required accuracy. Records of the calibration results (including the specific test equipment used) must be retained to ensure the calibration is traceable back to national measurement standards. The flight inspection organization shall ensure policies and procedures are in place to track the calibration status of equipment and recall equipment for calibration at the established intervals.

4. GROUND FACILITY DATA

Facility data sheets or computer files serve as a useful tool in providing the inspector and the flight inspection system with accurate information regarding facility survey data, facility and equipment types, frequencies, etc. Such information is normally prepared at the time of commissioning and revised as necessary to maintain current data. Its purpose is best served if the data are made part of a file to be carried in the aircraft or loaded into the flight inspection system.

5. RETENTION OF FLIGHT INSPECTION REPORTS AND DATA

Each flight inspection organization is responsible for ensuring that sufficient historical data are retained to establish the trends in facility performance over a reasonable interval of time. As a minimum, all commissioning inspection reports and data recordings should be retained in the facility file along with reports and data recordings from the last five periodic inspections. All special flight inspections carried out during this time period should be retained on file.

6. GROUND TEST REPORTS

It is recommended that the initial performance of a navigation aid facility be established through a formal proof of performance (POP) test and report. The facility is normally released for operational use once a satisfactory commissioning flight inspection is complete. It is normal practice that maintenance staff be certified to maintain the navigation aid in accordance with prescribed policies and procedures. These policies and procedures will normally specify what ground documentation and reports are required and the period for which they must be retained. It is recommended that the POP test report and reports on the implementation of modifications to the facility be retained throughout the life of the facility. Reports on routine maintenance actions should be maintained for a minimum of one year.

7. GROUND CALIBRATION REPORTS

Many of the components in a typical navigation aid system, as well as secondary or transfer standards, such as signal generators, must be calibrated on a periodic basis to ensure a facility is operating as intended. Reports of the calibration results (including the specific test equipment used) must be retained to ensure that measurements are traceable back to national calibration standards. The responsible maintenance organization shall ensure policies and procedures are in place to track the calibration status of equipment and recall equipment for calibration at the established intervals.



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Attachment C to Chapter 1

INTERFERENCE ISSUES

1. INTERFERENCE EFFECTS

Interference to a navigation aid can manifest itself in many ways. A VOR receiver may appear to operate normally but indicate a solid bearing to an adjacent co-channel facility. A localizer deviation signal may become erratic while FM broadcast is heard on the receiver audio output. The glide path signal may be lost momentarily as an aircraft passes over an industrial facility. A GNSS receiver used for position-reference may lose track of satellites due to interference. Interference may be caused by not providing adequate separation between facilities on the same frequency. Ground-based non-aeronautical services such as FM broadcast stations may be the cause. Interference may originate on board the aircraft due to a poor avionics installation or from carry-on equipment. There are many possible sources and the probability of interference occurring is increasing as the frequency spectrum becomes more congested.

2. INTERFERENCE SOURCES

Note.— The following sources account for most of the problems affecting radio navigation or radio communications receivers.

Ground-based aeronautical sources

2.1 Aeronautical facilities are engineered, installed and maintained to avoid causing interference to users of other aeronautical facilities. The service volumes of aeronautical facilities are protected from co-channel and adjacent channel interference by using frequency coordination procedures based on minimum and maximum field strengths and protection criteria promulgated primarily in Annex 10. In-band interference is usually caused by malfunctioning transmitters, frequency coordination problems and receiver operation outside the protected service volume of the aeronautical facility. The use of signal generators on operational aeronautical frequencies during avionics testing can cause interference problems.

Ground-based non-aeronautical sources

2.2 These sources include broadcast transmitters and emitters such as industrial, scientific and medical (ISM) equipment and power lines. RF emitters are normally licensed and must comply with International Telecommunication Union (ITU) Radio Regulations and domestic regulations. Malfunctioning transmitters and unintentional emitters are the cause of many interference problems.

FM broadcast transmitters

2.3 The FM broadcast services operating in the 88–107.9 MHz band can be a major source of interference in the adjacent VHF band 108–137 MHz, affecting ILS, VOR and VHF communications receivers. Two general types of interference can occur. The first is caused by FM broadcast emissions that fall inside the aeronautical band, such as

intermodulation products generated when multiple FM transmitters feed one antenna or out-of-band emissions from stations operating at the upper edge of the FM band. The second type is generated within the navigation receiver in response to FM broadcast emissions that fall outside the aeronautical band. These are usually intermodulation or receiver desensitization effects caused by high-level signals outside the aeronautical band.

2.4 Annex 10, Volume I, Chapter 3, 3.1.4 and 3.3.8, and associated guidance material in Attachment C, contain FM immunity performance criteria for ILS and VOR receivers and additional related ITU references. The ICAO *Handbook for Evaluation of Electromagnetic Compatibility Between ILS and FM Broadcasting Stations Using Flight Test*^{*} provides guidance on conducting flight tests of this kind of interference.

TV broadcast transmitters

2.5 Harmonics, intermodulation products and spurious emissions of TV video and audio carriers may cause interference to DME, VHF communications, VOR and ILS receivers, and GNSS.

Land mobile transmitters

2.6 In-band interference can be caused by spurious emissions from a single transmitter or by radiated intermodulation products created at a co-sited facility. VHF communications frequencies are often affected because a fixed/mobile service band lies immediately above 137 MHz. The mobile satellite service operating in the band adjacent to the GNSS band or the fixed service operating in the GNSS band in some States can cause interference to GNSS receivers.

Cable television distribution systems

2.7 These CATV systems distribute TV broadcasting signals on ILS and VHF communications frequencies. Most CATV systems use coaxial cables, which can leak RF signals and cause in-band interference.

Industrial, scientific and medical (ISM) systems

2.8 Specific radio frequency bands (e.g. centred at 13.56, 27.12 and 40.98 MHz) are allocated for the operation of ISM equipment. In-band interference to VHF communications, VOR and ILS localizer receivers may be caused by the radiation of harmonics of the ISM frequencies from malfunctioning or inadequately shielded ISM equipment. The interfering signal sweeps repetitively through a portion of the VHF aeronautical band affecting several aeronautical frequencies. The most common ISM interference sources are industrial equipment such as plastic welders.

Power line distribution systems

2.9 Power line carrier (PLC) systems inject signals into power lines for monitoring and control purposes. ADF receivers can experience in-band interference because some PLC systems operate within the NDB band and PLC signals can radiate from power lines.

* Available from the ICAO Air Navigation Bureau upon request (English only).

2.10 Corona noise and gap discharges from malfunctioning electrical equipment such as high-voltage bus-bars, switchgear, and insulators, can generate broadband impulsive-type noise, which can interfere with ILS localizer, VOR and VHF communications receivers in over-flying, low-altitude aircraft.

Other ground-based non-aeronautical sources

2.11 Low/medium/high frequency (LF/MF/HF) transmitters can cause co-channel and adjacent channel interference to ADF and HF communications receivers. High-power military radar may generate harmonic and spurious emission levels high enough to cause in-band and out-of-band interference to on-board pulse-type systems such as GNSS receivers. Radiated emissions from most information technology equipment (ITE) are regulated domestically. Malfunctioning ITE can cause in-band interference. Radiation of ITE clock frequency signals and their harmonics can interfere with VHF communications, ILS localizer, VOR and other receivers.

Airborne equipment sources

2.12 On-board aeronautical transmitters may cause in-band interference to aircraft receivers through harmonics of the intentional emissions or harmonics of local oscillator frequencies being conducted between units. Potential problems associated with portable electronic device installations on-board aircraft should normally be identified and resolved during airworthiness testing.

3. GENERAL METHODS FOR DETECTING AND RESOLVING INTERFERENCE PROBLEMS

3.1 There are many possible approaches to detecting and resolving interference problems. They all should be considered as tools to be applied when required.

EMC event-reporting system

3.2 An interference problem is often first observed by users of the navigation aid. Therefore, pilot and ATC reports are the first step in identifying the nature and approximate locations of where it occurs. The reporting system should be used to establish a point-of-contact between the users who observed the interference and the agency charged with resolving such occurrences.

Ground monitoring

3.3 The increasing pollution of the electromagnetic environment at or near airports is a major concern to many States. It can be a particular problem near major airports with a large number of aeronautical systems. The local electromagnetic environment tends to be more congested by the many ground-based non-aeronautical interference sources. Ground-based monitoring systems to detect interference events are being developed.

3.4 The protection of the integrity of the signal-in-space against degradation, which can arise from extraneous radio interference falling within the ILS frequency band, must be considered. This is particularly important where the ILS is used for Category II and III approach and landing operations. It is necessary, therefore, to periodically confirm that the radio environment at each Category II/III runway does not constitute a hazard.

Technical confirmation of the interference

3.5 Ground and/or airborne test equipment deployment to obtain technical measurements will depend on how and where the interference manifests itself.

3.6 Most flight inspection aircraft can readily record the effects of the interference on receiver AGC, cross-pointer, flag and audio signals, as well as determine the aircraft position and altitude when interference is observed. Confirmation of the interference characteristics and location by the flight inspection service is a second step toward solving the problem. More detailed information can be obtained about the relative signal levels and the frequencies being received at the aircraft antenna if the flight inspection aircraft is equipped with a spectrum analyser or field strength metre. Recording of the audio channel of the affected receiver, spectrum analyser or field strength meter is useful in identifying the interference source through its unique demodulated audio characteristics. A simple test such as inserting a suitable RF filter ahead of the receiver can often assist in identifying whether an interference source is in-band or out-of-band.

3.7 Confirmation of a suspected interference source can be achieved by switching the suspected source on and off several times and noting the resulting effects on the affected receiver.

3.8 It should be noted that there will be cases where the ground test equipment or the flight inspection aircraft may not be able to detect/confirm reported interference problems because:

- a) the receiver systems used in the air or on the ground (i.e. receiver, antenna, and cable system) may have significantly different performance characteristics from those receiver systems reported to have experienced interference;
- b) interference is intermittent and may not be occurring during the investigative flight test; or
- c) it may be difficult to find a ground observation point which corresponds to the interference conditions seen in the air.

Specialized electromagnetic interference (EMI) troubleshooting methods

3.9 Specialized equipment and computer simulation will likely be required if a source of interference cannot be readily identified. Many States have invested considerable time and effort on hardware and software techniques to resolve EMI problems. These techniques include:

- a) databases of potential interference sources;
- b) EMC analysis software;
- c) interference simulators;
- d) special ground or airborne data acquisition systems;
- e) interference direction-finding systems; and
- f) antenna calibration techniques.

Interference investigation

3.10 It may be helpful, in resolving the more difficult interference problems, to form an investigative team consisting of personnel representing (as required) flight inspection services, the State spectrum regulatory agency, aeronautical spectrum management and aeronautical facility engineering/maintenance. This team could seek input from the affected users and the owner/operator of the potential interference source, develop and implement test plans, analyse results and make recommendations for resolving interference problems.

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Chapter 2

VERY HIGH FREQUENCY OMNIDIRECTIONAL RADIO RANGE (VOR)

2.1 INTRODUCTION

General

2.1.1 This chapter provides guidance on the ground and flight inspection requirements applicable to both conventional (CVOR) and Doppler (DVOR) type VHF omnidirectional radio range (VOR), as specified in Annex 10, Volume I, 3.3.

System description

2.1.2 The VOR is a short-range radio navigation aid that produces an infinite number of bearings that may be visualized as lines radiating from the beacon. The number of bearings can be limited to 360, one degree apart, known as radials. A radial is identified by its magnetic bearing from the VOR.

2.1.3 The radials are generated in space by comparing the phase angle of two equal frequencies radiated from the beacon. One signal, called the reference, radiates omnidirectionally so that its phase is equal in all directions. The second signal, called the variable, radiates from a directional array. The phase of the variable signal received at the aircraft is dependent upon the radial on which the receiver lies with respect to magnetic north.

2.1.4 Both signals are in-phase at magnetic north. The phase of the variable signal lags that of the reference signal by an amount equal to the azimuth angle around the beacon.

2.1.5 Reserved.

2.1.6 Reserved.

Testing requirements

2.1.7 A summary of testing requirements is given in Table I-2-1.

2.2 GROUND TESTING

General

2.2.1 The following paragraphs contain information and guidance for establishment of an orderly maintenance programme for VOR facilities. A maintenance programme consists of standardized:

- a) periodic performance tests to determine if the facility is operating in accordance with established criteria;
- b) equipment adjustment procedures;
- c) periodic formal facilities inspections;
- d) logistic support procedures; and
- e) equipment modification as required.

Note.— Since the means by which VOR signals are produced vary from one manufacturer to the other, it would be impracticable to include detailed procedures in this manual for the different equipment employed in the various States. For this reason, broad guidelines are provided and adaptation to specific equipment will be required.

Ground performance parameters

2.2.2 Ground test requirements are listed in Table I-2-2.

Ground test procedures

2.2.3 The VOR should be inspected in accordance with the manufacturer's recommended procedures. The following procedures provide guidance for testing of VOR specific parameters specified in Annex 10, Volume I. The manufacturer's procedures should include at least these tests.

Rotation

2.2.4 Correct rotation should be confirmed. This can be performed during the measurement of a ground error curve to determine antenna pattern accuracy.

Sensing

2.2.5 Correct sensing should be verified by checking a radial other than 0° or 180°.

Frequency

2.2.6 Using the frequency counter determines the transmitter carrier frequency in accordance with procedures in the equipment instruction book. If the frequency is out of tolerance, adjust it in accordance with the equipment instruction book.

Pattern accuracy

2.2.7 A ground check is a means for determining course alignment errors. The actual courses produced by the VOR are compared (using monitor circuits) with simulated courses produced by a VOR test generator. Data recorded during the ground check are used to prepare a ground check error curve. Establishment of a ground check capability will enable maintenance personnel to restore a VOR to normal operation, following most repairs to the facility without a flight inspection. It is desirable to maintain the ground check error curve (maximum positive error to maximum negative error) within approximately 2.0° . If the facility cannot provide this level of performance, a broader value should be considered. The stability of the error curve spread is considered more important to the facility performance analysis than the magnitude of the error spread.

Example of procedure for conducting a ground check for a conventional VOR:

- a) Place a field detector into the 0° positioner bracket and feed signals to the monitor in the normal manner.
- b) Rotate the azimuth selector of the monitor for an "on course" indication (reference and variable signals in phase).
- c) Substitute signals from the test generator. This can be accomplished by temporarily switching the field detector and test generator cables.
- d) Without changing monitor adjustments, rotate the test generator dial until an "on course" is again established. Read and record test generator dial reading. The difference between the dial reading of the test generator and the location of the field detector is the amount of course error at that location.
- e) Repeat steps a) through d) for all bracket locations.

Plot a ground check error curve (amount of error versus azimuth) on rectangular co-ordinate graph paper.

Note 1.— Positioner brackets are installed on the edge of the counterpoise at every $22.5 \pm 0.1^\circ$ beginning at 0° . Alternatively, brackets could be mounted on poles appropriately spaced around the facility.

Note 2.— Course error is either plus or minus. Plus error means the course is clockwise from where it should be, minus error means the course is counterclockwise from where it should be.

Note 3.— An alternative method is to rotate the antenna through 360° and to plot the antenna characteristic from a single field monitor against the rotation angle.

2.2.8 Establishment of reference curve at commissioning. It is desirable to prepare a reference ground check error curve immediately following the commissioning flight inspection. This curve is no different from that described above except that it is an average of three separate ground checks conducted on the same day, if possible. The reference error curve serves as a standard for comparing subsequent ground checks. The reference error curve is updated whenever courses are realigned during a flight inspection.

Coverage

2.2.9 The coverage of the facility is established at the commissioning flight inspection. The standard operating condition of the facility should be established at this time including the carrier power level. Measure the RF power output using the wattmeter in accordance with the procedure in the equipment instruction book. Compare the level measured with the established standard operating condition at the periodic test.

Modulation

2.2.10 The preferred method is the use of a modulation meter. If a modulation meter is not available, an oscilloscope may be used instead.

9 960 Hz deviation

2.2.11 The deviation in a CVOR may be measured at the output of the FM modulation stage or by direct measurement of the radiated signal using a modulation analyser. The deviation is determined using an oscilloscope by displaying the 9 960 Hz signal and measuring the difference, Δt , in periods between the minimum frequency (9 960 Hz – 480 Hz) and the maximum frequency (9 960 Hz + 480 Hz). The modulation index is determined by the following equation:

$$\text{Modulation Index} = \frac{\Delta t}{60T^2}$$

Where $T = 1/9\,960$

In a DVOR, the deviation of the 9 960 Hz subcarrier is determined by the rotation speed of the switched antennas and the physical characteristics of the array.

9 960 Hz modulation depth of the radio frequency carrier

2.2.12 The CVOR 9 960 Hz modulation depth of the carrier frequency can be measured by directly using a modulation meter, modulation analyser, or an oscilloscope. All other modulation should be inhibited unless the characteristics of the modulation analyser allow individual separation of the modulating signals.

2.2.13 In the oscilloscope method, a portion of the RF carrier (modulated by one frequency at a time) is coupled to the oscilloscope synchronized at the modulating frequency. An amplitude modulated waveform is produced from which the high (E_{max}) and low (E_{min}) points are measured. These values may be substituted in the following formula and the modulation percentage determined.

$$M = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100\%$$

2.2.14 The modulation of the carrier for a DVOR is achieved in space by the combination of the reference signal and the switched 9 960 Hz variable signal. The modulation depth should be checked using a signal derived from a field monitor. A tuned modulation analyser is required due to the lower signal strength available.

30 Hz modulation depth of the radio frequency carrier

2.2.15 The CVOR variable signal modulation level (space modulation) is a function of the ratio of sideband energy to carrier energy radiated. The procedure in the equipment instruction book should be followed for adjusting the variable signal modulation level because different means (i.e. antenna systems) are employed in producing the rotating figure-of-eight radiation pattern.

2.2.16 A procedure for adjusting the variable signal level that can be adapted to most VOR facilities is as follows:

- a) Stop rotation of the figure-of-eight pattern.