DAY ONE

SPECIAL PRESENTATIONS

PROCEDURAL ASPECTS AND PROBLEMS

TUESDAY - JUNE 6, 2000

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THE INTERNATIONAL COMMITTEE FOR AIRSPACE STANDARDS AND CALIBRATION – ICASC -

ABSTRACT

Flight calibration is an international need whenever and wherever ground-based navigation aids are used to support flight operations.

People involved in this business have the possibility to meet every two years when an International Flight Inspection Symposium is held. In general these events are used to exchange views on experience and difficulties discovered in this field. Furthermore, information on new techniques for flight inspection is made available by industry.

In the two years gap between the events no published contact point or information medium is available to give continuous support.

The International Committee for Airspace Standards and Calibration - ICASC - was founded to overcome this problem.

The paper discusses
- the reason for founding the Committee
- the mission and vision
- the working procedures
- the composition
- the results and involvement up to now
- the information medium of this group.

It requests information from participants of the Symposium about additional needs of the users and the requests for additional support areas.

INTRODUCTION

During the 8th International Flight Inspection Symposium (IFIS) in Denver in 1994, it was determined that the rapid changes currently visible in business, industry and service companies have also affected flight calibration. Whereas, in the past, flight calibration methods and the techniques being used were in the foreground of the considerations and discussions, questions of organisation, privatisation and economics are now suddenly receiving more attention. There is a general impression that changes are now happening faster than in the past and that stock-taking and the exchange of ideas at symposium events every two years are no longer sufficient to deal with them.

During the symposium, the organiser, Mr. William H. Williams, Jr. (at this time: Program Director of Aviation System Standards, FAA) suggested that the developments should be observed critically in the interval between the events and that the resulting information be made available to the organisations, the industry and all interested persons.

The subsequent discussion showed that this proposal was supported by organisations, industry and universities and gave rise to the idea to form a group which would

1. Make efforts to bridge the gap between the symposia,
2. Act as a forum for the exchange of ideas between flight inspection providers, industry,

research and users,

3. Provide support for countries which act as hosts for future symposia and, finally,
4. Develop and maintain an information market for flight calibration affairs.

This suggestion was generally supported and subsequently led to the foundation of the International Committee for Airspace Standards and Calibration (ICASC).

THE COMMITTEE

At the invitation of Mr. William H. Williams, Jr., the inaugural meeting took place from May 24 to 25, 1995, in Brussels, Belgium. At this meeting, the group adopted the above-mentioned name, «International Committee for Airspace Standards and Calibration» and developed a charter which will soon be under revision to take into account the experience gained in the last five years.

ICASC Logo

The present charter defines the goals, objectives and tasks of the committee, together with the structure and the rules for membership.

Today, the committee consists of 15 members and is intended to present the world-wide flight calibration community and to represent the interests of industry, research and service provider. It is managed by a chairman, who is supported by a vice-chairman and a secretary's office.

The organisers of the preceding and next symposia participate as the guests of the committee. This is intended to ensure that experience gained at earlier events can be passed on directly.

At the very first session, the main emphasis of the work was defined and the following standing committees were set up:

- Business Practices and Assistance
- Technical Standards and Development
- Safety Management

In addition, a Steering Committee was established, consisting of the chairman, the vice-chairman, the chairmen of the subcommittees and the organisers of the preceding and next symposia.

Membership in the committee normally expires after four years, but can be extended.

In the meantime, the subcommittee «Business Practices and Assistance» has formed two working-groups for

- Communications and
- Site Selection.

In order to clarify the objectives and tasks the committee has undertaken, a «Mission Statement» and a «Vision Statement» were formulated:

Mission Statement:
Facilitate the exchange of information within the flight inspection community

Vision Statement:
To be the information HUB to the worldwide flight inspection community

The committee normally meets twice a year to define tasks and to discuss and evaluate the results. The assigned tasks are normally carried out by means of correspondence and telephone conferences.

RESULTS AND INVOLVEMENTS SO FAR

Until now, the committee has been active in the following areas and has also achieved the corresponding results:

- Guidelines,
- Provision of a means of communication,
- Support for countries hosting the Flight Inspection Symposia,
- Co-operation with ICAO.

Guidelines
Two guidelines have been developed

- Flight Inspection Organisations Safety Management Guidelines
- Flight Inspection Organisation Business Practices and Assistance Guidelines

1. Flight Inspection Organisation Safety Management Guidelines This document is basically a safety management manual which should be applied to flight calibration. The acceptance and introduction of such a guideline is, of course, the responsibility of each country or a corresponding organisation. In this respect, the existing material serves to support the execution of the related work.

In the section GENERAL SAFETY MANAGEMENT ISSUES, this document makes statements on the subjects of

- Organisation and management
- Exposition
- Aircraft, hardware and systems aspects
- Software aspects
- Operating instructions
- Personnel training and qualification requirements
- Aircraft operating aspects
- Legal requirements
- Organisational capabilities

The section SAFETY MANAGEMENT DEVELOPMENT deals with:

- Development of concepts
- Safety cases

The document is a preliminary final version and can be downloaded from the ICASC web site mentioned later.

2. Flight Inspection Organisations Business Practice and Assistance Guideline. This document functionally deals with the setting up and operation of a flight inspection organisation. The material is intended to provide assistance in the foundation and operation of a flight inspection organisation. Since the design of such an organisation depends greatly on the airspace to be served, the national and international rules which apply in this airspace, the number of aircraft used and the number of systems and procedures to be inspected, it must be adapted by each user to meet local requirements. It is intended, in particular, to provide assistance in the following areas:

- Organisation
- Planning
- Pricing
- Training and education
- Quality control
- Inspection and scheduling
- Quality procedures
- Safety standards
- Sales and marketing
- Finance and accounting.

Creation of a means of communication

Whereas the initially defined work made good progress, there was still the problem that all work was directed inwards, thus conflicting with the declared objective of the committee, namely to act as a forum with a wide basis for the exchange of ideas.

Finally, the Internet was identified as the only acceptable means of communication.

During the 6th International Flight Inspection Symposium in 1990, the FAA said that it would be willing to accept responsibility for the design and maintenance of a database concerned with flight inspection affairs. As a continuation of this work, the FAA promised to take over the setting up and maintenance of an ICASC web site. This is now available and can be reached under the following address:

http://avnwww.jccbi.gov/icasc/

The use of the Internet has met the objective of making information and documents available world-wide to persons and organisations interested in flight calibration. Direct contact can be made with the individual members of the ICASC, whose e-mail addresses are directly connected to the mail system in the ICASC web site.

In the meantime a Bulletin Board has been prepared which gives the opportunity to ask for advice in flight inspection-related areas. There is access to questions and answers for everyone. This feature of the ICASC web site will be a benefit for the whole flight inspection community.

The decisive factors are now how the users evaluate the work already done and whether communication via the Internet meets with general acceptance. In this respect, it is thus extremely important to learn whether this approach meets with the approval of the users. Furthermore the ICASC group is interested in receiving a response from the flight inspection community regarding the question which principles are of general interest and should be dealt with in the future.

Support for Site Selection of IFIS Events

In the past, the selection of a location for the next Flight Inspection Symposium was affected to a great degree by applications from countries or corresponding organisations and was thus more or less a random choice. For this reason, there were demands that this selection should be prepared more systematically. Since flight inspection is internationally oriented, many people wished that the event should not be concentrated so greatly on Europe or North America; instead, an effort should be made to find countries or organisations in other parts of the world who would be willing to host the symposium.

Another suggestion was that this approach should not be restricted to the next symposium; instead, preliminary planning should be carried out for the next two events.

The result of this was that the ICASC not only participated in finding an organiser for the 11th IFIS in the year 2000- which was achieved successfully - but has also made preparations for making a selection for the year 2002 and beyond.

Support for Host Countries for Future Events

Flight inspection symposia are meanwhile organised with a certain amount of tradition and certain standard. Regardless of this, each host country contributes its own flair and charm to the event.

It has become clear that support for the organiser by a standing committee is useful and an invaluable aid for the persons concerned.

Individual members of the ICASC participated intensively in the execution of the 9th IFIS in 1996 in Braunschweig, Germany. In their role as members of the Programme Committee, they were responsible for the selection of the submitted contributions and for the design of the agenda and the general procedures.

The ICASC has participated from the very start in the organisation of the 10th IFIS in Seattle and this year's 11th IFIS in Santiago de Chile, taking part in selecting the location, choosing the submitted contributions and defining the agenda.

Co-operation with ICAO

From the very beginning, the objective of the committee was not to compete in its activities with the International Civil Aviation Organisation (ICAO), but to support the activities of this organisation and to contribute to the execution of high-quality flight calibration and thus to safe flight operations.

In 1997, direct contacts were made with the ICAO and a common understanding was reached.

MEMBERS

At the moment, the following persons are members of the ICASC:

- Mr. Trevor Abrahams, Civil Aviation Authority, South Africa
- Captain Omar S. Barayan, Ministry of Defence and Aviation, Saudi-Arabia
- Mr. John Beddows, Civil Aviation Authority, United Kingdom
- Mr. Joe F. Doubleday, Federal Aviation Agency -AVN -, United States, Vice Chairman
- Mr. Sileno Goedicke, Ente Nazionale Di Assistanza al Volo, Italy
- Mr. Dieter Hielscher, DFS Deutsche Flugsicherung GmbH, Germany, Chairman
- Captain Wan Zali Bin Wan Kadir, Department of Civil Aviation, Malaysia
- Mr. Mel King, Airways Corporation of New Zealand, Ltd., New Zealand
- Mr. Alexander Kwartiroff, Parker-Hannifin Corporation, United States
- Mr. Asbjorn Madsen, Normac Flight Inspection System AS, Norway
- Dr. David Powell, Stanford University, United States
- Mr. Hervé Renouf, Service Technique De La Navigation Aerienne, France
- Mr. Onorio Rocca, RMS Instruments, Canada
- Mr. Jim Savage, Federal Aviation Administration, United States, Duty Station: Belgium
- Mr. Fernando Tellez, Direccion General De Aeronautica Civil, Chile

According to the charter, the committee currently consists of 15 members with representatives from all over the world..- After revising the existing charter, there will be an opportunity to further enlarge this representation where appropriate.

OUR REQUEST

Many tasks have already been performed by the ICASC in order to comply with the initially defined objectives. The flight inspection community now has the opportunity to evaluate this work and to determine whether it results in the desired advantages for systemisation of the flight inspection services and their daily work.

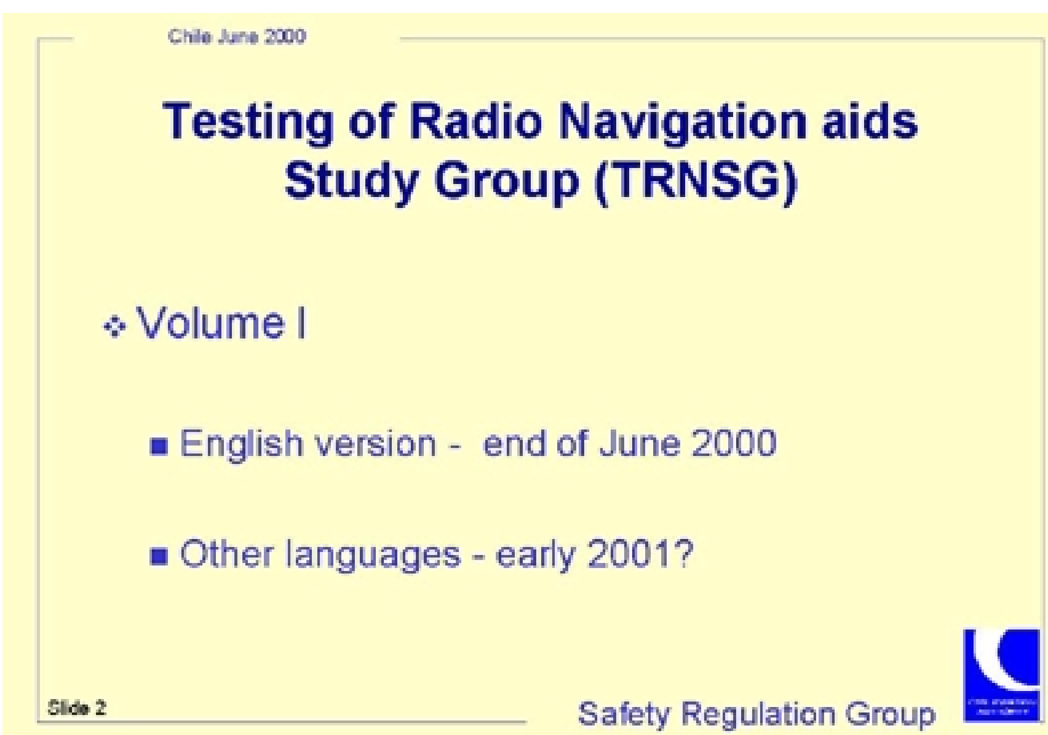
1. Future work of the ICASC. All suggestions which result in improvement and supplementation of the results achieved so far are welcome. Of particular importance is the question as to which basically new areas are interesting and should be further processed.

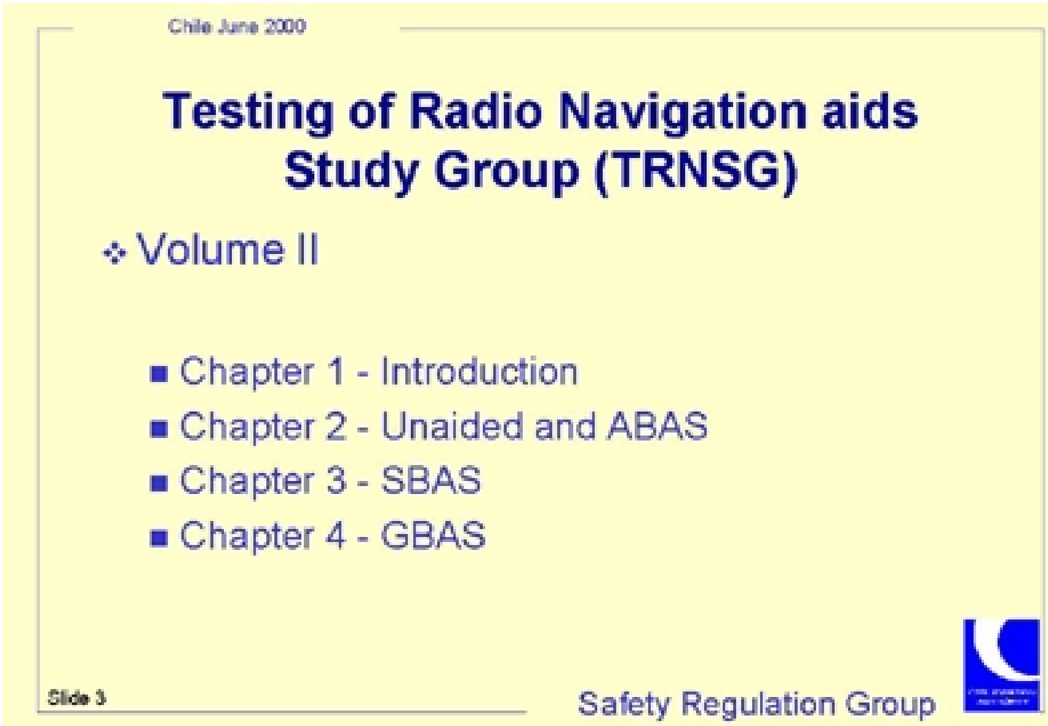
2. ICASC web site in the Internet. Evaluation of the Internet as the communication medium for flight calibration is of major importance. We hope that as many people as possible will participate in the further design of this medium. Take a good look at the available materials, both during and after the symposium, and let us have your comments.

3. Membership in the ICASC. If you are interested in supporting the work of the ICASC, if you think you can provide valuable technical input, if you are prepared to participate regularly in the sessions, and if you can justify a claim to global presence within the committee, please contact us during or shortly after the symposium.

4. Organisation of future IFIS events. As already mentioned, we are interested in planning future IFIS events in good time and including the future organisers in the preparatory work for symposia which are already planned. Please determine whether you can organise such an event. Locations in countries outside Europe and North America can help to emphasise the global importance of flight inspection


Chile June 2000
Testing of Radio Navigation aids Study Group (TRNSG)
John Beddows
Safety Regulation Group
UK CAA
Slide 1
Safety Regulation Group


Chile June 2000
Testing of Radio Navigation aids Study Group (TRNSG)
Volume I
English version - end of June 2000
Other languages - early 2001?
Slide 2
Safety Regulation Group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Testing of Radio Navigation aids
Study Group (TRNSG)
Volume II
Chapter 1 - Introduction
Chapter 2 - Unaided and ABAS
Chapter 3 - SBAS
Chapter 4 - GBAS
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Safety Regulation Group


Chile June 2000
Testing of Radio Navigation aids
Study Group (TRNSG)
Volume II
Initial meeting March 2000
Input from "Informal Group" used as starting point
Next meeting June 2000
Slide 4
Safety Regulation Group

Chile June 2000

Testing of Radio Navigation aids Study Group (TRNSG)

- Volume II
  - Chapters 1 and 2
  - English version could be available 6 months after TRNSG delivers final version
  - Chapters 3 and 4 are dependent on the GNSS SARPS

Slide 5

Safety Regulation Group

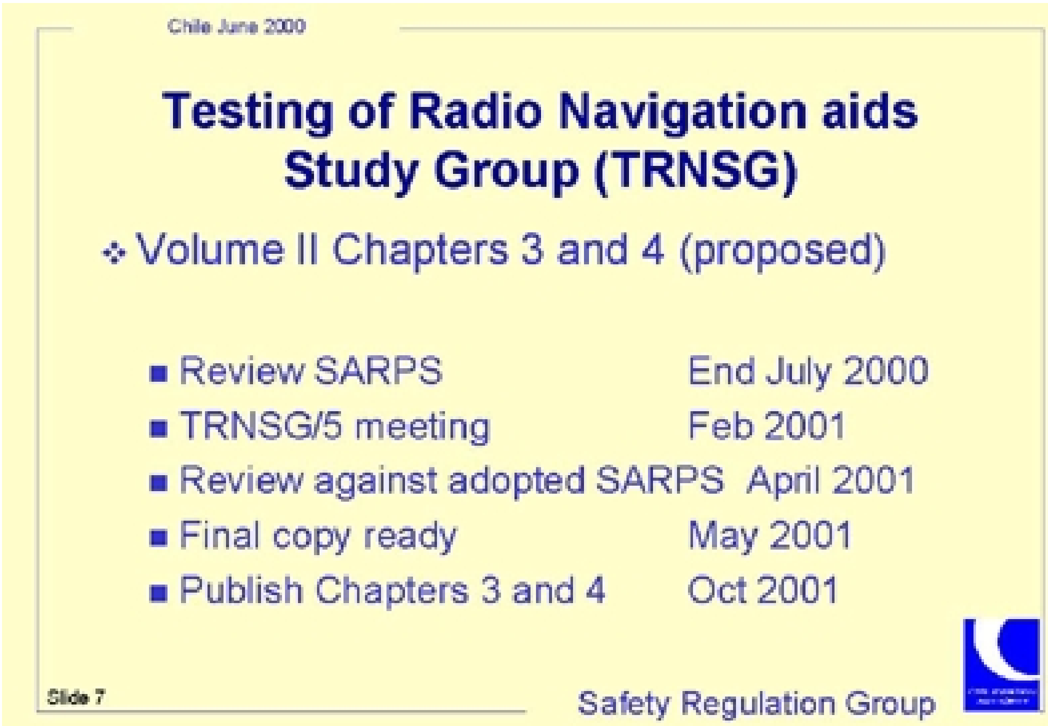
Chile June 2000

Testing of Radio Navigation aids Study Group (TRNSG)

- GNSS SARPS Unofficial dates
  - Unofficial validated SARPS June 2000
  - Validated SARPS Sept 2000
  - Council adopts SARPS March 2001
  - SARPS applicable Nov 2001

Slide 6

Safety Regulation Group


Chile June 2000
Testing of Radio Navigation aids Study Group (TRNSG)
Volume II Chapters 3 and 4 (proposed)
Review SARPS End July 2000
TRNSG/5 meeting Feb 2001
Review against adopted SARPS April 2001
Final copy ready May 2001
Publish Chapters 3 and 4 Oct 2001
Slide 7
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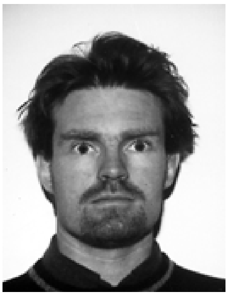

POSITION REFERENCE FOR ILS CATEGORY III - PITFALLS AND SOLUTIONS FOR IMPLEMENTING HIGH PRECISION DGPS-RTK

ABSTRACT

Normarc Flight Inspection Systems utilizes high precision RTK-receivers in its Flight Inspection Systems to provide the customers with an accurate position reference suitable for inspection of up to Category III facilities. During the last decade, with higher precision reference systems readily available, there has been a generation change in the flight inspection industry with regards to this.

This change has also brought with it the need for better understanding of the total accuracy of the position reference systems. Parameters that were insignificant with less accurate positioning systems, may now be contributing significantly to the overall error-budget.

Ground Facility Survey

The exact location of the Ground Facility to be inspected is one of the key parameters in the calculations. It does not help to know the position of the aircraft down to a few centimeters accuracy, if the ground facility location is only known within a few meters.

This is often overlooked, as the error induced may seem small compared to less accurate positioning systems. But it becomes crucial with the high accuracy of modern reference systems.

Graphs will be presented to show the influence of errors in the ground facility position on the total error budget.

Timing Considerations

The Flight Inspection Aircraft is basically comparing two signals: the radio signal from the ground facility, and the position reference from the Positioning Reference System. Based on the comparison of these two signals, the error of the ground facility is calculated. The timing of these two signals is very important.

The radio signal from the ground facility is passed from the receiving antenna through the airborne receiver, then through interfacing hardware and into the computer system. This signal chain introduces a delay in the signal, i.e. the signal has a certain age when it reaches the computer system.

Likewise, the position reference obtained from the RTK-receiver will pass through a similar chain before it reaches the computer system. It is important that the two signals are corrected for any time-differences before they are compared and the error calculated.

Graphs will be presented showing the influence of this on the total error budget, and what areas to pay special attention to regarding this problem.

Dynamics of Reference System vs. Navaids Signals

Another effect of the accurate GPS-based position reference systems of today, is the increased dynamics.

The ground facility signal is passed through a receiver in the aircraft. This receiver works like a low pass filter on the incoming signal. This means that if the aircraft experiences a sudden drop, due to for example turbulence, the signal from the receiver need some time before it settles at the new value.

The signal from the RTK-based position reference, on the other hand, will follow the exact dynamics of the aircraft. This may lead to the reference position curve having a more high frequency nature than the navaid signal. This high frequency will also be visible on the compared value between the two signals.

It is important to understand that this «noise» is caused by the fact that the reference system has better dynamics than the navaids-system.

Graphs will be shown showing this nature of the signals.

Aircraft Antenna Displacement and Attitude Information

The position of the navaid-antennas and the GPS-antennas on the aircraft may often be several meters apart on the aircraft. The position measured by the navaid-receiver is based on the location of the navaid-antenna, while the reference position from the RTK-receiver is based on the position of the GPS-antenna.

It is therefore necessary to compensate for the offset between the to antennas. To perform this compensation, the exact location of the antennas must be measured.

In addition to knowing the antenna placement, it is necessary to know the attitude of the aircraft to perform the offset calculations. The attitude includes heading, roll and pitch.

Based on the exact positions of the antennas, it may suffice with accurate heading-information to perform the offset calculations. The best accuracy is however obtained by having all three attitude parameters available to the computer system.

The accuracy of the attitude system itself is another parameter that must be taken into account. If the heading is significantly wrong, it will lead to errors in the offset calculations, and thus to errors in the final result.

Graphs will be included to show the effect of these parameters on the final error budget.

Conclusion

The appearance of more accurate position reference systems have led to previously less significant parameters becoming very important. It is crucial to understand this new situation when dealing with modern flight inspection systems with high demands of accuracy.

Once these parameters are understood and included properly into the flight inspection system, the system will be able to obtain an overall accuracy more than capable of performing flight inspection of Cat III facilities.

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CAPTURE EFFECT IN ILS RECEIVERS.
11th IFIS

ABSTRACT

ICAO Annex 10 requires that disturbances on the localiser centreline of an instrument landing system (ILS) (commonly referred to as bends) be controlled within strict limits. Bends are caused by unwanted reflections of the localiser signals onto the course centreline. To reduce this effect, many localisers radiate two separate signals. The first, known as the «course» signal, is radiated in the region close to the runway centreline, and the second known as the «clearance» signal is radiated in the remaining areas of coverage.

The reduction in bends is reliant upon the receiver's capture effect performance, whereby if two signals are within the pass-band but differ in frequency and amplitude, the receiver will tend to reject the weaker signal. The level of rejection depends on the amplitude difference between the two signals and the characteristics of the receiver's detector. The amplitude of bends due to clearance reflections is dependent on the level of residual clearance carrier on the centreline, and the receiver's capture performance.

This paper details an investigation into localiser receiver capture performance, the effects of clearance phase quadrature, and the impact on flight inspection and the commercial user.

BACKGROUND

Many peculiar effects experienced during flight inspection have, on subsequent investigation, been found to be a result of two frequency capture effects within the receiver. This subject has been addressed in papers presented at the 8th & 9th IFIS by this organisation. Those studies were primarily concerned with two frequency glidepaths and UHF passband ripple. This investigation has concentrated on localiser receiver capture effect performance. In FM receivers, the Demodulator (Limiter/ Discriminator combination) will only extract Zero Axis Crossings of the strongest of competing signals. E.g., if two signals have nearly equal strength, the stronger of the two will be «Captured» while rejecting the other. Depending on the receiver design, signals as close as <1-dB[3], the stronger will dominate. Simple AM demodulators of the type used in navigation receivers are unable to exploit this phenomenon to the same degree. This study has concentrated on assessing how different ILS receivers react to two frequency ILS signals, and the effects on the receiver of varying both the amplitude and phase relationship of the course and clearance signals.

The study comprised a series of test-bench measurements on a number of aircraft ILS localiser receivers. Two types of measurement were made, namely:

a pass-band ripple; and
b capture performance

Capture performance was assessed both with 'in-phase' clearance, and with 'quadrature' clearance.

In order to assess the effects on a variety of receivers, covering a reasonably broad spectrum, tests were carried out on the following types:

Marconi 6404A This receiver was the flight inspection variant of the '60' series receivers as used for the BAC Trident Auto land system in the 1960s. The receiver was originally a 20 channel set, subsequently modified to 40 channels, therefore some compromise could be expected in performance.

Bendix RNA34AF The flight inspection variant of the RNA34A, a common receiver typical of 1980s transport aircraft.

Collins 51RV-4 A common receiver, typical of 1980s transport aircraft.

Honeywell HLZ850 A state of the art Multi-Mode receiver representative of the current generation of navigation receivers, now entering service.

King KX175 An older generation basic General Aviation navigation receiver typical of older generation sets in light aircraft.

Normarc 3710 FTS A typical ILS Field Test Set of the early 1990s, commonly used for the engineering of ILS systems.

Passband Ripple.

Any ripple in the receivers pass-band will alter the perceived course/clearance ratio at the detector.

A precision DVM was used to monitor the receiver AGC test point, and a signal of -75dBm fed into the receiver at the tuned frequency. The DVM figure was noted. The signal generator was then tuned to the nominal frequency -15kHz. The attenuator (0.1dB resolution) was then adjusted to give the same figure on the DVM as previously set. The attenuator setting was recorded. The frequency was then incremented by 100Hz, and the process repeated until the nominal frequency +15kHz was reached. This resulted in a table of passband ripple, with a resolution of ±0.1dB, over a range of ±15kHz from the nominal frequency.

The readings noted for the attenuator settings at 100Hz intervals were entered into a spreadsheet, and a graph utility used to display the data in graphical form.

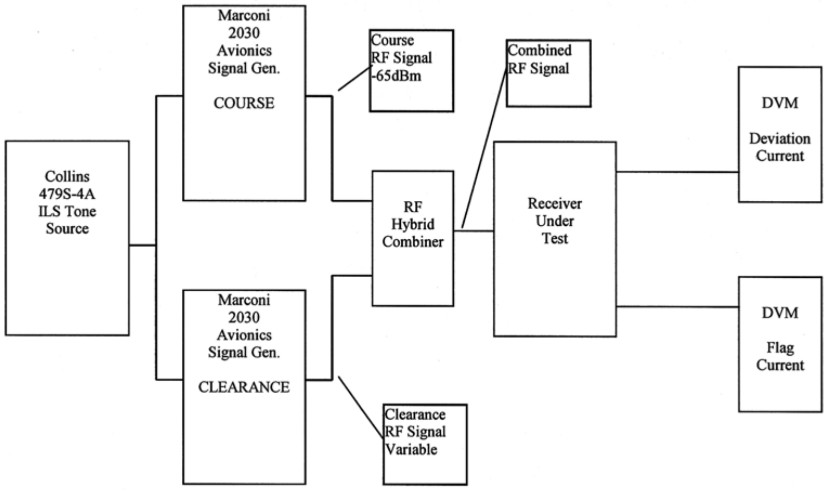
Receiver Capture Performance

Standard Two-Frequency ILS Localiser Signal

In order to assess capture performance, a single ILS tone source was used in conjunction with two signal generators in order to ensure that the course and clearance signals had the correct phase relationship as defined in ICAO annex 10[1].

The test equipment configuration is shown below.

Diagram 1.



The course signal consists of equal levels of modulation of 90Hz & 150Hz, with a sum of depth of modulation (sdm) of 40% (Standard ILS localiser CSB signal) at a level of -65dBm. This equates to a course signal level at the receiver input of -68dBm. The clearance signal consists of 20% of one tone and 60% of the other, giving an sdm of 80%. (Many unwanted clearance reflections have a high sdm). The level of clearance signal is set to -95dBm (30dB course/clearance ratio) and is incremented in 1dB steps to -65dBm, equal to the course signal. Deviation and flag currents are noted at each step.

The receiver is tuned to an ILS frequency. In this case, all tests are carried out at 110.10Mhz. The choice of frequency is not critical, as the IF passband is independent of frequency. The frequency chosen is approximately mid-band. For these tests, the course and clearance frequencies are offset by equal and opposite amounts from the nominal frequency by either ±4.5kHz or ±7kHz.

For each receiver, 8 tests were carried out with differing combinations of frequency offset and clearance sense as listed below:

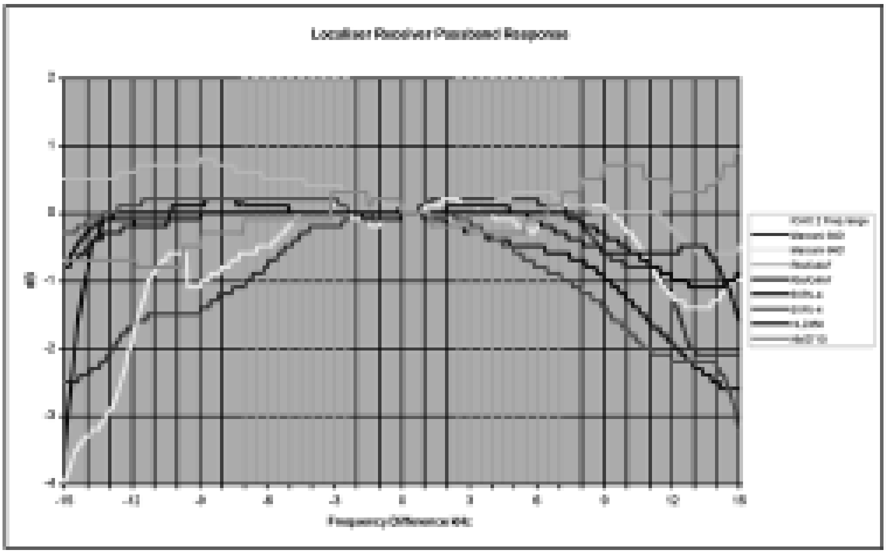
Test No.	Course	Clearance	Clearance Modulation Depth	
	Δf kHz	Δf kHz	90Hz	150Hz
1	-4.5	+4.5	20%	60%
2	+4.5	-4.5	20%	60%
3	-7.0	+7.0	20%	60%
4	+7.0	-7.0	20%	60%
5	-4.5	+4.5	60%	20%
6	+4.5	-4.5	60%	20%
7	-7.0	+7.0	60%	20%
8	+7.0	-7.0	60%	20%

Table 1.

Quadrature Clearance Two-Frequency ILS Localiser Signal

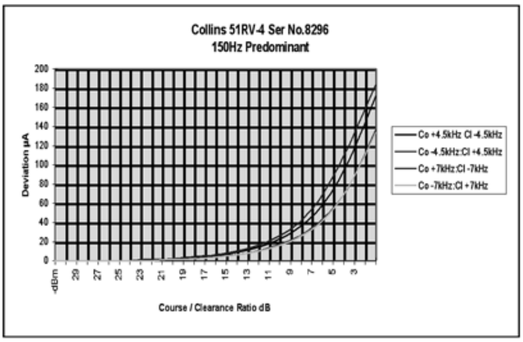
For this series of tests, the signals applied to the receiver under test were as per the previous tests except that the clearance signal tone phases were set in phase quadrature (90°) with those of the course signal, with one tone leading and one tone lagging with respect to the course signal.

In order to generate the phase quadrature signals, it was necessary for both signal generators to be in dual composite modulation mode rather than avionics mode. The 90Hz and 150Hz modulations were generated using the extremely stable internal modulation generators. The course signal generator



Graph 1

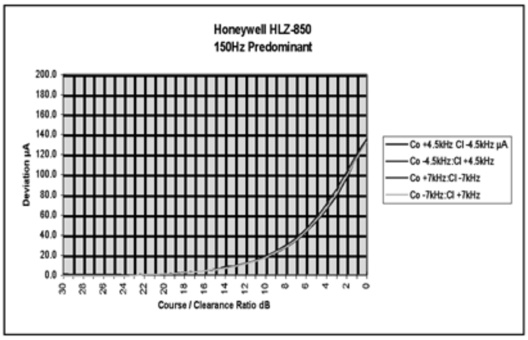
RF output was monitored using a Rohde & Schwarz FMAV modulation analyser to ensure the generation of a correct ILS signal. The clearance signal generator was then set up to match the course, and the phases of the tones adjusted relative to the course signal. This was monitored using a dual beam oscilloscope and audio phase meter. Long-term tests showed that the drift in phase was less than 3° per hour once the signal generators had been running for 12 hours or more.



Graph 2

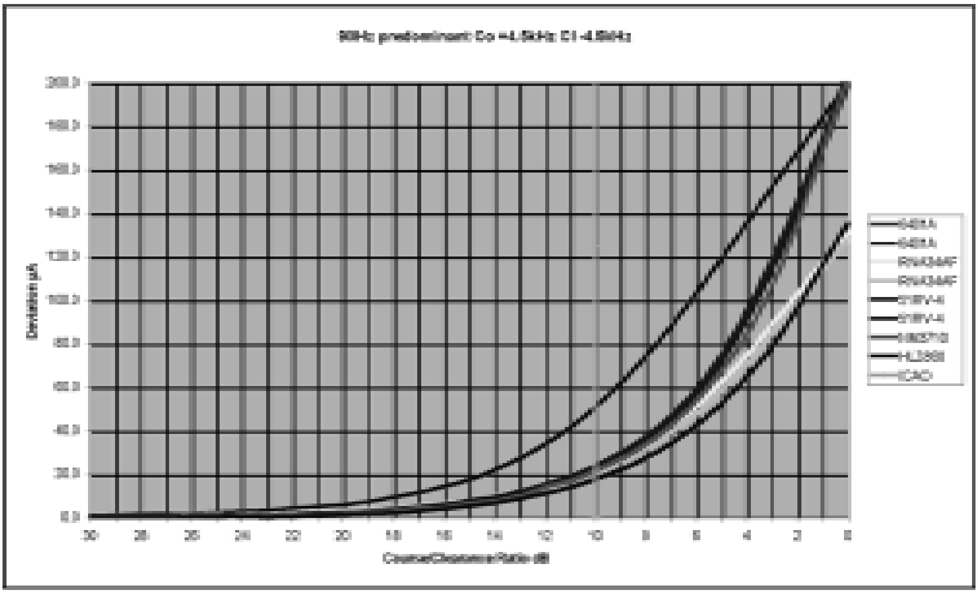
RESULTS

Pass band ripple tests showed that most receivers exhibited a difference of typically 1dB over the ICAO annex 10 frequency range for two frequency systems. These results are shown graphically below. VHF passband ripple is noticeably lower than the glide path UHF pass band ripple documented in previous research.



Graph 3

Results for the two frequency tests were specific to receiver type. The overall shape being receiver dependant, and the spread being proportional to the pass band ripple. This can be seen in the two graphs below comparing the receiver with the highest pass band ripple with the lowest.



Graph 4

Graphical results were produced for each receiver for each case identified in table 1. Although there was a greater spread of results with frequency difference for those receivers with higher passband ripple, there was no discernable difference between 90Hz predominant, and 150Hz predominant signal handling.

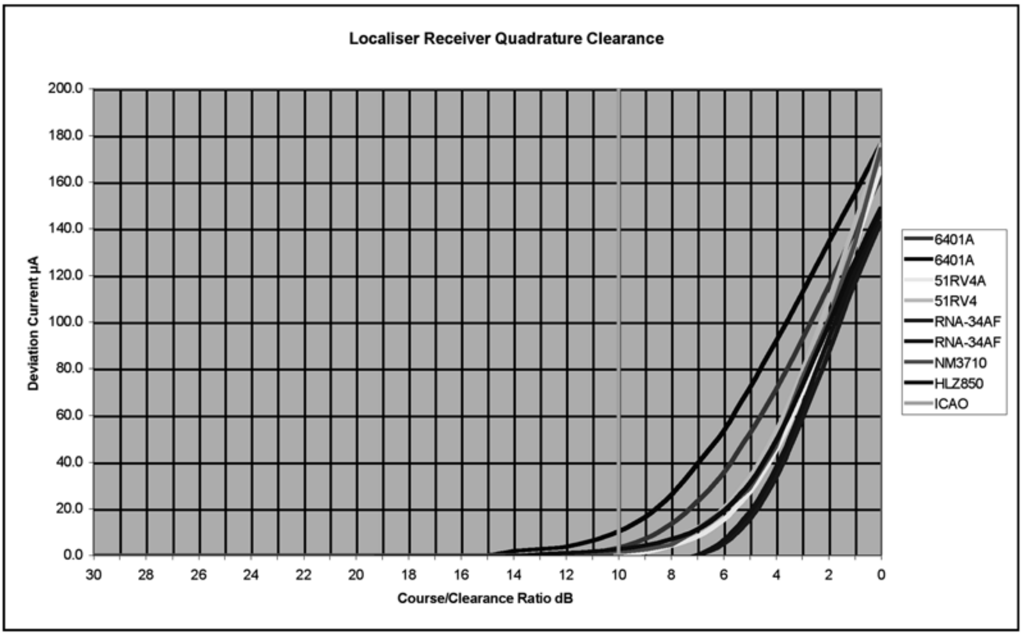
There was a noticeable difference in indicated ddm when the course and clearance signals were equal. It might be expected in this case that the indicated ddm would be in the region of 172µA, but this varied from 110µA to 220µA depending on the receiver type.

Comparison of receiver results is shown on the composite graph at the bottom of the page.
The ICAO annex 10 requirements for 10dB course/clearance ratio has been annotated on the graph for reference. With the exception of the Marconi receivers, all other types have a beam bend potential of 20-25µA at this point.

The graph above shows the results of the same tests, but this time, the course and clearance signals are in audio phase quadrature. With the exception of one of the Marconi sets, it can be seen that the maximum beam bend potential at the ICAO limit of 10db has been reduced to less than 5µA. Quadrature clearance reduced the Marconi receiver beam bend potential from 50µA to 10µA.

Observations during the quadrature clearance testing suggested that the phase angle between the modulating tones is very critical. An error of 5° could lead to opposite sense deviations being observed. In quadrature clearance, the clearance tone phases are modified with one tone leading the equivalent course signal tone by 90°, and the other tone lagging the equivalent course signal tone by 90°. This serves to maintain the composite ILS waveform. Phase angles other than 0° and 90° give rise to a distorted waveform.

To assess the effects of phase angles other than 0° or 90°, a standard ILS course signal was fed into the receiver. A clearance signal was synthesised



Graph 5

but not phase locked to the course. For differing levels of course/clearance ratio, the indicated deviation current was noted for each 10° phase change of the relative 90Hz components. Signal details are tabulated below:

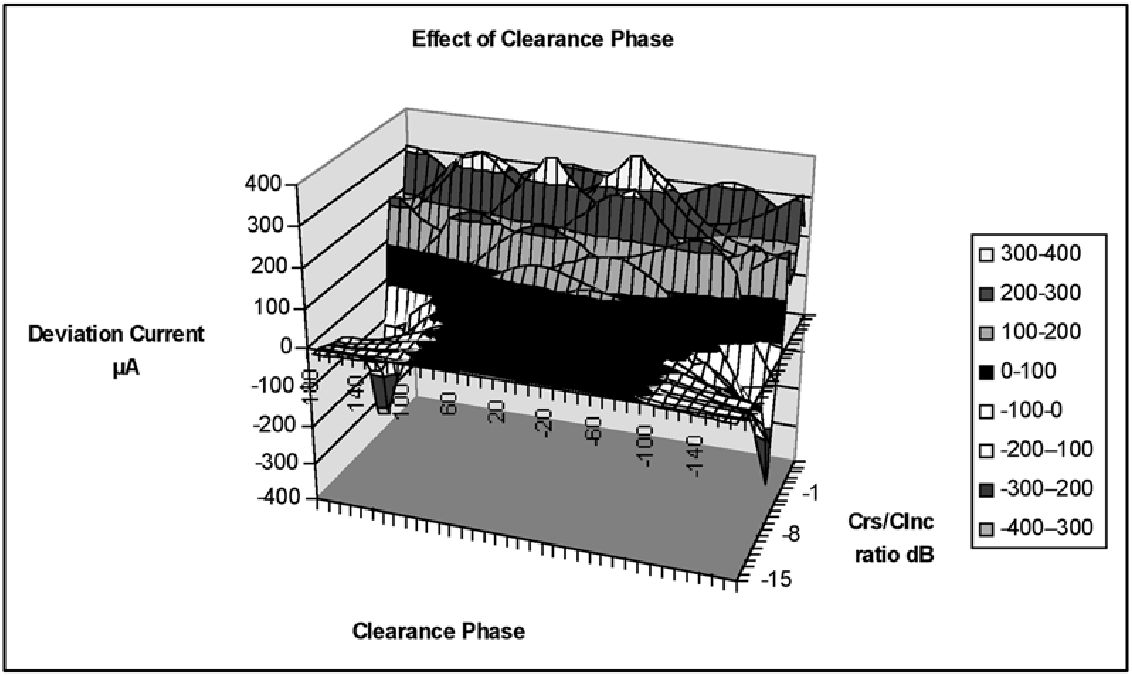
	Course	Clearance
Frequency	*+4.5kHz*	*-4.5kHz*
RF Level	*-65dBm*	*Variable*
ddm	*0*	*0.4 (90Hz)*
sdm	*40%*	*60%*

Table 2.

The equivalent clearance deviation current is 367µA.

The results are shown graphically below.

Although the graph appears complex at first sight, it shows the resultant deviation current (vertical axis) for changes in both course/clearance ratio and phase relationship. The ripples and unevenness in the graph are the result of an undetermined beat effect. This is thought to be caused by power supply noise. This aspect is still under investigation. However, the graph still clearly shows that as the phase angle exceeds 90°, a negative sense deviation current can occur. Tests using the 150Hz tone give similar results. What is not apparent from the graph is the result of a 150Hz predominant clearance signal for the conditions stated above, which use the 90Hz tone as the reference phase. A more detailed study is currently being carried out in this area to better define the effects and risks.



Graph 6

CONCLUSIONS

Passband ripple in localiser receivers is a much less significant problem than in glidepath receivers.

The capture performance of modern ILS receivers is very comparable for signal ratios of >6dB. Whilst older receivers may differ somewhat, there is no evidence of great variation amongst the modern units tested.

Reflected clearance on a two-frequency localiser has the ability to create a beam bend potential in excess of 25µA at the ICAO stated minimum course/clearance ratio of 10dB.

The use of quadrature clearance (as used in the STAN37 localiser system) has the prospective of reducing the beam bend potential due to reflected clearance by a factor of 4~5 at the ICAO stated minimum course/clearance ratio of 10dB.

The use of other clearance phase angles has the possibility of generating false guidance information under certain conditions, and more research is needed in this area to fully understand the implications and risks.

REFERENCES

1. ICAO DOC 8071
   Manual On Testing Of Radio Navigation Aids

2. ICAO Annex 10
   Aeronautical Telecommunications SARPS

3. ECE 480 website
   www3.ncsu.edu/ECE480/480_1.htm

ACKNOWLEDGEMENTS

All research carried out by Flight Precision Limited.

This study was sponsored by UK Civil Aviation Authority Safety Regulation Group. Full details of research and results are contained in paper:

INSTRUMENT LANDING SYSTEM LOCALISER RECEIVER INVESTIGATION STUDY

CAA SRG Project Ref 336
1999
63p.

Juan Oswaldo Hernández
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MAGNETIC NORTH ALIGNMENT FOR VOR STATION NOT USING THEDOLITE AND WITHOUT GPS REFERENCE

February 23, 2000

ABSTRACT

During VOR Flight Inspection, one of the procedures is the Magnetic North alignment of the station. For this procedure a radio-thedolite or recently DGPS is used as reference. If DGPS is not available and weather conditions don't permit use the theodolite, the Magnetic North alignment of the station can not be executed.

The method proposed in this paper to align the station, is based on the aeroplane navigation instruments information, using as principal reference the gyrocompass.

The Heading (HDG) is usually measured by a simple magnetic compass, but the error due to deviation of the needle is diminished using the gyrocompass. The Bearing (BRG) is measured by the VOR indicator, usually the Radio Magnetic Indicator (RMI) where HDG is also indicated. As will be shown these angles are correlated each other because both are dependent of the Magnetic North, and some error of the BRG indication can be detected through the HDG.

NAVIGATION ANGLES

In order to unify the concept of the navigation angles here we define them:

1. Heading HDG: Angle between airplane's Magnetic North and the prolongation of the airplane longitudinal axis.

2. Bearing BRG: Angle between airplane's Magnetic North and the imaginary line from the gravity centre of the airplane and the VOR antenna.

3. Azimuth A: Angle between VOR's Magnetic North and the imaginary line from the gravity centre of the airplane and the VOR antenna.

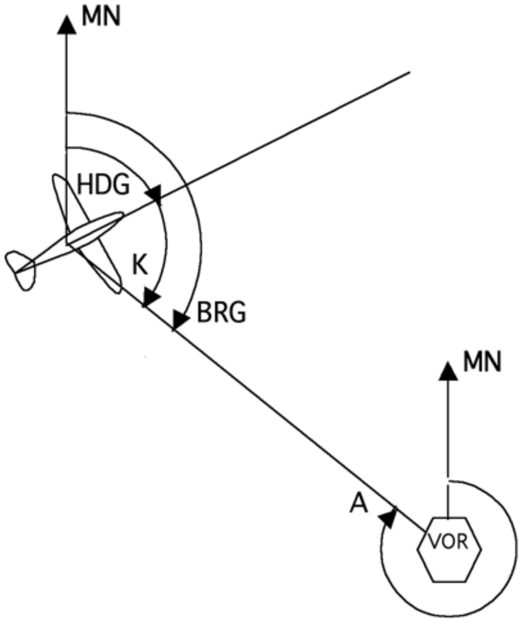
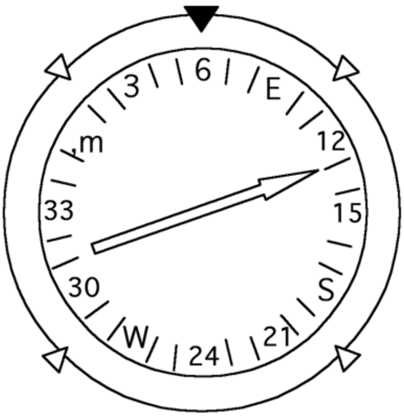


Figure 1. Navigation angles

4. Angle K : Reference angle equivalent to the difference between BRG and HDG.

These angles are measured always clockwise and are shown in figure 1, and their indication on the RMI is shown in figure 2.



HDG=60 A=310
BRG=130 K=70

Figure 2. RMI indication of Navigation angles

As can be seen from figures 1 and 2, navigation angles have the next relations:

HDG = BRG-K (1)
BRG = A±180° (2)

These relations are always true no matter the position of the airplane respect to the VOR station.

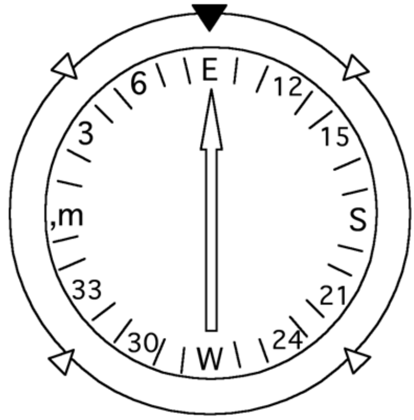


Figure 4. RMI indication HDG=BRG=90°, K=0°

Supposing the VOR Magnetic North is correct oriented, When aircraft is flying on radial 270 TO the station Heading and Bearing should coincide 90°, therefore angle K=0. When aircraft has crossed VOR station continuing on radial 90, Heading remains 90°, and Bearing becomes 270°.

The proposed method consists on the exactly measuring of the Heading. The relation (1) should be always satisfied, so flying on radial 270, Bearing and Heading should be 90°, and the needle should be pointing exactly to the upper lubber line. (See figure 4). When aircraft is flying on radial 90 from the station, the Heading remains as previous and Bearing changes to 270°, therefore the RMI needle should point exactly to the lower lubber line, that is to say K=180° (See figure 5).

MEASURING VOR MAGNETIC NORTH

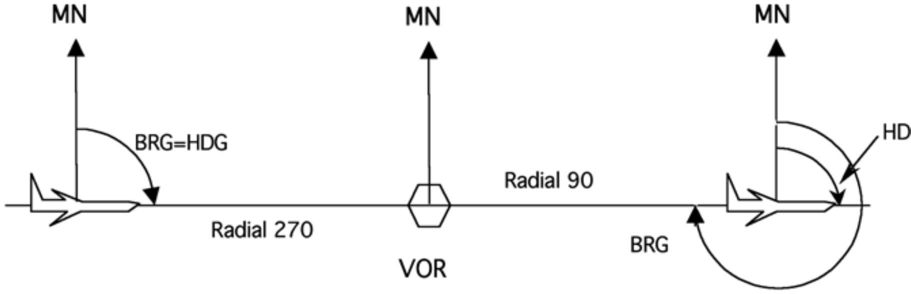


Figure 3. Flying TO and FROM the VOR station

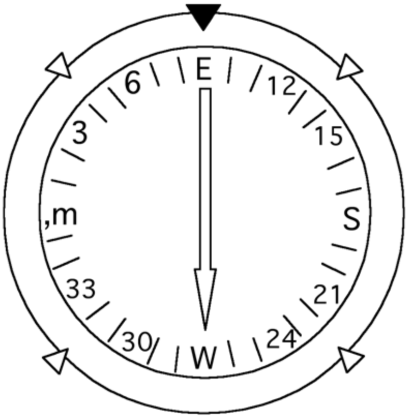


Figure 5. RMI indication HDG=90°, BRG=270°, K=180°

Now we will analyze the case when the VOR magnetic North is not correctly oriented. In this case the Bearing information is not correct and the relation (1) is not satisfied. Suppose for instance that VOR station is rotated clockwise 10°, i.e. the monitors have a phase error of -10°, (see figure 6).

As can be seen from figure 6, if the aircraft follows the VOR indication to flight on radial 270 the relation (1) is not satisfied because HDG=100°, BRG=90°, and although the airplane is flying TO the station *K* $\neq$ 0. This indication on the RMI is shown in figure 7.

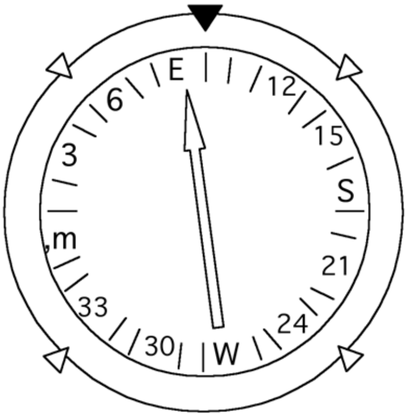


Figure 7. RMI indication from figure 6 where HDG=100° and BRG=90°.

The same happens when aircraft crosses the VOR station, flying on radial 90, then HDG=100°, BRG=270° and *K* $\neq$ 180º. This indication is shown in figure 8.

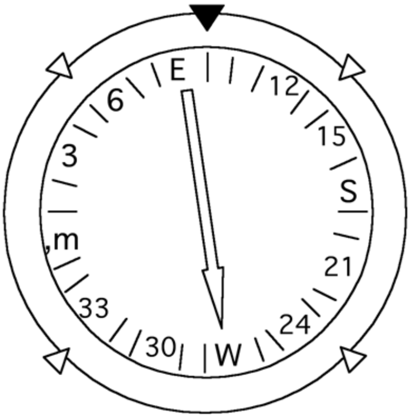


Figure 8. RMI indication from figure 6 where HDG=100° and BRG=270°.

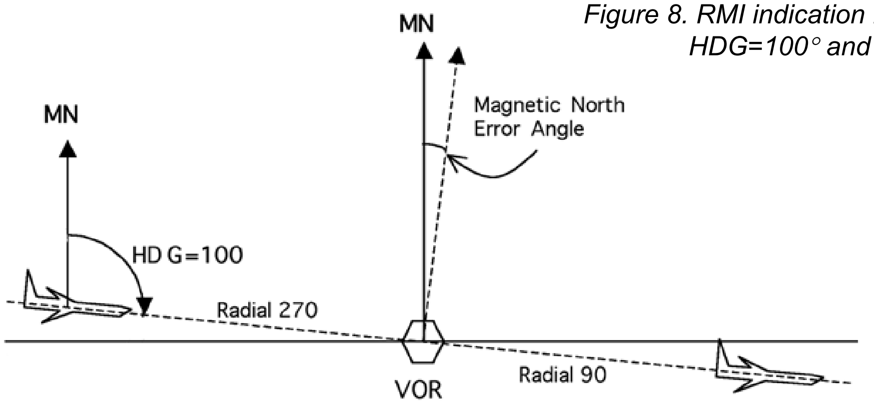


Figure 6. Incorrect VOR station Magnetic North orientation

It is clear comparing the figure 4 with 7, and figure 5 with 8 the error due to the improper alignment of the VOR Magnetic North.

In order to demonstrate the effectiveness of the proposed method some flight experiments were realized with the Flight Inspection System of the Aeronautica Civil of Colombia (Norway Navia FIS and the airplane is Cheyenne III) obtaining accurate results that were confirmed later using theodolite as reference.

It is important to make clear that this method can be used flying on any radial, in order to explain in an easy way here we have chosen radials 270 and 90. To use this method, the direction of wind should be taken in account to avoid error. For any radial we choose, when the airplane is flying TO the station K should be 0°, and flying FROM the station K should be 180°. The angle K is indicated on the RMI, and is the angle between the upper lubber line and the tip of the needle.

CONCLUSIONS

The proposed method to align the VOR Magnetic North can be used when DGPS is not available and weather conditions are not proper to use theodolite as reference.

A properly calibrated gyrocompass is necessary in order to obtain accurate results.

The wind direction should be known to select the radials where the aircraft should fly TO and FROM the station.

To demonstrate the effectiveness of the proposed method, some experimental flights were executed with the FIS of the Aeronautica Civil of Colombia.

REFERENCES

1.- ICAO Annex 10. Aeronautical Telecommunications, Navaids.

2.- FAA United States Standard Fight Inspection Manual. ZVN-820.

3.- АВТОМАТИЧЕСКИЕ РАДИОКОМПАСЫ. В. Т. ТИМОФЕЕВ, А. М. КЛУГА

4.- АВИАЦИОННАЯ РАДИОНАВИГАЦИЯ. А.А. СОСНОВСКИИ.

5. Manual de inspeccion en vuelo, edición brasilera.

United States of North America
Federal Aviation Administration
Aviation Systems Standards
Flight Inspection Operations Division
Howard M. Ryder and Charles J. Barbeau

HYMAN FACTORS AND FLIGHT INSPECTION
JUNE 05, 2000

ABSTRACT

Human Factors in Flight Inspection

The Flight Inspection Operations Division (AVN-200) is evaluating the area of Human Factors as applied to Instrument Flight Procedures. Human Factors has always been a major part of both instrument approach procedure design and flight inspection evaluations. However, newly designed instrument approaches using Area Navigation (RNAV), the aircraft Flight Management System (FMS), the Global Positioning System (GPS), and various data bases defining waypoints as part of the instrument approach has added a new dimension to Human Factors.

Complex instrument approach procedure design, communications, and the ability of the pilot to interpret the instrument procedure greatly affect human factors. All of these factors combined should result with a pilot landing safely at his destination. However, if an accident occurs, pilot error is often to blame. The question is, «Pilot Error or poor human factors?»

AVN-200 will be adding new areas to be applied to human factors while conducting flight inspection.

HUMAN FACTORS

PURPOSE

To identify and evaluate new flight inspection procederes applied to human factors.

BACKGROUND

1. Federal Aviation Order 9550.8 states «Human factors entails a multidisciplinary effort to generate and compile information about human capabilities and limitations and apply that information to equipment, systems, facilities, procederes, jobs, environments, training, staffing, and personnel management for a safe, comfortable, effective human performance.»

2. The United States Standard for Terminal Instrument Design, or TERPS, (FAA Handbook 8260.3B) provides specific guidance for approach procedure design. Emphasis is placed on three basic factors contributing to overall system accuracy: ground element, airborne element, and flight technical or pilotage element. Instrument approach

procederes should be designed for simplicity and safe operations. Human factors such as cockpit workload, pilot error, and memory limitations have been considered. From a pilot's standpoint: «The procedure must be flyable and should be as simple as possible. The text should be clear, concise, and use standard phraseology.

3. The United States Standard Flight Inspection Manual (FAA Order 8200.1) specifically addresses human factors in Section 214 of the manual. Human factors «in the context of flight inspection is a question of whether a flight procedure is operationally safe and flyable for a minimally qualified sole pilot flying an aircraft with basic IFR instrumentation in instrument meteorological conditions using standard navigation charting.» The tolerance applied to an instrument procedure is for the procedure «to be safe, practical, and easily interpretad with minimal additional cockpit workload.»

4. Aviation Systems Standards uses the World Geodetic System 1984 (WGS -84) for international datum. The North American Datum of 1983 (NAD-83) is used for United States data in the design of terminal and enroute instrument approach procedures and flight inspection. Vertical data is either North American Vertical Datum of 1988 or National Geodetic Vertical Data of 1929.

5. A typical flight inspection mission will take about two to three hours. A three-man crew, two pilots and one airborne electronic technician, will conduct the flight inspection. Prior to flight, the crew will meet with airport authorities, navigation maintenance personnel, and air traffic to brief the flight profile and discuss any problems associated with the flight inspection.

DISCUSSON

1. Instrument Procedure Design

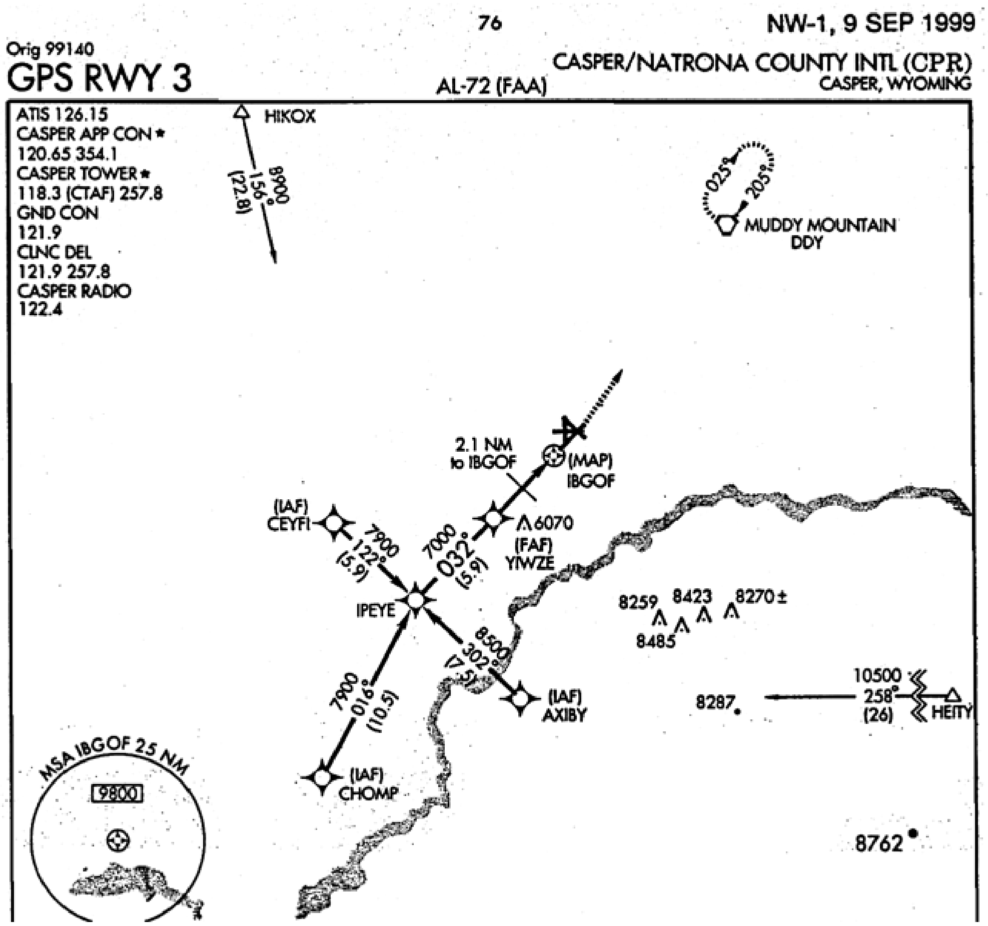
The National Flight Procedures Office (AVN-100) is responsible for preparing civil instrument approach procedures in the United States.

a. The application of human factors begins with the design of a standard instrument approach procedure (SIAP) in accordance with FAA Handbook 8260.3B. GPS procedures are developed in accordance with FAA Order 8260.38A- FMS in accordance with FAA Order 8260.4OB; and RNAV in accordance with FAA Order 8260.48. The datum used for designing an instrument procedure is NAD 83 for conterminous United States and WGS 84 for internacional (Note: Databases used worldwide may not be the same). During the design, the procedure specialist will develop the various segments of the approach and assign names to new fixes. The names are taken from an allocated list provided to AVN-100. Once the SIAP is completed, it is reviewed for accuracy and scheduled for flight inspection.

b. The application of human factors based on ground based navigational systems is usually straightforward. The majority of approaches are usually simple in design requiring minimal cockpit workload for a single piloted aircraft in instrument flight conditions. Human factor issues that are discovered during flight inspection are discussed and resolved. However, the advent of RNAV, FMS and GPS instrument procedures has opened a new world of human factors. For example, refer to the following GPS approach into Casper, Wyoming.

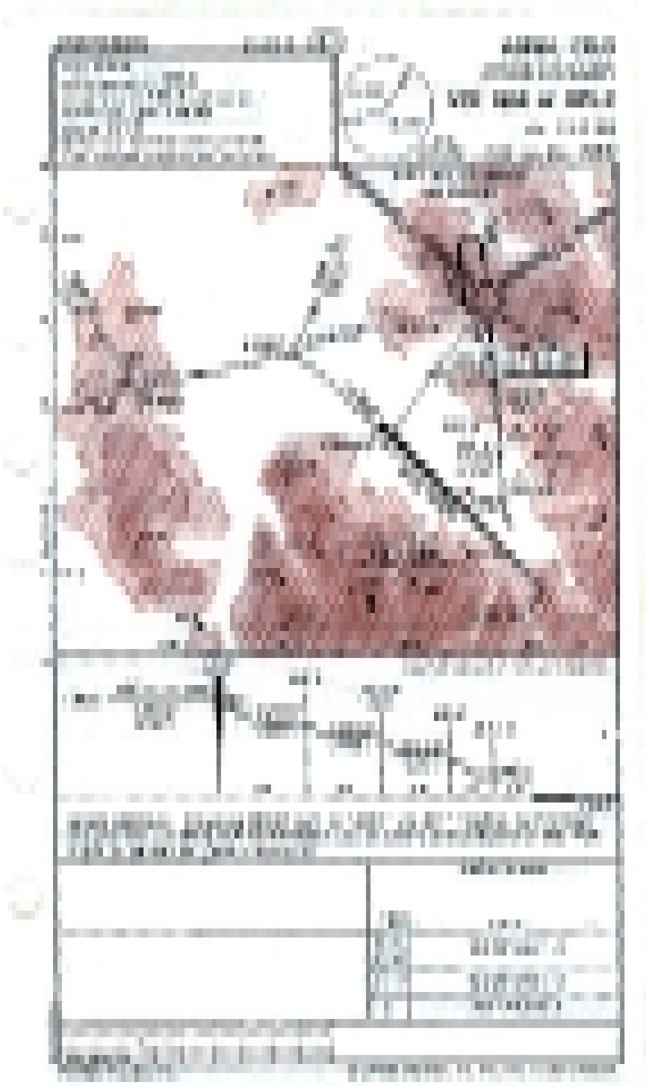
This approach is a stand-alone type GPS procedure designed on a «T» concept (Note: The Initial Approach Fixes shape the letter T). The names used for the various fixes are Chomp, Ipeye, Axiby, Ceyfi, Yiwze and Ibgof. Some of the names sound unusual because the standard lists of names for fixes and waypoints are running out, causing new names to be used that are difficult to pronounce. As the number of RNAV, FMS, and GPS procedures increase, so will the number of complex names increase. Communication problems could occur.

c. Fix and waypoint accuracy are paramount in procedure design, especially when stand alone FMS and GPS procedures are designed. Mathematical models used by the procedure specialist for determining latitudes and longitudes are not the same as those used by the National Flight Data Center (NFDC). The difference is minimal but the same mathematical models should be used for standardization.



2. Flight Inspection

Flight inspection in the 21st Century verifies that a given procedure is supported by a navigational system; ground based, airborne (using FMS), or satellite (GPS). Once the instrument procedure is scheduled for flight inspection, the flight inspection crew will review the SIAP, collect all data and charts necessary for flight inspection, brief the flight profile and flight inspect the procedure. To give a better idea of the overall process, refer to the VOR DME or GPS approach into Aspen, Colorado, below:



The approach procedure into Aspen (published by Jeppesen) is an excellent example of why flight inspection is necessary. The procedure uses Red Table VOR DME or GPS to a missed approach point 11 DME from Red Table. At the minimum descent altitude of 10200 feet, you initiate the missed approach by intercepting a back course localizar and finally arriving at GLENO intersection for holding. (Note the mountainous area South of the localizar with a spot elevation of 14130 feet).

As a flight inspector, you should be concerned about the following human factors:1. The flight inspection crew is dealing with precipitous mountainous terrain. Weather will have to be clear of clouds for all flight inspection maneuvers for both commissioning and future periodic inspections. 2. The procedure is not a simple SIAP. It requires two VHF radios and two different types of VHF radio navigation (VOR and Back Course Localizer). 3. Memory items are distracting due to multiple letdown altitudes on the approach while in mountainous terrain and the use of a back course localizar, outbound, for a missed approach. 4. Cockpit workload, even with two VHF navigation receivers, is heavy because of crossing radials required to identify CROWS, LINDZ, and GLENNO intersections in addition to intercepting the back course, outbound, for the missed approach.

5. The required change in altitude (2385 Ft) and descent gradient from the missed approach point to the runway is high. 6. Proper programming of GPS waypoints prior to takeoff for flight inspection purposes is prudent, if not mandatory. (Note: For commissioning purposes, the coordinases from the procedure forms may require conversion for GPS and FMS loading of a flight plan. Future periodic inspections should require a comparison of the published SIAP versus procedure forms coordinase information.)

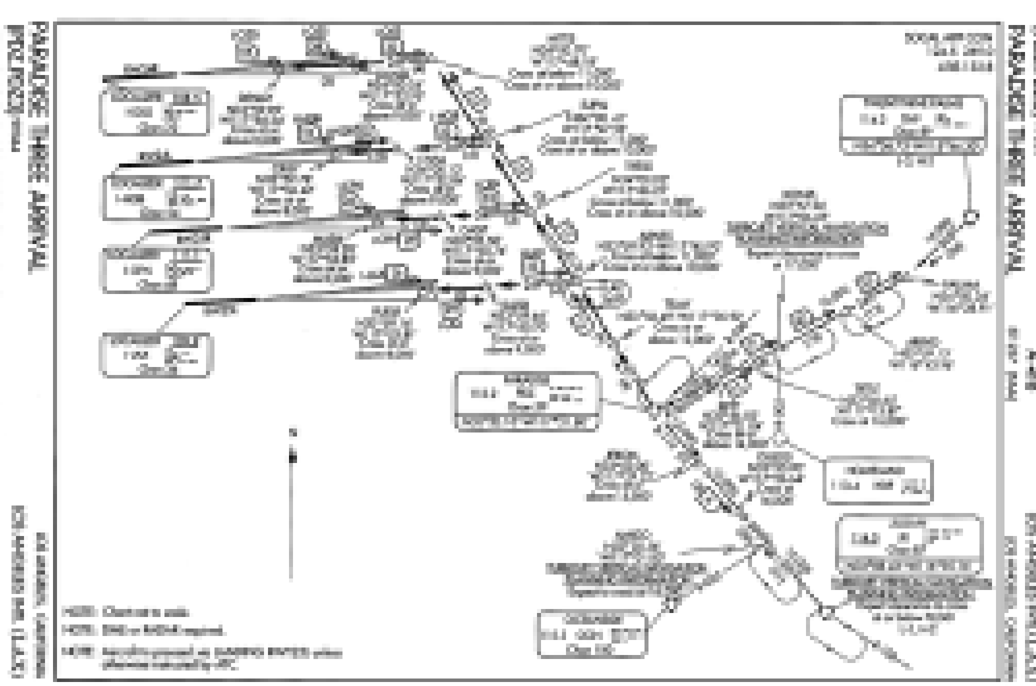
The Aspen SIAP has been flight inspected and is considered safe. The approach is used daily by private, corporate, and commuter aircraft flying overhead the airport and landing on runway 33.

3. Procedure Complexity and Flight Inspection.

The Aspen approach is just one of severas instrument approach procedures throughout the world that are complex and hard to understand for the most experienced crews, let alone a pilot or flight crew flying the same approach for the first time. Today, with increased air traffic and use of RNAV, FMS and GPS procedures, severas instrument approach procedures have become quite interesting. New RNAV, FMS, and GPS instrument procedures have been designed that are called stand-alone, where no ground based navigational support is required. In addition, the three dimensional capabilities of inertial navigation systems coupled with FMS and GPS have led to the development of numerous RNAV arrival and departure routes.

All instrument procedures, especially stand-alone procedures should require a minimum of a commissioning type flight inspection with emphasis on the following human factors: 1. Procedure design complexity should be simple. 2. Chart information kept to a minimum. 3. STAR should be inspected from an airline perspectiva for descent rates and airspeeds ensuring cockpit workload is minimal. The STAR should allow for a slowdown point for landing configuration. 4. Waypoint names should be easy to pronounce.

For an example of procedure design complexity, refer to the Paradise. Three Arrival into Los Angeles, California.



The Paradise Three arrival is typical of most arrivals into Los Angeles International Airport. The majority of arrivals deal with mountainous terrain requiring several letdown points. For flight inspection purposes, consideration should be given to flight inspecting this STAR with a high-speed aircraft to simulate descent profile representativa of airline aircraft. If this is not possible, then an aircraft simulator should be used to evaluate speed controls, descent rates, and cockpit workload. Additional human factors involved with the STAR are the following: 1. Chart clutter is high. Multiple letdown actitudes are used with very little distance between flxes. Some of the letdown actitudes could be combined or eliminated. Crossing restrictions of a 1000 feet difference (Cross at or below 11000' and Cross at or above 10000') are combined at the extended course centerlines of the localizar. Four choices of instrument landing systems (ILS) are available. Latitude and longitude information is distracting. 2. Cockpit workload is high. Descent rates are high which in turn makes it difficult for the aircraft to descend and slowdown for landing configuration.

4. Charting Standards and Symbology

Different charting publications and organizations use differen styles for charting of enroute information and approach charts. Some charts, such as Jeppesen, include terrain features, some don’t. Symbology for navaids, fixes, and waypoints differ. In addition, newly designed RNAV, FMS, and GPS procedures include «flyover» versus «flyby» waypoints. New charting requirements have been developed for RNAV SIAPs which will list separate minimums for Wide Area Augmentation System (WAAS), Lateral Navigation LNAV, and Vertical Navigation (VNAV). For flight inspection, intended symbology should be verified and properly flown as published.

5. Human Role - Pilot Error or Human Factor

Pilot error is most often cited as a main cause to aircraft accidents. The pilot or crew lost situational awareness somewhere during the flight. Was the accident really caused by pilot error or were there certain human factors that contributed to the accident? Were communications satisfactory and understood? Flight deck automation and use of RNAV, FMS, and GPS have increased the possibility of the pilot or crew making a programming error. Air traffic, TERPS specialist and flight inspectors have to work together to design and evaluate instrument procedures to determine that the procedure is safe, simple as possible, easy to interpret, and cockpit workload is minimal. When human factor issues negatively impact an instrument procedure, resolve the issues prior to publication.

6. Recommendations

a. All instrument procedures should have a commissioning flight inspection to evaluate human factors.
b. Areas of mountainous or precipitous terrain should be published on all approach charts (Jeppesen, NOS, NOAA).
c. Establish a new data base using alpha-numeric for naming fixes and waypoints that are easy to pronounce and understand.
   Communication evaluations should include fix and waypoint names for interpretability. For example at Casper, Wyoming, CASO1, CASO2, to CASO6 could be used instead of Chomp, Ipeye, Axiby, Ceyfi, Yiwze and Ibgof. An approach to another runway would be identified with CAS11, CAS12, and so on.
d. A standard mathematical model for waypoint design and publication should be used. The waypoint data that is flight inspected should be exactly the same as published.
e. Cockpit workload should be a separate item in human factors for flight inspection purposes.
f. Evaluate aircraft descent and climb rates for STARs and SIDs. When necessary, evaluate these procedures using either a high speed aircraft or a simulator.

CONCLUSION

The use of instrument approach procedures should aid the pilot in completing a safe landing. Approach procedures that are poorly designed or complex must be avoided. The advent of RNAV, FMS, and GPS instrument procedures has added new areas to consider when applying human factors.

Aviation System Standards and the Flight Inspection Operations Division are working hard to identify new areas to be applied to human factors. Proper application and evaluation of human factors will increase flying safety.

REFERENCES

1. FAA ORDER 9559.8
2. UNITED STATES STANDARD FOR INSTRUMENT DESIGN, FAA HANDBOOK 8260.3B,
3. CIVIL UTIILIZATION OF GLOBAL POSITIONING SYSTEM (GPS), FAA ORDER 8260.38A
4. FLIGHT MANAGEMENT SYSTEM (FMS) INSTRUMENT PROCEDURES DEVELOPMENT, FAA ORDER 8260.40B
5. AREA NAVIGATION (RNAV) APPROACH CONSTRUCTION CRITERIA, FAA ORDER 8260.48
6. UNITED STATES STANDARD FLIGHT INSPECTION MANUAL, FAA ORDER 8200.1

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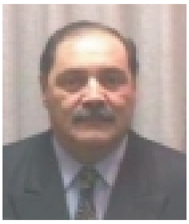
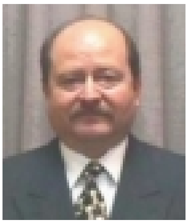




«FLIGHT INSPECTION AND ATC PROCEDURES IN REMOTE AREAS» «EASTER ISLAND AND FALKLAND ISLANDS»

EASTER ISLAND - ISLA DE PASCUA

FLIGHT INSPECTION AND ATC PROCEDURES

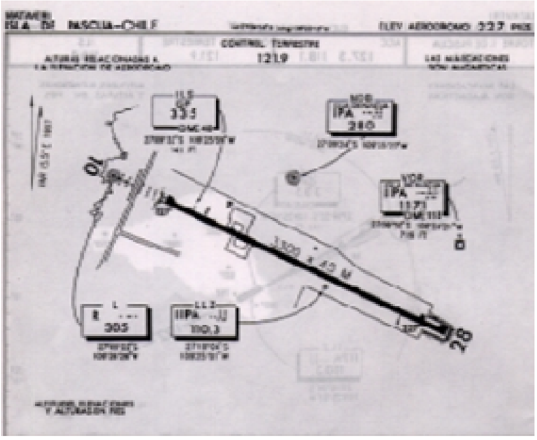
According different suggestions and in order to accomplish the flight inspection community necessity around the world, for remotes areas where flight inspection service is difficult to achieve, the ICASC Committee requested to the Chilean team to prepare a paper regarding to Easter Island.

For Chilean Government and specifically for DGAC, it is very expensive to provide real safety in Easter Island, because the DGAC has to keep an aircraft stored in the Island for 4 months and restore the plane each time that flight inspection happens. The Flight Inspection Team has to a travel by commercial airline every time that the evaluation and navaids check has to be made.

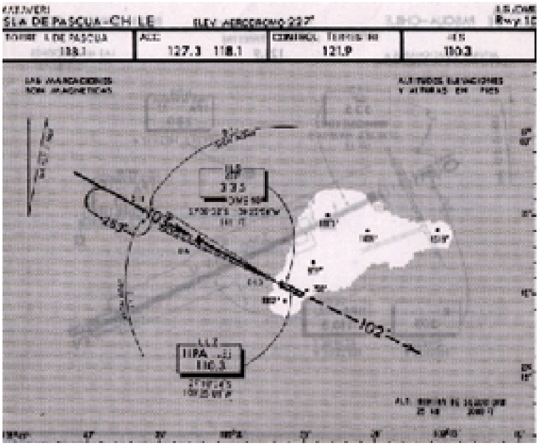
A semiautomatic console brought from the continent, is mounted on the Piper Seminole and after 10 to 15 hours of installation, the aircraft is ready to start the flight inspection to the island facilities.

Another aspect that is relevant to show is the topography structure of the Island (ground site), and what are the many problems and deficiencies we have to deal with, the offset Localizer for example, and what happens with the glide slope in a runway with down slope error. In this aspect the threshold of runway 10 has a 127 ft. elevation and threshold of runway 28 has 187 ft. elevation, which gives a difference between thresholds of 60 ft. (20mt.)

Through many years flight inspection has been done in Easter Island, starting with a single ADF approach, going later with a VOR, DME and now with DME/ ILS. This means that the DGAC staff has developed a very good planning, flight check, in flight procedures, navaids accuracy and flyability, instrument procedures and related issues.



Chilean experience about the ATC instrument flight procedures design has been as rich as flight inspection, and from the beginning with a single ADF, passing though a VOR, DME now we have designed procedures for an offset ILS. The results up to now has been really very good.



In this 21st century, DGAC is thinking about the new technologies and how they could be applied to the Easter Island procedures using eventually GPS, DGPS, WAAS, LAAS or any other future navigation system.

BACKGROUND

Rapa Nui (Easter Island in native language) is located 2040 nautical miles from the west Chilean coast, in the middle of the South Pacific Ocean, and 2.300 nautical miles from the Polynesia (Papeete - Tahiti).

Easter Island was inhabited by polynesian people around 1722 and the Chilean government annexed the Island in 1888.

The island is formed by three extinct volcanoes and it is very well known by its huge carved stone heads and the hyerogiyphic tablets.

The island is a triangular shaped portion of land having a population of 3.500 people, with an area of 117 squared kilometers.

THE PAST

At the beginning, Mataveri Airport had only two air navigation aids, a 3.000 watts NDB and later a 100 watts VOR.

The evaluation and flight inspection to those navaids were made by a Boeing 707 belonging to Lan Chile airlines. On board were installed a portable console from the Federal Aviation Administration, and flight inspection was made.

TO DAY

Actually there is an agreement signed on August 16, 1987, between the Governments of Chilean Republic and United States, which defines the use of the Mataveri Internacional Airport for the Space Shuttle as a landing alternativa in case of an emergency and rescue.

Through this agreement the Dirección General de Aeronáutica Civil of Chile has the compromise to facilitate what be necessary, in case that any space shuttle could make an emergency landing in the island.

Actually DGAC is responsable for the aeronautical services, facilities installation and its maintenance, equipment and navaids and its operational and technical certification.

Due to the distance between the Chilean coast and the island, the cost of the works, improvements and any development to be made into the island, are one of the highest priorities and sensible issues that the Chilean Government and DGAC have in mind.

TOMORROW

The DGAC commitment is to maintain and improve day after day the flight safety, to implement new and updated technologies, to establish GPS, DGPS, WAAS, LAAS approaches and the use of all the facilities in this far away island.

SAFETY ASPECTS

Chile is proud to inform to the internacional flight inspection community and to the civil/military aviation around the world, that from the beginning, Mataveri Airport and DGAC aeronautical services do not register any incident or accident on the route Santiago - Easter Island - Papeete - Easter Island Santiago.

CONCLUSIONS

It is very easy to understand and to analyze two aspects related to flight inspection into the island: the first one is the decision from the Chilean Government through DGAC to improve every day the flight safety to air navigation without taking into account how much it is the cost. Everybody knows that safety has no price. The second aspect is the participation of the internacional community in providing the technical necessary elements in order to permit that the air operations continue, as to day, without any air/ground incident nor accident.

Nowadays the use of GPS navigation system as a suplemental system of navigation for IFR flight in domestic routes will provide an excellent tool for users of the Chilean Airspace. As the GPS is being used worldwide and having into account the internacional experience the DGAC will continue working on the subject.

The DGAC must continue the work diligently to ensure that this tool can be used effectively in the Chilean Airspace and the aim in the short term is to permit the use of GPS as a primary means for IFR flights, only in RNAV an some oceanic routes; and for VFR flights as a suplemental means in the airspace except in terminal areas and approach procedures.

Existing regulations need to be revised to reflect the availability, precision and continuity throughout the airspace at any time.

As operational experience is gained with the use of GPS, the DGAC needs to be sure that operational availability and capabilities will be at maximum, to ensure that GPS service interruptions are minimized while maintaining safety as the first and highest priority.

The safety issue has been accomplish in a 100% by the DGAC, through the rules, procedures, technical and operational developments and the most important resource, «the DGAC people that works everyday for improving the air safety under the Chilean sky.»

Mr. Collin Chitty
Director, General Manager
Flight Precision Limited
United Kingdom

FALKLAND ISLANDS - ISLAS MALVINAS

FLIGHT INSPECTION

Since January 1997 Flight Precision Limited (FPL) has successfully carried out 120 day flight inspections of the various navaids at Mount Pleasant Airport (MPA) in the Falkland Islands. The work has been organised as a long distance detachment from FPL's base in the UK, some 8,300 nm distant. The operating concept makes use of the unique modular design of FPL's Aerodata FIS units which lend themselves to transportation to remote sites. These comprise racks for mounting on seat rails approximately 1,200 x 510 x 1,250 mm in dimension and weighing 150 kg. These are interchangeable between each of the company's King Air B200 and Conquest C441 aircraft.

A week before the inspections are due FPL's crew, a Navaid Inspector, a Radar Inspector and a Ground Tracker Operator, demount and disassemble a FIS system from one of the aircraft and pack these components together with the ground station equipment into shipping containers. These are then dispatched via a freight handler to fly as cargo on a regular scheduled Tristar from RAF Brize Norton. FPL's crew fly on the same aircraft carrying the laser tracker as «hand baggage» on the flight deck.

On arrival at MPA the equipment is unloaded by RAF personnel, collected by the Falkland Islands Government Air Service (FIGAS) and transportes by road to its operating base at Stanley Airport, approximately 35 miles away.

FIGAS engineers then install the FIS kit in one of their Britten Norman BN 2B -26 Islander aircraft modified to accept the FIS equipment and with flight inspection antennae preinstalled in accordance with FPL's design.

Flight Inspections at MPA are carried out as day sorties from Stanley Airport with the aircraft flown by a FIGAS pilot. On completion of the work FIGAS engineers demount the FIS unit for FPL's crew to box up for the return trip to the UK.

Detachments are normally completed within 2 weeks and the equipment is reinstalled in an FP aircraft within 3 weeks. This is, of course, dependent on the weather which can, and does, change quickly and frequently. «All 4 seasons in a day and most of them gusting force 6 and above!»

As may be envisaged the success of this logistics challenge depends very much on the skill, ingenuity and teamwork of the FIGAS, RAF and FPL staff involved.

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ILS QUALITY CONTROL REFERRED TO NATIONAL STANDARDS AND DETECTION OF DISTURBING SOURCES

ABSTRACT

The precision of the received guidance information during instrument landing primarily depends as well on the quality of ground based localizer and glidepath transmitter as on environmental influences of the radio field covered by the system. The systems required angular coverage makes the transmitting antennas illuminate variant obstacles like the ground, terminals and other buildings, fences and aircraft reflecting the guidance signals with different Doppler shift from the approaching aircrafts point. Todays flight inspection periodically measures the resulting effects on landing precision by calibrated reference receivers - but actually this kind of quality control is neither referred to national standards nor does it allow the identification and analysis of the quality diminishing sources.

The paper proposes a Doppler method which presents the received guidance signal in time and frequency domain against national standards «Volt» and «Hertz» during approach and landing. Particularly the spectrum shows the DDM originally transmitted by the ground antennas and differently Doppler shifted the carrier and side bands of the reflections by the environment. Installing an additional ground station which only transmits a very stable carrier the received spectrum aboard shows both the direct received signal and the variance of reflections differentially Doppler shifted by aircraft motion. Further interest is focussed on localization of reflective sources. By using the aircraft's precise velocity and position information derived from the Flight Inspection System in conjunction with the Doppler information it is possible lo calculase the reflectors position. Some results from first field tests are presentes in this paper.

INTRODUCTION

Radio navigation systems like VOR and ILS transmit in different directions differently modulated signals indicating the radials. In addition to the directly transmitted signal the aircraft receives various reflections from buildings and landscape indicating other radials and thus creating radial errors.

The moving aircraft «sees» the ground transmitter and the reflecting objects under different angles and with different relative speed. Consequently, direct signal and reflections get different Doppler frequency shifts which can be measured and selected in the frequency and time domain by appropriate techniques.

Due lo relatively small total Doppler shifts and even smaller differences the technical equipment and software requires a very high stability and selectivity in frequency domain in particular if this technique shall also be able lo identify reflecting objects in the vicinity and shall describe their reflection characteristics.

The receipt and analysis of the signals in space in that way allows a separate observation of the transmitting system (e.g. field strength, modulation) on the ground and of the contributing environment illuminated by the ground system calibrated in national standards like Volt and Hertz. Therefore the receipt and analysis of the signal in space is of interest for flight inspection with respect lo quality assurance and identification of error sources.

In the period 1975-1985 the instituto got certain experience in that way by the development of experimental VHF-, L- and C-Band equipment and by various field tests at several airports [1, 2, 3, 8]. But the absence of both sufficiently powerful computers for signal processing and flight path measurement to that time prevented further successful work. The cooperation with Flight Inspection Internacional (FII) in Braunschweig reactivated the project delivering the necessary accurate real time flight path data, access to proper aircraft antennas and free of charge flight hours for the instituto.

THE NEW EXPERIMENTAL SYSTEM

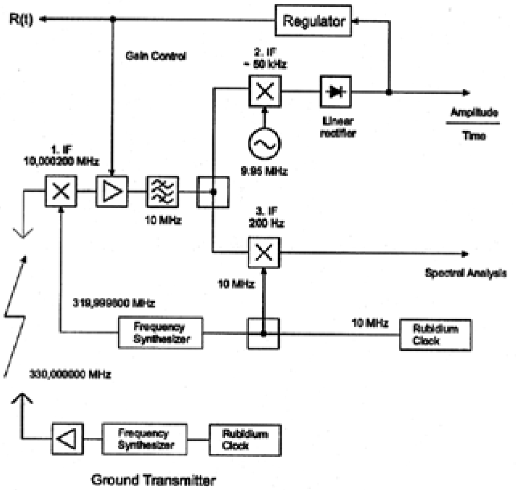


Figure 1: RF part of system

Due to the small volume available for that purpose in the FII aircraft the airborne equipment was redesigned to a compact twin-receiver usuable for VHF/UHF-receipt and delivering a first intermediate frequency (1 F) of about 10MHZ with 30 or 70kHz respectively as shown in Fig. 1.

The enormously high stability requirements makes it necessary to synchronize the frequency synthesizer by a Rubidium clock to deliver the local oscillator signal for superimposition. Same reasons require a Rubidium-clock supported transmitter on the ground for experimental purposes.

The output of the first IF signal was splitted into two channels:

- the lower to be converted by Rubidium-clock frequency 10MHZ down to 70 or 200 Hz for practical spectrum analysis
- the upper channel to be down-converted to 50 kHz and linearily rectified for proper presentation in time domain.

Because of the required dynamic range (-30 to -110dBm) the receiver is gain controlled, however, extremely slow to prevent that the received signal mix cause an additional amplitude modulation of the IF signals which originally are not part of signal in space.

The control voltage and both channels for spectrum analysis and time domain presentations are sampled by A/D-converters and fed digitally to the airborne computer being a part of the receiver which also gets the real time time-synchronized flight path data from the Flight Inspection System (FIS).

LOCALIZATION OF REFLECTIONS

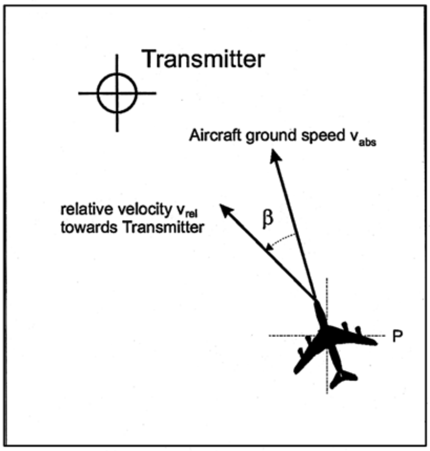


Figure 2: Aircraft's relative velocity towards Ground Station

Knowing the aircraft's position and motion vector as well as the position of a transmitter one can calculase the resulting relative speed v_{rel} towards the transmitter (Fig. 2). Due to aircraft's motion the nominal frequency f_0 is Doppler shifted and received as

$$f_D(v_{rel}) = f_0 \cdot \left(\frac{v_{rel}}{c_0} + 1 \right). \tag{1}$$

Inversely, if an additional unknown reflector is present (see Fig. 3) its relative velocity and angle β can be derived from this.

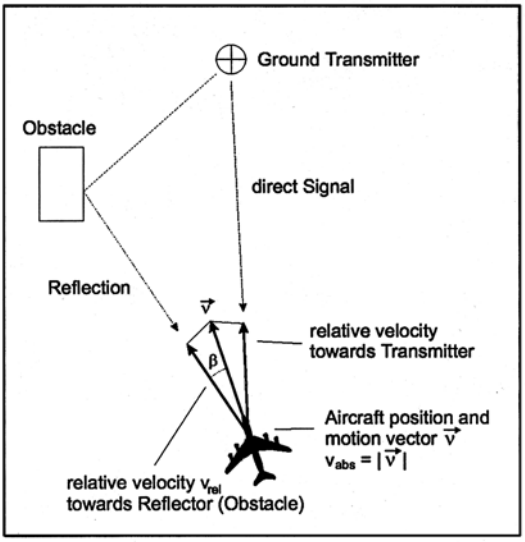


Figure 3: Relative velocity to objects

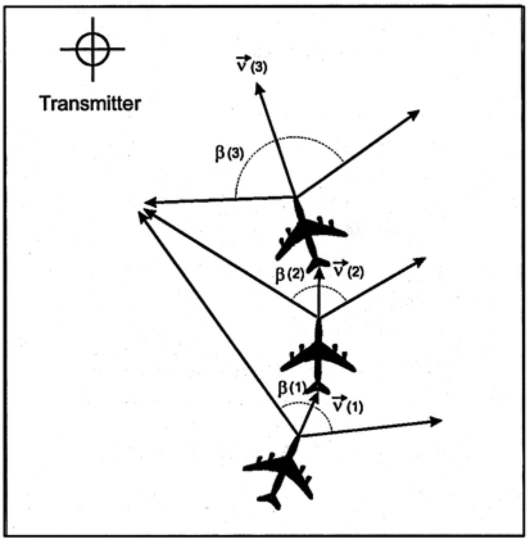


Figure 4: Unique identification during turn

Geometric considerations in the horizontal plane then deliver the reflection's angle of incidence

$$\beta = \arccos\left(\frac{v_{rel}}{v_{abs}}\right) \tag{2}$$

with v_{abs} being the ground speed.

Equation (2) results in an ambiguous solution so a unique identification of the reflectors direction in case of one-dimensional motion is only possible if a map containing buildings is available. Describing a curve movement in contrast, the lines of incidences cros each other at one point as shown in Fig. 4 while those on the other side diverge.

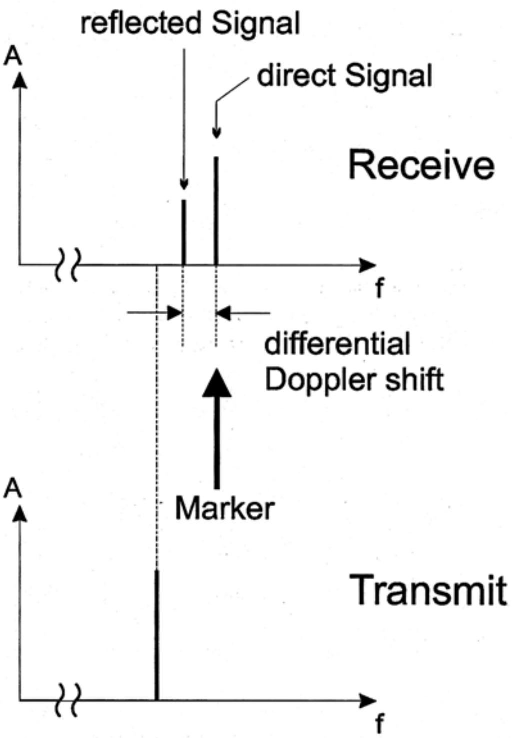
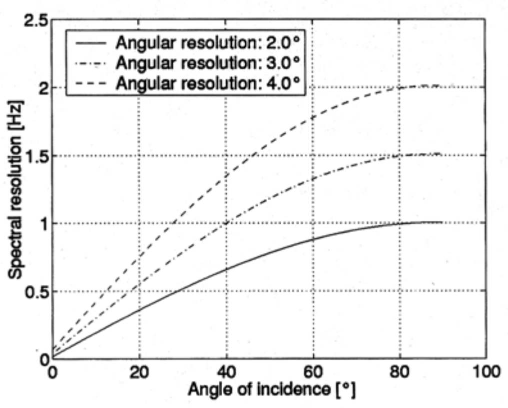


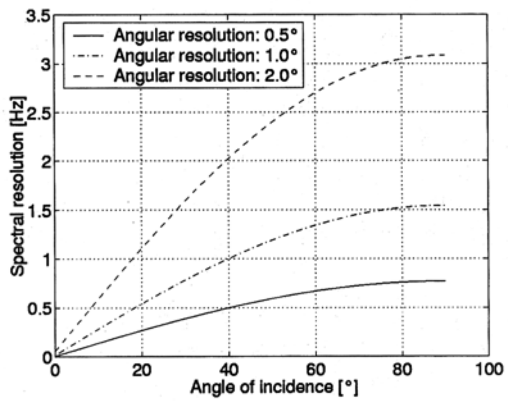
Figure 5: Frequency domain and marker of direct signal

The conditions in frequency domain are demonstrated by Fig. 5 in which two received signals are Doppler shifted against the nominal carrier frequency. If the transmitter's position and the flight path are known then the deviation of the direct signal can be precalculated by applying eq. (1) and marked in the spectrum. This fact leads to the capability of a priori distinction between the direct signal and the reflections as shown later on.

A further topic of interest is the spectral resolution of the received signals and its influence on the accuracy of the calculated angles of incidence.



(a) VHF, f_0=108.0MHz



(b) UHF, f_0=330.95MHz

Figure 6: Spectral resolution for selected angles of incidence

Focussing on angles from 0º to 90º towards aircraft's heading and selected sectors $\Delta\beta$ the required resolution is derived from eq. (1,2):

$$\Delta f_D = \frac{f_0 \cdot v_{abs}}{c_0}(\cos\beta - \cos(\beta+\Delta\beta)) \qquad (3)$$

Fig. 6 shows the resuits with common VHF/UHF frequencies f_0 and a flight speed of 80m/s.

Spotting on an angular resolution $\Delta\beta$ = 3º on VHF a frequency resolution of 1 Hz is sufficient whereas this value leads to a 3 time higher resolution on UHF.

GETTING THE DOPPLER SHIFT

The recorded data of the receiver's output IF exist in time domain and must be transformad into frequency domain by appropriate methods in order to calculate the Doppler shift.

Although there are new model-based methods for spectral estimation [7] with enhanced resolution the classic Discrete Fourier Transformation (DFT) is applied. Due to aircraft's motion the circumstances are *instationary* - a fact which must be taken into consideration while using the DFT. Using a sample rate f_s and N samples, the spectral resolution is given by

$$\Delta f = \frac{f_s}{N} \qquad (4)$$

Better resolution causes a frequency error calculating the Doppler shift because the signal changes more or less quickly within the observation time

$$To = \frac{1}{\Delta f}. \qquad (5)$$

depending on the passing distance between aircraft and reflector.

A derivative of the DFT appropriate for instationary applications is the *Short Time DFT* (STDFT)

$$\underline{X}(n,m) = \frac{1}{N}\sum_{k=m-N+1}^{m} x(k)\, h(m-k)\, e^{-2\pi j \frac{n}{N}(k-m+N-1)} \qquad (6)$$

using the *window function* h and the sample increment m which characterizes the temporal movement of the window within the given data. Refer to [4, 5, 6] for its derivation and basics of Digital Signal Processing in general.

Due to the fact that the signal's frequency to be tranformed is normally no integer multiple of the increment Δf the DFT effects *leakage*: side lobes with decreasing amplitudes are placed next to the main spectral line which cannot be located exactly. To diminish this effect a special window function h is selected which decreases the side lobes while enlarging the N samples with an amount of zeros before transformation delivers a more accurate position of the main maximum (*Zeropadding*).

Two features have to be examined applying the STDFT:

a) Frequency error

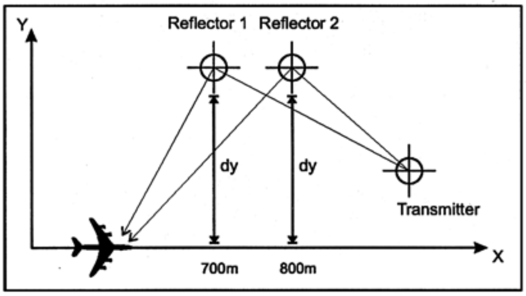


Figure 7: Passing by two Reflectors

For estimating the frequency error caused by motion within a supposed observation time see a geometric scenery depicted by Fig. 7 and consider Reflector 2 first. The aircraft passes by the reflector and therefore the nominally received antenna voltage aboard is a function containing an integral argument:

$$U(t) = \hat{U} \cdot \cos\left(\int \omega(t)dt + \varphi_0\right) \qquad (7)$$

The discrete transformated Doppler shifted signal then is given by

$$\underline{X}(n,m) \quad \bullet\!\!-\!\!\circ \quad U(kT) \quad . \qquad (8)$$

Fig. 8 shows both the continuous Doppler frequency and that derived from the transformation above as a function of the momentary distance X using the following parameters:

- velocity: $(v_x, v_y)^T = (80,0)^T\ m/s$
- RF: f_0 = 108.0MHz (VHF), nominal IF: f_{IF} = 70Hz
- sample rate: f_S = 1 kHz
- increment: $m = N \cdot 0.1$

The absolute error depicted in Fig. 9 mostly consists of values below 1 Hz even observing 1.0 s so one can conclude that the DFT is applicable.

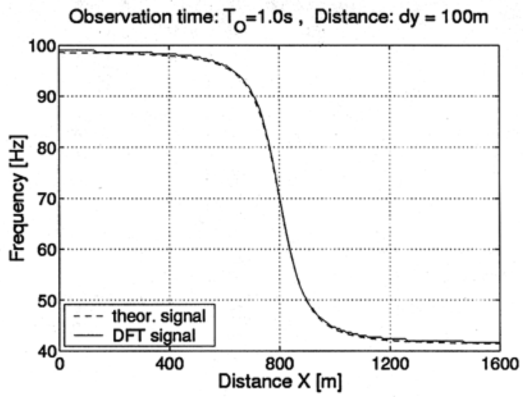
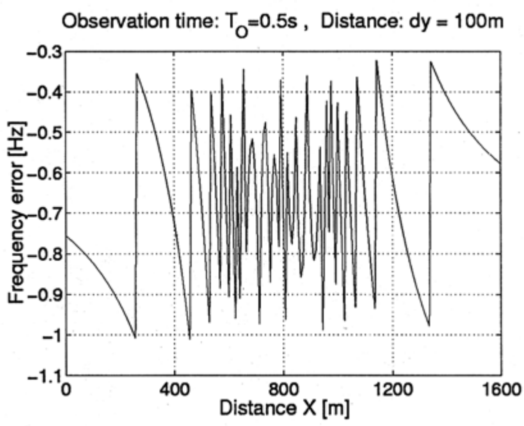


Figure 8: Doppler shifted Intermediate Frequency



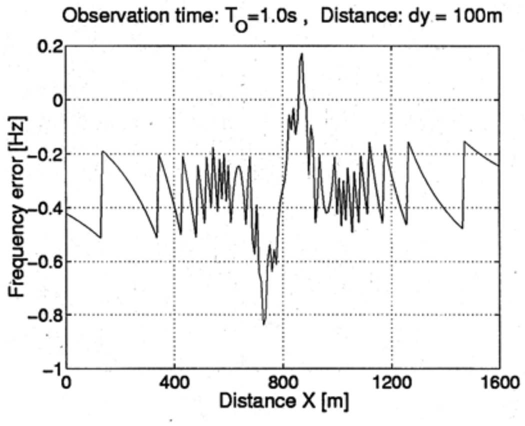


Figure 9: Absolute Frequency error

b) Selectivity

Taking also reflector 1 into consideration with a reflected amplitude twice as strong as of reflector 2 focusses the interest on the window function h in order to separate the received signals in frequency domain after transformation by eqs. (6,8). The nominal Doppler shift of both frequencies is shown in Fig. 10. The importance of selecting the window becomes clear at distance X close to the turning point of the Doppler shift, i.e. 568 m, where the rectangular window causes multiple artificial maxima without reference to reality. In contrast to that, the VON HANN window separases both signals with the correct amplitudes due to its higher side lobe suppression.

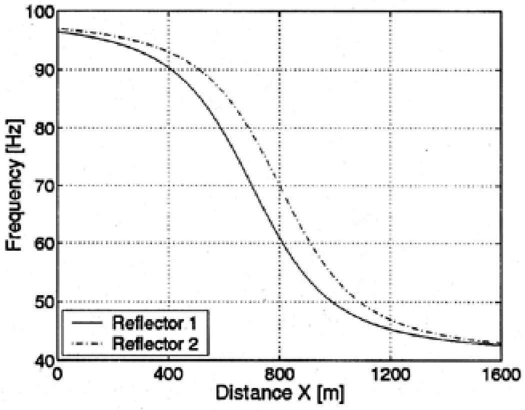


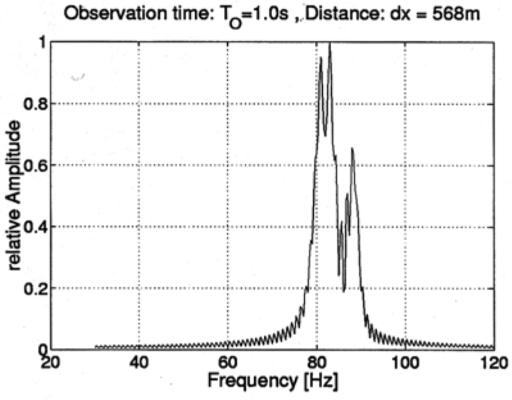
Figure 10: Nominally Doppler shifted IF

Energetic concerns

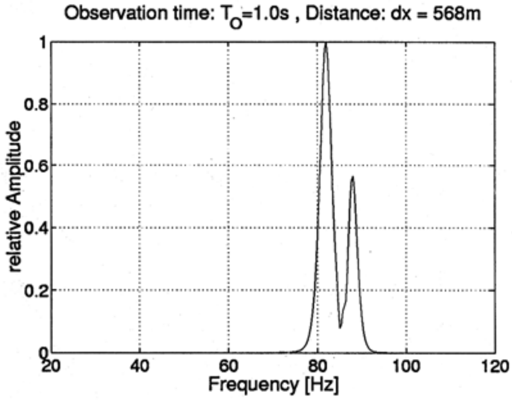
The energy of a signal can be calculated both in time and frequency domain as describes by PARSEVAL'S equation [4]:

$$\int_{-\infty}^{\infty} x^2(t)dt = \frac{1}{2\pi}\int_{-\infty}^{\infty} |\underline{X}(\omega)|^2 d\omega \quad (9)$$

Therefore it is possible to separate the direct signal if its frequency is marked as formerly describes so one can spectrally isolate the portions of reflections. As a result, the *Multipath-to-Direct* ratio (M/D) is derived which characterizes the reflective environment.

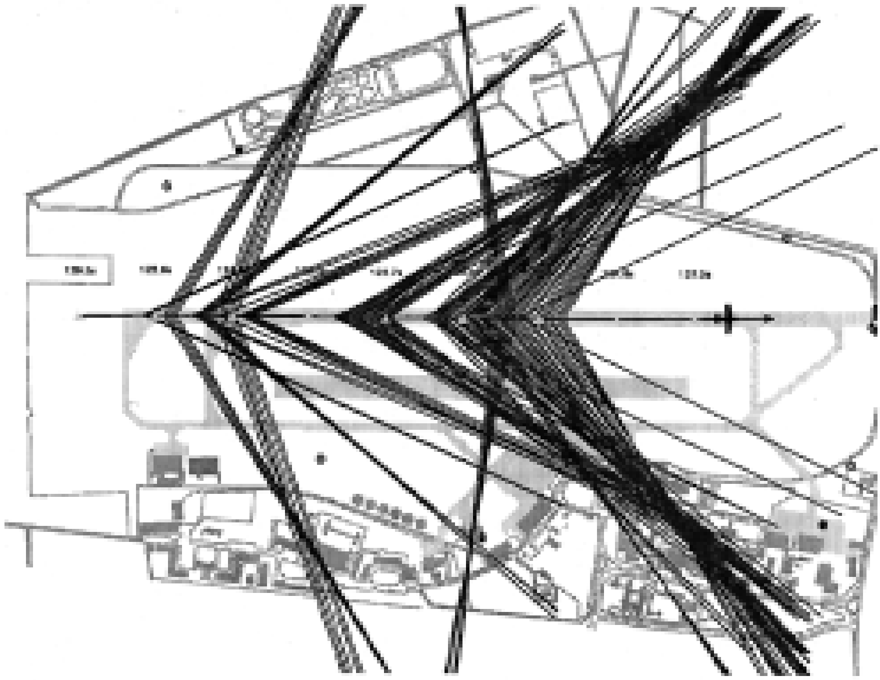


(a) Rectangular window

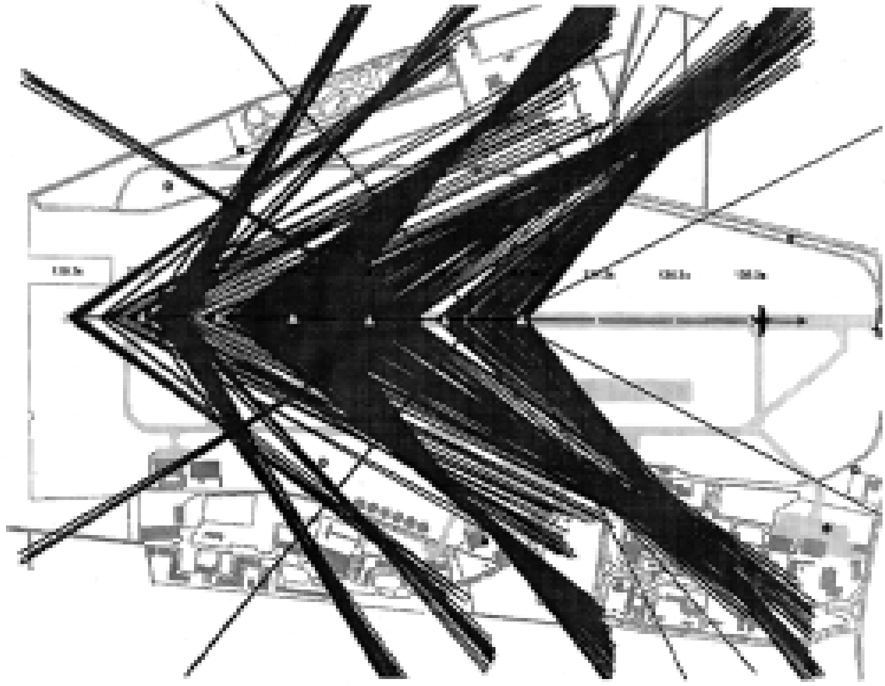


(b) VON HANN window

Figure 11: Influence of window functions



(a) VHF, f_0=108.9MHz



(b) UHF, f_0=330.95MHz

Figure 12: Approach to Braunschweig airport, runway 08

For the validation of the experimental system and its software up to now some field tests were flown with an FII aircraft at Brauschweig airport.

For this purpose two 5 W transmitters for 108.0 MHz and 330.950 MHz were instalen at the end of runway 08 and their position precisely determined by laser tracker. The two logarithmic transmitter antennas were directed to 260º azimuth. An electronic map of the airport was available but not yet of its environment. The STDFT paramaters for transformation were chosen according to the results of the former section.

Fig. 12 depicts the reflections' angles of incidence along the flight path 50ft over the runway for both frequency bands. The time labels in the map correspond to the time scale in Fig. 13 which shows the field strength of the direct signal and the energetic percentage of all received reflections versus time. Typically the reflections in Braunschweig are smail (VHF: less than 2%, UHF: less than 0.5%) but good enough for the validation of the system.

The angles of incident reflections point clearly to the significant buildings on the airport as the presumption to identifiy reflecting sources and to select and reconstruct their reflection strength in time domain.

During a circle in 4.4km distance from the airport (Fig. 14) relatively strong reflections (UHF) were received from airport site (time stamp 9.0s). In the time domain channel the addition of the rather smail direct signal and the reflection beat with about 20Hz Doppler shift difference and with an amplitude of 2000 ± 1500 mV which already indicates 80% of the direct signal (Fig. 15).

Around the time center 9.1 s the received spectrum was analyzed in Fig. 16 in which an arrow marks the pre-calculated frequency line of the direct signal. The other lines in that spectrum are received reflections in space considerably larger than the direct signal to that time. Fig. 17 finally shows the intensity of reflections referred to the direct signal's amplitude during that flight time.

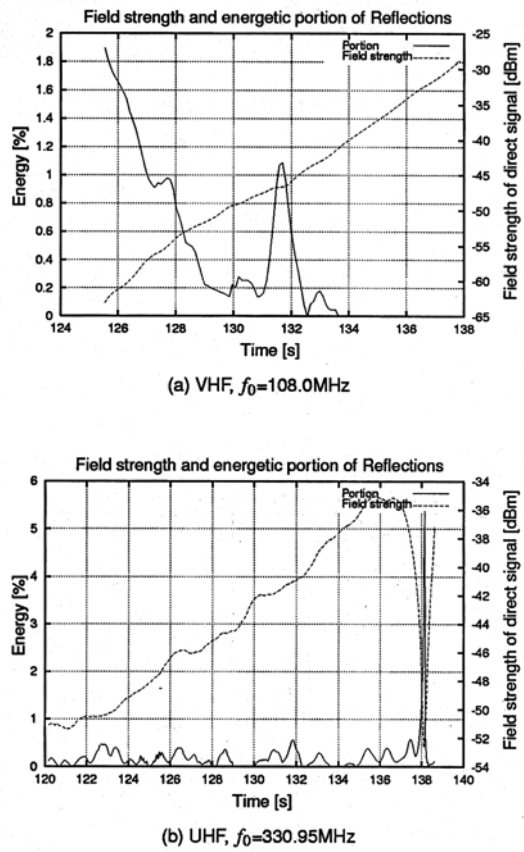


Figure 13: Field strength and reflecitivity during approach

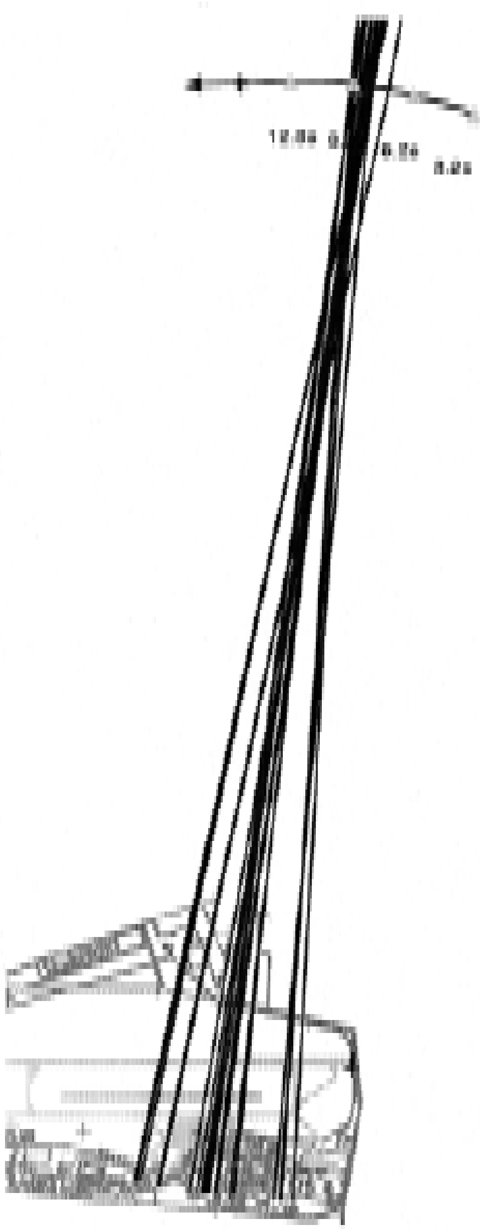


Figure 14: Reflections during circling, UHF

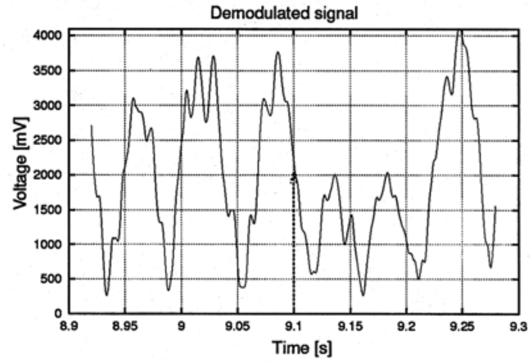


Figure 15: Beat after linear rectification

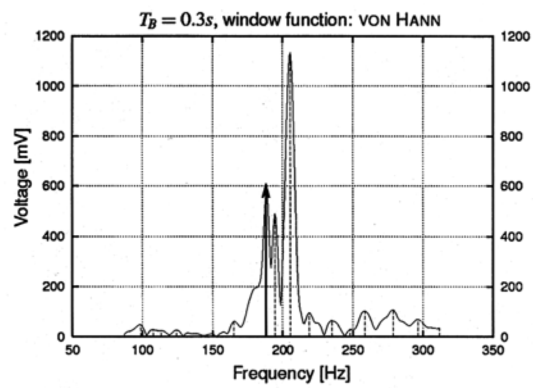


Figure 16: Doppler shifted reflections and marked direct signal

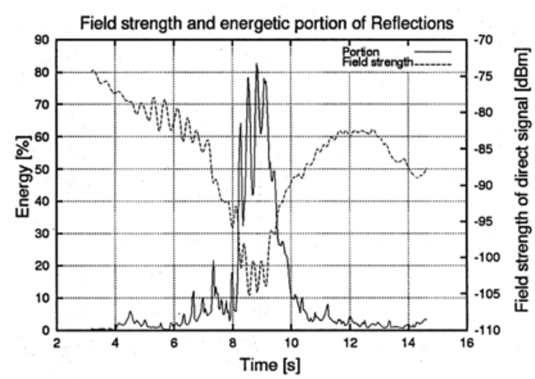


Figure 17: Field strength an reflectivitiy

CONCLUSION

The receipt and analysis of the signal in space obviously promises the separate measurement and inspection of the system on the ground and of the contributing environment illuminated by the ground system.

The first field tests in Braunschweig identified reflecting objects as the basis for further description of their reflectivity. More practicar knowiedge in that way may help to design new buildings and to match the regulations of authorities.

Further flight tests on other airports are intended which have significant reflective environments creating problems for higher levels of instrument flights.

CONTRIBUTIONS

As mentioned above the fruitful and motivating cooperation with Flight Inspection Internacional (FII) reactivated this project. Such a cooperation overcomes also all those airworthiness problems with aircraft antennas, installation of cables, electromagnetic compatibility as well as computer interfacing and protocols aboard for getting real time flight path data and charges for flight hours which normally represent huge problems for university institutes.

REFERENCES

[1] P. Form and R. Springer. *Fortschritte bei der Messung u. Darstellung realer Mehrwegeausbreitung*. Nr. 81-09-02. Mitteilung aus dem SFB 58 der TU, 1981.

[2] P. Form and R. Springer. *Multipath Propagation Measurements by Doppler Technique*. Digital Communications in Avionics. AGARD, 1987.

[3] P. Form, R. Springer, and U. Stoldt. *Messungen des Einflusses stat. u. dyn. Interferenz auf einen ILS-Empfänger u. Messung des Capture-Effektes bei Zweifrequenzverfahren*. Mitteilung aus dem SFB 58 der TU, Nr. 56,1976.

[4] R. Hoffmann. *Signalanalyse und -erkennung. Eine Einführung für Informationstechniker*. Springer, Berlin, 1998.

[5] K.D. Kammeyer and K. Kroschel. *Digitale Signalverarbeitung. Filterung und Spektratanalyse*. Teubner, Stuttgart, 1998.

[6] U. Kiencke. *Signale und Systeme*. Oldenbourg, München/Wien, 1998.

[7] S. Qian. *Frequenzanalyse, basierend auf Modellen*. Elektronik, Nr. 2 u. 4, 2000.

[8] W. Schroer. *Verbesserte Nachbildung von Bodenreflexionen*. Mitteilung aus dem SFB 58 der TU, Nr. 81-09-02, 1981.

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CUSTOM REPORTS FROM STANDARD RESULTS

ABSTRACT

The format and content for final reports for flight inspection are as varied as the customers that require them. While the FAA and ICAO dictate the standards and results of the various flight inspections, each country seems to tailor the flight inspection final report according to local custom. Flight inspectors can now take standard results using either FAA or ICAO tolerances and produce custom flight inspection facility reports or final reports.

INTRODUCTION

Working with current and potential customers, an enhancement to the Sierra Data Systems (SDS) Flight Inspection System (FIS) was identified. The incorporation of automatic results computation on the FIS had already been a major improvement in the FIS. Taking that one step further is incorporating a mechanism to generate the final reports electronically. To provide support to the agencies defining requirements and to the customers' specific needs, a generic approach to final reports has been implemented. This paper discusses our approach, the challenges encountered, one customer's implementation and future work in this area.

OUR APPROACH

Working closely on design reviews with our Brazilian customer on the SIVAM contract, we defined a generic approach to final reports. This provides the flexibility to let the customer implement their proprietary final report format from a specified final report data format. Specifically, the approach involves storing results data from a flight on a FAT-16 (DOS) formatted magneto optical disk in ASCII delimited format. This allows the files to be read from a magneto optical device mounted on a Windows PC and imported to many of the common office products, including word processing, spreadsheets or databases.

CHALLENGES ENCOUNTERED

An electronic final reports enhancement to the FIS has been discussed for the past few years. The obstacles to implementation included the proprietary file format of the real-time operating system, the availability of driver support for the mass storage device, and an approach to documenting the interface. These challenges were met with advancements in technology.

RTOS proprietary file format
The SDS FIS runs on a real-time operating system. The nature of RTOS was that all aspects have been proprietary with no support for alternate formats. Enhancements to the RTOS now makes it possible to use the FAT-16-format, (commonly called DOS format) devices. The system now writes to and reads from FAT-16 devices in addition to the proprietary file system.

Magneto optical drive support

Drivers for the mass storage device used on the SDS FIS in the past have not been available for the configuration we had devised. With the availability of drivers for alternate Windows SCSI configurations, it has become possible to offer this approach to customers. Now it does not require an engineering degree to configure the hardware setup of a magneto optical disk on a Windows PC!

Documentation/Code marriage

An important factor in this approach is documentation of the ASCII comma delimited final reports files because the files on a disk are of no use without a definition of the data. An ingenious solution was designed which combines the source code, version control, ftp and Microsoft Office. As shown in Figure 1, the Interface Control Document is used to generate the source code. Although not totally out of the loop, the engineers' aversion to documentation is minimized.

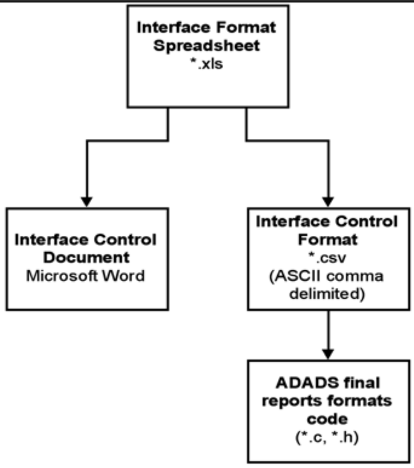

Figure 1. Interface Control Document Generation Process

ONE AGENCY'S IMPLEMENTATION

The Brazilian Flight Inspection Agency is replacing an SDS semiautomatic flight inspection system with an automatic flight inspection system. Along with performing computations that in the past had to be done by hand, the new automatic system provides many improvements, including electronic final reports. Initially, three Microsoft Office products

GPS NPA REPORT

Final Report Filename	CACWAIVE GPSNPA 11-04-00 16-22,		
Facility ID	CACWAIVE,	Date	11/04/00,
Profile	GPSNPA,	Time	16:22:29,
Submode	,	Tolerance Mode	FAA,
Position Estimation	INS/GPSSU,	Inspection Type	Periodic,
Pilot	DON ALEXANDER ,	Flight Inspector	GARY HANES ,
Co-pilot	R.BROCK ,	Airplane ID	N23592 ACFT #1 ,

Waypoint ID	Type	Range to WP (feet)	Bearing at WP (dg)	UTC Hours	UTC Minutes	UTC Seconds	Altitude at WP (feet)	Roll at WP (dg)
,	,	1746.40,	103.35,	22,	22,	12,	3168,	18.8,
,	,	120.48,	106.82,	22,	25,	13,	3167,	-0.6,
,	,	438.38,	177.12,	22,	27,	10,	3168,	-1.5,
,	,	5.08,	114.36,	22,	30,	15,	3162,	0.2,
,	,	11.93,	187.33,	22,	32,	47,	1609,	4.6,
,	,	0.00,	0.00,	0,	0,	0,	0,	0.0,
,	,	0.00,	0.00,	0,	0,	0,	0,	0.0,
,	,	0.00,	0.00,	0,	0,	0,	0,	0.0,
,	,	0.00,	0.00,	0,	0,	0,	0,	0.0,
,	,	0.00,	0.00,	0,	0,	0,	0,	0.0,

Segment HDOP	Worst HDOP	Time Worst Hours	Time Worst Minutes	Time Worst Seconds	Range of Worst (nmi)	Roll of Worst (dg)
0.86,	0.88,	22,	25,	13,	10.02,	0.2,
0.84,	0.84,	22,	30,	15,	5.01,	4.7,
0.00,	0.00,	0,	0,	0,	0.00,	0.0,

Segment HFOM	Worst HFOM	Time Worst Hours	Time Worst Minutes	Time Worst Seconds	Range of Worst (nmi)	Roll of Worst (dg)
57.09,	57.41,	22,	25,	13,	10.02,	0.2,
56.68,	56.81,	22,	30,	15,	5.01,	0.0,
0.00,	0.00,	0,	0,	0,	0.00,	0.0,

Figure 2. Example Final Report

were considered to generate the report -- a word processor (Word), a relational database (Access) and a spreadsheet (Excel). After working with each product, Excel was identified as the best tool to generate the final report. Excel was chosen because the complexity in terms of steps and functionality was much less than the database, Access. The word processor was eliminated because it did not meet the requirements to archive historical inspection data. A sample final report, created automatically in the Brazilian format, is shown in Figure 2.

FUTURE WORK

In some cases, it is important to provide the flight inspection customer with immediate results when the flight is finished. To accommodate customers with this requirement, immediate interim results can be incorporated into the system.

Researching the alternatives to electronic final reports revealed many alternatives. For example, the multistep process presently required to get the data to the form could be upgraded to a one-step solution.

Also with the flight inspector no longer performing the computations, a future enhancement to the system would be to use a SATCOM link to download the replay data and results for consultation with an experienced flight inspector.

CONCLUSION

The advancements in technology were the key to providing a generic approach to electronic final reports. This new approach provides a flexible solution that meets the requirements of our customers to generate final reports in their proprietary formats.

REFERENCES

Instructions for Flight Inspection Reporting, DOT Federal Aviation Administration, September 8, 1998.

Sierra Data Systems

Custom Reports from Standard Results

Terry Lynn Collins

Software Engineer

Sierra Data Systems

Buffalo, New York

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Sierra Data Systems

Custom Reports from Standard Results

- Background
- Challenges Encountered
- Solution
- What's Next

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Background

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- Customers have unique results reporting requirements for FIS.
- Customers have individual FIS system requirements.
- Apply „Unified FIS" philosophy to results reporting.

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Background (cont'd)

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- Generic Approach
  - Able to support unique customer requirements
- Manage Large Quantity of Data
  - Generic solution means that all data stored
- Support Office Suite of Tools (Database, Spreadsheet, Word Processor)

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Challenges Encountered

- RTOS Proprietary File System Format
  - No support for alternate file system
- Magneto-Optical Drive Support
  - No driver support for alternate file system
- Document/Code Marriage
  - How to manage interface documentation

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Solution

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Getting to the Solution

- Flight Inspection Results Data
- Final Report
- Interface Control Document

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Document/Code Marriage

- Automate the Process

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Document Generation Process

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- Version Control
- Modify Spreadsheet
- Update ICD
- Generate Source Code
- Version Control

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One Customer's Approach

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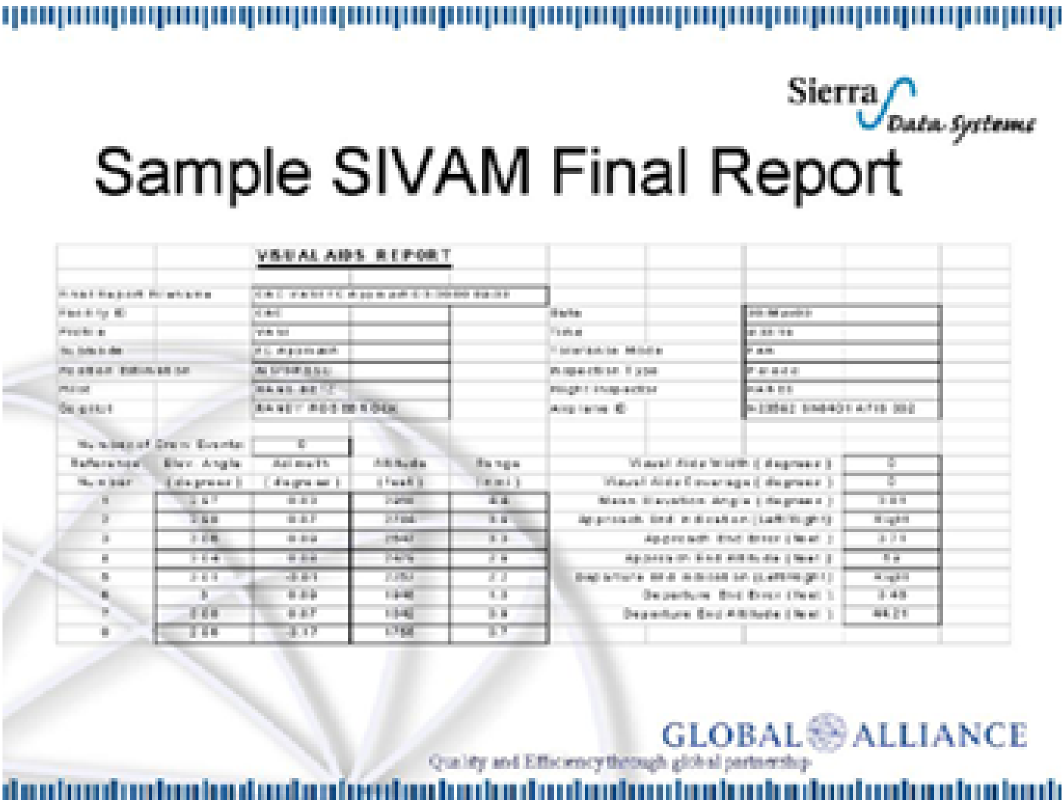
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Sample SIVAM Final Report
VISUAL AIDS REPORT
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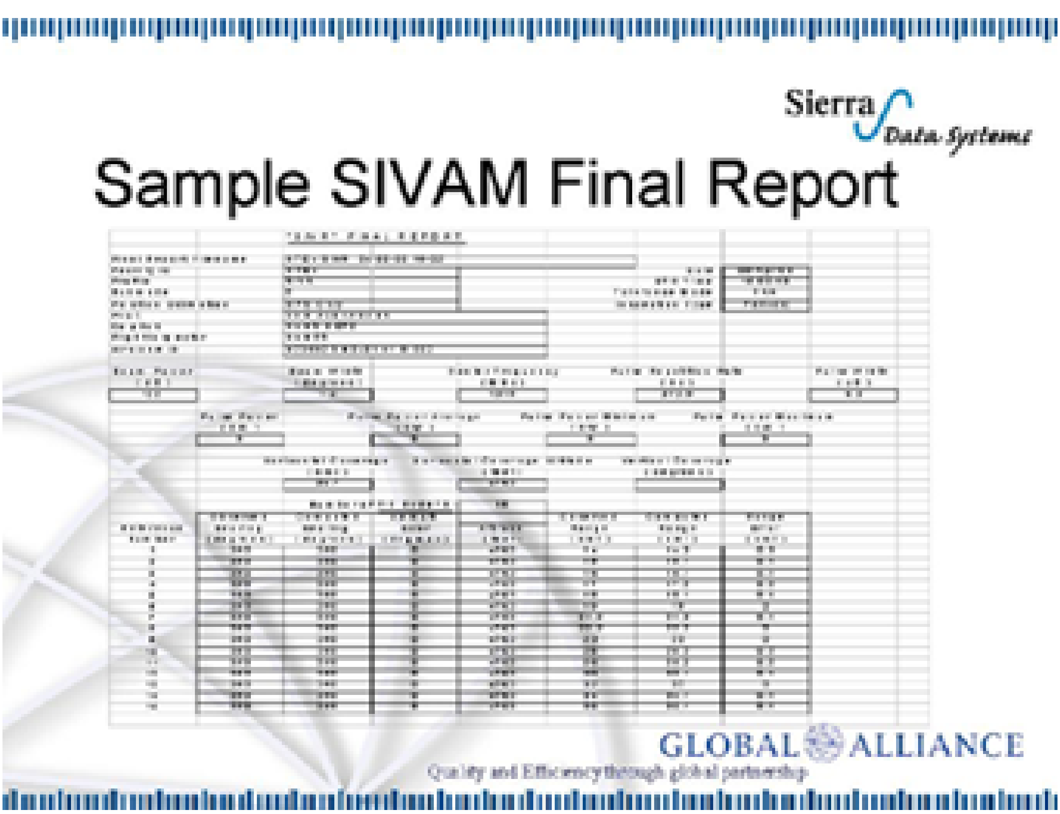
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Sample SIVAM Final Report
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What's Next

- Improve the process
- Incorporate immediate interim results
- Implement network

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- Any Questions?
  - Please visit the Sierra Data Systems Booth

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Direction Générale de l'Aviation Civile

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ORIGIN AND LOCATION OF NAV/COM FREQUENCIES JAMMINGS

ABSTRACT

The purpose of this paper is to hilight difficulties of flight inspection services to identify COM and Nav frequencies jammings and to find quickly their location. The results of an experiment based on an aircraft mounted specific Direction Finder which could be used for that purpose are presented.

BACKGROUND

In many countries, frequency aeronautical spectrum is managed by state agencies or national services. Most of the time, these agencies have a legal power against jammers but no airborne tools.

Flight inspection services have airborne tools but no legal power on that matter. Laws concerning broadcasting, in force in countries which have common borders with France (7) may be stronger or weaker than our's.

Broadcaster responsability is considered with a variable view in each country. Most of the time, broadcasting results are not considered (in a regulatory view).

Considering our « smail » european countries, it is obvious that there are no borders for jammings.
If we look at the french national 1998 jamming report, we find not less than 862 cases reported by pilots and ATC.
Among these cases:

- a Cat 1 Localizer by unidentified jamming,
- a Cat 3 Localizer jammed by a private broadcaster, discovered during a flight inspection,
- an ILS jammed by an unidentified source,
- a Cat 3 Localizer (Charles de Gaulle airport) jammed during one day by a private radio inducing three go around in real Cat 3 conditions (note that these aircraft were equipped with FM immune receivers),
- an enroute ATC frequency jammed at level 250 or above by a foreign broadcasting station during six months, inducing ATC delays and frequency closures.

Many other cases of VHF jamming have been observed.
Leaded by Air Navigation Direction, a national jamming research plan was settled last year.
Flight inspection was requested to investigate for tools able not only to detect jammings but also to locate them quickly. We were supported in that research by SOCATA (general aviation manufacturer) avionic service which considered that the MDF 124 from Rockwell Collins (DF for rescue research) could be used for that purpose.

After some investigations and a visit to french customs having that system mounted on F406 for rescue and «other purposes», we decided to check the MDF 124, in a first step on a TB20 before trying to install it on a pressurised aircraft (BE90).

An MDF124 was proposed free of charge by

Rocwell Collins (France) for that experiment which took place during the last two months of 1999.

SUBJECT

1 Jamming research aircraft equipment:

a ATR 42:

- ESM 500 Rhode & Schwarz test receiver connected to COM or NAV antennas,
- ESVN 20 Rhode & Shwarz spectrum analyser connected to COM or NAV antennas
- SONY voice recorder,
- PC connected equipped with a data base of boadcasting stations, antenna locations and frequencies.

b BE 200:

- EB 200 Rhode & Schwarz test receiver connected to COM or NAV antennas,
- SONY voice recorder,
- PC connected with the same data base.

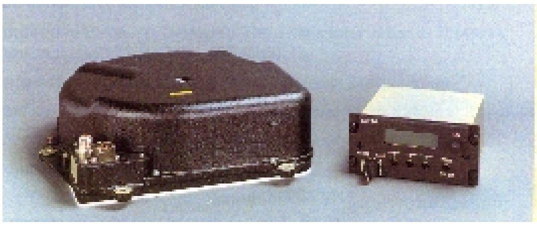
This passive equipment does not permit to locate easily and quickly an identified jamming.
Main use of these analysers is to identify jammings, by listening and scanning COM/NAV frequencies, by analysing the signal and recording it, and at last to try to determine the type of jamming (A1, A2, B1, B2) we have found.

2 Description of the MDF 124:

It is a full stand alone DF. This version provides a search and rescue (SAR) platform (V/UHF).
It has an embedded synthesized receiver which covers the V/UHF 100-406 Mhz range. It has a fully static rotating antenna, a unique signal processing and a bearing computation from last actual bearing and current bearing during beacon's silences.

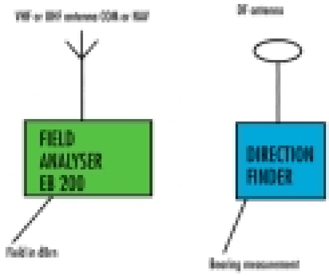
a Operationnal caracteristics:

- Frequency range: 100-406 Mhz
- Antenna modulation: 100-400 Mhz (AM)
- Embedded receiver: 25 khz channel spacing
- Range at 10000ft:
  - more than 100NM (1W souce power)
  - more than 40NM (200mw source power)
- Bearing accuracy:
  - 3º axis
  - 10º outside
- Bearing Output:
  ARINC 407 and ARINC 429
- Bearing Input:
  ARINC 429 or ARINC 407
- Physical characteristics:
  Power: 27,5 V dc 700mA
  Synchro output: 26V ac, 400 Hz,
- Dimensions:
  MDF 124 F (V2): height 90mm,
  diameter 315 mm,
  BC 124F (V2) 66,6x146x150 mm
  Weight:
  MDF 124 F (V2): 3,5 kg
  BC 124 F (V2): 0,7 kg



b Aircraft system installation:

MDF 124 antenna is installed below, as close as possible of the aircraft center of gravity.



The operator was installed in the rear seat and has the MDF 124 and an EB 200 on his left.
EB 200 was connected to a specific antenna, but it should be possible to connect it to the MDF 124 antenna by using the external mode.
To avoid any pollution by the aircraft converters, a 28 V dc battery was installed in the cargo compartment.

This simplistic installation had three purposes:

- to evaluate the sensitivity of the MDF124 and check if this system is convenient with our needs,
- to evaluate the accuracy of omnidirectionnal bearings,
- to determine methods for using that DF and identify which modifications have to be proposed.

3 Flights:

Twenty five hours were done in eight flights. Two flights were dedicated to determine system sensitivity and bearing accuracy.

- Sensitivity checks: a transmission was send from our service with a power of 200mW; bearing informations were lost at 55 NM at 6000 ft and level of signal received was of -94 dBm.
- Bearing accuracy checks: those bearings were compared to VOR informations (VOR colocated). At 6000ft and 35 NM from our station.
- An accuracy of 5º to 10º in axis and 10º to 15º out of axis has been recorded.
- All other flights were dedicated to already detected jammings (but not located). Some of these jammings had been detected for months.

Results: three jammings were easily located (one of them was outside of national airspace). We had no succes for locating other identified jammings which were not continuously working.

Improvements needed on the MDF 124:

- Install a 12 dB variable attenuator and try to have a better frequency
selectivity to avoid a receiver saturation by transmetters using great power.
- Frequency scanning: actually of 25kHz, will be reduced to 12,5 kHz.
- Possibility to have AM/FM demodulation in NAV/COM bands.
- The use of a receiver using a passive antenna is necessary to identify jammings.

Rockwell Collins is working on these points.

CONCLUSION

Our main concern was to make the proof of concept to use the MDF 124 for jamming location: we reached the target since we were able to locate easily some jammings. Using a light aircraft was only related to that experiment. It is obvious that a pressurized aircraft is the best tool to have a better radioeloctrical downview. Such an aircraft is also necessary since many jammings occur on frecuencies used for high altitude enroute sectors.

Considering our flight inspection service, there are two different needs :

- To use flight inspection aircraft to search jammings on frequency analysers during ferry flights and navigation systems inspections (what we do already).
- To use a dedicated aircraft (which could be also a flight inspection aircraft) to locate jammings already identified, in a first time on V/UHF bands and then later in upper bands (keep GPS jammings in mind).

Why to insist on a dedicated aircraft ?:
mainly because jammings (most of them) are not working continuously and are not predictable.

Such an aircraft needs to be available most of the time bocause shutting down an ILS on a large airport or a frequency of an approach control center or an enroute control center may cause many delays and cost a lot of money to the airlines. The comparison of the gap between aircraft operation cost and airline delays cost is impressive.

At the time I write this paper, an installation of a MDF 124 on a BE 90 is expected to start as soon as we take delivery of a modified version of this system in order to have a jamming location tool available in the middle of the year 2000.

ANNEX

ESM 500 characteristics:
Test receiver: 20 to 1000 Mhz
IF panorama.

ESVN 20 characteristics:
Test receiver: 20 to 1000 Mhz

EB 200 characteristics:
Miniaturized portable professional
receiver: 10 kHz to 3 GHz.

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PROBLEMS AND SOLUTIONS FOR ILS CATEGORY III AIRBORNE AND GROUND MEASUREMENTS -- EUROPEAN AND US VIEWS AND PERSPECTIVES

ABSTRACT

Instrument Landing Systems (ILS) require careful airborne and ground measurements to maintain accuracy and integrity. Both the data collection methods and the mathematical techniques used on the collected data can influence the results, often in amounts that are significant with respect to the tolerances.

Some selected parameters of the ILS measurements which can be particularly challenging are localizer alignment and structure, and glide path angle and threshold crossing height (TCH). This paper describes these challenges, citing both European and United States (US) experiences and views, with specific examples and data. It discusses the technical issues involved, and makes recommendations for measurement methods (e.g. data filters, sensor antennas), mathematical treatments of data (e.g. averaging and weighting schemes), and process standardization. Results of alternative measurement setups gained by simulations will be presented for the clarification of the technical problems and for support of the proposals.

BACKGROUND

Instrument Landing Systems (ILS), especially those expected to operate within Facility Performance Category III tolerances, require careful airborne and ground measurements to maintain accuracy and integrity.

Although these measurements are often more demanding than laboratory-type engineering measurements, they must be made in a field environment with substantial multipath effects, from moving platforms, and in a time-critical environment. The measurements may be made frequently or at many locations, sometimes by non-engineering personnel, making reliance on standardized procedures important, both for repeatability at a single location and for comparison between multiple installations.

While this paper discusses European and US views, it does not attempt to present a complete and harmonized view over all European countries, but instead gives condensed general summaries and focuses on special parameters. Individual deviations from the discussed «European views» can exist.

SPECIFICATIONS AND MEASUREMENTS PRACTICES

The main electrical characteristics of the ILS are defined in the International Civil Aviation Organization's (ICAO) Annex 10 /1/. However, some of the parameters are not defined completely and sufficiently. Electrical parameters have to be verified by measurements, either by ground check or flight check measurements. Due to the international use of the ILS and the safety issues involved, these measurements should be defined uniquely and standardized completely.

The goal of a well-defined and standardized measurement is that an identical ILS should show almost the same measurement results wherever located, i.e., a certain ILS should meet the same operational category each time it is installed under the identical environmental conditions. This is in particular important despite the increasing multipath problems due to the constructional activities on almost all major airports constituting increasingly difficult sites for ILS /2,3/.

International guidance for some of the measurements and the treatment of the resulting data can be found in ICAO's manual on Testing of Radio Navigational Aids, Document 8071. However, some details are either not defined or not published, and substantial differences in techniques exist between various flight inspection and ground maintenance organizations and their regulatory bodies. This is despite the general idea of standardization inherent in the ICAO documents.

It is a common practice in engineering that all measurements should be repeatable, and in principle show (almost) the same results each time the measurement is performed. However, this is possible only when all technical and operational aspects as well as the measurement setup are well defined. New technological developments and adaptations of the measurement equipment, as well as improvements of the measurements themselves, are not prohibited.

Standardization and definition of measurements is a vital aspect also for the numerical analysis and simulation (modeling) of the ILS. In principle the identical definitions and «analog practices» should be used, or the predictions and the measurements will not be comparable.

LOCALIZER MEASUREMENT ISSUES

Alignment. Although seemingly simple in concept, measurement of a localizer's alignment is affected by the amount and type of crosspointer filtering, the location in space in which the measurement is made, and the choice of numerical processing method.

European Practices. In Europe, the general method of establishing localizer alignment is to adjust and calibrate the Localizer on the ground in the far field of the Localizer antenna, by exactly phasing the radiators pair by pair. The ground adjustment is then confirmed during a flight test, by the application of the linear regression method on flight measured data taken on the glidepath. The equipment is the same as used for structure measurement. Standard receivers and their inherent processing and sampling techniques are used.

US Practices. Initial establishment of alignment on the ground is the same as for Europe. The U.S. flight inspection organization, Aviation System Standards (AVN), obtains localizer alignment with an airborne measurement by sampling crosspointer values at an 8 Hertz rate. The receiver incorporates a 1.0 second low-pass filter prior to the sampling. An additional 0.125 second filter function is applied by the processing and display system, to eliminate wideband noise not contained in the receiver output. (A new receiver will add an additional 0.5 second filter option.)

Alignment is defined as the average value of the crosspointer, measured on an approach during the last mile of flight prior to the threshold /4/. Once alignment is suitably optimized, ground maintenance personnel document a reference DDM value immediately after the flight measurements are complete. This ground reference measurement of alignment, and subsequent periodic ground maintenance checks, are made at a ground check point that is relatively free of multipath and near the approach threshold. To increase immunity to measurement effects from moving objects, a directional antenna is often used, typically a 4-element Yagi /5/.

Crosspointer Filtering. Crosspointer current (DDM in µA) is routed in the receiver through a lowpass filter. This filter is incompletely described in Annex 10, with only the time constant being defined. Further, this definition is found in the «green pages» of Annex 10, and therefore is not, unfortunately, compulsory. The actual filter in receivers may be much different from this simple definition. (Additional filtering discussion is found in the Localizer Structure section below.)

The filter is often implemented as a simple, first order, lowpass function, for which the corner frequency (i.e., a response of -3 dB or 70.7%) equals the reciprocal of the time constant. ICAO's Annex 10 specifies the time constant for localizer (and glide slope) guidance as 92.6/v, where v is the measurement platform's velocity in kilometers per hour.

Although the type of filter and its corner frequency will affect structure measurements greatly (see Structure discussion below), these choices can also have an effect on alignment measurements, depending on the frequency and location of any multipath contaminating the crosspointer trace. Figure 1 shows an example of how varying the filter time constant or corner frequency changes the appearance of the recording and potentially the resulting alignment.

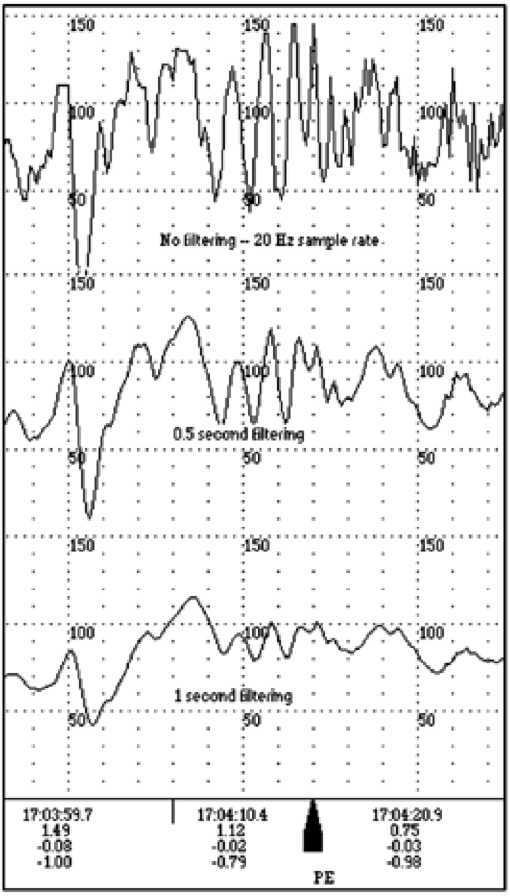

Figure 1: Effects of different time constant filters

Numerical Processing. Standard linear regression methods are used to determine alignment. This is relatively noncritical because a centerline shift can be created only under special multipath situations where the object is very close to centerline. However, sometimes there are differences between the ground adjustment and the flight check alignment. This is normally due to multipath, for which the effect is different as seen during flight on the glidepath than on the ground.

Structure. Although measurement of localizer structure suffers from several challenges, repeatability problems caused by the method of measurement (in flight or on the ground), and the choices of receiver antenna pattern and crosspointer filtering characteristics have the greatest effects on the results.

European Practices. In Europe, Category III localizer structure is a compulsory ground measurement in most countries, by periodic on-runway measurements, sometimes on a weekly basis. This is in addition to normally required flight checks. The data taken during touchdown and rollout of the aircraft are not processed in most of the countries, except in very special cases.

US Practices. In the U.S., localizer structure measurements are made by AVN personnel during an approach, using the same equipment characteristics as for determining alignment. A standard approach is flown to threshold, followed by touchdown and rollout for a commissioning check or a low-altitude pass down the runway for subsequent checks. For Zones 4 and 5 (over the runway), structure tolerances are applied to the graphical average value of the alignment in those zones.

Vertical Positioning. When a multipath environment exists near and over the runway, the resulting localizer (and glide path) structure has three-dimensional characteristics which can cause difficulties in repeating measurement results. If localizer structure measurements are made with an aircraft in flight, small variations in vertical positioning between measurements can greatly affect the announced structure, especially for zones 4 and 5. In these situations, Zone 4 results are primarily dependent on the aircraft threshold crossing height and whether the pilot descends further or promptly levels off, while Zone 5 is primarily dependent on the actual aircraft height over and down the runway.

To illustrate, Figure 2 shows two recordings made on a Category III localizer by the same aircraft from a series of successive approaches. In both recordings, the threshold is at the left vertical mark, Zone 4 is the segment between the two vertical marks, and vertical scaling is 10 µA per division. The maximum Zone 4 structure values of 10 and 3 microamperes for the two runs consume 200 and 60%, respectively, of the Zone 4 structure tolerance.

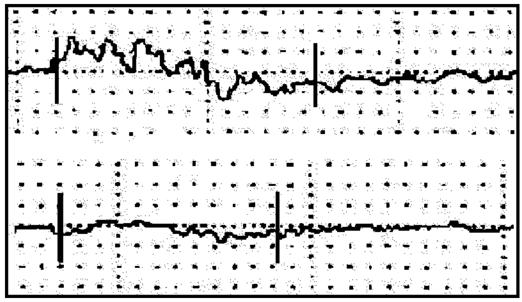

Figure 2. Zone 4 Structure - 10 µA & 3 µA, from a series of successive measurements.

Antenna Patterns and Multipath. Measurement of localizer structure is also affected by the receiver antenna pattern, for both airborne and ground methods. Any non-zero structure implies a multipath environment, which by definition has signals arriving simultaneously at the antenna from different directions. Thus variations in antenna pattern from one measurement to another will cause structure announcements to change.

Aircraft Antenna Pattern Variations. Since it is difficult to obtain similar antenna patterns on different aircraft, measurement of structure values

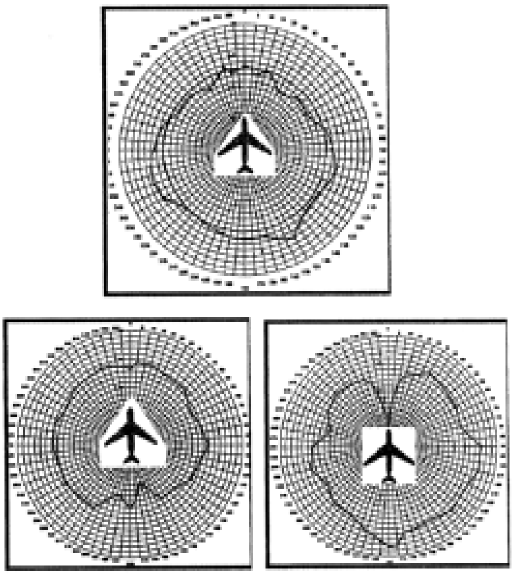

Figure 3a (top): Lear 60 Nav antenna
Figure 3b (below): Challenger Nose (L) and Tail (R) Nav antennas

in flight can also vary with aircraft type. Any difference in antenna patterns between aircraft types is particularly troublesome if more than one type is used for flight inspection at a given localizer. Figures 3a and 3b contrast the measured VHF navigation antenna patterns between two flight inspection aircraft, and between two locations on a single aircraft, during initial antenna testing. The large notch in the forward direction for the tail antenna of Figure 3b is of course highly objectionable, and this antenna location had to be modified before placing it into use /6/. If this relocation had not been possible, the antenna would have had to be restricted to orbital flight measurements only.

Antenna Pattern Characteristics. The (receiving) antenna pattern has a large effect on the measured DDM performance, because the signal-to-noise ratio (direct to multipath ratio) determines the DDM distortions. Unfortunately, ICAO's Annex 10 and the 8071 testing document do not recommend a typical antenna pattern for ground or airborne use. Two pattern characteristics will be discussed.

Numerically, the pattern characteristics that most affect structure measurements are the front-back and front-side ratios. These compare the antenna response between the forward and rearward directions, and between the forward and side directions (90° off centerline) respectively. These values are tabulated in Table 1 for the Figure 3 test patterns.

Differences in the front-side ratio cause the largest affect on structure magnitude when the aircraft is abeam a reflector, as is typically the case for an air traffic control tower. Differences in the front-back ratio cause the largest affect when the reflector's position during the measurement appears to change from approximately the 12 o'clock to the 6 o'clock position as the aircraft completes a single approach. This is typically the case for a reflector near the approach threshold of a Category III runway, where structure measurements are made on both sides of the reflector. Fortunately, this latter case is in practice an infrequent effect.

Aircraft & Antenna	Front-Back Ratio, dB	Front-Side Ratio, dB
Lear 60	-1	-4
Challenger Nose	+ 6	0
Challenger Tail	-28	-24

Table 1: Figure 3 Antenna pattern characteristics

Pattern Front-Back Effects. To illustrate the effects of non-zero front-back antenna pattern ratios, Figure 4 shows Localizer crosspointer response in Zone 4 for a single aircraft using a single antenna, while taxiing toward and away from the localizer. The slow scalloping visible in the «toward» recording is completely absent in the «away» recording, due to the front-back ratio.

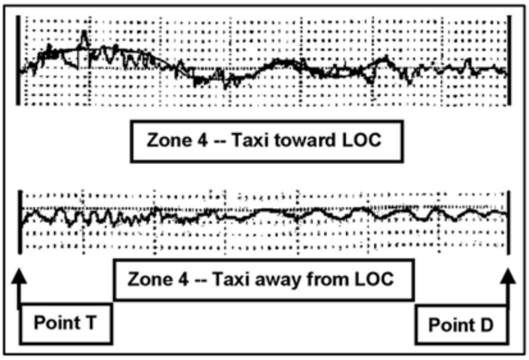

Figure 4: Zone 4 Taxiing Opposite Directions

Pattern Front-Side Effects. The effects of a large front-side antenna pattern ratio are shown in Figure 5, containing Zone 4 recordings measured at Spokane, Washington. A military hanger abeam the threshold provides multipath signals which arrive off the left wing of the approaching aircraft. Computer modeling of the hanger closely matches the flight recordings.

Figure 5 contrasts the results from two different, in-trail flight inspection aircraft whose antenna pattern front-side ratios differ by 4.5 dB. The uncorrected crosspointer recordings have been positioned so that their vertical threshold lines coincide. An out-of-tolerance 6µA «bump» (circle), just inside the

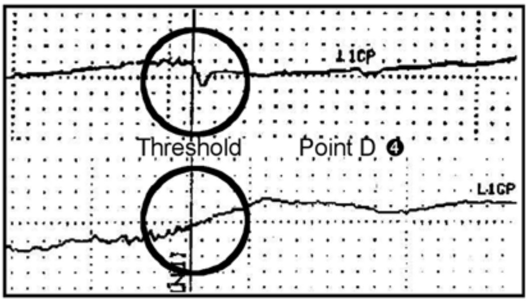

Figure 5: Zone 4 differences between aircraft types

threshold in the upper recording from one aircraft, is entirely missing (circle) in the lower recording, as measured with the second aircraft type. The 4.5 dB difference in antenna pattern front-side ratios causes the Zone 4 structure announcements to vary between aircraft types over a number of in-trail measurements by an average ratio of 6:1.

Ground Antenna Choices. The effects of the antenna pattern are similar for ground measurements of structure, as exercised widely in Europe. Figure 6 illustrates how the antenna pattern can affect structure measurements on the ground. It shows the multipath from two scattering objects affecting Zone 5, superimposed by the patterns for five readily-available antennas. The antenna patterns are scaled so that each has the same response for the direct (down the runway) signal from the localizer.

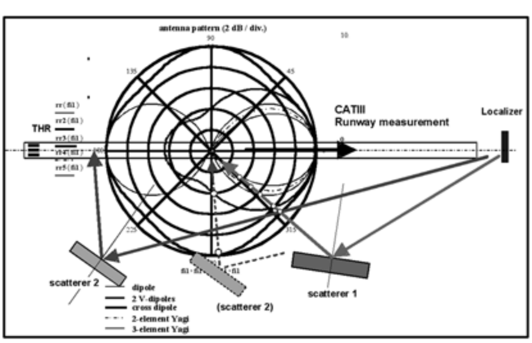

Figure 6: Two schematic scatterers and five different ground antenna patterns

Table 2 shows the response differences between the five antenna types, for the single scatterer 1 at bottom right in Figure 6. The scalloping amplitude, observed at the location shown and using the 3-element Yagi, would be approximately 55% of that observed at the same location with a nearly omni-directional crossed dipole antenna, due to the 5.3 dB difference in their responses. At other locations for the ground measurement, the difference in antenna response can be even more dramatic, especially when considering the effects for dual frequency localizers. For example, if the scatterer's multipath arrives broadside to a dipole (scatterer 2 in Fig. 6, solid and «hashed» indications), there will be no response due to the nulls perpendicular to the runway, and the «measured» scalloping magnitude will be zero at that location.

Antenna Type	Response to Scatterer 1, dB
Crossed Dipole (turnstile)	-1.1
2V Dipole	-1.8
Dipole	-3.6
2-element Yagi	-5.8
3-element Yagi	-6.4

Table 2: Ground antenna response

The nearly omni-directional pattern of the crossed-dipole (turnstile) antenna may seem to be the worst case presenting all DDM-distortions. But in fact it is undesirable for ground measurements due to the change in antenna phase response with large variations in azimuth (360° azimuth equals to one cycle in phase). This creates an artificial centerline shift when approaching the localizer by distorting the antiphase symmetry of the SBO characteristics.

Figure 7 shows the expected DDM-distortions of a tower-crane /7/ when using a dipole and a crossed-dipole (turnstile) as the sensor antennas for the ground measurement. It is clear that the DDM errors are quite different, with the DDM errors of the turnstile antenna showing an additional alignment artifact related to its phase cycle.

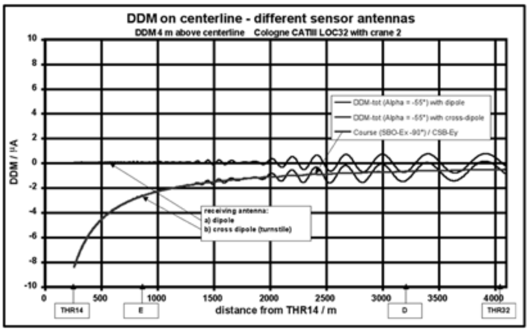

Figure 7: Comparison of the DDM-response for two ground measurement antennas

The 2V dipole is an adapted Yagi antenna consisting of two V-shaped dipoles, and may be the best choice for a ground measurement antenna. By optimizing the individual V-dipole lengths, the V-angle and spacing, the front-side and front-back ratios can be optimized to approximately 6 dB. Since aircraft nose antennas tend to have this kind of antenna pattern, with a moderate suppression to the side and back directions, ground personnel using a 2V Dipole should be able to closely duplicate airborne indications in the same regions of space.

If the measurement antenna is not reasonably standardized and if much different antennas are used as outlined above, the same installation may be fully accepted for CATIII in the first country and fully rejected in the second country. This situation is in sharp contrast to the idea of ICAO standardization.

Filtering Effects on Structure Measurements. Although ICAO's Annex 10 defines the time constant or corner frequency of the receiver DDM filter, the steepness of its cutoff function is undefined. The steepness is numerically described by a Q, or quality factor, and is primarily dependent on the number of poles implemented in the filter design.

To illustrate the effects of the number of poles used on the filter's characteristics, Figure 8 shows the amplitude response of several filter implementations and how they vary widely at higher frequencies. As expected, a high-order (many-pole) digital filter has a much sharper cutoff than lower-Q (typically analog, 1-pole or 2-pole) filters. Since most Category III aircraft are equipped with «digital» databus receivers, structure measurements made with a similar filter will most closely match the typical user's results.

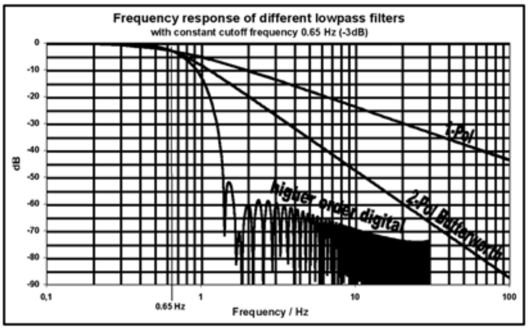

Figure 8: Filter frequency response curves for 3 filter types

Figure 9 shows numerically calculated unfiltered and filtered results for localizer DDM distortions resulting from a tower crane /9/. Three filters are applied, each with the same edge or corner frequency of 0.65Hz. However, the filters differ in the number of poles implemented: «normal» or 1-pole at top, 2-pole Butterworth in the center, and a multiple-pole digital filter at bottom. It can be clearly seen that the high order digital filter is very effective. Technically speaking, this high effectiveness is related in this case to the frequency range of the DDM scallops. However, a real case was modeled in this multipath scenario for a medium aperture dual frequency localizer.

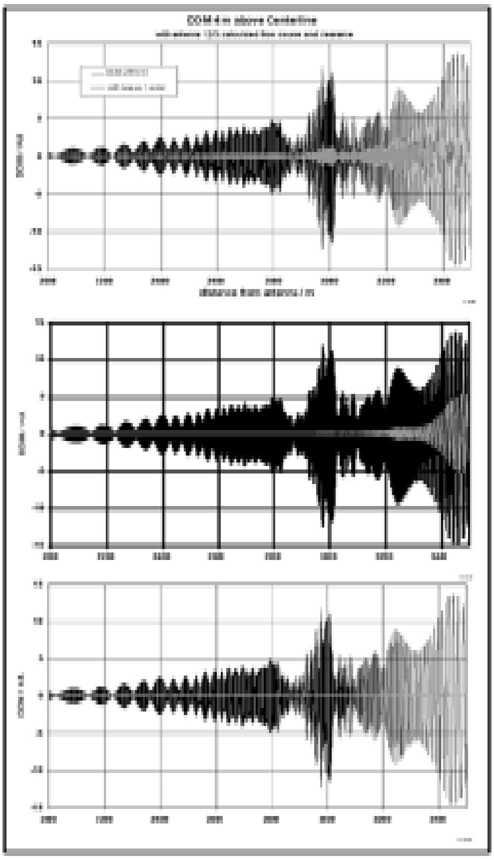

Figure 9: Effects of filter type on CATIII structure measurements with high-frequency multipath

GLIDE PATH (GP) MEASUREMENT ISSUES

The ILS glidepath subsystem is determined by two major parameters which are highly safety critical, i.e. the glidepath angle and the threshold crossing height (TCH). Both parameters seem to be well defined in Annex 10 and the associated documents. But the definitions are qualitative, and the quantitative evaluation in the guidance material (green pages) can be misleading. In fact, these parameters and their measurements are not uniquely and sufficiently defined.

Calculation Method and Weighting. The glidepath angle is defined as the slope of the averaged or interpolated line between the ILS points A and B, relative to the horizontal plane. This seems straightforward, but several questions arise:

1. Which kind of averaging or interpolation should be applied? In Europe, many people use the «linear regression» calculation weighted by the least squares fit scheme. In the U.S. /8,9/ this is accomplished at present using the data from Zone 2, but soon this may be changed to use data only between 6000' and 1000' prior to threshold. The extrapolation of the linear regression line to a point above the threshold defines the Reference Datum Height (via Zone 2) or the Achieved Reference Datum Height (via the 6000'-1000' segment), to differentiate these values from a calculated TCH value. Of course, this scheme can be applied easily in the simulation process also.

2. Should the DDM values used in the averaging or interpolation process be equally weighted between the points A and B? Explained differently, should a certain DDM error magnitude have the same effect on the computed glidepath angle and TCH, regardless of its position between A and B? Probably most readers will answer «yes». However, note that tolerances are operationally more critical close to the runway. Therefore, a bend of a specific amplitude (µA) and length should yield a greater effect on the glide path angle and TCH when the bend is close to point B than when it is close to point A.

Measurement and Calculation Problems. The interpolation technique is based on the measurement of the DDM errors relative to the «ideal glide-path,» for which the angle is unknown and has to be measured. It is obvious that this task is an iterative problem. The intention of the definition of the glidepath is that an interpolation must be applied for the spatial curve defined by the common locus of all the points for which DDM=0. This curve can be calculated easily in the numerical simulation, but a correct measurement is difficult to achieve, due to Flight Technical Error (FTE) from wind and/ or piloting errors, and due to performance irregularities of the glidepath itself. The common locus for the DDM=0 points can be found by numerically applying the approximately known displacement sensitivity, from the measured three-dimensional position of the aircraft, to the measured DDM on that path. The remaining problem is the correction for the unknown actual displacement sensitivity for each point.

A short parametric numerical study has been conducted to clarify the problem. A total of 101 sets of synthetic glidepath crosspointer data was generated, representing data collected during 101 approaches on the glide path. Each simulated approach data set contains 101 DDM values between ILS points A and B. All the data values for an approach are set to 0 DDM, except one data point which is set numerically to 100 µA. The location of the 100 µA point is systematically moved, so that each approach has the single data point error in a different location. A linear regression least square method has been applied to each approach, and the resultant glidepath angle and TCH have been calculated. Figure 10 graphs the angle and TCH for the simulated approaches.

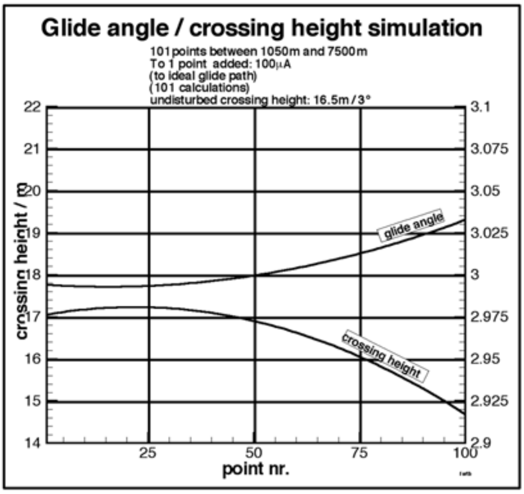

Figure 10: Evaluation of GP angle and TCH by synthetic data sets, constant DDM error

It can be clearly seen that, perhaps surprisingly, the single point DDM error has a larger impact on the calculated parameters at larger distances than at close-in distances. The reason for this phenomenon is the angular mechanism of the ILS – a 100µA error represents a larger absolute physical deviation from the glidepath for a large distance than for a short distance. But the inter-/extrapolation scheme is based on absolute coordinates.

If a constant absolute deviation of 100m is introduced systematically, rather than a constant 100µA DDM error, then the error function for both parameters is of opposite sign, and the effects on the calculated path angle and TCH are quite different. Figure 11 graphs these results.

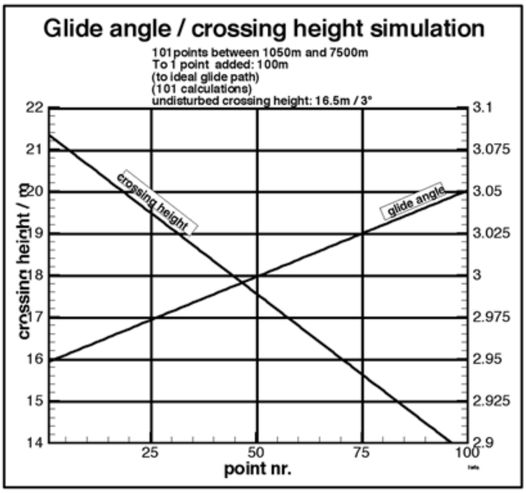

Figure 11: Evaluation of GP angle and TCH by synthetic data sets, constant physical error

A physically and operationally reasonable compromise is to introduce a weighting function for the DDM errors. This function would down-weight the error effects for more distant parts of the measurement for a constant net effect, regardless of the distance.

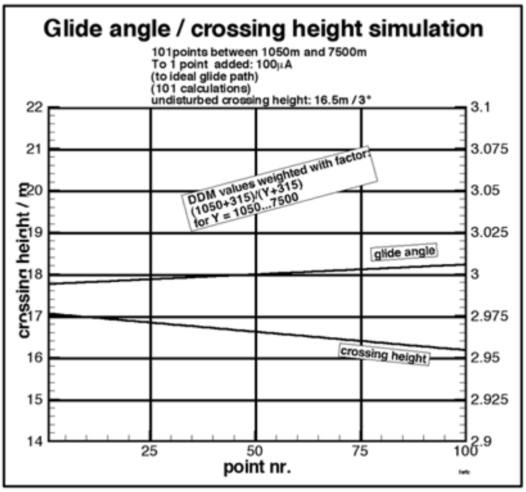

Figure 12: Evaluation of the GP angle and TCH by a suitable non-optimized error weighting

Figure 12 shows a preliminary, non-optimal proposal where the DDM-error is weighted as a function of the distance. However, the operationally important close-in DDM-errors are unchanged. The resulting GP angle and TCH are nearly independent of the location of the systematically introduced error point.

Threshold Crossing Height Considerations. In most cases as known, the threshold crossing height is determined by a simple formula given in ICAO Annex 10 (guidance material, green pages, Att. C §2.4.9):

$$D = \frac{H + Y}{\tan(\Theta + \alpha)}$$

where α is the forward slope of the reflection terrain in front of the glideslope system.

TCH Calculation Limitations. This formula requires the measurement of the glidepath angle Θ as discussed previously. This angle is used to calculate the crossing height via a simple geometrical relationship, taking into account the height difference Y between the base height of the glideslope mast (or some reference height at the position of the mast) and the threshold. There are a number of technical and physical arguments against the application of this simple formula:

1. Formally, this formula has never been meant for the purpose of determining TCH; it is intended only for a (rough first) estimate of the positioning of the glideslope mast.

2. This formula is applicable only for lateral ideally flat and non-skewed ground. The height of the ground at the mast foundation and the «reference point» are identical in this case, but only in this case.

3. In three-dimensional cases, this formula is completely wrong and yields incorrect TCH values. Differences of up to several meters are encountered which seem to indicate out of spec conditions for correctly installed systems. If the ground can be described as a double sloping plane, a modified extended formula may yield better results. However, the determination of the forward and lateral slopes is meaningful only in simple cases, and in general this approach of an average plane is too theoretical and may also yield large errors. Both slopes depend on the extension of the averaging plane or on the averaging process for the plane approximation. See Figure 13.

4. The application of this formula is not an independent measurement of TCH, and strictly speaking it is not a measurement at all as claimed.

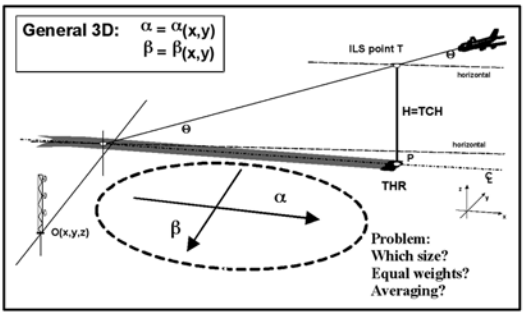

Figure 13: Geometry of the glideslope and a 3D-reflection ground

TCH Measurement Criteria. For a real measurement of the TCH (as well as for the glidepath angle), the following criteria should be met:

1. The determination of the TCH must be executed solely by airborne measurements of the appropriate quantities (DDM, related geometrical coordinates, etc.).

2. The position and height of the glideslope mast as well as the height of the ground in the reflection area should not be part of the primary calculation of the TCH.

3. The common locus of the DDM=0 points should be measured as closely as possible. This can usually be met by using the autopilot during the measurement to better follow the DDM=0 curve, and applying the displacement sensitivity to get a better iterative result for the DDM=0 locus.

4. The time and space correlation between the measured DDM and the geometrical coordinates should as good as technically possible.

TCH Measurement Accuracy. The accuracy and the spread of the measured TCH depends very much on the accuracy of the measured aircraft 3D coordinates during the flight process. The achievable tolerances have to be evaluated for each type of positioning system. For example, the angle tolerance of a well-adjusted laser theodolite should not exceed ±0.005°, which corresponds to a height measurement error of about ±3cm at threshold or about ±12cm at point B when positioned in the region of the glideslope mast. Similar tolerances should be achievable with precision DGPS based systems. In total, a typical TCH uncertainty of <±0.30m should be achievable. This is a safe figure compared to the nominal tolerance of ±1.5m, and more reasonable than the perceived high accuracy of TCH calculations from the equation given previously. It is a quite normal nature of tolerances that this estimated uncertainty of ±0.3m will yield slightly varying TCH for every measurement.

TCH Proposal. It is proposed to install and commission all glideslope subsystems on large airports for a nominal crossing height of 16.5 m, which accommodates the 1.5m tolerance applied to the specified minimum of 15 m.

CONCLUSIONS

a. The international specifications (ICAO Annex 10, DOC 8071) are not complete and unique with respect to the discussed ILS-parameters.

b. Localizer alignment measurement methods are not fully defined. Different numerical methods and different segments of approach data from airborne measurements are used to determine localizer alignment.

c. Airborne measurements of localizer structure in Zones 4 and 5 are easily contaminated by effects from aircraft positioning, receive antenna pattern, and receiver crosspointer filtering characteristics. These effects can vary widely from measurement to measurement, and between aircraft of differing types.

d. Conducting structure measurements in Zones 4 and 5 on the ground can eliminate the structure variations and dependencies discussed above, since the measurement conditions can be easily controlled and repeated. This will also reduce the high cost of flight measurements, although difficulties in obtaining runway access for the ground-based measurements may partially offset the costs saved.

e. Glide path angle and TCH measurements are not well defined.

f. The commonly-used TCH equation is not an appropriate substitute for an airborne measurement method.

g. TCH measurement uncertainties of 0.3 m (20% of the 1.5 m typical tolerance) can be achieved. This tolerance seems to be acceptable despite the safety issues involved.

RECOMMENDATIONS

a. Update and standardize ICAO specifications and guidance material by providing more detail, to obtain more internationally comparable measurement results.

b. Define localizer alignment measurement methods internationally, to include the numerical processing method and the segment of the measurements data to be used, using formal engineering principles.

c. Accomplish localizer Zones 4 and 5 structure measurements on the ground, to eliminate repeatability problems caused by aircraft antenna patterns and small changes in aircraft positioning between measurements.

d. Accomplish ground measurements of localizer Zones 4 and 5 structure with an antenna for which the pattern most closely matches Category III users' antenna patterns. An optimized 2V dipole is recommended to best correlate with modern Category 3 aircraft indications. In any case, avoid antennas using dipole elements e.g. simple dipoles and standard Yagi's.

e. Perform ground measurements of localizer Zones 4 and 5 structure with a receiver and display system filter that not only complies with ICAO's specified time constant, but also exhibits a sharp cutoff to match modern Category III airborne receivers.

f. Define glidepath angle and TCH measurement methods internationally, to include the numerical processing method and the segment of the measurements data to be used, using formal engineering principles.

g. Apply a weighting function to the measured data when determining glidepath angle and TCH, to reflect operational needs and conditions.

h. Standardize glide path TCH values at large airports to be 16.5 m, to protect for measurement and evaluation uncertainties and tolerances.

REFERENCES

/1/ ICAO Annex 10
ICAO DOC 8071

/2/ G. Greving, M. Theobald, ILS Sustainability in Obstacle Rich Environment, Proc. ISPA 95, Braunschweig, February 1995, pp.325-334

/3/ G. Greving, Aspects of Operation and Flight Check of ILS under Difficult Site Conditions, Proc. 9th IFIS, Braunschweig, June 1996, pp. 68-77

/4/ Order 8200.1A, United States Standard Flight Inspection Manual, May 1996, Changes 1 & 2

/5/ Order 6750.49A, Maintenance of Instrument Landing Systems, U.S. FAA

/6/ Hale, Clee; Antenna Modeling and Tests on Lear 60 and Challenger 601ER, U.S. National Flight Inspection Symposium, Seattle, WA, June, 1997.

/7/ G. Greving, Numerical System-simulations Including Antennas and Propagation Exemplified for a Radio Navigation System, appears in the May Issue of the German scientific magazine AEÜ «Archiv für Elektronik und Übertragungstechnik»

/8/ Order 8240.47B, Determination of Instrument Landing System (ILS) Glidepath Angle, Reference Datum Heights (RDH), and Ground Point of Intercept (GPI), 12 November 1996, U.S. FAA

/9/ Notice 8240.36, Subject/Change in Order 8240.47B, Determination of Instrument Landing System (ILS) Glidepath Angle, Reference Datum Heights (RDH), and Ground Point of Intercept (GPI), 17 February 1999, U.S. FAA

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ILS CERTIFICATION REQUIREMENTS

ABSTRACT

ILS certification of particular Cat. II/III ground installations according to ICAO Annex 10 Standards And Recommended Practices (SARPs) requires a considerable amount of time and effort to demonstrate the compliance with the continuity of service requirements. For countries operating a number of identical installations there is a particularly strong motivation to look for more expedient procedures.

A promising way to achieve this goal is the exploitation of the knowledge of the reliability performance of a number of ILS devices with similar infrastructure, rather than treating each system in isolation. DFS has commissioned DERA, UK, to further explore the possibilities for such a «class technique» approach, whilst still meeting the requirements of Annex 10.

The results of this study have been submitted to the AWOG/6, who set up a specific project team «to harmonise the methods used in Europe to demonstrate compliance with ILS (MLS/GLS) continuity of service requirements».

This paper addresses the problem field and presents results achieved so far by AWOG in developing relevant European Guidance Material for eventual later inclusion in an appropriate ICAO document.

BACKGROUND

The Instrument Landing System, ILS, is a non-visual precision approach aid that provides lateral and vertical guidance from localiser and glide path equipment respectively. Internationally agreed Requirements and Guidelines for ILS are contained in ICAO Annex 10 (Ref. 1).

The loss of an aircraft due to a non-aircraft guidance system failure could be caused either by a ground equipment integrity failure or by a continuity of service (COS) failure occurring at a critical stage of an aircraft's approach. To limit the risk caused by a COS failure, ICAO has defined the minimum requirements shown in Table 1. The COS requirements can be expressed in terms of a probability of an unanticipated cessation of the signal-in-space in excess of a minimum acceptable time (an Outage) in a specified period of time or, equivalently, a Mean Time Between Outage, MTBO.

Experience has shown that COS observed in an operational environment can vary significantly from that calculated from equipment MTBF specifications. ICAO recommends that COS performance be confirmed by evaluation in an operational environment.

Category	Minimum Continuity of Service	MTBO (Hours)
I	1 - 4 x 10^{-6} in any period of 15 seconds	1000*
II	1 - 2 x 10^{-6} in any period of 15 seconds	2000
III	1 - 2 x 10^{-6} in any period of 30 seconds (localiser) 15 seconds (glide path)	4000 2000

* Recommendation

Table 1 ICAO Annex 10 COS Requirements

Guidance is also provided that the evaluation period should be sufficient to demonstrate compliance with the COS requirements to high degree of confidence, typically 90%, and that a one year minimum period should be adopted so as to reflect environmental factors. The high confidence requirement necessitates a protracted evaluation period. ICAO guidance states that when several near identical systems are being operated, it may be possible to exploit accumulated knowledge across systems, thus reducing the evaluation period. For the purposes of this paper, the method of exploitation of accumulated operational knowledge across ILS ground equipments is termed a Class technique.

CLASS TECHNIQUE

A Class is defined as a group of ground systems whose cumulative operating time and associated outages can be considered as originating from one individual system. A single statistical test can therefore be used to demonstrate the reliability of several systems. An integral part of a Class method is the strict enforcement of configuration controls such that all systems are near identical; and member systems are installed and maintained to a common standard.

RELIABILITY

The probability that a constant outage rate system has no outages in an observation time t can be expressed as:

$$P = e^{-t/\theta}$$

where θ is the mean time between outages.

The exponential probability density function describes the COS/MTBO equivalence relationship given in Table 1.

GUIDANCE MATERIAL

This paper presents guidance material describing activities necessary to certify new ILS ground equipment against the reliability requirements defined by ICAO. Consideration is also given to the certification of subsequent systems of a previously certified type and to the monitoring of the reliability of systems following initial certification.

The guidance material procedures reflect the a *priori* reliability knowledge of the system to be installed. If the knowledge is limited to that calculated from equipment MTBF specifications (an inaccurate guide) the onus is on the procedures relating to operational environment observations to ensure the demonstration of the required reliability to a high degree of confidence. Conversely, if substantial historic knowledge has been obtained from a number of systems in an operational environment, and if a significantly variation in those systems' reliability has not been observed, then a substantial period of observation of a subsequent system is not required: the high degree of confidence has already been demonstrated. An intermediate position would be if some historic data is available providing a degree of confidence that the system to be installed meets the reliability requirements, but doubts exist due, for example, to the observation of a rogue system.

NEW SYSTEM CERTIFICATION

The reliability of a new system has not been established in an operational environment; it must therefore be demonstrated, to a high degree of confidence, that the system, or type of system, possesses the required reliability.

Two suitable statistical methods for demonstrating reliability are fixed duration and sequential tests. Given the high degree of uncertainty as to the reliability of new systems, the tests are required to provide strong positive evidence as to the system's reliability. To adopt a working hypothesis that the system meets the reliability requirement, and only be persuaded otherwise if strong evidence is found to the contrary, is not sufficient.

Fixed Duration Test

In a fixed duration test a decision is made to accept or reject a system after a pre-determined time depending upon the observed number of outages. The test can be made to ensure that on acceptance the system's reliability has been demonstrated to a required level of confidence. A second design factor is the assurance that the probability of rejecting a system with a reliability in excess of that required is small. These two design factors can be expressed in terms of risks to the consumer and producer. The test duration and the accept/reject threshold are designed such that both the consumer and producer demands are satisfied.

Sequential Test

The method selected for inclusion in the European Guidance Material is the sequential test method. A sequential reliability test continuously make a decision to accept, reject or to continue to make further observations of the system under test. A sequential test is generally quicker than an equivalent fixed duration test. The test can be implemented graphically. Accumulated outages are plotted against observation time until either the accept or reject portion of the decision boundary is crossed. A suitable decision boundary can be derived from the ICAO reliability requirement with associated confidence level (the consumer requirement) and appropriate producer requirements. A description of the derivation of appropriate decision boundaries following the method described by MIL-HDBK-781A, Ref. 2, is given in Appendix A.

Decision boundaries corresponding to the demonstration that a system's reliability exceeds the values given in Table 1 with 90% confidence are shown in Figs 1 to 3. A one year minimum certification time has been applied to the 1000 hr reliability demonstration decision boundary.

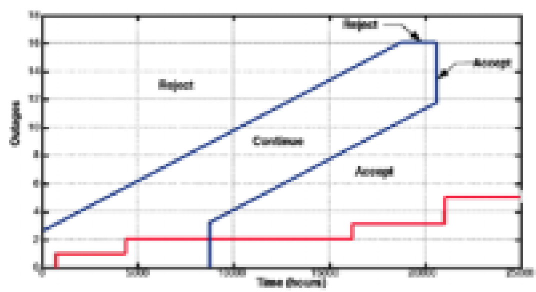

Fig. 1 1000 hr Decision Boundary

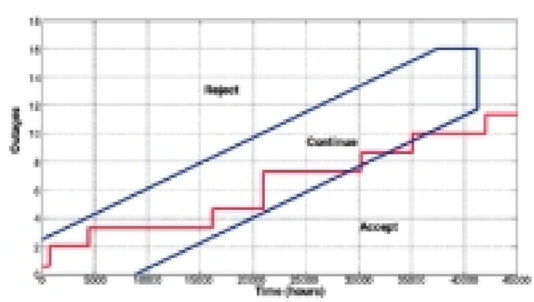

Fig. 2 2000 hr Decision Boundary

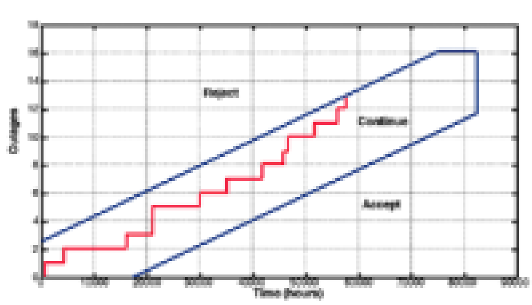

Fig. 3 4000 hr Decision Boundary

Class Approach to Sequential Test

If multiple near-identical systems are to be installed, a single sequential test plan can be used to demonstrate the reliability of all systems. An example installation programme for a class of 5 CAT III Localiser systems and associated sequential test plan as a function of true (not accumulated) time are shown in Fig. 4 and Fig. 5 respectively.

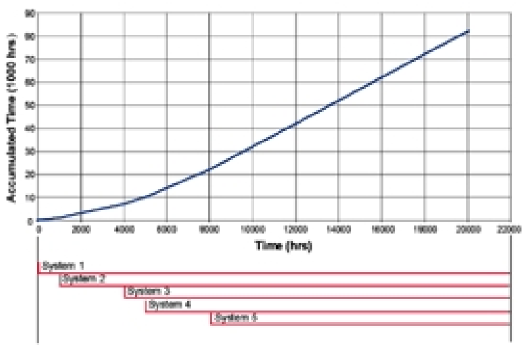

Fig. 4 Example 5 System Cumulative Time

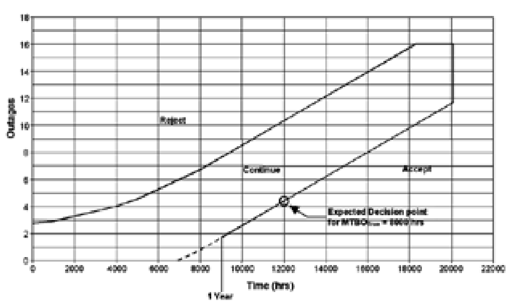

Fig. 5 5 System Class Sequential Test, CAT III Localiser

The expected accumulated test time for the 90% confidence CAT III localiser sequential test is approximately 42000 hours if the true MTBO were 8000 hours. With the installation procedure described by Fig. 4, this test time is accumulated after approximately 12000 hours.

Rogue Systems

There is a risk that the reliability demonstration procedure may be contaminated by a 'rogue' outlier system. It is essential that such a rogue system be removed from the group of systems. But equally a system must not be removed from the group if the unusual performance of that system is merely a statistical rarity. A large variation in the observed MTBO of the same type of ILS system is to be expected due to the small number of outages. It is desirable to have a procedure available to remove a system from the group when the variation of that system from the group is significantly greater than would be expected. A mechanism to enable the removal of a system from a class is to use a test of discordancy (Ref.4). A sequential test of discordancy can be used to continuously examine whether a system's performance is so different from the performance of the other systems that it can be justifiably removed from the Class. The test can be designed around the fact that if all systems possessed the same reliability, the arrangement of outages between systems has a multinomial distribution.

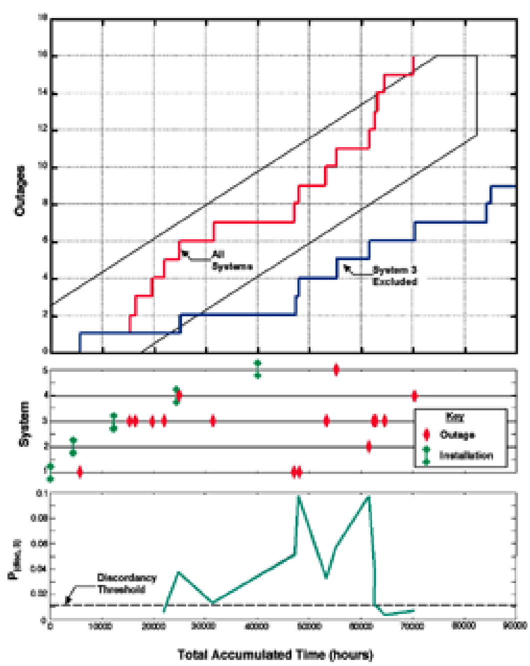

Fig. 6 Example Discordancy Test

An example scenario is shown in Fig. 6. The total number of outages within the class and a breakdown of those outages by system are shown in the first two plots. System 3 exhibits significantly worse reliability performance than other systems, which calls into question the assumption that systems within the class possess the same level of reliability. With the suspect System 3 included, the class is rejected, however, if this system is excluded an accept decision is made.

As a guide, a measure of probability of the observed level of discordancy of system 3, P(disc,3), (i.e. how unusual is the system, is its reliability performance at the extremes of the expected reliability distribution?), is plotted as a function of accumulated operating time of the whole class in the final graph of Fig. 6. When P(disc,3) falls below a threshold corresponding to a low level of significance, (i.e. its reliability record is very unusual) then System 3 can be removed from the class. A significance level of 5% implies that if the systems within the class were the same, the measured level of discordancy (unusualness) would occur less than 5% of the time. The value of 5% is considered to be sufficiently low so as to result in minimal interfere to the sequential test. A precise discordancy decision should be obtained from a simulation of an actual situation.

Once removed from a class, a rogue system is to be treated as an individual new system. A rogue system may not re-enter the class unless the source(s) of the system's outages is subsequently traced and rectified. If a rogue system is detected and removed, the type of system is deemed to be outlier prone, which has implications for the time required for the installation of subsequent systems of the same type.

60% Confidence Option

At AWOG/6 a Certification Project Team (PT/Cert) was established to harmonise the methods used in Europe to demonstrate compliance with the ILS (MLS/GLS) continuity of service requirements as defined by ICAO Annex 10 (including Amendment 74) and to develop relevant European Guidance Material.
In the process of developing guidelines, two major issues of concern were highlighted by European states:

1. The present ICAO provisions regarding the requirements for continuity of service as defined in Annex 10 para 3.1.3.12.3, do not recognise the use of level 3 localisers to support Category IIIA operation.
2. The 90 % confidence level required for demonstration of Continuity of Service will result in a very long and overly stringent certification process.

Although not anticipated when Amendment 74 was approved, it was recognised that these issues will have a negative impact on European All Weather Operations. A PT/Cert proposal was developed which recognises the use of CAT IIIA level 3 operations and provides guidance that, for initial reliability demonstration, a 60% confidence level is acceptable. (Level 3 corresponds to the CAT II requirement given in Table 1).

In light of developments within PT/Cert, this paper details a 60% confidence sequential test that results in significantly reduced certification times of new systems compared to the 90% test.

The corresponding sequential tests if 60% confidence is to be achieved are shown in Figs. 7 to 9. In the case of a 1000 hour sequential test confidence percentages are shown without a one year minimum test time. If the one year minimum is applied the test becomes a fixed duration test of one year.

The expected accumulated test time for the 60% confidence CAT III localiser sequential test is approximately 13000 hours if the true MTBO were 8000 hours: one third that of a 90% confidence test.

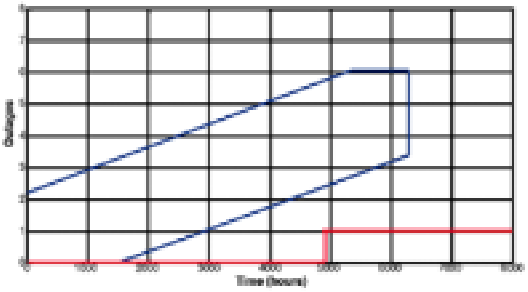

Fig. 7 1000 hr Decision Boundary

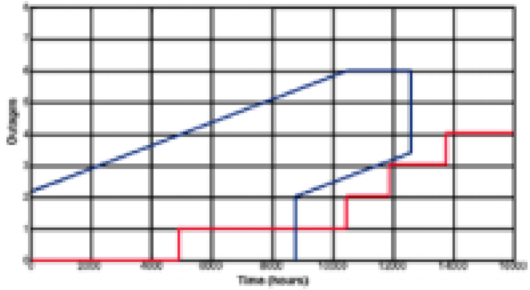

Fig. 8 2000 hr Decision Boundary

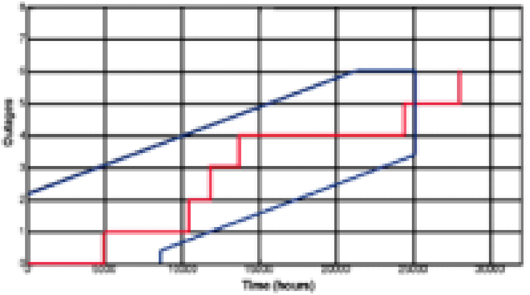

Fig. 9 4000 hr Decision Boundary.

The initial reliability demonstration to a high degree of confidence, for example 90%, may not strictly necessary to ensure that the system operates with a reliability in excess of that required. It can be argued that given that the system's reliability will be continuously monitored post-certification an initial lower confidence level could be used with a higher level, 90%, achieved at a later date.

SUBSEQUENT SYSTEM CERTIFICATION

Class Approach

The introduction of a subsequent system need not require a re-certification as if the system were new. If the subsequent system is nearly identical to the type of system that has been previously certified, then the system could be operational in a time significantly less than that required for the certification of a new system. The reliability demonstration requirement becomes more a requirement to demonstrate correct installation than a requirement to re-certify assuming no previous knowledge. A minimum time of 1-3 months is proposed for the demonstration of correct installation of subsequent systems.

The fast-track route to subsequent system certification is dependent upon the degree of belief that the system to be installed possesses sufficient reliability. If substantial historic knowledge has been obtained from a number of systems in an operational environment, and if a significantly variation in those systems' reliability has not been observed the fast track-route may be applied. The sequential discordancy test performed during the certification of the group of systems can be used to assess whether a substantial variation in reliability has been observed.

If the reduced confidence level of 60% is to be used, it is recommended that the fast-track route for the certification of subsequent systems be denied until it has been demonstrated that the Class type meets the reliability requirement with 90% confidence.

A subsequent system certified via the fast-track route will initially be subject to a more stringent post-certification monitoring system than for new systems.

Intermediate Approach / Outlier Prone

An intermediate approach could be adopted if some operational reliability knowledge has been gained, but the information is either limited in extent or has revealed evidence of significant variation in reliability between systems within a class.

Under such circumstances a sequential test can still be used, but, in contrast to that required for a new system, it is to be conducted such that the *Upper* test MTBO is equal to the required MTBO (Appendix A). The sequential test is therefore consistent with a working (null) hypothesis that the subsequent system meets the reliability requirement. The working hypothesis has been established by the class certification procedure, however a sequential test is performed on the subsequent system because there remains a not insignificant risk that the subsequent system is a rogue system.

Individual Method

If a system is not of the same as a previously certified type, the subsequent system is certified following the procedures for a new system.

POST CERTIFICATION MONITORING

A method to assess the behaviour of a particular installation is to calculate the average MTBO over the last five to eight failures. This technique presents difficulties when a class system has been used during the classification phase. It is likely that no single system within a class will have experience five failures and so an MTBO point estimate would lack confidence. A class MTBO monitor overcomes this problem but difficulties arise when the class MTBO monitor's point estimate becomes less than the requirement: a reduction in operation level of the whole class may result, even though it may be only a single, atypical, class member causing the 'classification Level event'.

A solution is to use individual monitors, but to initialise them with the class point estimate obtained when the class is accepted (the total accumulated operating time divided by the total number of outages). The class point estimate can be considered to have come from, for example, the last five outages. The starting point estimate for an individual MTBO monitor can be represented by 5 equally spaced 'virtual' outages producing a point estimate corresponding to the class point estimate (Fig. 10). To cater for the case when a class of systems is certified with no outages, a maximum MTBO initialisation of twice the required value is proposed.

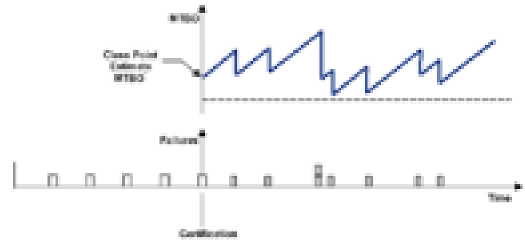

Fig. 10 Individual MTBO Monitoring Following Class Certification

For subsequent systems that have been certified via the fast track route, the monitoring process should be modified so as to be more sensitive to insufficient reliability.

ICAO recommends that a category designation should not be subject to frequent change. A failure of the point estimate to meet the alert limit results in a re-designation of the system. It is recommend that target reliability levels be set for the equipment reliability such that if met re-designation of a system's category is unlikely. If the point estimate falls below the target MTBO value then procedures may need to be reviewed to increase system reliability. For the purpose of comparison with the target value, point estimates may be obtained from more than one system and/or from more than 5-8 outages. Proposed target MTBO levels are given in Table 2. The probability of observing an MTBO point estimate obtained from 5-8 outages less than 4000 hours as a function of true MTBO is shown in Fig. 11.

Facility Performance Category	Sub-system	MTBO Target Hours	MTBO Alert Hours
III (Level 4)	Localiser	6000	4000
III (Level 3)	Localiser	3000	2000
III	Glidepath	3000	2000
II	Localiser	3000	2000
II	Glidepath	3000	2000
I, Level 2	Localiser	1500	1000
I, Level 2	Glidepath	1500	1000

Table 2 MTBO Reliability Target and Alert levels

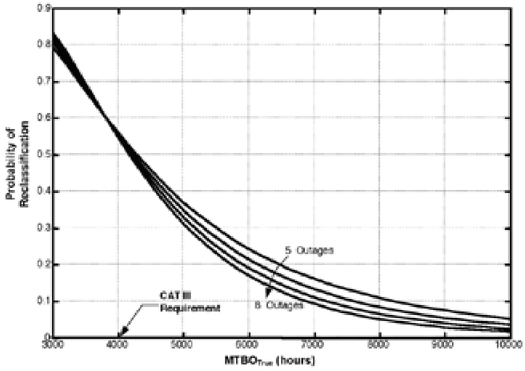

Fig. 11 Probability of Reclassification

CONCLUSIONS

The results achieved so far by the AWOG Certification Project Team indicates that there is significant scope within ICAO Annex 10's requirements and guidance material to reduce the ILS certification times by exploiting accumulated observation time from a number of installations. Suitable procedures should reflect the *a priori* reliability knowledge of the system to be installed. The procedures described in this paper put the onus on obtaining reliability knowledge in an operational environment, as theoretical reliability predictions, based on equipment MTBF specifications, are considered to be an inaccurate guide.

For new systems the use of accumulated operating time across a number of systems can result in significant reductions in certification times.

Once a type of system has been certified, if a subsequent near identical system is installed and maintained to the same standard, a fast-track route can be justified. The reliability demonstration requirement becomes more a requirement to demonstrate correct installation than a requirement to re-certify assuming not previous knowledge.

An intermediate approach is proposed which could be adopted if a degree operational reliability knowledge has been gained, but the information is either limited in extent or has revealed evidence of significant variation in reliability between systems of that type.

It is noted that following certification the system's reliability is continuously monitored. Target MTBO values are described which if met should make category re-designation unlikely.

ABREVIATIONS

AWOG: All Weather Operations Group (ICAO European Regional Planning Group)
DERA: Defence Evaluation and Research Agency
DFS: Deutsche Flugsicherung GmbH (German Air Navigation Services)
GLS: GNSS Landing System
SARPs: Standards And Recommended Practices

REFERENCES

1. International Standards and Recommended Practices Aeronautical Telecommunications Annex 10, Volume 1 (Radio Navigation Aids).
2. MIL-HDBK-781A, Handbook for Reliability Test Methods, Plans, and Environment for Engineering, Development Qualification, and Production, 1st April 1998.
3. C. M. Bryant, Confidence Limits on MTBO for Sequential Test Plans of MIL-STD 781, Technometrics, Vol. 21, February 1979.
4. V. Barnett, T. Lewis, Outliers in Statistical Data, ISBN 0 471 99599 1

Appendix A - Reliability Demostration Using Sequential Test Plans

INTRODUCTION

This Appendix describes the MIL-HDBK-781A (Ref. 2) method for the derivation of sequential test decision boundaries and associated confidence limits.

A sequential reliability test is a statistical test whereby observations are continuously made and a decision is made whether to accept or reject the system or to continue to take further observations before reaching a decision. The approach results in the development of a simple graphical method in which accumulated outages/failures are plotted as a function of time. An accept or reject decision is made when the predetermined decision boundaries are intersected.

DEFINITION OF TERMS

A sequential test can be designed around an upper and lower MTBO and associated risks. The test is designed around the following parameters:

Consumer's risk (β). Consumer's risk (β) is the probability of accepting equipment with a true mean-time-between-failures (MTBO) equal to the lower test MTBO (θ_1). The probability of accepting equipment with a true MTBO less than the lower test MTBO (θ_1) will be less than (β).

Producer's risk (α). Producer's risk (α) is the probability of rejecting equipment which has a true MTBO equal to the upper test MTBO (θ_0). The probability of rejecting equipment with a true MTBO greater than the upper test MTBO will be less than (α).

Discrimination ratio (d). The discrimination ratio (d) is one of the standard test plan parameters; it is the ratio of the upper test MTBO (θ_0) to the lower test MTBO (θ_1) that is, $d = \theta_0/\theta_1$.

DECISION BOUNDARY DERIVATION

For a constant outage rate equipment with an unknown MTBO of (θ), the probability of failing (r) times in an accumulated operating time (t) is:

$$\mathrm{P}(r) = \left(\frac{t}{\theta}\right)^r \left(\frac{e^{-t/\theta}}{r!}\right) \qquad \text{(A-1)}$$

The sequential test must prove that (θ) is at least equal to or greater than the lower test MTBO (θ_1). If the true MTBO is exactly equal to the lower test MTBO the probability of failing (r) times in the operating time (t) is P_1.

In order to structure the sequential test an upper test MTBO, (θ_0), must also be selected. If the equipment's MTBO were equal to (θ_0) the probability of (r) failures in the interval (t) would be P_0.

The probability ratio is expressed as:

$$\mathrm{P}(r) = \frac{P_1(r)}{P_0(r)} = \left(\frac{\theta_0}{\theta_1}\right)^r e^{-[(1/\theta_1)-(1/\theta_0)]t} \qquad \text{(A-2)}$$

This ratio is computed continuously during the test and compared to two predetermined constants (A) and (B), using the decision rules of a through c:

a. If P(r) becomes < B, accept and stop testing.
b. If P(r) becomes > A, reject and stop testing.
c. If B < P(r) < A, continue testing.

The constants (A) and (B) are:

$$A = \frac{(1-\beta)(d+1)}{2\alpha d} \qquad \text{(A-3)}$$

$$B = \frac{\beta}{(1-\alpha)} \qquad \text{(A-4)}$$

The graphical sequential test procedure is derived as follows:

Two lines are plotted on graph paper with t (cumulative test time) as the abscissa and r (number of failures) as the ordinate, the constants (a and c) are the intercepts of these lines with the ordinate and (b) is the slope.

The numerical computation of a, c, and b is given by:

$$a = \frac{\ln B}{\ln (\theta_0/\theta_1)} \qquad \text{(A-5)}$$

$$b = \frac{(1/\theta_1 - 1/\theta_0)}{\ln (\theta_0/\theta_1)} \qquad \text{(A-6)}$$

$$c = \frac{\ln A}{\ln (\theta_0/\theta_1)} \qquad \text{(A-7)}$$

By drawing a horizontal line at ($r = r_0$) and a vertical line at ($t = T_0$), the test is truncated. A method for finding suitable truncation values is described in Ref. 2. The accept reject criteria are summarised in Fig. A-1.

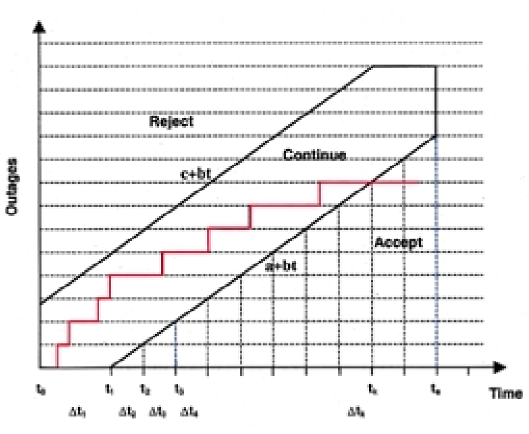

Fig. A-1 Graphical Representation of a Sequential Test

CONFIDENCE LIMIT COMPUTATION

This method for estimating confidence limits (described in Ref. 3) can be used to estimate the confidence limits on MTBO at the completion of the sequential tests described in MIL-HDBK-781A Test Plans I-D through VIII-D.

Considering the failure time plane given in Fig. A-1, the probability of observing δ_m failures between times $t_{(m-1)}$ and $t_{(m)}$, assuming exponential equipment possessing an MTBO of θ, is:

$$P\{\delta_m \text{ failures in } (t_{(m-1)}, t_{(m)}); \theta\} = \exp\{-\Delta t_m/\theta\}(\Delta t_m/\theta)^{\delta_m}/\delta_m! \qquad \text{(A-8)}$$

Similarly the probability of observing $\delta_1, \delta_2, \ldots, \delta_k$ failures within times $\Delta t_1, \Delta t_2, \ldots, \Delta t_k$ assuming that the total number of failures at time t_k is i and that no decision boundaries have been intercepted before t_k is:

$$P\left\{(\delta_1,\delta_2,\ldots\delta_k); \sum_{m=1}^{k} \delta_m = i, \text{ no termination before } t_k, \theta\right\}$$

$$= \prod_{m=1}^{k} \exp\{-\Delta t_m/\theta\}(\Delta t_m/\theta)^{\delta_m}/\delta_m!$$

$$= \exp\{-t_k/\theta\}(1/\theta)^i \prod_{m=1}^{k}(\Delta t_m)^{\delta_m}/\delta_m! \qquad \text{(A-9)}$$

The probability of i failures in a total test time t_k without prior termination, assuming an exponential equipment with an MTBO of θ, is obtained by summing all possible paths ($\delta_1, \delta_2, \ldots, \delta_k$ combinations) resulting in an accept decision at time t_k:

$$P\{(i,t_k);\theta\} =$$

$$\sum P\left\{(\delta_1,\delta_2,\ldots\delta_k); \sum_{m=1}^{k} \delta_m = i, \text{ no termination before } t_k, \theta\right\}$$

$$= \exp\{-t_k/\theta\}(1/\theta)^i \sum_{S} \prod_{m=1}^{k}(\Delta t_m)^{\delta_m}/\delta_m! \qquad \text{(A-10)}$$

A lower 100(1 - γ) % confidence limit on acceptance, θ_L,γ,i, can be computed such that:

$$\gamma = \sum_{q=0}^{i} P\{(q,t_q);\theta_{L,\gamma,i}\} \qquad \text{(A-11)}$$

where,

t_q is the time corresponding to the intersection of the accept boundary with q outages.
i is the number of failures on acceptance.

The lower confidence limit, θ_L,γ,i, is therefore the MTBO that results in the probability of acceptance at or before i outages being equal to γ.

EXAMPLE TEST PLAN

Sequential tests can be designed to demonstrate the lower test MTBO at the required confidence level. The worst case lower 100(1 - β) % confidence limit on acceptance is approximately equal to the lower test MTBO, θ_1.

A requirement is to demonstrate an MTBO of 4000 hours at 90% confidence equates to a consumer risk, β, of 0.1 and a lower test MTBO, θ_1, of 4000 hours. To complete the test a realistically attainable upper test MTBO, θ_0, must be chosen, e.g. 8000 hours, and an associated producer risk, e.g. (α= 0.1, that a system with a true MTBO of 8000 hours would be rejected.

The decision boundary defining parameters are given in Table A-1.

a	-3.17
b/hr	1.8×10^{-4}
c	2.75

Table A-1 Decision Boundary

Following the guidance given in Ref. 2 results in the test being truncated after 82400 hours or after 15 outages.

11th IFIS Santiago - Chile
05-09 June 2000

ILS CERTIFICATION REQUIREMENTS

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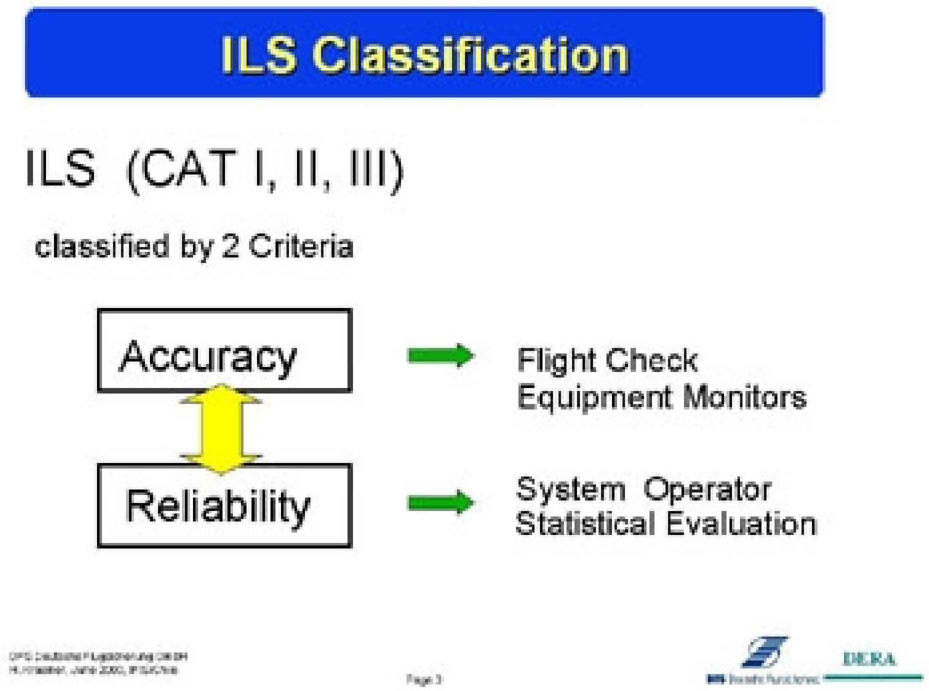
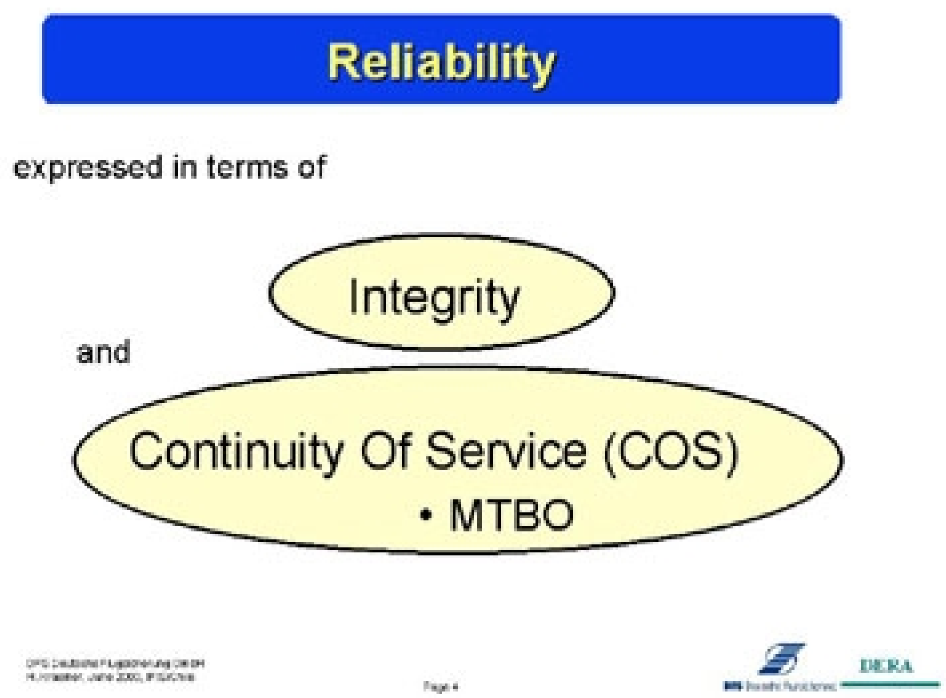
Content and Topics

- ILS Classification Criteria
- Amendment 74, ICAO Annex 10
  - Impact on Classification and Certification
- Individual and Class Certification
- Conclusions

DERA


ILS Classification
ILS (CAT I, II, III)
classified by 2 Criteria
Accuracy
Reliability
Flight Check
Equipment Monitors
System Operator
Statistical Evaluation
DERA


Reliability
expressed in terms of
Integrity
and
Continuity Of Service (COS)
• MTBO
DERA

Reliability Specification

- ICAO Annex 10 Vol. I and Attachment C:
  - before Amendment 74:
    - *green pages* ➡ recommendation
  - with Amendment 74:
    - *white pages* ➡ requirement
    - extended requirement

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DERA

Integrity and Continuity Of Service Objectives

Level Category	*Integrity*	*Continuity of Service (minimum)*	*MTBO (hours)*
1 CAT I		Not demonstrated or less than required for level 2	
2 CAT I	$1-10^{-7}$ in any one landing	$1-4\times10^{-6}$ in any period of 15 seconds	1000
3 CAT II	$1-0{,}5\times10^{-9}$ in any one landing	$1-2\times10^{-6}$ in any period of 15 seconds	2000
4 CAT III	$1-0{,}5\times10^{-9}$ in any one landing	$1-2\times10^{-6}$ in any period of 30 sec. (localizer) 15 sec. (glide path)	**4000** localizer 2000 glide path

Page 6

DERA

COS and MTBO

COS $\rightarrow$ $P = e^{-t/\Theta}$ $\rightarrow$ MTBO

$$\mathrm{MTBO} = \frac{\text{Time of Operation}}{\text{Number of Outages}} \times \text{Stat. Factor (C,F)}$$

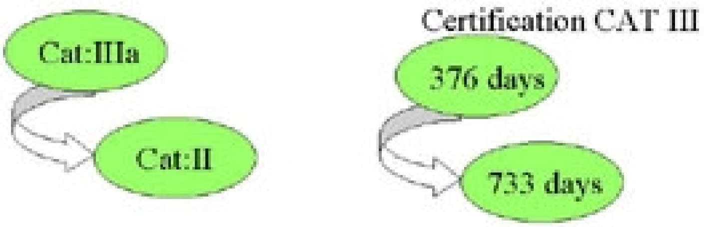
- The MTBO is to be demonstrated
- The demonstration is termed Certification

Page 7

DERA

Amendment 74
Impact to Classification and Certification

- No CAT IIIa operation with level 3 Localizer
- Downgrade of systems from CAT III to CAT II
- COS demonstration for CAT I systems
- Considerably protracted duration for a certification



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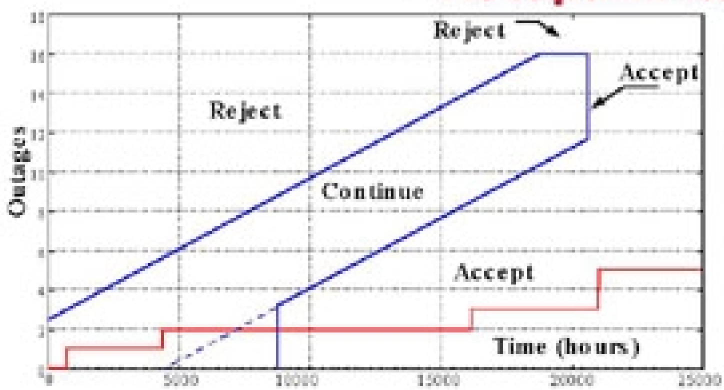
DERA

ILS Certification Practice

Present certification practice

The Sequential Test

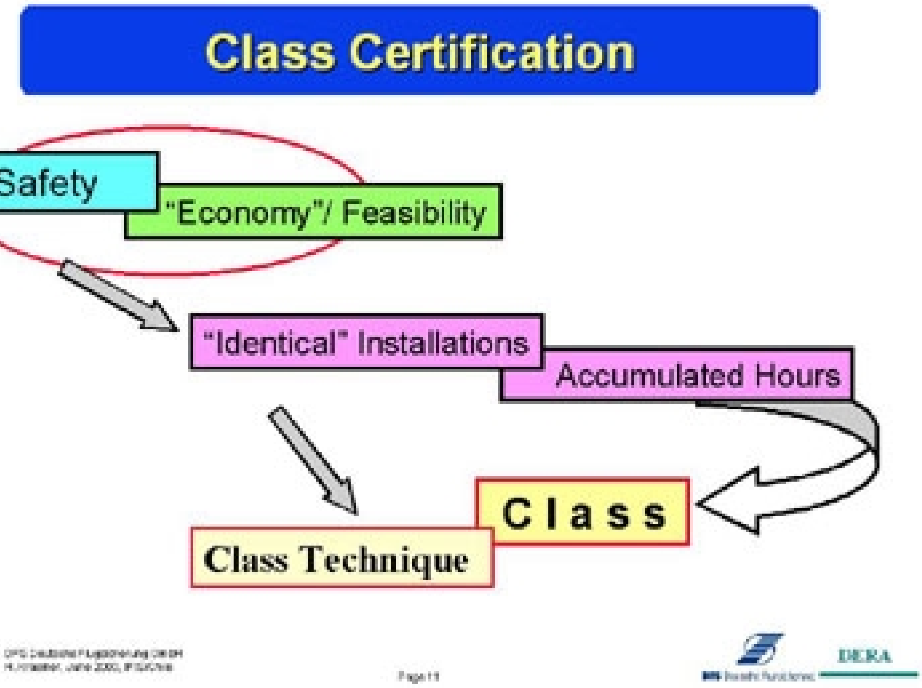


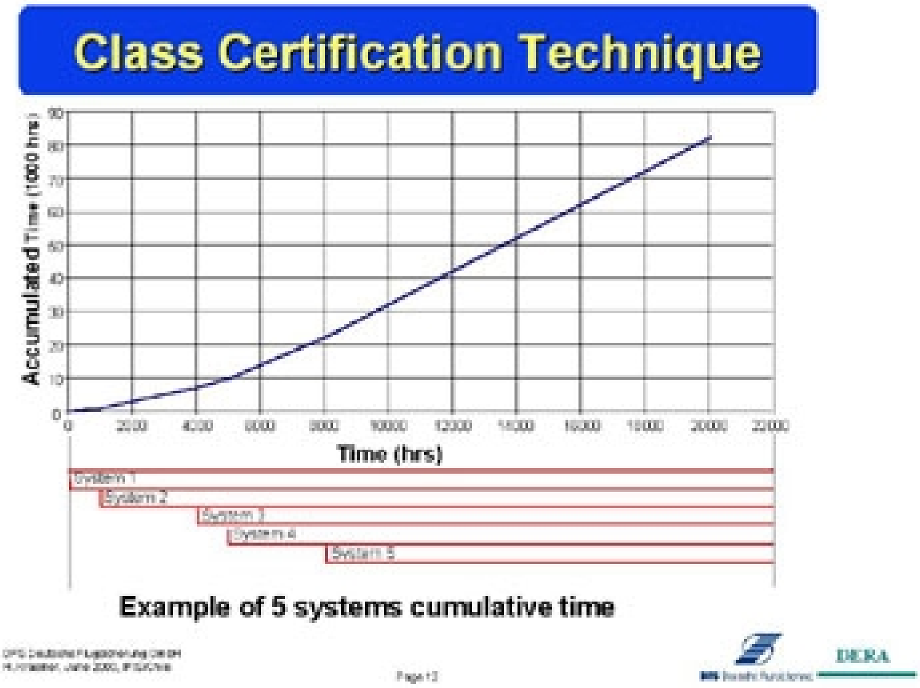
Example of a 1000 hr MTBO reliability test (90% confidence)

Certification Analysis

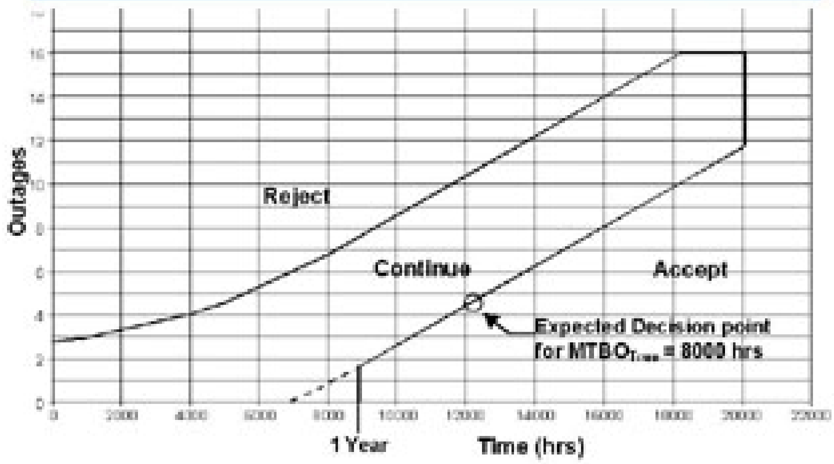
Certification problems to the **individual** system certification imposed by the Amendment 74

- Protracted certification time for each system
- 90% confidence level is hardly ever achievable
- One year minimum certification
- No exploitation of knowledge of similar systems


Class Certification
Safety
"Economy"/ Feasibility
"Identical" Installations
Accumulated Hours
Class
Class Technique
DERA


Class Certification Technique
Accumulated Time (1000 hrs)
Time (hrs)
System 1
System 2
System 3
System 4
System 5
Example of 5 systems cumulative time
DERA

Class Certification Technique

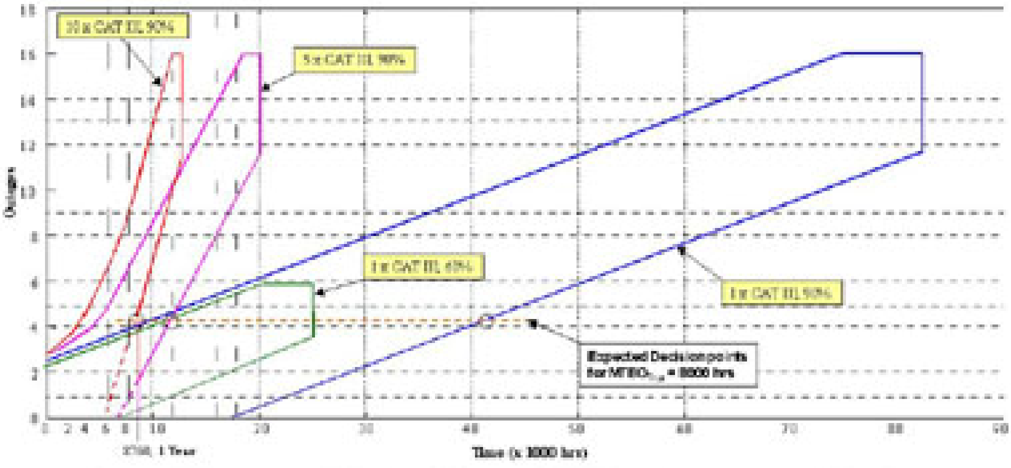


Example of 5 Systems Class Sequential Test

Page 13

DERA

Class / Individual Certification Boundary's Comparison



Sequential test boundaries for Class and Individual system certification

Page 14

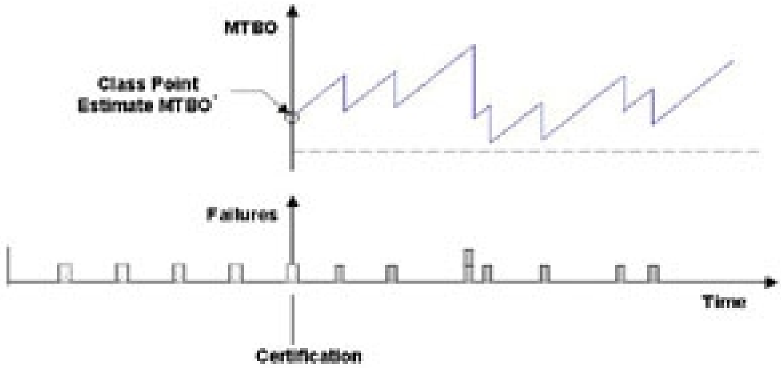
DERA

Subsequent System Certification

- Subsequent system installations after establishment of a Class do not need full certification test like a new type of system/installation
- Only installation review is required (1-3 months)
- Fast track route for subsequent system installations only after the Class has been demonstrated COS with 90% confidence
- Stringent post-certification monitoring for the subsequent installation required

DERA

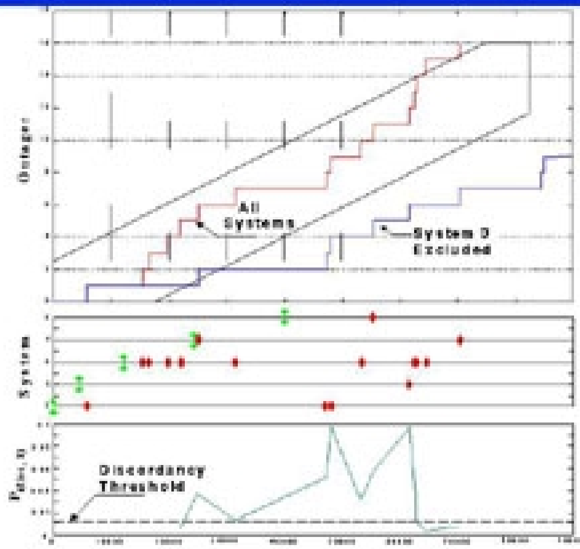
Post Certification Monitoring



Individual MTBO Monitoring Following Class Certification

DERA

Class and Rogue Systems



Class Analyses

Advantage

- Considerably **faster certification** for a group of installations
- Achieving and maintaining the **highest degree of safety**
- **Subsequent system** certification of class-type systems within 1 - 3 months time ☺

Disadvantage

- Particular failure of **one** system may result in a reduction of operation level of the **whole class**
- **Higher invest** for maintenance and installations because of the requirement of **identical** procedures and installations

☹

Conclusion

- Class Certification and Class Operation will cope with the ICAO increased safety requirements in an economical and practicable way
- Solution to the impact of ICAO Amendment 74 for single system installations is still required

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ANTENNE FAILURE - REASON FOR FALSE ILS COURSE GUIDANCE?
March 05, 2000

ABSTRACT

The calibration of Instrument Landing Systems (ILS) requires measurement equipment of high accuracy and integrity. This paper describes the outage of an airborne ILS receiving antenna, which was installed at a calibration aircraft. This outage was leading to false measurement results up to CAT I tolerande limits concerning the localizer.

In general such an antenna failure may also occur at other receiving antennas and may cause false ILS course guidance. Aircraft for all weather operations are equipped with at least two independent receivers due to safety reasons. But usually they are fed by the same antenna. In case of such an antenna malfunction there is no chance to detect and to indicate the failure.

For the time being the reason for such behaviour is not cleared completely. Some additional trials and analyses must be done to explain the appeared effects and to build a theoretical model. This paper will introduce the maifunction and will give some ideas and stuff for further discussions.

THE EFFECT

An abnormal course displacement of the localizer signal was measured during routine flight inspection for a CAT III ILS. The measurement result was

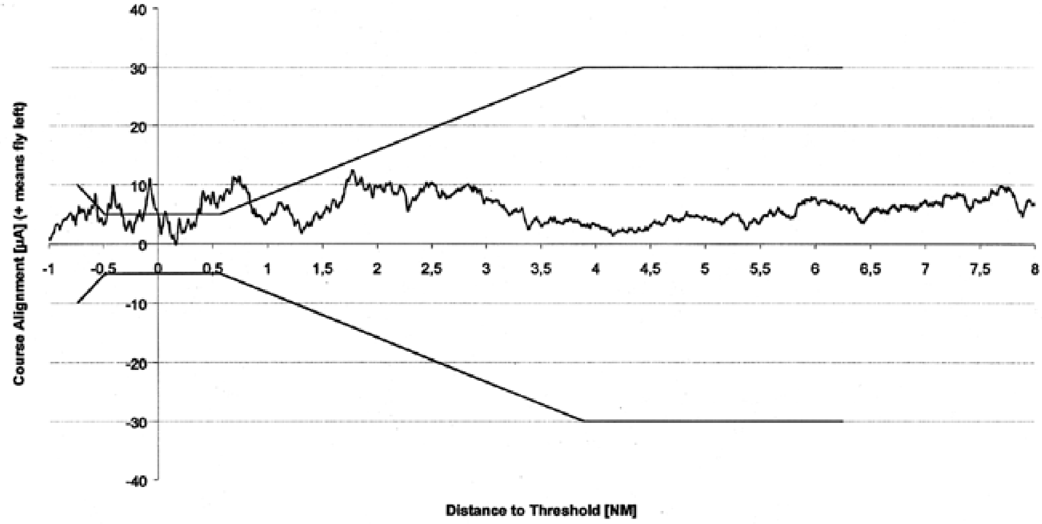

Figure 1: Abnormal Course Alignment (measured with the damaged top antenna) and CAT III tolerance limits referred to centreline.

completely different in comparison to routine checks performed before. The structure of the signal contained much more bends than measured in the past. Like illustrated in figure 1 it seems to be an large and constant offset between DDM=0 and centreline. The displacement of the localizer course signal has maximum values of approximately 10µA («fly left») near at the threshold, which is clearly unacceptable for CAT III operations. The affected ILS is a dual frequency installation. Some more approaches were made to analyse the effect. At first, the measurement was repeated by using another antenna mounted at the tail unit of the aircraft. The result is shown in figure 2. Please note, that the alignment offset nearly disappears and the course structure locks much better.

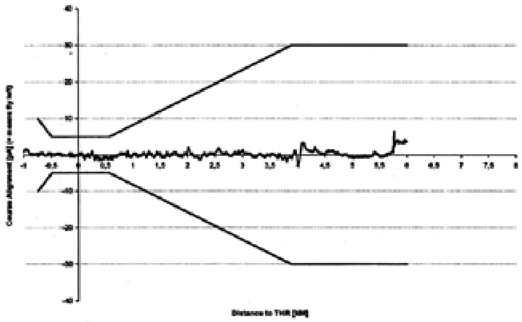

Figure 2
Normal Course Dispiacement (measured with the tail antenna) and CAT III tolerance limits referred to centreline

To find more details, the clearance transmitter was switched off. The atypical displacement and the bad course structure could not be measured again without clearance signal neither with the top nor with the tail antenna. Details are shown at Figure 3a and 3b.

The surrounding terrain of the airport may be considered as urban, where reflections are to be expected. The horizontal characteristic of the tail and top antenna are quite similar. What is causing the measured false course guidance?

However, the ILS abnormality was falsified with ground measurements and by using another calibration aircraft. The used top antenna was found finally as error source.

To complete the collection of facts, it is to note, that such constant course displacements (about 5µA) were to observe at other airfields too - independent from the topography. Unfortunately, the orientation of the measured offset was not always «fly left». As most significant example an offset of about -14µA («fly right») was measured at a single frequency installation.

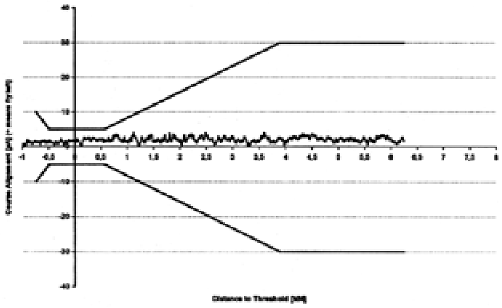

Figure 3a

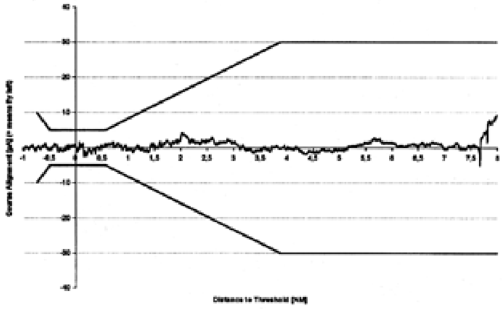

Figure 3b

Course Displacement measured without clearance signal and CAT III tolerance limits referred to centreline

a) with the damaged top antenna
b) with the tail antenna

THE ANTENNA PROBLEM

There are several antennas mounted at the calibration aircraft. Usually the top antenna will be selected for measurements during approaches. The disposition of the antennas on the aircraft is illustrated in figure 4. At the radio frequency strap of the measurement equipment (Aerodata Flight Inspection System, AD-FIS) between the antenna

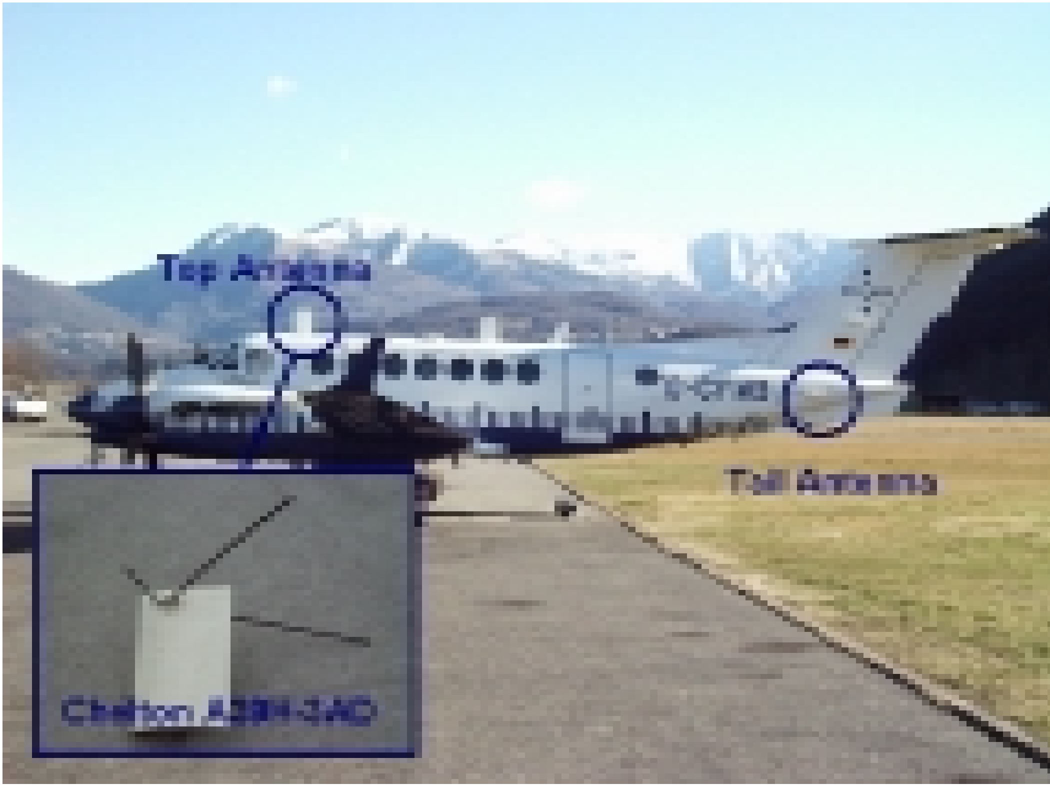

Figure 4
Antenna disposition of the Calibration Aircraft (Beech King Air 350, Flight Inspection International): the damaged top antenna is zoomed

and the receiver (King/Bendix RNA-34AF) are only passive elements applied.
After uninstalling the affected antenna (Chelton A39H-3AD, see figure 4) from the aircraft, a loose connection inside of the antenna was found as damage. The break was not stable, so that it was possible to meet better match (see figure 5) by moving one end of the dipol mechanically. A network analyser was used to determine the mismatch parameter S11, which is defined as the ratio between the reflected and the injected power. Diagram 5 shows, that this antenna defect may be detestable by checking the match.

The S11 value of about -5dB at 110Mhz is a good indication for a malfunction.

As the antenna is damaged a distortion of the antenna pattern is to be expected. The horizontal radiation pattern was measured under free field conditions without the influence of the aircraft fuselage. As illustrated in figure 6 the pattern of the damaged antenna is astonishingly similar to the pattern of a functional dipol, for which a «lying eight» is to be expected. The maximum of the pattern looks about 10º to the right (cockpit view). Further the antenna was manipulated mechanically for the best match. In this state the measurement of antenna pattern was repeated (see figure 6, doted line). For this manipulation (assuming that it comes close to the characteristic of a funciona antenna) the amplitude is stronger and the slight rotation disappears.

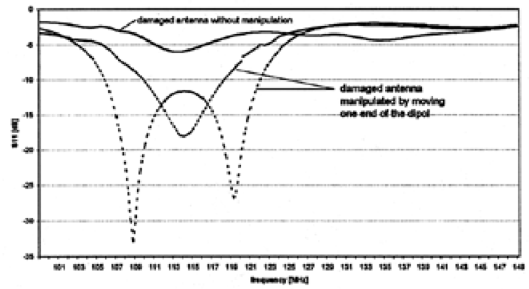

Figure 5
The match of the damaged antenna. The doted lines representing the change of the match, when moving the end of the dipol mechanically.

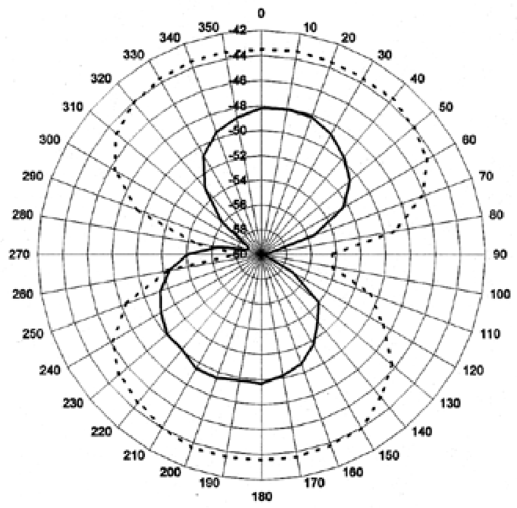

Figure 6
Horizontal pattern of the damaged antenna. The doted line is the case of best match by manipulating the break mechanically (which may correspond to a functional antenna).

DISCUSSION

Phase centre

Some experts are of the opinion, that a distortion of the antenna pattern may shift the phase centre of the antenna. Following that assumption, the measured course displacement must depend on the distance to the localizer. This theory may not meet the facts comprehensively, due to a constant error offset independent from the distance is to explain.

Vibration effects - Modulation

When the aircraft is airborne, the dipol will oscillate mechanically due to it's flexible construction. Now the electrical break may cause periodical jumps in the amplitude of the receiving signal, which is corresponding to an additional modulation. If the frequency of such modulation would be near to 90Hz or 150Hz and if this additional modulation would be stable during the approach, a constant shift of DDM and SDM may be observed. The maximum difference of SDM for the approaches with the damaged top and the tail antenna was about 1,5 percent. If the difference in SDM would be caused by 1,5 percent difference of DDM, it should have the consequence of about 10µA alignment error. This model is not applicable to explain the reason why the effect disappears when switching off the clearance transmitter and why the offset is shifted sometimes to the opposite side.

Figure 7 contains the result of a very simple experiment for the determination of the resonance frequency of the antenna. A CW transmitter was instalen in front of the aircraft. The antenna was forced to oscillate and this will modulate the carrier with the resonance frequency of the antenna. The ILS receiver is able to put out a monitor signal, which is easily to analyse with a memory scope. In case of a functional antenna of the same type the resonance will occur at 15-17Hz (see figure 7a).

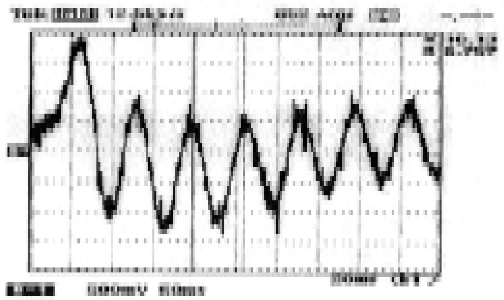

Figure 7a

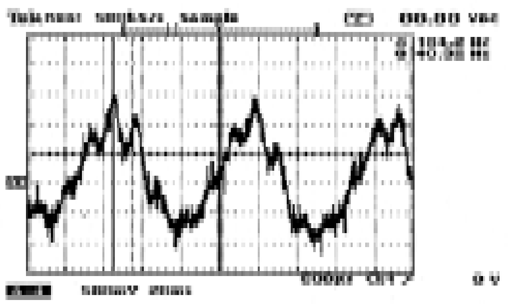

Figure 7b

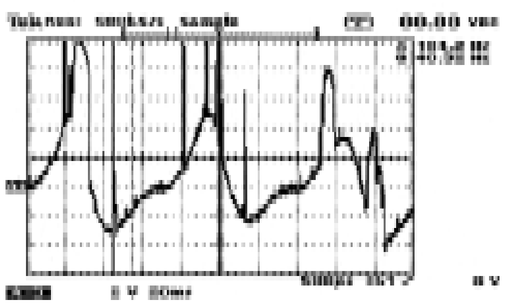

Figure 7c

Resonance frequency:
a) functional antenna
b) harmonies at the damaged antenna
c) spikes due to the break at the damaged antenna

The experiment was repeated with the damaged antenna. The results are illustrated in figures 7b and 7c. In accordance to the measurement with the functional antenna the first harmonic frequency is the same. But there are a lot of components higher order up to spikes which are caused by the break. The spikes may have a wide frequency spectrum. It is planned in the future to measure this frequency spectrum during the flight.

Vibration effects - Mismatch

Based on the comments to the match of the damaged antenna (figure 5) it may be possible, that vibrations during the flight can cause slow and fast changes concerning the match. The receiver may get into trouble to capture on the course signal correcto. In this case the influence of reflections in urban vicinities to the signal structure is much stronger than measured usually. That theory will not meet the fact of a constant alignment offset and stands against the measured alignment error at a single frequency installation.

Antenna pattern

The antenna pattern may have influence to the measured course alignment, especially if reflections attach significance. But the constant alignment error offset is not to be explained with the pattern illustrated in figure 6. In fact the distortion of the antenna pattern is a slight rotation comparable with the wind correction angle during a crosswind approach. Might be there are dynamic effects during the flight, which will distort the pattern in a unknown way.

CONCLUSIONS

The paper has introduced the outage of one antenna exemplary. Additional trials and investigations must be done to clear the effect and to create a theoretical model. It is not sure if the appearance of error may be significant or typical for other antenna failures. But the example shows, that antenna failure may cause false Course Deviation Indication (CDI) concerning the alignment and structure. The malfunction may not be indicated (no warning flag). The faise ILS course guidance may exceed the tolerance limits. Therefore the effect is to regard as dangerous for CAT II and CAT III operations. The measurement of the antenna match and antenna pattern should be added in the routine maintenance program for calibration aircraft. Statistical Analyses about the probability of malfunctions of airborne antennas would be important for further steps to avoid accidents.

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METHODS OF COMPUTING GLIDEPATH CHARACTERISTICS IN MODERN FLIGHT INSPECTION SYSTEMS

ABSTRACT

Depending on the equipment used for flight inspection and the defined national procedures different methods are internationally applied to calculate glide path characteristics.

This paper describes and discusses flight procedures and analyzing methods for determining glide path angle, structure, width and threshold crossing heights.

On glide path facilities with difficult siteing the ILS Reference Datum Height and the achieved ILS Reference Datum Height very often turn out to be unacceptable after being flight checked. Under consideration of the ICAO guidelines this critical aspect of an adequate aircraft wheel crossing height at threshold is discussed as well.

INTRODUCTION

The guidance material for determining glide path characteristics by flight inspection like angle, width, structure and threshold crossing height is given in the ICAO documents Annex 10 and Doc 8071.

These international guidance materials outline the framework and define the basic standards for measuring and computing glide path parameters. In addition national standards exist, which detail the framework given by ICAO in order to provide more practical instructions to flight inspection crews. However, these national interpretations of the ICAO guidelines vary in procedures and used calculation methods significantly. This is especially true for glide path characteristics.

In many cases the interpretation of the ICAO guidelines is left to the flight inspection system manufacturer and the flight inspection crew. This is, because side parameters that have an effect on the computation of the glide path characteristic values are specified unclear or even not at all by the ICAO or national guidelines.

Also, depending on the hard- and software technology used in flight inspection systems different implementations for computing glide path characteristics are possible. By physical nature the different implementations lead to different inspection results.

The different possible procedures and calculation methods also make it quite complicated for internationally operating flight inspection crews to provide comparable and consistent results to the ILS operating authorities. This is of course also true for manufactures of flight inspection systems, who have to deal with different national standards and therefore to implement different versions of computation methods.

In the past and even today especially the measurement and interpretation of the threshold crossing height has lead to intense discussions within the national authorities.

This paper describes and summarizes possible flight procedures and calculation methods for determining glide path characteristics and finally recommends a method, which can be implemented in modern flight inspection systems.

Methods for Computing Glide Path Characteristics

The concept for computing glide path characteristics like angle, width and structure is based on the assumption that the glide path radiates an inverted cone of 0 ddm from a point normally at the base of the glide path mast, at an elevation angle θ. The locus of 0 ddm along the extended runway centre line describes a hyperbola, since the apex of the glide path cone is offset from the runway centre line. The shape of the hyperbola is defined by the relative positions of the glide path mast and the runway centre line. A large effect to the shape of the hyperbola has the glide path reflection plane, which can have a forward and/or sideways tilt angle. However the actual glide path can be quite irregular due to terrain effects in front of the glide path and the 0 ddm locus as seen from the runway centre line does not necessarily have to have the shape of a hyperbola.

$$Angle\,[\mathrm{deg}] = \overline{Ele}[\mathrm{deg}] - \left(\overline{Dev}[\mu\mathrm{A}] \cdot \frac{Width[\mathrm{deg}]}{300}\right) \qquad (1)$$

with

$\overline{Ele}$: mean flown reference angle between ILS points A and B

$\overline{Dev}$: mean deviation between ILS points A and B

$Width$: glide path width (nominal or actual)

In the ideal case of an inverted cone, the ddm 0 glide path extension down to threshold is the asymptote to the hyperbola (fig.1). The angle of the rising asymptote θ defines the glide path emanating from point E, which is at the base of the glide path mast. The threshold crossing height is then defined as the height of the asymptote above threshold.
The basic glide path parameters that have to be assessed during flight check are

- glide path angle θ
- structure
- width or displacement sensitivity
- threshold crossing height (TCH)

Glide Path Angle and Structure Measurement

ICAO defines the glide path as «That locus of points in the vertical plane containing the runway centre line at which the ddm is zero, which, of all such loci, is closest to the horizontal plane» and the glide path angle as «The angle between a straight line which represents the mean of the ILS glide path and the horizontal».

According to ICAO the glide path angle should be ascertained only by flight check between the ILS Points A and B. This means that we have to measure the locations in space where 0 ddm occurs with a positioning reference system or so called truth system. The positioning reference system should have an accuracy of approximately $\pm 0.01°$ as seen from the glide path emanating point. Since the aircraft can not exactly follow the locus curve of 0 ddm, the displacement sensitivity needs to be taken into account for angle measurements. Typically formula (1) is used for computing the glide path angle.

When using this formula for computing the glide path angle the following assumptions have been made

- the emanating point of the glide path signal is known, respectively the origin of the asymptote (aiming point)
- the actual displacement sensitivity

is known. The aiming point of the glide path is required for computing the mean flown reference elevation angle. This aiming point should be determined after the installation of the glide path on the airfield or whenever changes to the antenna system are made. If the extended straight line of the glide path in the plane of the runway centre line does not agree with the assumed emanating point significant errors are introduced to the angular measurement.

The other significant parameter that effects the angle measurement is the actual displacement sensitivity of the glide path. For flight checks in general it is assumed that the displacement sensitivity is linear throughout the calibration range from ILS point A to B, which is only true for ideal glide path installations. However for practical reasons it can be accepted to calculate with the average displacement sensitivity over the calibration range. In order to minimize the error for the angular and moreover the structure measurement the assessment of both glide path parameters, angle and structure, should only be done with the actual displacement sensitivity. This of course requires, that the actual displacement sensitivity has been determined prior to the angle and structure measurement.

Width Measurement

One common procedure to determine the displacement sensitivity or width for a glide path is to fly offset approaches on 75µA above and below path. The ddm output from the navigation receiver and the flown reference elevation angle are averaged between ILS point A and B. Typically the formulas (2) to (4) are used for computing the glide path width.

After both offset approaches have been flown the total width can be calculated by using formula (2). If the glide path angle has been determined prior to the width measurements formulas (3) and (4) allow to compute the sector width. Formula (2) should only be used under the assumption that the width of the upper and lower sectors are symmetrical, otherwise an error is introduced into the width calculation. Formulas (3) and (4) can be used under the assumption that

$$Width[\deg] = 300 \cdot \frac{\overline{Ele_{150}}[\deg] - \overline{Ele_{90}}[\deg]}{\overline{Dev_{90}}[\mu A] - \overline{Dev_{150}}[\mu A]} \tag{2}$$

or

$$Width_{150/90}[\deg] = 75 \cdot \frac{\overline{Ele_{150/90}}[\deg] - Angle[\deg]}{\overline{Dev_{150/90}}[\mu A]} \tag{3}$$

and

$$Width[\deg] = 2 \cdot (Width_{150} + Width_{90}) \tag{4}$$

with

$\overline{Ele_{150/90}}$: mean flown reference angle between ILS points A and B on 150 Hz and 90 Hz side

$\overline{Dev_{150/90}}$: mean deviation between ILS points A and B on 150 Hz and 90 Hz side

$Angle$: actual glide path angle

- the aiming point of the glide path signal is known, respectively the origin of the glide path asymptote
- the actual glide path angle

is known. One can see that the formulas for computing the glide path angle and the width strongly depend on each other, therefore only after all three approaches, centre line, upper and lower sector approach have been flown the glide path characteristics angle, structure and width can be computed iteratively.

In order to reduce the effects of the flight technical error, which is basically compensated by the positioning reference system and taking the displacement sensitivity into account the calibration aircraft should fly as closely as possible to the 0µA signal on the centre line approaches and the 75µA signal on the width approaches as radiated by the glide path. The calibration aircraft can fly either the ILS signal itself or the signal computed by the positioning reference system. The reference signal is preferred, since it provides a stable guidance signal throughout the approach. However the average flown path should be close to the 0µA and 75µA signal as radiated by the ILS. Trials have proven that an average deviation of ±5µA from the desired flight path is possible, when the guidance signal is coupled to the autopilot of the flight inspection aircraft.

Other sources of error, besides the one that already have been mentioned and which also affect the accuracy of the measurements are

- errors introduced by the signal reception equipment (e.g. specific nav receiver problems, filter delay problems, aircraft antenna effects)
- incorrect compensation of aircraft attitude especially under windy conditions
- accuracy of the positioning reference system or truth system

All three-error sources should be minimized in order to get reliable and consistent results for angle, structure and width measurements. An overall measurement uncertainty of less then ±0.02º (2σ) should be achievable with modern technologies for the angle and width determination.

According to the formulas (1) to (4) the determination of the mean flown elevation angle is of great importance to the measurement. Basically 2 types of positioning reference systems are in common for determining the elevation angle of the aircraft throughout the approaches. These are theodolites, which normally directly output the aircraft elevation and azimuth angle and more modern 3 dimensional positioning reference systems, which in addition provide accurate distance information. Typically the more modern 3 D positioning reference systems are used in computer based flight inspection systems, which allow to mathematically transform the provided aircraft position into various other coordinate systems required for computing the ILS characteristics.

The usage of both reference systems is discussed in the following.

Use of Theodolites

Assuming that the glide path forms an ideal inverted cone the best position of a theodolite for glide path measurements would be in the base of the glide path mast where the signal has its geometrical origin or in the aiming point (fig. 1). Normally a theodolite cannot be positioned directly at the glide path base and in addition too much azimuth movement would be involved to track the aircraft all the way down to threshold. Nor is it possible to place the theodolite in the aiming point, which is a point in the runway plane.

For tracking purposes a much better position is to place the theodolite close to the runway and slightly behind the glide path antenna. However in this case the glide path angle and the elevation angle as seen from the theodolite do not fully agree upon each other and the difference will appear in the glide path error curve.

Moreover significant angular elevation errors occur, if the terrain in front of the glide path is difficult, respectively if the reflection plane has a forward and/ or sideways tilt angle.

One can see that the location of the theodolite on the airfield is of great influence to the glide path measurement, because it strongly depends on the knowledge of the glide path aiming point, where the theodolite should be placed ideally.

Using 3D Positioning Reference Systems

Computer based flight inspection systems using 3 dimensional positioning reference systems allow for a more sophisticated technique to compute the basic glide path parameters angle, structure and width. 3D truth systems compute the aircraft position throughout the ILS approaches in all three space coordinates (Lat, Lon, Alt) at certain time intervals.

A computation rate of 10Hz for the truth position of the flight inspection aircraft is sufficient.

Together with the knowledge of the runway and glide path geometry data the absolute aircraft position can be mathematically transformed into the local runway or glide path system. Since precise 3 D aircraft truth position is available a numerical method can be applied to calculate the locus curve of ddm=0 between ILS points A and B. It is most adequate to use the mathematical method of 'Least Error Squares'. The principle is shown in figure 2. The slope of the regression line results is the glide path angle and the height at which the extrapolated line passes threshold defines the threshold crossing height (TCH). This method has the great advantage of being basically independent from glide path geometry data, especially from the aiming point, which is required to calculate the mean flown elevation angle in the formulas (1) to (4).

$$\Theta_m = ATAN\left(\frac{z - GPz}{\sqrt{(x-GPx)^2 + y^2}}\right) - \frac{Dev \cdot Width_{150/90}}{150} \qquad (5)$$

$$x_{Reg} = \sqrt{x^2 + y^2} \qquad (6)$$

$$z_{Reg} = TAN(\Theta_m) \cdot \sqrt{(x-GPx)^2 + y^2} + GPz \qquad (7)$$

with

x, y, z: Aircraft reference position in [m]

GPx, GPz: Aiming point in the plane of the rwy centre line

$Width_{150/90}$: 150 and 90 Hz sector width

and

Regression Line: $y = m \cdot x + b$ (8)

with

$$m = \frac{n \cdot \sum(x_{Reg} \cdot z_{Reg}) - \sum x_{Reg} \cdot \sum z_{Reg}}{n \cdot \sum(x_{Reg}^2) - \sum x_{Reg} \cdot \sum x_{Reg}} \qquad (9)$$

$$b = \frac{\sum(x_{Reg}^2) \cdot \sum z_{Reg} - \sum x_{Reg} \cdot \sum(x_{Reg} \cdot z_{Reg})}{n \cdot \sum(x_{Reg}^2) - \sum x_{Reg} \cdot \sum x_{Reg}} \qquad (10)$$

and

Glide Path Angle: $\Theta_{Reg} = ATAN(m)$ (11)

Threshold Crossing Height: $TCH = b$ (12)

The formulas (5) to (12) are used for computing the regression line. Within these formulas the aiming point and the displacement sensitivity is used to compensate for aircraft deviations from the ddm=0 loci. In order to minimize the errors for aircraft deviations from the ddm=0 loci the same regression method as applied for centre line approaches should be applied for the upper and lower sector approaches on the 75µA loci. After all three approaches, centre line, upper and lower approach have been flown the three regression lines can be computed iteratively. In addition the approaches should be flown autopilot coupled and as close as possible to the 0µA and 75µA loci. From the three-regression lines glide path angle, threshold crossing height, upper and lower sector width can be computed (fig. 2). The intersection of the regression lines also defines the aiming point, which then is used for calculating the glide path structure. The main advantages of this numerical method are

- most adequate method for computing glide path angle, crossing height and width
- basically independent of glide path geometry data
- provides comparable and consistent results for the glide path measurements

Due to other error sources, as previously mentioned, involved in determining the regression line, the measurement uncertainties for the glide path parameters can be estimated. With modern flight inspection technologies it should be possible to determine the slopes of the regression lines, respectively the glide path angle and width, with a measurement uncertainty of $\pm 0.02°$ (2σ). The $\pm 0.02°$ uncertainty for the slopes then leads to a measurement uncertainty for the threshold crossing height of ± 1.3m (2σ). The uncertainty for the crossing height is high compared to the ICAO tolerance, which states a crossing height between 15m and 18m.

Consistency between Flight Check and ILS Glide Path Siteing Procedures

The glide path characteristics derived from the flight check should reflect the predicted installation parameters of the glide path system. For this it is essential that the glide path installation and flight check procedures comply with each other. The guidelines and specifications for both procedures are given in Annex 10 and Doc 8071, however especially on glide paths with difficult siteing the guidelines are not sufficient, because they are based on ideal assumptions.

A glide path should be projected in such a way that the essential parameters glide path angle and threshold crossing height meet the given tolerances. In order to make optimal use of the tolerance ranges for both parameters the threshold crossing height should be projected to 16.5m and the glide path angle typically to 3.0°. The mathematical method applied to predict the crossing height and the angle should be based on the loci of ddm=0 represented as a straight line between the ILS points A and B/1/ . Of course the same method for measuring angle and crossing height then should be applied when flight checking the glide path in order to get consistent results. Great attention to data consistency between geometrical parameters used for glide path siteing and geometrical data used for the flight check should also be given. This is especially true for the exact locations of the runway threshold (ILS reference datum), the extended runway centre line and the glide path mast itself, since all parameters are of significant influence to the measurement results.

The classical simplified installation procedures for glide path siteing are based on formulas that assume the glide path locus in the vertical plane of the runway centre line to be a perfect hyperbola. These well known formulas also take into account the forward and sideward slope of the reflection plane. Today very often glide paths are installed on difficult sites, where these classical installation procedures cannot be applied satisfactory. In this case a more sophisticated approach should been made. Computer aided methods, like the general three-dimensional UTD-approach /2/ for the analysis and optimization of the glide path seem to be most appropriate.

Discussion of ICAO Tolerances for Threshold Crossing Height

During glide path commissioning flight checks it very often turns out that the threshold crossing height is out of the specified tolerances (15m - 18m) as given by Annex 10. It turned out that this is especially true for glide paths on difficult runway sites. There are basically the following reasons for this:

- the measurement principle used in the flight inspection system
- the measurement uncertainty of the flight inspection system
- incorrect installation of the glide path due to the difficult site

When the measurement principle used for determining the crossing height is based on a glide path aiming point as described earlier and this aiming point does not reflect the real situation then significant errors are introduced. A much better way is to use the regression line method, since it is independent of a known aiming point.

The large measurement uncertainty of ± 1.3m (2σ) for determining the crossing height during flight check, when applying the regression line method, should be taken into account for evaluating the result. The uncertainty can be statistically reduced to an acceptable value by increasing the number of centre line approaches. In addition it is very important that the calibration aircraft maintains a stable flight path around ddm=0. This is especially true for glide paths with irregular structures, because measurement errors will be introduced due to the variation of the displacement sensitivity throughout the approach.

However, if all error sources have been minimized during flight check and the crossing height still turns to be out of tolerance then it can definitely be seen as a siteing problem of the glide path installation.

It is actually difficult to verify and meet the tight tolerance limits for the threshold crossing height as given by ICAO, especially on irregular glide paths, due to the fact that quite a number of error sources are involved. But of what importance is the desired threshold crossing height to operational aspects of a landing aircraft? The desired crossing height of 15m - 18m should ensure safe guidance over obstructions and also safe and efficient use of the runway served.

If the given tolerance limits are exceeded by 100% then the theoretical touchdown zone varies by only 100m. On long runways the theoretical variation of the touchdown zone has only very little effect on the operation of aircrafts during landing. More over a change in the crossing height from the desired values has even less effect in reality on the touch down point of an aircraft, when flying the ILS with the autopilot engaged. Typically the glide path signal will be disconnected from the autopilot at a radio altimeter indication of approximately 130ft. The autopilot then goes into an attitude hold phase having memorized and averaged its approach for the last 10 seconds on the glide path. At approximately 70ft the radio altimeter takes over the vertical guidance, flaring out the aircraft for landing.

One can see that the aircraft actually uses the glide path signal only before ILS point C. The flight path of the aircraft close to threshold is basically defined by a short portion of the glide path signal before ILS point C and even more by the characteristic of the autopilot using the radio altimeter.

Therefore it is more appropriate to determine and evaluate the achieved ILS reference datum as defined in Annex 10. ICAO defines the achieved reference datum height as «the mean observed position of that portion of the glide path typically between points 6000ft and 1000ft from threshold being represented as a straight line and extended to touchdown. The point at which this extended straight line meets the line drawn vertically through the threshold at the runway centre line is the achieved ILS reference datum.»

The appropriate method to compute the achieved ILS reference datum would be to use the regression line method for the portion of the glide path between 6000ft and 1000ft before threshold. Nevertheless the effect of the glide path signal, respectively of the related crossing height, to the actual flight path over threshold of an aircraft close to landing is of minor importance. Therefore the significance and the tolerance limits for the crossing height as determined by flight check should be reconsidered.

Practical Results from a Glide Path Inspection

On a difficult glide path site two different mathematical techniques have been used to derive the structure, angle and width. Figure 3 shows the structure by emulating the classical theodolite method with the emanating point of the glide path been assumed at the base of the antenna mast. A strong skew is present in the error trace, especially at distances close to threshold. A bend in the structure at the vicinity of point B appears to be out of tolerance. Applying the regression line method gives totally different results as seen in figure 4. The glide path is now within tolerance and the computed angle and threshold crossing height are significantly different. It is noticable that the glide path flare characteristic is reversed.

CONCLUSION

In order to get consistent and reliable results on glide path measurement during flight check the following procedures and computation techniques should be used:

- apply a numerical and iterative computation technique for determining structure, angle, width and threshold crossing height.
- fly the approaches autopilot coupled, so that the average flight path is as close as possible to the 0µA and 75µA glide path signal. Use the position reference system as input for the autopilot.
- especially on difficult glide path sites apply a modern computer based technique to project the glide path installation.
- when evaluating the measured threshold crossing height consider the measurement uncertainty and its importance to operational aspects during landing.

REFERENCES

/1/ GREVING G. Numerical analysis and Flight Check of ILS for Difficult Sites, 10th IFIS, Seattle 1998

/2/ GREVING G. Computer aided site analysis and site adapted installation - Efficient commissioning of landing systems, 8th IFIS, Denver 1994

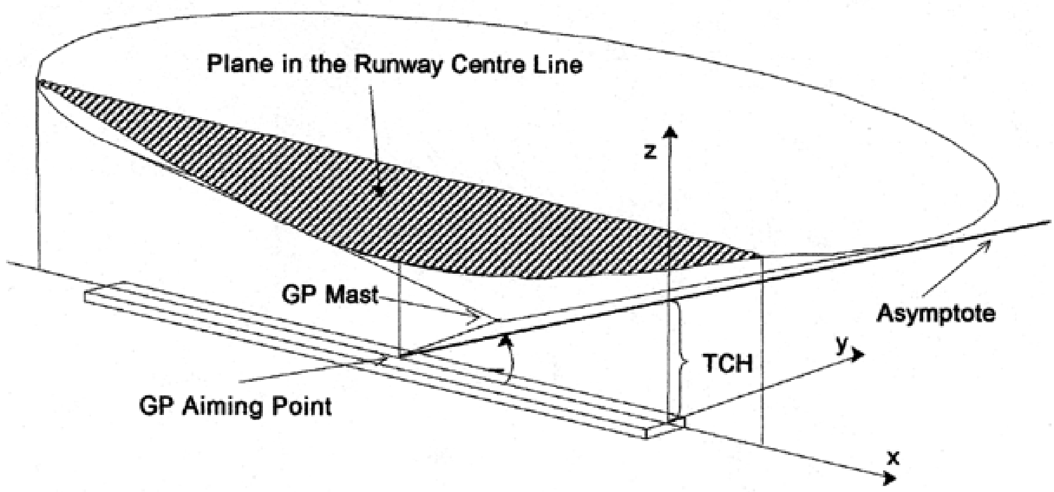

Figure 1: Glide Path Geometry

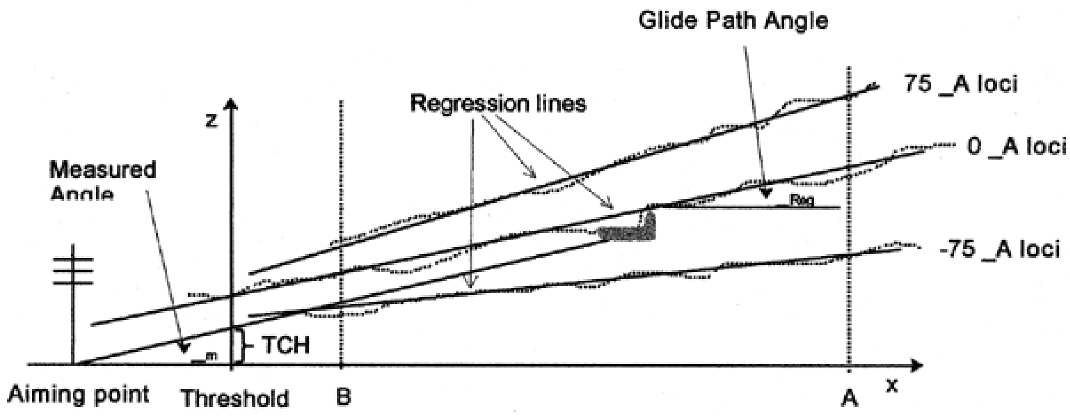

Figure 2: Glide Path Geometry applying a regression line between ILS points A and B for entre line and 75_A offset approaches.

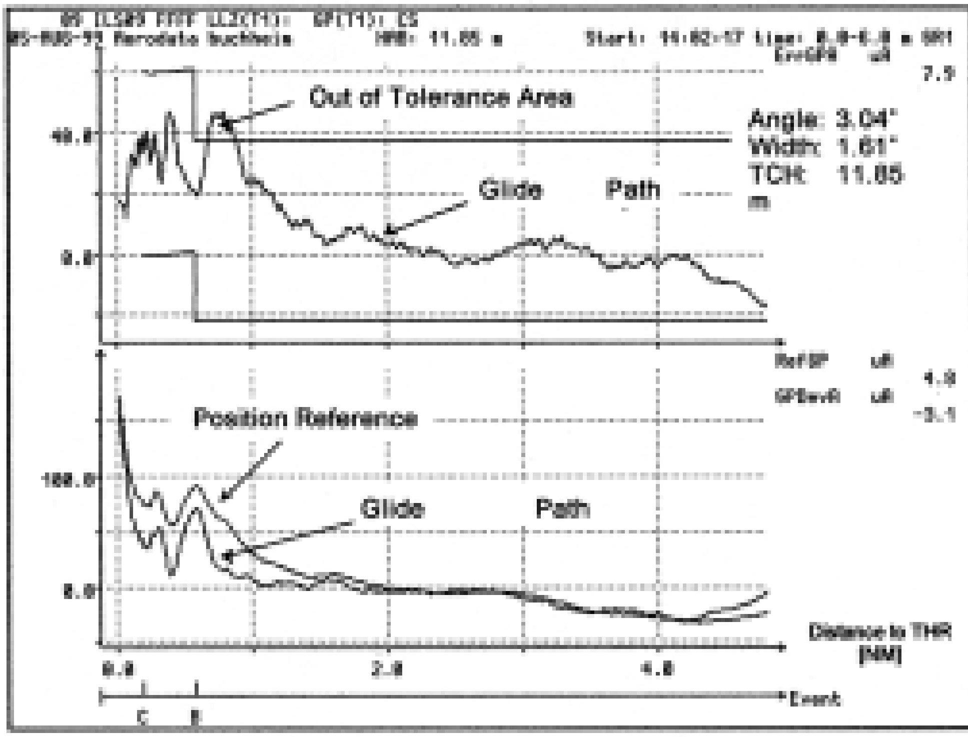

Figure 3: Glide path error trace assuming the emanating point at the foot of the glide path mast

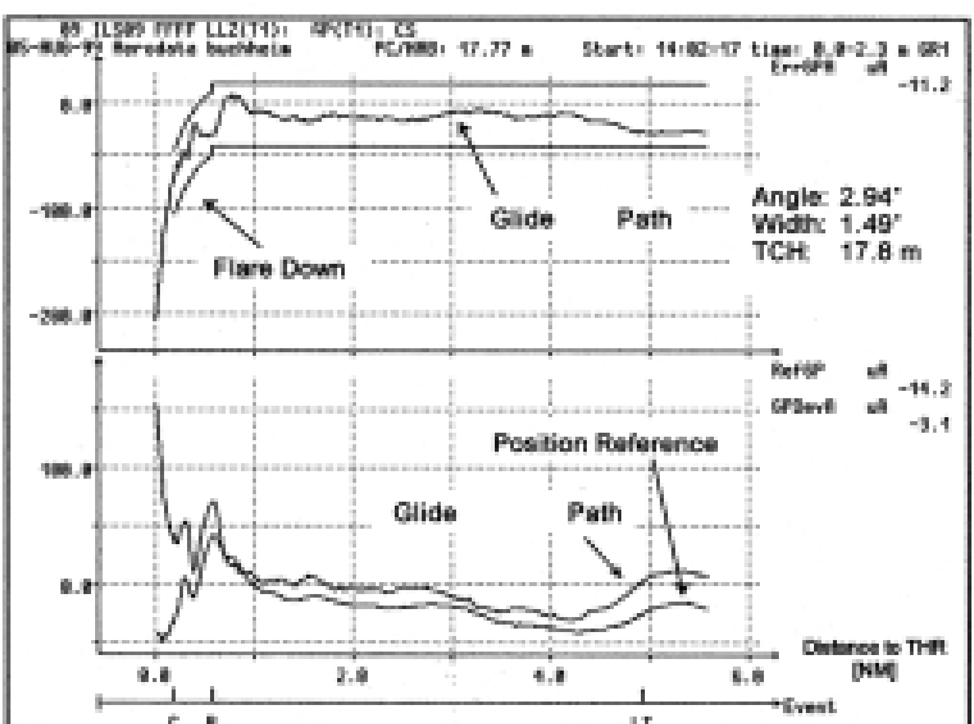

Figure 4: Glide path error trace after applying a regression method between ILS points A and B

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AIRBORNE INTERFERENCE INVESTIGATIONS A HIGHER LEVEL OF SAFETY ON EARTH AND IN SPACE

ABSTRACT

Electromagnetic Interference in aviation has been present since radio waves were first sought as an effective useful way to provide airmen navigating aids and effective means to communicate with ground operators. The early radio spectrum was a large open field with very few frequencies in use. This provided plenty of space to safeguard against interference. Today, the radio spectrum is like a big global city with little real state left to build any new structures. The radio spectrum is in a continuing depletion mode. Every year there are new technologies being developed which require the use of the radio spectrum. Aviation spectrum is viewed as beach front property and many industries are after this property.

When the radio spectrum began to be used for aviation it was by necessity that, despite the technological challenges of the time, there was no other effective way to provide the required information to the aircraft. A long «wire» carrying clear data and voice could not be attached to an aircraft. Non aviation communication industries resorted to «wire» simply because it could carry a signal better than the «wireless» technologies at the time. This fact helped keep interference to the aviation radio spectrum manageable. Our global society and the explosion of new digital and analog «wireless» technologies however, are saturating and continue to fill the radio spectrum at an unprecedented rate. With the radio spectrum so congested there is no room for error or malfunction that can be tolerable by any given system. Digital «wireless» technologies use less transmission power but are more susceptible to loss of synchronization which amount to longer times to recover. When malfunctions occur then the interference impact can only be minimize by how quick can the interference be identified and mitigated. The United States Aviation System Standards and Flight Inspection Community has fully engaged in the interference detection and location line of work. This paper summarizes the program, the existing capability, equipment used, some case examples and the future capabilities under way for locating interference to satellite base global navigation.

INTRODUCTION

The United States National Airspace System (NAS) radio spectrum has been protected over the years by skilled spectrum engineers that investigate, locate and mitigate a large variety of different sources of interference. The aviation radio spectrum has been manage well by these engineers allowing sufficient time for locating a source of interference, mitigate it, and minimize the impact it causes on the National Airspace System. In the last decade of the previous millennium the amount of interference incidents had tripled and the potential impact to the air traffic system as well as the safety of the flying public increased. These and other factors contributed to seeking an improved strategy for locating and mitigating sources of interference to reduce these potential impacts and maintain a higher level of safety by keeping the radio spectrum free of interference. These improved strategies establish innovative partnerships and collaborative efforts which bring flight inspection to the interference investigation arena by providing the airborne platform and allowing to achieve an unprecedented level of interference location and mitigation.

BACKGROUND

During 1995 the United States Aviation Systems Standards organization began the Flight Inspection Improvement Process program. This effort coupled with efforts initiated by Airways Facilities engineers from several FAA regional organizations created the Navigational Aids Signal Evaluator program. Immediately after the office of Spectrum Policy and Management partnership with these organizations to create the airborne Radio Frequency Interference capability for a comprehensive NASE/RFI program which was implemented in 1997. This year marked the long sought capability first envisioned during the 1980's and presented for the first time by FAA Spectrum Management leaders during the historical 1990 Sixth International Flight Inspection Symposium held in Washington, DC USA. At the 1998 Tenth International Flight Inspection Symposium held in Seattle, WA USA the initial system capability was presented. During this Eleventh International Flight Inspection Symposium the unprecedented success will be shared and the path for a new dawn within Flight Inspection services is emerging as aviation transitions from ground based navigation to satellite based navigation. The aviation spectrum can no longer stand unattended and the Flight Inspection airborne detective work is the key added resource needed to keep it interference free.

INTERFERENCE SOURCES

In the past most interference problems occurring within the US National Airspace System were caused by non-government transmitting devices and systems. These interference problems have been experienced by many international Civil Aviation Authorities of other countries specially in Europe. Traditionally, commercial TV/FM broadcast, cable system, industrial, scientific and medical equipment, commercial paging transmitters, amateur radio repeater stations, power lines and land mobile services will be among the identified culprits.

Figure 1: Amateur Repeater affecting SCT Frequencies

Figure 1 shows an amateur repeater affecting VHF and UHF communication frequencies in the Southern California TRACON area.

Today, all these systems continue to affect aviation's radio spectrum with the addition of cellular base station transmitters, satellite mobile terminals, spread spectrum local networks, RF wireless networks, and the emerging wide band radar technologies. Figure 2 shows a satellite telephone terminal that generated a spurious interfering signal in the L1 passband of the San Juan CERAP WAAS reference station ground receivers. This particular system generated a spurious signal on frequency 1580.7 MHz when it was not being operated. The signal was present during system idle mode and will disappear when the system was in its normal operating mode.

Figure 2: Satellite Telephone Terminal

All these wireless RF technologies concentrate large amounts of data and information to provide customers greater features and benefits. This ever increasing density of information being transmitted, leaves very little margin for error and often the shortcomings are overcome with increase transmission power of components that are, by the technological benefit they provide, non linear. It is then that the slightest weather phenomena, geomagnetic storms, lightning storms and other causes create the non-linearities that result in interference.

When interference to aviation is reported by the users of the NAS spectrum the first course of action is to investigate if it has or can be detected by a ground resource or facility such as an Air Traffic Control Tower. When this is the case, FAA spectrum specialists can quickly deploy ground mobile direction finding equipment to the vicinity of this facility since most likely the source is within the facilities radio line of sight. Figure 3 shows a typical Portable Interference Monitoring Detection System (PIMDS) deployed to investigate interference affecting the San Juan Puerto Rico Wide Area Augmentation System Reference Station (ZSU WAAS) reported by the facility engineers.

Figure 3: Portable Interference Monitoring Detection System

When the interference is reported by the ground facility as intermittent and can not be detected by the PIMDS then the immediate deployment of the Transportable Interference Monitoring Detection System (TIMDS) is executed. This mobile unit allows the interference investigators to attain a greater range near the facility with added capabilities and can be left unattended for data collection during long periods of time. This system provides the capability to detect potential interference to the Global Positioning System L1 frequency as well as L2 and the future planned L5 frequency. In addition once is established at an initial location it can be controlled remotely by a Fixed Interference Monitoring Detection System (FIMDS) via telephone lines. Figure 4 shows a typical FAA TIMDS unit deployed to investigate interference affecting Los Angeles International Airport communication frequencies controlled by the Los Angeles FIMDS Node Master. TIMDS are located around the United States within the FAA Regional boundaries. Currently there are eleven TIMDS units.

Figure 4: Transportable Interference Monitoring Detection System

When the interference is only reported by aircraft pilots, locating the source with the ground resources becomes a very difficult task. This task is even more difficult when the altitude of the aircraft is such that it becomes impractical to deploy any ground resource until the geographical area of search can be reduced to a manageable size. This ground investigation difficulty is due to the large geographical area produced by the radio line of sight (RLOS) of the aircraft. The equation that determines the RLOS is; $\sqrt{\mathbf{2h}}$, where **h** is the altitude of the aircraft in feet. If the RLOS in desired in nautical miles then the formula is; $\mathbf{0.87\sqrt{2h}}$, where **h** is again the altitude of the aircraft in feet. This means that for an aircraft flying at 15,000 feet the area of search is approximately 123 nautical miles.

AIRBORNE RFI INVESTIGATION

Over the years the FAA airborne interference investigation capability was performed on an «as needed basis» with a small number of assets and during those RFI events that were causing severe impact to NAS operation. These FAA airborne assets were mostly utilize for research programs within the agency and often were not readily available for engaging on immediate airborne interference investigations. During 1997 the FAA Aviation Systems Standards program began the NASE/RFI service. This innovative new service now provided the opportunity for FAA spectrum management specialists to have immediately available a crew of airborne detectives that could reduce the area of geographical search to a few miles.

During 1995 and 1996 the FAA Spectrum Policy and Management program had engineers working on adapting the existing ground capabilities into the airborne platform. The NASE/RFI service prove to be very successful to a point that interference to NAS air-ground communications was now being detected and identified within one day of the mission starting time. This gave way to the emergence of the Airborne Interference Monitoring Detection System (AIMDS). Figure 5 shows the location of a pirate FM Broadcast operation identified within one day allowing immediate legal action by the Federal Communications Commission.

Figure 5: Pirate FM Broadcast affecting VHF communications

AIRBORNE IMDS

The AIMDS obtains bearings to the source of interference in real time allowing crews to immediately maneuver the aircraft to obtain cross bearings that will provide the triangulation needed for determining the potential location of the source. Figure 6 shows the type of bearing display obtained from the AIMDS in the stand alone as well as computer controlled mode for data storage.

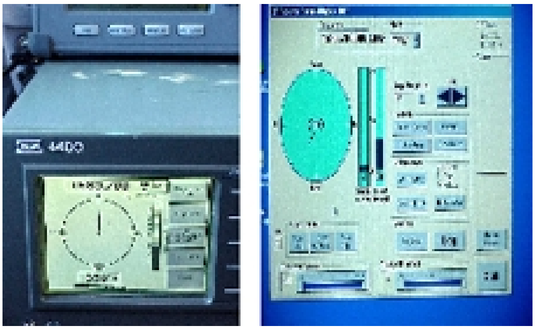

Figure 6: AIMDS Bearing Display

In addition, with the suite of on board spectrum analyzer and receiver equipment, essential interference signal characteristics and information is obtained for identifying the type of RFI signals. Figure 7 shows the spectra of an interference signal detected in the L1 passband of the San Juan WAAS reference station receivers determined to be a satellite telephone terminal.

Figure 7: L1 Interference Signal Affecting WAAS

These capabilities allow specialists to speed the detection and location of the potential RFI source by recording their sound characteristics or their spectral behavior. Early this year 2000 two missions were concluded within a few hours from the time they started including the crew landing and continuing with a PIMDS unit until the source was shut down. Flight Inspection crews are engaging in the search of the interference source until its final location is positively identified and are assisting spectrum specialists in mitigating the source. The NASE/RFI service has proven to be an essential service for NAS interference resolution and is improving as the spectrum and flight inspection partners become more experience in each platform. Figure 8 shows one of the FAA's Aviation Systems Standards (AVN) King Air BE-300 equipped with the AIMDS. This aircraft model was implemented first since the largest number is available in the fleet inventory.

Figure 8: AVN AIMDS King Air BE-300

The AIMDS is composed of a direction finding processor, which is common to the ground based PIMDS and TIMDS, Spectrum Analyzer and GPS receiver equipment. The AIMDS can be operated in a stand alone mode or controlled with a standard Windows operating system computer or laptop. Figure 9 shows the basic components of the AIMDS configured on the FAA's Aviation Systems Standards (AVN) King Air BE-300 airframe. Additional AVN airframes such as the Challenger, LearJet and Hawkers are planned for obtaining AIMDS capability by the end of 2002. In addition, the long term future plans are to integrate the functions and data collection capabilities from the AIMDS as an existing stand alone system into the Flight Inspection Systems (FIS) equipment suite currently operated by the flight inspection technician. This will allow for a two mode operation in either stand alone with local automated capabilities for data and bearing information storage or fully FIS automated for bearing information data link to ground IMDS resources.

Figure 9: AIMDS Components

The added benefit when the AIMDS is in computer control mode either with a local laptop or the FIS computer system is the bearing mapping overlays. These allow for accurate analysis of a particular suspected source of interference being investigated. With the use of a commercial Windows based mapping tools such as MapInfo or any other suitable tool that could be interfaced to the AIMDS GPS receiver the DF bearing overlays can be generated. Figure 10 shows some of the results that can be obtained when overlaying the bearings on a mapping analysis tool.

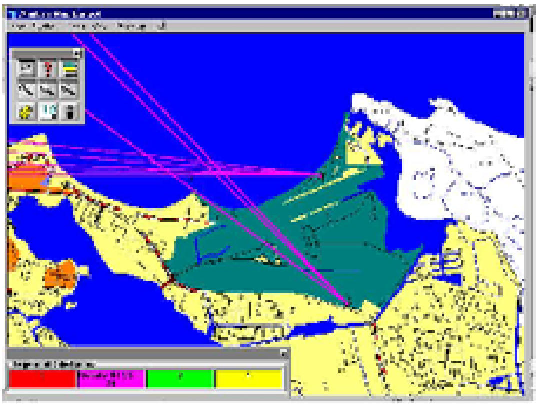

Figure 10: AIMDS Map Overlay Analysis Tool

The use of a mapping tool then provides the means for triangulating and identifying an area. This information presently is passed on to ground resources such as the PIMDS, TIMDS or FIMDS for manually adding these bearings to any additional bearings obtained by these platforms. In the future this information is planned to be down link to the ground resources (PIMDS, TIMDS or FIMDS) so that automatic triangulating processing for immediate response to the location suspected can be achieved. Figure 11 shows the existing FIS suite in the FAA Aviation System Standards BE-300 used by the mission specialists and planned for AIMDS integration.

Figure 11: FAA FIS on King Air BE-300

Although the AIMDS system components can cover the frequency band and spectrum used for GPS navigation, the current direction finding antenna array available is for VHF spectrum. In fact the receiver and direction finding processor can be used from 20 to 3000 MHz with the appropriate antenna connected. The antennas that provide direction finding capability (in the GPS band) used in the PIMDS and TIMDS are the mobile type but not approved for airborne applications. In addition, two separate antenna are used in the PIMDS and TIMDS to cover the L1, L2 and L5 frequencies. In the case of the FIMDS, one 15 feet antenna provides coverage from 20 to 3000 MHz.

At the printing of this paper, two antennas for GPS airborne direction finding with the AIMDS have been tested yielding marginal results, and others have been identified as potential candidates. It is expected that while the 11th International Flight Inspection Symposium is under way, a suitable antenna would have completed testing with good results. Figure 12 shows the VHF direction finding antenna array currently in service with the FAA Aviation System Standards King Air BE-300 airframe.

Figure 12: VHF AIMDS Antenna Array

As mentioned, down link of the mapping overlay information is an area that is being developed. Some of the alternatives under consideration include utilizing channels within the future next generation digital communications time division multiple access. Other less sophisticated alternative discussed are via SATCOM service or VHF FM communications, as currently used under the Aviation Systems Standards NASE portion of the NASE/RFI service.

Once the means for down link of the bearing information map overlays in the AIMDS is established, then interconnection with other platforms, such as the PIMDS, TIMDS and FIMDS could provide one comprehensive real time interference monitoring detection system. The ultimate goal is for achieving a cohesive all platform system which could potentially pinpoint a source of NAS interference within a few hours or perhaps in less than one hour from the first reports received.

The all related platforms Interference Monitoring Detection System IMDS comprehensive real time capability will be particularly key and crucial as the aviation community transitions from ground based to satellite based navigation. The IMDS will continuously monitor the spectrum utilize for aviation, detect any interfering signals and provide the necessary tools for collecting the data and evidence necessary for coordinating mitigation trough proper agency and proponent coordination.

While the FAA Aviation Systems Standards and Spectrum Policy and Management offices continue the development work of integrating the AIMDS data link with the ground platforms (PIMDS, TIMDS and FIMDS), the capability for AIMDS GPS interference detection and location continues in parallel. The initial capability being focused on the most simple stand alone mode. Figure 13 shows the simplest concept being focused at present where a direct correlation of direction finder bearing to GPS receiver radio frequency interference (RFI) loss of signal can be identified.

Figure 13: DF LOB correlation to GPS signal loss.

The FAA program offices of Aviation System Standards and Spectrum Policy & Management are also analyzing the applicability of other new direction finding technologies for use in the GPS spectrum. These technologies are being researched by the United States Department of Defense. These new technologies also make use of advance digital signal processing and active nulling antennas. Other systems utilize beam forming techniques and active anti-jamming circuitry. These techniques and technologies at press time of this paper are planned to be researched, tested and proven feasible for flight inspection at the FAA's research Technical Center. The initial airframe to be use is the King Air BE-300.

CONCLUSION

The formal flight inspection airborne direction finding capability sought out during the 1990 Six International Flight Inspection Symposium held in Washington, DC USA is well under way. This capability prove valuable, successful and effective under the FAA's Aviation System Standards Navigational Aids Signal Evaluator and Radio Frequency Interference program. The NASE/RFI service as presented during the tenth International Flight Inspection Symposium held in Seattle, WA USA is timely, responsive and provides resolution to interference affecting the US national airspace system before it has any impact to the users.

The success of the initial NASE/RFI interference detection capabilities in early efforts provided the basis for the emergence of a proven fully operational Airborne Interference Monitoring Detection System (AIMDS). The AIMDS is now being improved to include capabilities to data link, detect and locate interference to the GPS spectrum. Additional technologies for direction finding in the GPS spectrum are also being researched.

It is without a doubt that the added investigative airborne interference function and service being provided by the FAA Aviation System Standards Program and the Spectrum Policy & Management

Program has made a significant difference in the impact to NAS operations and safety of the flying public. The impact to Air Traffic Services and a substantial time response (and cost related savings to commercial users and the government) in determining the cause of the problem has been achieved. The current level of response by all IMDS platforms is planned to be improved as satellite base navigation increases and more transportation users become more dependent upon the GPS technology.

REFERENCES

ICAO Aeronautical Telecommunications
ANNEX 10, Volume I, Volume II, July 1996

ITU Manual of Radio Regulations, 1990

US Standard Flight Inspection Manual
FAA Order 8200.1A

US Spectrum Engineering Procedures Manual
FAA Order 6050.32A

Six International Flight Inspection Symposium Final Proceedings, 1990.

Tenth International Flight Inspection Symposium Final Proceedings, 1998.