MODELLING THE EFFECTS OF ENGINEERING MAINTENANCE ERRORS IN AIR NAVIGATIONAL AIDS

Case of Instrument Landing Systems in Kenya

BY

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ABSTRACT

Instrument Landing System (ILS) is a ground-based instrument approach system that provides precision guidance to aircrafts approaching and landing on a runway using combinations of radio signals. The problem of monitoring the ILS signal has been investigated for a number of years. Both experimental and theoretical studies have yielded information about system performance, but little has been done to model effects of maintenance engineering errors in the ILS localizer. The composite signal from the ILS localizer operates in a manner to maintain stable equilibrium by ensuring that its courseline information is in tandem with the runway centerline. However, errors due to drifts in electronic component values have the tendency to destabilize this equilibrium. The bearing of drift errors on parameters of signal quantities and their subsequent effects on lateral courseline information has significant impact on approaching and landing aircrafts. The purpose of this study is to conduct a test experiment based on linear continuous-time state equations and develop models for analyzing ILS localizer maintenance engineering errors. The second purpose is to design a MATLAB tool to be used in predicting the effects of these errors on aircrafts approaching Kenyan airports. It will be ascertained that this study shall contribute in enhancing the design process of instrument flight approach procedures for air traffic control services and thus reducing the number of aircraft accidents that occur within airport zone boundary.

INTRODUCTION

1.1 Background

As the worldwide air transportation traffic volume grows rapidly, safety in aviation becomes a burning problem over many countries today. Aviation accidents may result in human injury or even death. It influences the reputation and the economy of the air transportation industry of a country. According to Mineata (1997), when the accident rate is applied to the traffic forecast for 2015, the result would be the crashing of an airliner somewhere in the world almost every week. Braithwaite and Faulkner (1998) stated that in order to achieve safety and reduce accident rate, risk must be quantified and balanced with appropriate safety measures.

Accident statistics based on International Civil Aviation Authority (1997-2006) show that 51% of air accidents occur during final approach, landing and take-offs of an aircraft (Kebabjian, 2008). It is indicated that final approach, landing and take-offs are the periods when the flight maximizes usage of Air Navigational Aids (Navaids). When an aircraft is about to make an approach and landing on an airport during bad weather conditions, there is need to radiate navigational information to carter for lost visibility. Navaids are used for this purpose. One of the Navaids systems used is the Instrument Landing System (ILS).

An ILS is a ground-based instrument approach system that provides precision guidance to an aircraft approaching and landing on a runway, using a combination of radio signals. With reference to Greenwell (2000), ILS consists of two independent sub-systems, one providing lateral guidance (localizer) and the other providing vertical guidance (glide path) to aircrafts approaching a runway. A modulation depth comparison of two radio signal beams radiated strategically from the localizer (LOC) and received by the ILS receiver in the aircraft provides course-line information (runway centre-line) while a similar comparison from the glide path (GP) provides the slope information (inclination angle). Air navigational aids must keep a certain degree of accuracy set by International Civil Aviation Organization (ICAO). Accuracy standards are enforced by flight inspection organizations which periodically check critical parameters using properly equipped aircrafts to calibrate and certify ILS precision.

ICAO annex 10 (2000) presents some of the engineering errors that occur in ILS localizer as a result of momentary drifts in critical parameters due to geographical factors, human manipulations and design constraints. The three types of errors are; parallax errors, multipath propagation errors and Maintenance Engineering Errors (MEEs). Maintenance engineering errors come as a result of difference in the signal parameters received on the runway centerline due to drift in value of circuit components. MEEs can also be caused by maladjustment of signal levels that lead to deviation of ILS courseline from runway centerline. The worst case of these errors is the provision of false ILS information that misguides the aircraft to miss the runway centerline and crash outside or within the airport. This proposal is focused to study the effects of MEEs on ILS signal using modeling and simulation. Huschem (1994) experiment found that ILS signal could be suitably modeled along linear continuous-time state model equations. These findings were later enhanced by the research conducted by Tromboni (2010).

1.2 Problem Statement

The signal from the ILS localizer operates to maintain stable equilibrium by ensuring that its courseline information is in tandem with the runway centerline. The drifts in electronic component values have the tendency to destabilize this equilibrium and thus creating a window for aircraft accidents. Air navigational aids and aircrafts operate in real-time domain that involves human life and expensive equipment. This constraint makes the study of effects of maintenance engineering errors risky and probably unattainable in real time. The purpose of this study is to conduct a test experiment using linear time-invariant state equations to develop models for analyzing ILS localizer maintenance engineering errors. Another purpose is to design a MATLAB tool to be used in predicting effects of these errors on aircrafts approaching Kenyan airports.

1.3 Objectives

The broad objective of this study is to analyze and predict the effects of maintenance engineering errors in air navigational aids using modeling and simulation.

The specific objectives;

1) With reference to state model equations for linear continuous-time systems and ILS localizer signal equations, develop canonical state variable model for localizer systems in Kenya.
2) Perform experiments to determine matrix constants for the ILS localizer state variable model.
3) Using ILS localizer state variable model design a MATLAB program to simulate maintenance engineering errors and predict the magnitude of their effects on landing aircrafts.

1.4 Research Questions

1) What is the state variable model for ILS localizer systems in Kenya?
2) What are the matrix constants for the ILS localizer state variable model?
3) How can effects of Navaids maintenance engineering errors be predicted?

1.5 Justification and Significance of the Study

The study of maintenance engineering errors in Navaids aims at facilitating minimization of the errors through design and maintenance of Navaids. Minimizing the errors shall reduce the number of accidents that occur during instrument landing of aircrafts. The study shall enhance the designing of instrument flight approach procedures for air traffic control services. Simulations can be useful in the validation of Navaids behavior with respect to specific scenarios and other existing infrastructures in the area, and to identify the overall preferred solution to exploit the instrumented environment (Tromboni, 2010). The models and simulations cannot substitute the actual flight data, but shall atleast reduce the volume of data required to gain an understanding of possible scenarios and of the differences among possible solutions. With more descriptive models of engineering error behaviors, simulations could additionally serve to predict the outcome of variable and unintended behaviors (Shah, 2008). According to Greving (2008) more and more signal distortion and interference problems for navigation, landing and radar systems are encountered today. A reliable prediction of the effects on these systems by complex objects is required in advance. This task can be solved today by advanced systems simulations using models. He observed that compromises for fast computer versus accuracy and reliability of results were unacceptable. It is quite obvious that modern modeling theory is reliable in general if the adequate methods and tools accompanied by relevant knowhow are applied.

LITERATURE REVIEW

Shah (2008) presented the view point that air navigational aids (Navaids) exhibit behaviours that emerge from the combined actions of individuals within the system and hence such behaviours cannot be predicted by examining individual behavior alone. Simulations include physical models of technology behaviour and description of their operating environment. Simulation of these individual models acting together can predict the result of completely new transformations in procedures and technologies. While simulations cannot include every aspect of system behaviour, they can provide quick cost effective insights that can supplement other forms of analysis.

2.1. The General ILS Theory

The ILS system consists of the LOC which gives azimuth lateral information, the GP which provides the inclination or elevation information and marker beacons which give the pilot visual and aural indications. Thus the ILS system gives the air craft information about its position in both azimuth and elevation in relation to a predetermined approach profile. A cross-pointer instrument in the air craft receives the LOC and GP signals, and the pointer position varies depending on the position of the air craft.

2.2. The principle of the ILS Localizer

According to Greenwell (2000) the localizer transmitter operates within the frequency band of 108 to 112MHZ with channel separation of 200KHZ. Its antenna system is strategically designed and placed symmetrically around the centerline of the runway and approximately 300 metres behind the runway stop-end. Information about the position of an air craft is achieved by modulating the transmitted carrier with tone frequencies, 90HZ and 150HZ. The radiation pattern of the antenna system has such a form that 150HZ modulation is predominant on the right hand side of the course-line, seen in the approach direction while 90HZ modulation is predominant on the left side. See figure 2.1. The two tone frequencies are amplitude modulated to a depth of 20% with tolerance of $\pm$2% and harmonic distortion less than 10%. The course-line of a localizer is theoretically a straight line consisting of all points where equal levels of 90HZ and 150HZ are received or all points where the difference in depth of modulation (DDM) is equal to zero. The course-line is usually adjusted to coincide with the center-line of the runway. The receiving equipment of the localizer in the Air Craft (AC) is a cross-pointer instrument that reacts to the difference in depth of modulation between 90HZ and 150HZ dots. The identity (ID) of ILS facility is provided by 2 or 3 letters of the Morse code amplitude modulated at 10% and transmitted by the LOC.

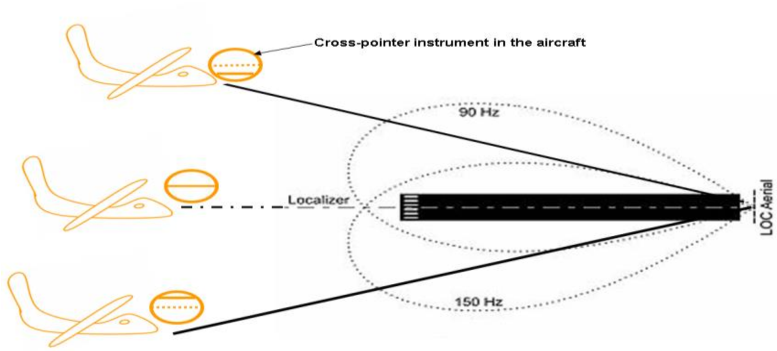

Fig.2.1. Principle of the ILS Localizer

2.3. Signal Generation in ILS System

According to Gordon (2006) and Greenwell (2000) the ILS principle is based on comparison of depths of modulation for two tones. These two tones 90Hz and 150HZ are modulated on the same carrier and form a signal called CSB (Carrier and Side Bands). This is done in the electronic part of the ground equipment. Further, the same tones are used for producing a combined sideband signal designated SBO (Side Bands Only). When the two Radio Frequency (RF) signals, CSB and SBO, are mixed in the near-field and far-field of the antenna, a new modulation process called space modulation (SM) is obtained, causing the depth of modulation of CSB signal to be dependent on the amplitude and phase relationship between CSB and SBO in each point where they are mixed. By comparing depths of modulation after detection of the RF signals, the air craft receiver finds the magnitude and direction of the air craft's displacement from the desired course-line.

The CSB signal is an RF signal modulated by two sinusoidal Audio Frequency (AF) signals, 90HZ and 150HZ. The SBO signal is also RF signal but with suppressed carrier. It consists of two Double Side Band Suppressed Carrier (DSBSC) signals. Thus in the SBO signal there exist one DSBSC signal for 90HZ modulation and one DSBSC signal for 150Hz modulation. The CSB and SBO are generated by both the LOC and GP equipment. However, for the LOC, depth of modulation is 20% and for GP, modulation is 40%. Both CSB and SBO are created in a modulation process and the AF signals (90HZ and 150HZ) are supplied by the same source. However different requirements concerning both AF and RF phase relationships exists for these two signals. Per definition 90HZ and 150HZ should be IN-PHASE for CSB signal as shown in figure 2.4. Also per definition 90HZ and 150HZ should be in PHASE-OPPOSITION for the SBO signal as shown in figure 2.5. Notice that after 3 cycles of 90HZ and 5cycles of 150 HZ, the AF signals are IN-PHASE for CSB and in PHASE-OPPOSITION for SBO.

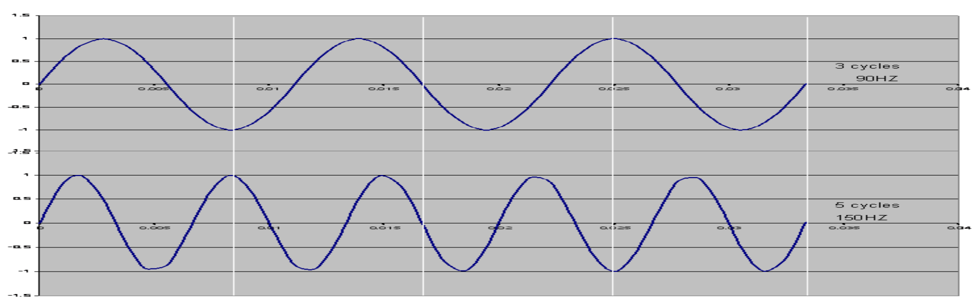

Fig.2.4. 90HZ and 150HZ IN-PHASE for CSB signal per definition

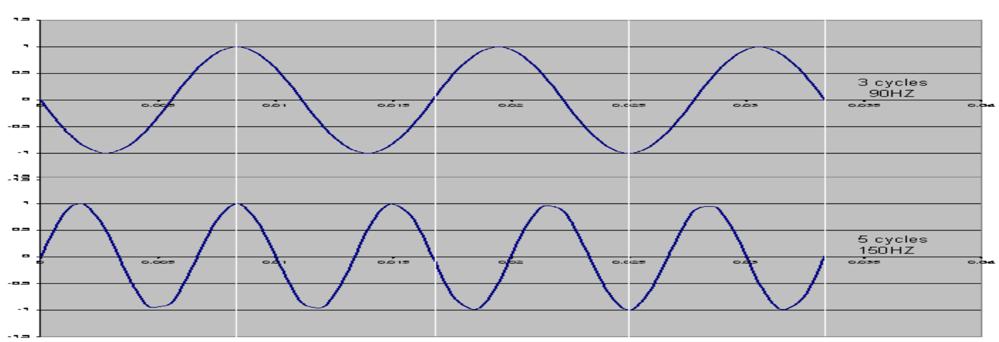

Fig.2.5. 90HZ and 150HZ in PHASE-OPPOSITION for the SBO signal

2.3.1. The CSB Signal

The CSB signal can mathematically be expressed as follows:

$$E_{CSB} \equiv E_c Cos2\pi f_c t + E_{90} Sin2\pi f_{90} t Cos2\pi f_c t + E_{150} Sin2\pi f_{150} t Cos2\pi f_c t \quad ....Eq. 2.1$$

$$Where: \ E_c Cos2\pi f_c t = The\ Carrier\ in\ CSB\ Signal,$$

$$E_{90} Sin2\pi f_{90} Cos2\pi f_c t = LSB + USB\ of\ 90HZ\ in\ CSB\ Signal$$

$$and\ \ E_{150} Sin2\pi f_{150} t Cos2\pi f_c t = LSB + USB\ of\ 150HZ\ in\ CSB\ Signal$$

$$m_{LOC} = \frac{E_{90}}{E_c} = 0.2 = Loc\ depth\ of\ \text{mod}ulation,\ m_{GP} = \frac{E_{90}}{E_c} = 0.4 = GP\ depth\ of\ \text{mod}ulation$$

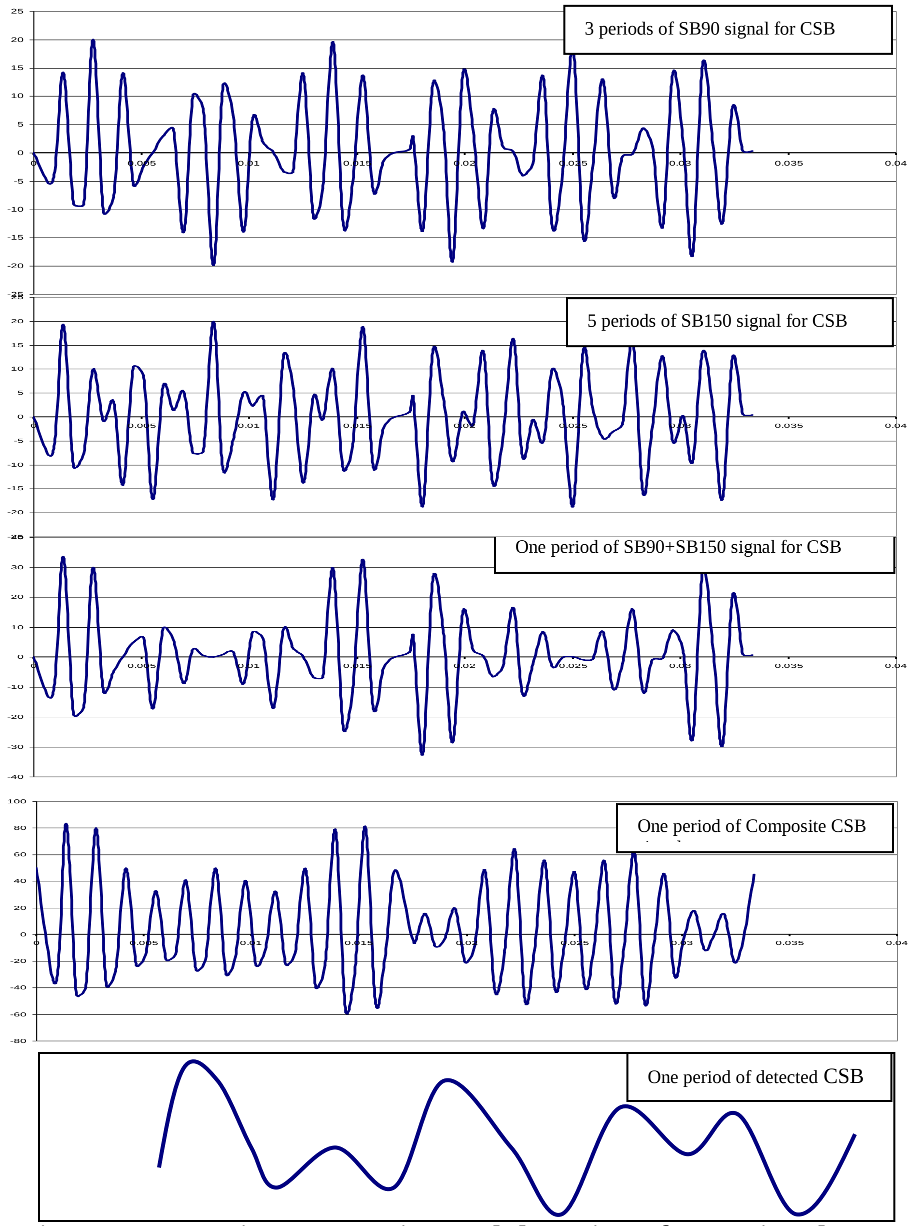

Fig. 2.6.Generation, processing and detection of CSB signal

2.3.2. The SBO signals

The SBO signal has two sidebands that are in PHASE-OPPOSITION per definition. The sideband, SBO90, associated with 90Hz and the sideband, SBO150, associated with 150HZ are consequently in PHASE-OPPOSITION. These two sidebands are generated separately as equivalents of DSBSC signals. The SBO signals are graphically shown in figure 2.7 and figure 2.8.

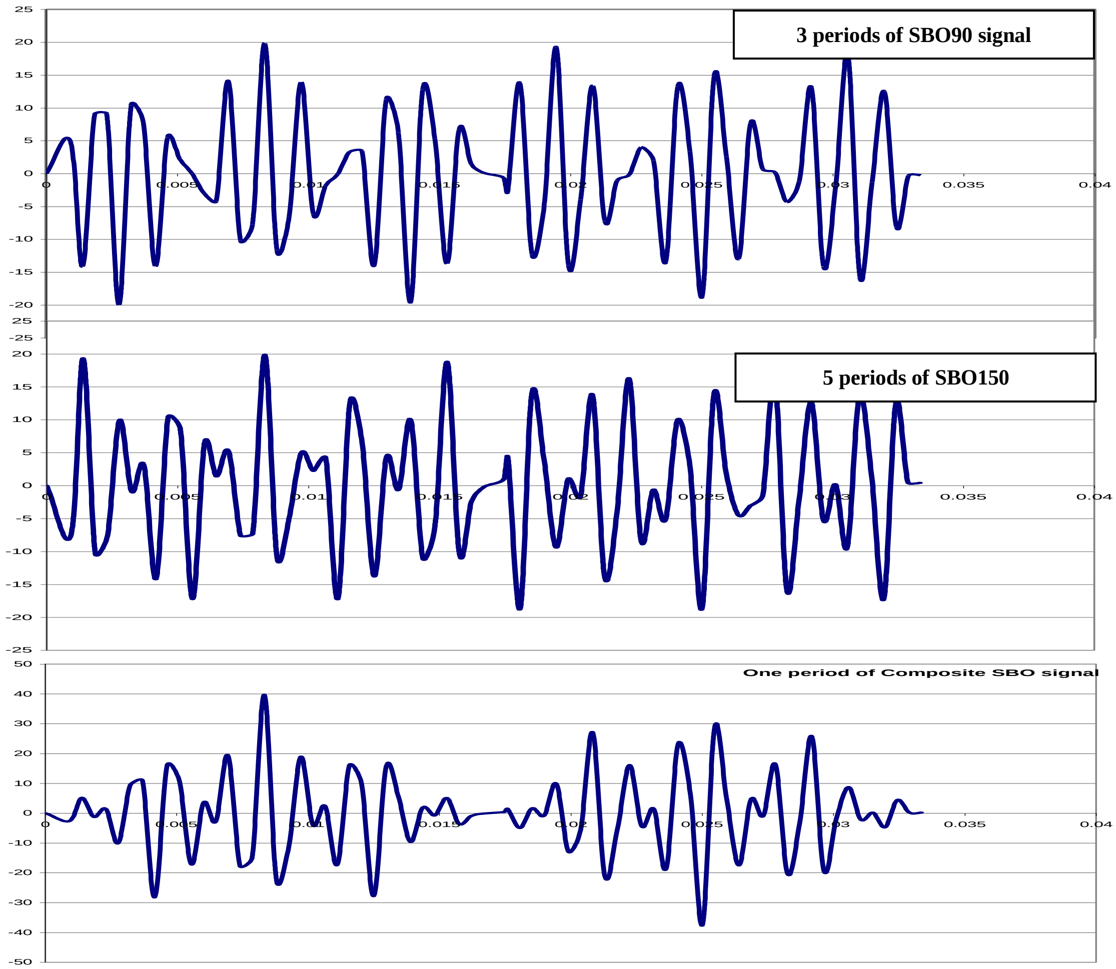

Fig. 2.7. Generation of SBO signal

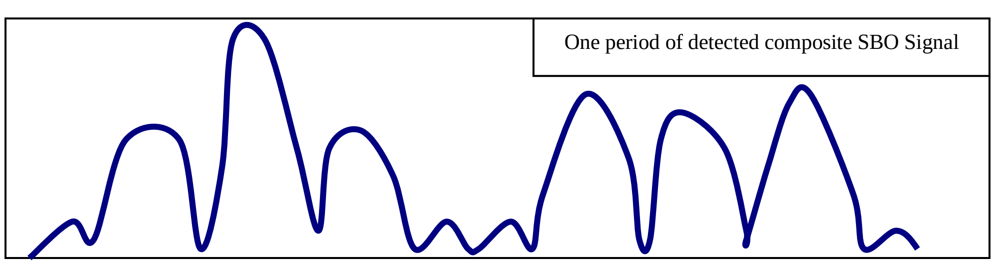

Fig.2.8. One Period of detected composite SBO signal

The mathematical expressions for the signals in figure 2.7 are as follows:

$$\mathrm{E}_{SBO90} = \mathrm{K}Sin2\pi f_{90}tCos(2\pi f_c t + \pi) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.2.2$$

$$\mathrm{E}_{SBO150} = \mathrm{K}Sin2\pi f_{150}tCos(2\pi f_c t) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.2.3$$

$$K = Amplitude\,of\ each\,sideband,$$

$$and\ for\ proper\,operation, K = K_{90} = K_{150}$$

$$If\ K_{90} \neq K_{150}\,then\,\mathrm{E}_{SBO90} \neq \mathrm{E}_{SBO150}$$

$$\mathrm{E}_{SBOtotal} = \mathrm{K}Cos2\pi f_c(Sin2\pi f_{150}t - Sin2\pi f_{90}t) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.2.4$$

The expression for the radiated SBO signal in the far field will somewhat be modified as the signal attenuation and phase shift in the space as well as antenna characteristics must be taken into consideration.

2.4. Radiation of ILS localizer signals

With reference to Biermann (2008) the principle for localizer radiation can simply be explained by a three-element antenna system. These antennas are arranged as a horizontal array on the extension of the runway centerline and perpendicular to it facing the approach direction of the runway. The central antenna radiating the CSB signal is positioned directly on the centerline's extension while the two other flank antennas radiating the SBO signal are positioned one on each side at a distance of half wavelength from the CSB antenna. The resultant radiation patterns are as shown in figures 2.9. In figure 2.9e, the number of radiating elements is increased to 13 (1 central antenna and 6 flank antennas on either side), thus enhancing directivity. The DDM is only dependant on the SBO level since the carrier is constant within the course sector. Typical example is the JKIA ILS.

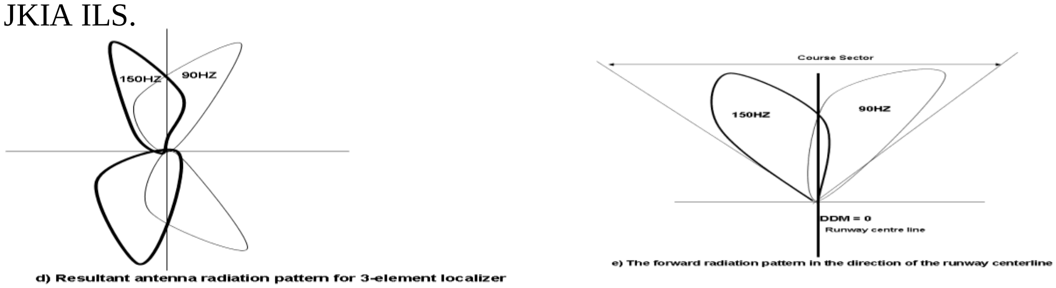

Fig.2.9. The principle of the radiation pattern of the localizer

2.5. Errors in ILS system

According to Marcum (2002) the problem of monitoring the performance of the Instrument Landing System (ILS) has been investigated for a number of years. Both experimental and theoretical studies have yielded information about system performance, but the problem has by not been completely solved. Major error sources contributing to ILS performance were identified as electronic component drifts and/or failures, scattering from nearby reflective surfaces, and changes to the ground plane in the vicinity of the ILS. Transmitter signal errors can affect the radiated antenna signals that form the ILS courseline. Radiated signal integrity is verified by integral monitoring**.** An integral monitor samples the antenna currents, verifying that the transmitted signals are capable of generating the commissioned courseline. Integral monitors are calibrated by flight measurements to determine what changes in transmitter signal causes the courseline to go out of tolerance. Reflective objects near the ILS produce multipath errors, which cause roughness, course bends, and scalloping in the approach region. ILS critical areas were established to reduce multipath interference from objects such as structures, vehicles, and aircraft stopped on the ground. The ILS critical area is a region in front of each radio navigation antenna system where these objects are restricted. This procedure reduces certain types of errors to what might be expected from terrain irregularities

Most of the errors mentioned above are minimized or completely eliminated during design and installation of Navaids. However, MEEs persist because of their operational and dynamic nature. The major contributing source to MEEs is electronic component drifts and failures, and human errors arising from inaccuracies in setting up system parameters. This type of errors comes as a result of varying differences in the signal parameters received on the runway centerline. These signal parameters along the runway are phase and power levels of CSB, SBO90 and SBO150. It is required that 90HZ signal level should be equal to 150HZ signal level along the runway centerline, which means that the difference in depth of modulation (DDM) should be null. However, due to drift or faulty circuits in the equipment or maladjustment of signal levels, it is possible that the two signal levels are not equal, which means that the ILS courseline does not coincide with the runway centerline. Such errors are purely a maintenance problem and their modulating effect introduces displacement errors in the flight motion as the aircraft approaches the airport.

2.6. Modeling of ILS Localizer

Hueschem and Knox (1994) conducted experiments to model ILS localizer signal on runway 25L at Los Angeles airport California USA. A joint NASA/FAA flight was made to obtain and develop information suitable for mathematically modeling the localizer signal from an instrument landing system (ILS) at ranges from 10 to 32 nm from the localizer antenna for future simulation studies. An additional purpose of the test was to determine and document the location of the ILS localizer signal for future airplane tracking tests. This test was conducted on runway 25L at the Los Angeles International Airport. During the flight tests, localizer deviations were recorded as the airplane was flown along two preprogrammed paths that had multiple straight-leg segments perpendicular to the runway centerline. The "truth" position of the airplane, as tracked with precision ground-based radar, was recorded as the airplane was flown along the paths. Differential Global Positioning System (DGPS) navigation was used to ensure that the flight paths were repeatedly flown to obtain a consistent set of data for statistical analysis. The desired lateral portion of the ILS localizer signal recorded corresponded to a difference in depth of modulation equivalent to a signal level of +150uA at the ILS receiver output. The flight test procedures and post-flight data analysis performed on the computed differences between the recorded ILS data and recorded precision radar tracking data were described. The data analysis showed that the ILS signal could be suitably modeled with a linear equation. The ILS courseline was found to be offset to the left of runway centerline by 0.071°. No major beam bends were observed in the data although two insignificant beam bends of approximately 0.01 ° were observed at 12 and 20 nm from the localizer antenna.

Another research work related to Hueschem and Knox (1994) was conducted by Marcum (2002). He designed a monitor that was shown to be theoretically capable of determining the effects of snow cover and standing water in the vicinity of an Instrument Landing System (ILS), thereby reducing the number and length of outages. He presented a discussion of errors and calibration, along with an example of a practical design. He also examined the effects of snow on ILS and derived a concise description of the conditions that cause the system to go outside the designated tolerances. Further, by measuring changes in the image radiation from the ILS glide Slope, he used a formulation of geometrical optics to show that ILS signals have characteristics of a linear continuous-time state.

Cortesi et al. (2002) using the ILS localizer at Venice international airport, set up a whole airport model and simulations were carried out in order to collect data measured along the runway axis with a van and along the approach path with a flight inspection aircraft and compared it with computed data. The goal of this simulation activity was to measure the degree of accuracy of the numerical model of the airport which was judged good enough for the purpose of commissioning. This experiment enhanced the knowledge that airport models can be simulated to provide crucial data for design and commissioning of Navaids.

Biermann et al. (2008) and Greving (2008) described the aspects of state-of-the art system simulations by evaluating actual examples, such as the new Airbus A380 with respect to the instrument landing system, large extended structures in a close distance to navigation systems and arrays of wind turbines close to enroute navigation and ATC radar stations. They examined complex distortions and interference problems for navigation, landing and radar systems. The task was to obtain a reliable prediction of the effects on these systems as a result of distorting objects. This task was solved by system simulations using numerical methods. They showed that by applying numerical methods even complicated cases can be simulated reliably and accurately.

These findings were later enhanced by Tromboni and Palmerini (2010) when they conducted a research on navigational aids performance evaluation. They dealt with evaluation of expected performance of aircraft approaches and landings operated with different navigation systems, both traditional and satellite-based. Flight dynamics characteristics and control authority of the approaching aircraft were considered in order to obtain an overall maneuver evaluation. The technique from the presented analysis was applied to different operating conditions, taking into account aircraft requirements, navigation systems features, and environmental constraints. They aimed to offer a tool to be used in preliminary design phase for system performance analysis in different scenarios, such as airport ground systems adoption and air traffic control requirements compliance. A numerical code referring to the presented analytical model was implemented and some applications concerning the system's performance evaluation and planning were proposed to illustrate the algorithm capabilities. The tool and the proposed analysis technique were indeed successful in providing a quantitative assessment of the differences among several possible approaches.

Tromboni and Palmerini (2010) analysis was based on a model for the flight mechanics of the approaching/landing aircraft. The scheme proposed by Bryson (1994) was selected, with an algorithm based on the linearized motion equations obtained by perturbing an equilibrium configuration typical of the descent phase. Resulting relationship assumed the classical aspect:

$$\dot{x} = Fx + Gu,$$

$$y = Hx + Lu,$$

where F represented the natural dynamics of the state x and G was the distribution matrix for the control vector u. The controlled dynamics was completed by an observation section, which did provide the relationship among the measured variables y, the state and control vectors, as function of dynamic observability matrix H and of a control observability matrix L. To provide a realistic case, the aircraft was considered as equipped with a Stability Augmentation System (SAS), and therefore targeting steady conditions. These actions were computed via a Linear Quadratic Regulator (LQR), which certainly applied to the selected linearized dynamics and was capable to provide the optimal solution by minimizing a quadratic performance index:

$$J = \frac{1}{2}\int_0^\infty (x^T Ax + u^T Bu).dt$$

Where A and B were weighting matrices associated with the tolerances acceptable on the state and control vectors.

2.7. The Proposed System and Gaps in the Previous Studies

Tromboni and Palmerini (2010) conducted an experiment that determined matrices F, G, H and L in addition to matrices A and B. They were able to design and implement a numerical code model which was tested by a set of actual flight data gathered during flight tests performed at Linate airport in Milano Italy in December 2005. Also a tool was developed in MATLAB to simulate the approach, implementing different modules specifically tailored to each flight phase.

Whereas Tromboni and Palmerin (2010) dealt with evaluation of expected performance of aircraft approaches and landings operated with different ILS systems, taking into account aircraft maneuvers and environmental constraints, they did not examine the electrodynamics of the ILS signal in relation to courseline information and runway centerline. They didn't consider the quality, accuracy or control and stability of the ILS signal along the runway centerline. Flight dynamics characteristics and control authority of the approaching aircraft were considered in order to obtain an overall maneuver evaluation but not to control signal generated by the ILS system. Nevertheless, they were able to relate classical linear control theory equations and flight dynamics characteristics that encompasses ILS signals.

It is therefore evident from previous studies that little has been done to study and model the electrodynamics of an ILS signal. The signal from the ILS localizer operates to maintain stable equilibrium i.e. to maintain its courseline information in tandem with the runway centerline. There is a tendency to destabilize this equilibrium via drift in electronic component values. The bearing of these drift errors on parameters of signal quantities and the subsequent effects on lateral courseline information has significant impact on approach and landing of aircrafts. This proposal offers to provide a solution by conducting a test experiment based on linear continuous-time state equations and develop models for analyzing ILS localizer maintenance engineering errors. The second purpose is to design a MATLAB tool to be used in predicting the effects of these errors on aircrafts approaching Kenyan airports. The procedure for performing this experiment shall involve using a van to transverse the ILS localizer course sector of 35 degrees and a radius of 4nm at Jomo Kenyatta International Airport Nairobi. Various tools and equipment shall be used collecting data on ILS signals received within the course sector. This data shall later be tested and validated by the actual flight calibration data collected in October 2009. These data shall be used to develop models to analyze effects of maintenance engineering errors on approaching /landing aircrafts. From the models, a tool shall be developed in MATLAB to simulate these effects. The selection of the MATLAB environment was due to its capability to handle matrices and easiness of use and availability of routines to help in control design.

The foundation of this study is to expound on the knowledge that ILS signal can be suitably modeled around linear time-invariant state equations. It follows that the ILS state model has inputs and outputs that are approximately linearly related. Having established this relationship, the ILS can be modeled such that a revolutionary change in the input parameters can result in a predictable output. The purpose of this study therefore is to analyse the effects of maintenance engineering errors on ILS courseline deviations using modeling and simulations.

METHODOLOGY

Introduction

In Navaids, system behaviours at a higher level of abstraction are caused by behaviours at a lower level of abstraction which could not be predicted or made sense of at the lower level. The agents in the higher level of abstraction include Navaids technicians, air traffic controllers and pilots. The lower level of abstraction includes ILS and aircraft technology behaviours. See figure 3.1

While models can provide what the responses would be to a variety of conditions, only simulation can predict what specific conditions they will actually encounter. Simulation is used to see what activities may be demanded of an individual when a revolutionary change is made to the ILS system to see what system-wide behaviour would be in response to the changes. The proposed methodology includes a method of predicting impact of revolutionary changes to an Instrument Landing System (ILS).

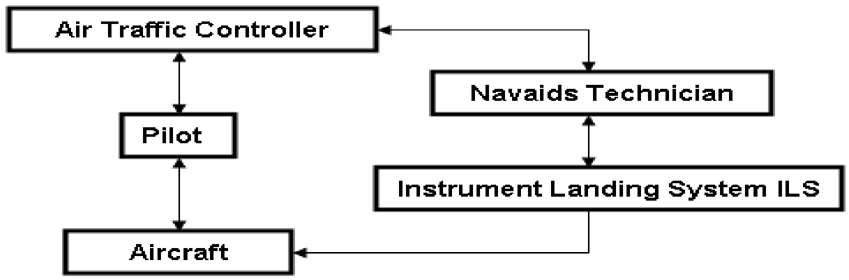

Fig. 3.1. Model agents-technology interaction

Maintenance engineering errors come as a result of difference in the signal parameters received on the runway centerline. It is required that 90HZ signal modulation level should be equal to 150HZ signal modulation level along the runway centerline, which means that the difference in depth of modulation, DDM should be null. However, due to drift or faulty circuits in the equipment or maladjustment of signal levels, it can be found that the two signal levels are not equal, which means that the ILS courseline does not coincide with the runway centerline.

3.1. Test Site

The test site of the experiment shall be Jomo Kenyatta International Airport. It will be carried out within ILS localizer course sector of 35 degrees which shall coincide with a DDM of 150uA. The coverage distance shall be 4nm from the localizer.

3.2. Equipment

Spectrum analyzer to measure radio frequency (RF) power in CSB and SBO signals.

RF power meter to measure the power transmitted by the ILS equipment.

Digital multi-meter to measure voltage levels of 90Hz and 150Hz signals generated in the ILS equipment.

ILS portable receiver to measure DDM at selected points within the course sector.

DGPS to measure azimuth position at every point the DDM is determined across the course sector.

Dual transmitter ILS localizer to generate the signals.

Van to enable movements within the ILS course sector.

3.3. Procedure

The first step of the experiment shall be to establish the edges of the course sector (35 degrees) and the coverage distance (4nm) as seen in figure 3.2. Fix and record the voltage signal levels of 90Hz and 150Hz as generated by the ILS localizer. Also fix and record in milli-watts the RF power level of the carrier signal as generated by the ILS equipment. Use a van to make steady transverse ground movements across the course sector along the coverage distance in the fore-course direction. At every steady distance record RF power levels of CSB and SBO in milli-watts, record the DDM value in micro-amperes and the azimuth position in degrees. Repeat the above procedure but in the back-course direction. Record the average values.

The second step of the experiment is to introduce and fix a 1% variation (error) in the signal levels of 90Hz and 150Hz and another 1% variation (error) in the carrier signal. Record the corresponding variations (errors) in the DDM, CSB and SBO at every azimuth position in the front-course and back-course directions. Record the average values. Step 3 to step 25 are incremental loops of second step.

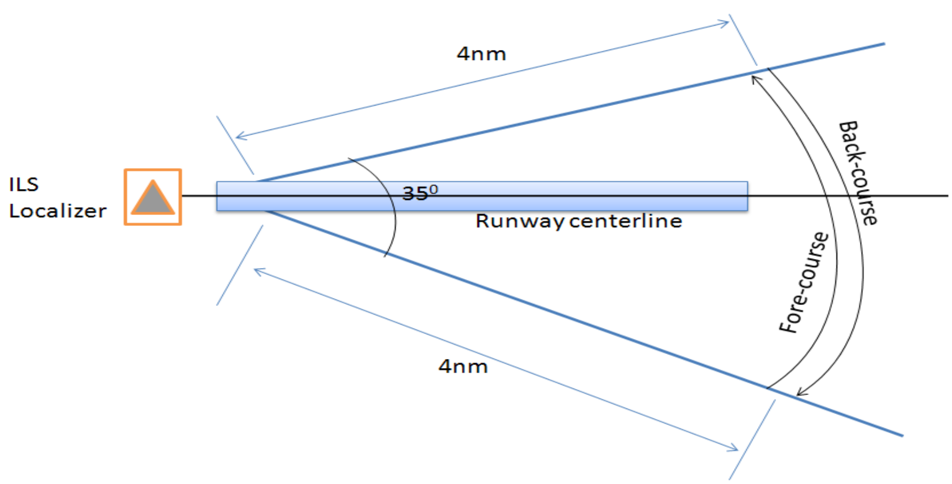

Fig. 3.2. Designed course sector for the test experiment.

After designing and implementing a numerical model, it shall be tested and validated by a set of actual flight data gathered during flight tests performed at Jomo Kenyatta international airport in October 2009 and by another actual flight test data to be gathered in February 2012 at the same airport. After the model is tested and validated, simulations will be conducted by introducing random variations (errors) in the state variables (Carrier, 90Hz and 150Hz levels), observing subsequent errors in input variables (CSB and SBO power levels) and determining the resulting errors in output variables (DDM and Azimuth).

3.4. ILS localizer signal MEEs variables and constants

The concept for ILS localizer signal modeling is as indicated in Figure 3.3.

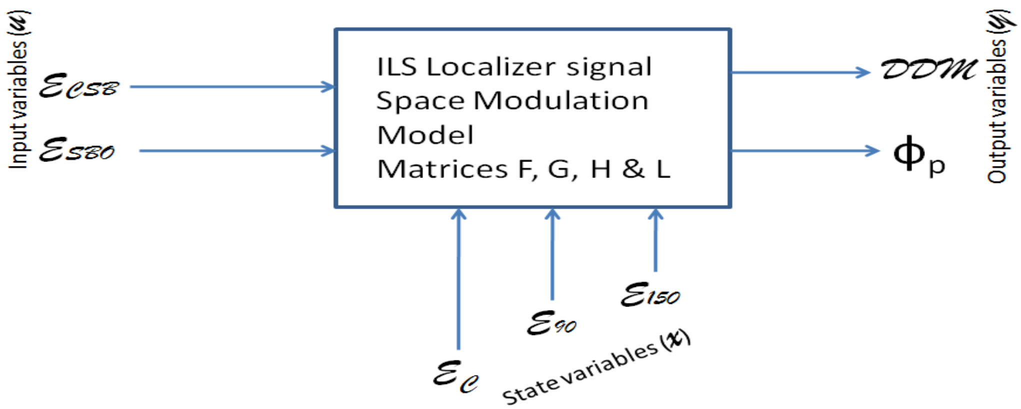

Fig. 3.3. Concept of ILS localizer signal modeling

$$\Delta \dot{x} = F\Delta x + G\Delta u \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.3.1$$
$$\Delta y = H\Delta x + L\Delta u \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.3.2$$

Where x = state variables

u = input variables

y = output variables

D*x*, D*u* and D*y* are errors resulting from revolutionary changes in the respective variables As previously stated by Tromboni and Palmerini (2010), matrix *F* represents the natural dynamics of the state *x* and *G* is the distribution matrix for the control vector *u*. The controlled dynamics are completed by an observation section, which is to provide the relationship among the measured variables *y*, the state and control vectors, as function of dynamic observability matrix *H* and of a control observability matrix *L*.

The ILS localizer is designed to generate signals whose parameters can be varied by human manipulations, failures, drifts in circuit component values and disturbance from the environment. For this experiment the input variables relationship shall be as follows;

$$where\ \Delta\dot{x} = \begin{bmatrix} \Delta\frac{d\varepsilon_c}{dt} \\ \Delta\frac{d\varepsilon_{90}}{dt} \\ \Delta\frac{d\varepsilon_{150}}{dt} \end{bmatrix} = \begin{bmatrix} \Delta\dot{\varepsilon}_c \\ \Delta\dot{\varepsilon}_{90} \\ \Delta\dot{\varepsilon}_{150} \end{bmatrix},\ \Delta x = \begin{bmatrix} \Delta\varepsilon_c \\ \Delta\varepsilon_{90} \\ \Delta\varepsilon_{150} \end{bmatrix}, \Delta u = \begin{bmatrix} \Delta\varepsilon_{CSB} \\ \Delta\varepsilon_{SBO} \end{bmatrix}$$

$$and\ F = \begin{bmatrix} a_{11}\, a_{12}\, a_{13} \\ a_{21}\, a_{22}\, a_{23} \\ a_{31}\, a_{32}\, a_{33} \end{bmatrix}, G = \begin{bmatrix} b_{11}\, b_{12} \\ b_{21}\, b_{22} \\ b_{31}\, b_{32} \end{bmatrix}$$

$thus;$

$$\begin{bmatrix} \Delta\dot{\varepsilon}_c \\ \Delta\dot{\varepsilon}_{90} \\ \Delta\dot{\varepsilon}_{150} \end{bmatrix} = \begin{bmatrix} a_{11} a_{12}\, a_{13} \\ a_{21}\, a_{22}\, a_{23} \\ a_{31}\, a_{32}\, a_{33} \end{bmatrix} \begin{bmatrix} \Delta\varepsilon_c \\ \Delta\varepsilon_{90} \\ \Delta\varepsilon_{150} \end{bmatrix} + \begin{bmatrix} b_{11}\, b_{12} \\ b_{21}\, b_{22} \\ b_{31}\, b_{32} \end{bmatrix} \begin{bmatrix} \Delta\varepsilon_{CSB} \\ \Delta\varepsilon_{SBO} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.3.3$$

Similarly, output variables relationship shall be as follows;

$$where;\ \Delta y = \begin{bmatrix} \Delta DDM \\ \Delta\Phi_P \end{bmatrix}, H = \begin{bmatrix} c_{11}\, c_{12}\, c_{13} \\ c_{21}\, c_{22}\, c_{23} \end{bmatrix}, L = \begin{bmatrix} d_{11}\, d_{12} \\ d_{21}\, d_{22} \end{bmatrix}$$

$Thus;$

$$\begin{bmatrix} \Delta DDM \\ \Delta\Phi_P \end{bmatrix} = \begin{bmatrix} c_{11}\, c_{12}\, c_{13} \\ c_{21}\, c_{22}\, c_{23} \end{bmatrix} \begin{bmatrix} \Delta\varepsilon_c \\ \Delta\varepsilon_{90} \\ \Delta\varepsilon_{150} \end{bmatrix} + \begin{bmatrix} d_{11}\, d_{12} \\ d_{21}\, d_{22} \end{bmatrix} \begin{bmatrix} \Delta\varepsilon_{CSB} \\ \Delta\varepsilon_{SBO} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.3.4$$

a_{11}…….. a_{33} are constant elements of matrix F

b_{11}…….. b_{32} are constant elements of matrix G

c_{11} ……. c_{23} are constant elements for matrix H

d_{11} ……. d_{22} are constant elements for matrix L

Determining the constants for matrix F, G, H and L is the onus of the test experiment

3.5. State model

The onus is to determine matrices F, G, H and L. These shall be determined by performing experiments that involve introducing errors in each of the parameters X (t) and U (t), and observing corresponding changes in Y (t). To determine matrix F, G, H and L, a 15-test experiment shall be performed and data recorded as in table 3.1.

Table 3.1
Tabulation of test data to determine matrix F, G, H and L

Test	**Settings**		**Front-course**		**Back-course**		**Mean**	
	$\Delta x(\%)$	$\Delta \dot{x}(\%)$	$\Delta u(\%)$	$\Delta y(\%)$	$\Delta u(\%)$	$\Delta y(\%)$	$\Delta u(\%)$	$\Delta y(\%)$
1	0	-	-	-	-	-	-	-
2	1	-	-	-	-	-	-	-
3	2	-	-	-	-	-	-	-
4	3	-	-	-	-	-	-	-
5	4	-	-	-	-	-	-	-
6	5	-	-	-	-	-	-	-
7	6	-	-	-	-	-	-	-
8	7	-	-	-	-	-	-	-
9	8	-	-	-	-	-	-	-
10	9	-	-	-	-	-	-	-

Thus, repetition of error variations by test experiment represented in table 3.1 will result into 25 simultaneous equations based on Eq.3.3 and Eq.3.4. The generated equations shall have 25 unknown constants a, b, c and d in matrices F, G, H and L respectively. These simultaneous equations shall be solved using MATLAB programs to determine the constants. The selection of the MATLAB environment was due to its capability to handle matrices and easiness of use, as well as having wide choice of available routines to help in control design. With complete determination of matrices F, G, H and L, the ILS state model shall be represented by Eq.3.3 and Eq.3.4.

3.6. Simulation of state model

The state model represented in Eq.3.3 and Eq.3.4 shall have matrices F, G, H and L determined. Thus, variation of state and input variables shall affect the output variables.

Introduction of errors in the state and input parameters shall generate corresponding errors in the output. The simulations shall be used to determine the relationship and magnitude of these errors. The magnitude of effect of Maintenance Engineering Errors (MEEs) on DDM can be calculated. The magnitude of deviation from ILS courseline will be predicted and so is the deviation from the runway centre line caused by MEEs. Based on these data a MATLAB tool shall be developed for future use in analyzing and simulating maintenance engineering errors.

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