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ATC OPERATIONAL ERROR ANALYSIS

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16. Abstract

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position and arrival time errors at specified fixes. If this algorithm were too dependent on a perfect 4-D guidance capability, then it would be expected that the landing rate might decrease, missed approaches might increase, and possible conflicts between aircraft might occur. Whereas, if you were evaluating a metering and sequencing algorithm and wanted to determine its response to missed approaches, one might arbitrarily specify that certain aircraft will be missed approaches and turn them back to the metering and sequencing algorithm for re-sequencing.

The aforementioned method will suffice to determine the effects of blunders on the performance of some of the algorithms utilized by an ATC concept but will not work when one is trying to quantify collision risk, missed approached risk, or any other variable involving risk. Most formulations for defining risk involve error distributions of one or more quantities and the generation of these error distributions is where the problem arises. There are three known ways of generating these distributions and they are as follows 11:

1. Experiments - actually going out in the field and measuring the quantities
2. Real time simulation
3. Fast time simulation

Since for 4GATS systems the experiments are not possible, the data must be generated through simulation using Monto Carlo techniques. To carry out these simulations requires detailed models describing the equipment and human characteristics as they might relate to a given concept. In order to determine these models, one must have a well defined concept which includes airspace structure, rules and procedures, responsibility for actions and the equipment to be used along with the man/machine interfaces. With the aforementioned information, one can then attempt to model functional and operational errors as they might affect this concept. Also, the amount of simulation required can be sizeable, e.g., it has been pointed out in reference 11 that to get an accurate estimate of a quantity of the order of 10-6 (collision risk) could require 10^7 computer runs.

CONCLUSIONS AND RECOMMENDATIONS

Based upon this study of operational errors, the following conclusions can be drawn:

1. In order to analyze blunders one needs a well defined system especially at the man-machine interface; therefore, trying to do detailed modeling of operational errors (blunders) for a future ATC system at the current stage of system definition is next to impossible.

2. An introducing the "effects of blunders" type of approach should be sufficient to evaluate the performance of test algorithms.

3. Evaluating risk for future systems, e.g., collision risk or missed approach risk, will involve a tremendous amount of effort both from a system modeling standpoint and also from a computer time standpoint (Monte Carlo runs).

However, it must be recommended that as soon as the fourth generation air traffic control system begins to formalize, a more detailed analysis of operational errors should be undertaken. This work effort should involve not only system designers, but human factors and safety engineers to produce the level of detail necessary to assess important quantities such as collision risk and missed approach risk for this new system.

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The primary causes of operational errors are discussed and the effects of these errors on an ATC system's performance are described. No attempt is made to specify possible error models for the spectrum of blunders that can occur although previous results are reviewed. Methods of handling blunder effects in preliminary evaluation experiments are outlined and the requirements for future work in the area of blunder analysis are discussed.

1. INTRODUCTION

This report dealing with operational errors is in response to Task 2B as outlined in the 4GATS Program Implementation Plan (1). The work contained herein is being conducted along with a similar effort in the area of functional error analysis (2) as groundwork for future experiments that will examine the sensitivity of the performance of candidate ATC concepts to various error sources.

Operational errors as considered in this report are errors committed by the human elements in the operation of the ATC system. Thus, operational errors are due to goofs or blunders on the part of either the pilot or the controller or both. This is in contrast to functional errors which will be considered as errors arising from the equipment involved with the ATC process. This distinction between error types is somewhat arbitrary. In a more general sense, the work blunder (3) is often used to describe any occurrence, either human or equipment induced, that causes the system to operate outside of the error tolerances for which it was designed or expected to operate. Typically, these rare unexpected events are due to human blunders.

The importance of human engineering a future ATC system to obviate human errors cannot be over-emphasized. It has been pointed out by Cornell (4) that, "seemingly inexplicable, in-consistent and unpredictive human goofs account for 50-70% of all failures of major weapons and space vehicles. This puts human errors ahead of design errors and lapses of quality control in manufacturing.....as a source of system troubles." In the realm of air traffic control, it appears that near misses and mid air collisions are caused more by gross blunders than from the accumulation of small errors (5).

2. OPERATIONAL ERROR ANALYSIS

The fact that all the equipment within an ATC system can be working perfectly and that airplane accidents can still occur leads one quite naturally to the study of operational errors. In this section of the report, the primary causes of operational errors are analyzed and the possible effects of these errors on the performance of an ATC system are discussed. Also, the questions of whether it is necessary to generate and whether it is possible to generate detailed models of operational errors for future generation ATC systems at the current stage of system definition are addressed.

2.1 Causes of Operational Errors

It is important to distinguish between the causes and the effects of operational errors. It is the causes of these errors that the human factors and safety analysis engineer must isolate in order to evaluate the probability of an event happening. Operational and more generally human errors are typically the result of the following four causes (4):

1) failure to follow procedures
2) incorrect diagnosis of a particular situation (errors of judgment)
3) misinterpretation of information or commands
4) insufficient attention or caution

Utilizing these four basic causes, it is possible to list many goofs and blunders that arise in the operation of an ATC system (where the system is taken to include both the controlled aircraft and the ground based ATC system). Some typical blunders are as follows, where the cause is first listed and some possible errors resulting from this cause follow:

Pilot Blunders

1) failure to comply with flight rules, e.g., operating an aircraft at the wrong altitude for a direction of travel or with an excessive airspeed for a given airspace region

2) incorrect diagnosis of a situation, e.g., committing an aircraft to land under adverse visibility conditions or trying to take off on too short a runway

3) misinterpretation of information, e.g., misunderstanding or misinterpreting an ATC directive or misreading a cockpit instrument

4) insufficient attention or caution, e.g., failure to verify that equipment is operating properly or careless operation of the aircraft

Controller Blunders

1) failure to follow procedures, e.g., not maintaining the required separation minimums between aircrafts

2) incorrect diagnosis of a situation, e.g., misjudging closing rate between two aircraft or gambling on the capabilities of an aircraft to perform a mission

3) misinterpretation of information and commands, e.g., misunderstanding pilots' response or misreading information from a radar screen

4) insufficient attention or caution, e.g., missing an aircraft on the radar screen due to inattention or controlling an aircraft in a very sloppy manner

2.2 Effects of Operational Errors

The primary effect of blunders by the pilot is to cause deviations in the aircraft's assumed or desired path. Controller blunders can lead to similar deviations and can also result in the aircraft operating on an erroneous path. The ultimate effects of these blunders on an ATC system's performance could be to cause serious accidents or large delays depending upon the environment in which the aircraft is operating.

Most ATC systems have a certain safety factor or coast time inherent to their operation; therefore, it is most often the persistence of a blunder over a finite period of time that results in a catastrophe. Since most future ATC systems talk in terms of packing more airplanes into a given amount of airspace, the detection and corrective reaction time to blunders will be smaller and smaller for these systems.

Many advanced ATC system planners see automation as the primary means of reducing blunders in future systems. But, like most cures, automation creates a whole new class of human errors (6). These errors are again related to the four previously defined causes and involve blunders like failing to pick up malfunction indicators (a case where an equipment failure is transformed to a human error), lacking confidence or suspecting the automatic system and erroneously resorting to the manual mode, and also taking the wrong action following a system malfunction. If possible, most blunders are alleviated before the fact by applying sound design principles and human engineering the system to prevent them. Most of the previously mentioned blunders occur at the man/machine interface of the automated system. This interface will require special attention from both a design and human factors standpoint if the fourth generation system is to be made workable.

Since even in the best designed system, blunders can still occur, it is necessary to have a means of detecting their occurrence. The primary detection system for cockpit blunders in use today is the ground surveillance radar system. This system has its problems though, as coverage is often limited and radar gives no altitude information. Thus, blunders are often not detected especially during the approach and landing phase of flights. A possible future method of detecting both cockpit and ground controller blunders would be to have aircraft equipped with air to air ranging equipment combined with situation displays. This system could act as a secondary surveillance system and would also allow the pilot to monitor what is happening. A system of this type is currently being studied by Mark Connelly et al (7) of MIT in support of TSC's 4GATS Operational Concepts Group.

2.3 Modeling Blunders

In order to model blunders in a stressed ATC environment, one must have information on what blunders could possibly occur along with their probability distributions and also what percentage of the aircraft operating in the airspace might possibly have committed blunders. Generating the aforementioned information is a virtually impossible task, even for an existing ATC system as demonstrated by the dearth of information on blunders in existence for today's system. The principle source of data on the frequency of occurrence of blunders exists only for blunders that result in fatal accidents. It would be expected that only a small percentage of blunders actually result in fatal accidents; therefore, this data base does not present enough information for one to say anything intelligent about the frequency of occurrence of blunders.

One example of a situation where empirical information was gathered which was independent of fatal accidents was a study of navigation accuracy in the North Atlantic performed by NATSPG (8). In this study, the actual location of aircraft was determined by a surveillance system located on ships anchored in the North Atlantic. This data was compared with where the aircraft was supposed to be and an error distribution curve was plotted. It was found that the tails of this error distribution curve contained many more events than would be expected from either a Gaussian or a First Laplacian error distribution. These excess events were attributed to blunders of one form or another. Based upon studying this data, a zero mean uniform distribution over a set of plausible values was proposed as a possible distribution for the blunders (9). It must be mentioned that this method of modeling blunders gives no information on the causing mechanism. For the previously discussed situation, there appeared to be an equal probability of large and small errors arising. The overall distribution of errors is then found by convolving the Gaussian or First Laplacian distribution with the uniform distribution.

A recent example of utilizing the aforementioned reasoning appears in reference (10). They represented the error distribution for an aircraft operating in the North Atlantic with a IMU as the sum of a time varying Gaussian process (IMU) and a zero mean uniform distribution over a given heading range (blunders).

It is difficult to assess the validity of blunder models without the luxury of empirical data, i.e., when one is given an actual distribution of events and told to model it whether a model is good or bad can be readily ascertained, e.g., the Reich model (9). Whether the uniform distribution can be used in general to describe blunders is not apparent. When no empirical data is available, whether a model represents a physical phenomenon becomes very subjective. This is a problem that will haunt any blunder modeling involved with 4GATS.

2.4 Introducing Operational Error Effects into ATC Concepts Simulations

Ideally, what one would like to do is evaluate ATC concept response to blunders in a realistic manner. This would entail introducing blunders into the concept simulation at either a realistic or worst case rate of occurrence, letting these blunders propagate into adverse effects and then assessing the ATC system's capability to respond to these effects. As mentioned previously, this is an extremely difficult task. Therefore, one is left with what appears to be the only viable alternative and that is to arbitrarily introduce the possible effects of blunders and then see how the concept responds. How blunder effects are introduced into a simulation is very dependent upon what one is trying to evaluate.

For example, if the sensitivity of a terminal area metering and sequencing algorithm to sloppy pilotage is being assessed, the effect of sloppy pilotage could be introduced by causing a certain percentage of aircraft in the system to develop large position and arrival time errors at specified fixes. If this algorithm were too dependent on a perfect 4-D guidance capability, then it would be expected that the landing rate might decrease, missed approaches might increase, and possible conflicts between aircraft might occur. Whereas, if you were evaluating a metering and sequencing algorithm and wanted to determine its response to missed approaches, one might arbitrarily specify that certain aircraft will be missed approaches and turn them back to the metering and sequencing algorithm for re-sequencing.

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- experiments - actually going out in the field and measuring the quantities
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Since for 4GATS systems the experiments are not possible, the data must be generated through simulation using Monto Carlo techniques. To carry out these simulations requires detailed models describing the equipment and human characteristics as they might relate to a given concept. In order to determine these models, one must have a well defined concept which includes airspace structure, rules and procedures, responsibility for actions and the equipment to be used along with the man/machine interfaces. With the aforementioned information, one can then attempt to model functional and operational errors as they might affect this concept. Also, the amount of simulation required can be sizeable, e.g., it has been pointed out in reference (11) that to get an accurate estimate of a quantity of the order of 10^{-6} (collision risk) could require 10^{7} computer runs.

3. CONCLUSIONS AND RECOMMENDATIONS

It is therefore concluded that trying to do detailed blunder modeling is beyond the scope of the present research effort and is probably unnecessary to answer the type of questions that need to be answered over the next year. It is recommended that an "introducing the effects of blunders" type of approach be utilized for the preliminary concept evaluation work. It must be pointed out that in order to evaluate risk, one cannot use the aforementioned reasoning but must face up to the task of accurately trying to model operational errors.

It must also be recommended that as soon as candidate concepts have passed some of these preliminary tests and ideas begin to formalize on what the fourth generation ATC system will be, a more detailed analysis of blunders should be undertaken. This work effort should not only involve system designers, but also human factors and safety engineers in order to produce the level of detail necessary to assess important quantities such as collision risk and missed approach risk for these new systems.

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