A SIMULATION FACILITY FOR ASSESSING THE NEXT GENERATION OF 4-D AIR TRAFFIC CONTROL PROCEDURES

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by

A. Benoît* and S. Swierstra

EUROCONTROL
European Organisation for the Safety of Air Navigation

Rue de la Loi, 72
B - 1040 Brussels

SUMMARY

Until recently, aircraft operation in Air Traffic Control simulations was generally treated in an extremely simplistic manner which failed to take account, in particular, of specific airline procedures and the variations resulting from different aircraft series, power plants, take-off mass and the trajectory patterns recommended for final approaches.

The aim of this paper is to describe a method whereby the characteristics of any airline or air traffic control procedure may be analysed in terms of trajectories, control load, fuel consumption and flight cost. Furthermore, the program developed provides a high degree of realism in the performance of Air Traffic Control simulations as required for systems such as the Zone of Convergence concept.

1. INTRODUCTION

The introduction of advanced digital data processing facilities in the air/ground control loop will constitute an essential characteristic of the next generation of Air Traffic Control (ATC) systems. It is expected that this revolutionary step will make as great an impact on system operation as the introduction of radio telephony or radar in the past. Computers already play an important role, but at a secondary level, e.g. in the processing of flight plans and radar data, and the operation of synthetic radar displays.

Although discussion of the characteristics of the "next generation" system to some extent requires the use of a crystal ball, system designers agree on the broad lines to be followed. The aim is to integrate, as far as is possible, from an air traffic management point of view, the en-route sectors and the terminal area in order to constitute what may be regarded as one large, extended area, surrounding and including a main terminal (TMA) and possibly secondary airports also. This area, which is referred to as a Zone of Convergence (ZOC) would then cover an area of 100 to 200, or ideally 300 nautical miles around the airport or airports concerned.

The ZOC concept, as developed in EUROCONTROL's Engineering Directorate, provides for economical, conflict-free flight paths for outbound, overflying and inbound traffic and, with respect to the latter, an optimised landing sequence. Next generation ATC systems of this type will be of considerable advantage to both Air Traffic Control and aircraft operators. Various studies and experiments have already demonstrated a fundamental improvement in safety levels as well as a reduced workload on the ground and in the air. They have also highlighted the considerable potential for fuel economies, e.g. up to 6 tons of fuel per hour in the case of the total traffic inbound to London Heathrow and Gatwick Airports.

It has become apparent from the tests carried out that the ATC simulation facilities currently available for the organisation of real-time simulations of this type of air traffic management system are not adequate. The large-scale ATC simulators are mainly oriented towards en-route rather than TMA control. In an en-route environment, a simple aircraft model is sufficient to present realistic flight paths to the controllers. However, the study of the feasibility and efficiency of control strategies in an integrated en-route/TMA environment requires realistic aircraft behaviour. This is particularly important for the purposes of assessing whether specific control instructions would lead to a violation of certain safety margins in the operation of the individual aircraft, and the subsequent effects on overall system efficiency and stability.

**Dr. A. Benoît is also Chargé de cours, Faculté des Sciences Appliquées, Université Catholique de Louvain, B-1348 Louvain-la-Neuve.*

Clearly, for the purposes of such experiments, the ideal procedure would be the operation of a number of real airline flight simulators of the appropriate types by qualified crews equal to the number of aircraft simultaneously present in controlled airspace. This approach would doubtless result in very realistic and interesting experiments, but is not feasible owing to coordination and communication requirements and the cost of the relevant exercises.

This paper describes what we believe to be a second-best method. It details a flight simulation facility (FSF) specifically designed for real-time ATC simulations and experiments. This facility incorporates adequate features to enable realistic aircraft behaviour - as seen from the ground - and correct simulation of both airline and ATC procedures. It can be operated either by a person other than a pilot using what will be referred to as an Automatic Flight Operating System, or manually by a qualified pilot using a standard alphanumeric computer terminal as interface.

Section 2 describes the environment in which the ATC flight simulator is likely to operate. Section 3 concentrates on the interface between the flight simulator facility and the ATC unit, together with the resulting requirements in respect of modes of operation and other general design considerations. Section 4 deals with the "cockpit" display, which constitutes the basic pilot-simulator interface. An example of a flight is shown in Section 5. Finally, a discussion of the profile calculation method and the availability of aircraft performance data follows in Section 6.

2. NEXT GENERATION OF ATC SYSTEMS

2.1. Air traffic management in a Zone of Convergence

The Zone of Convergence concept constitutes a typical example of the next generation of Air Traffic Control systems. It is an overall air traffic management system which integrates the climb, cruise and descent phases of flight or appropriate parts thereof, depending on the extent of the controlled airspace. The ZOC system consists of two basic modules. Air traffic management of inbound, outbound and overflying traffic is handled by the ROSAS module (Regional Organization of the Sequencing and Scheduling of Aircraft). This also projects a landing sequence on the basis of, on the one hand, the requirements expressed by each of the aircraft operators, in particular, the ideal cruise and descent speed profiles and preferred approach procedures, and, on the other, the instantaneous load on runway facilities. The second part, the CINTIA 4D-flight control module (Control of Inbound Trajectories of Individual Aircraft), translates the clearances into control directives, which are presented to the ATC controller in terms of radar vectors and/or speed directives e.g. in an additional data line in the standard aircraft label on the radar screen.

The structure of these control directives is such that they can be transmitted via a standard radiotelephony channel and/or automatically via a digital air/ground data link, e.g. one of the facilities provided for in the Mode S of the monopulse secondary radar system.

2.2. Assessing system performance

The potential advantages of the next generation of air traffic management systems such as the ZOC can be evaluated using 'fast-time' simulation models, which assume accurately recorded aircraft behaviour, no meteorological conditions and no human errors or communication problems. These experiments enable an estimate to be made of the upper limit of the potential advantages of such systems, and make possible parametric studies of the impact of various control and management strategies on overall system efficiency.

In order to study man-machine interfaces, coordination problems and system performance under realistic operating conditions, real-time simulations of the full system or specific parts thereof are essential. The large-scale ATC simulation facilities are mainly designed to evaluate typical en-route problems, such as new route structures, inter-sector coordination, etc. When designing an ATC simulation facility, the main aim is to create realistic controller work positions and position modularity with a view to adapting as quickly as possible to changing requirements.

A simulation facility of this nature can generate sufficiently realistic responses to controller directives in an en-route environment. However, the evaluation of ZOC-type systems should also include pilot workload assessment based on the format and contents of the ATC instructions transmitted, possible violation of the safety procedures of specific airlines, particularly during the initial and final flight phases, and controller and sytem reaction to the performance limitations of specific aircraft types.

As has already been mentioned in the Introduction, the simple aircraft models and pilot-operators would be replaced in the optimum evaluation environment by a series of airline flight simulators, each operated by a qualified crew. As this is obviously not feasible, an aircraft flight simulator model has been designed which reproduces aircraft behaviour accurate enough to provide reliable assistance in the studies and experiments described above, but which is nevertheless sufficiently flexible and user-friendly to be successfully integrated into existing real-time ATC simulation facilities.

The next Section discusses in more detail the design considerations specific to the ATC flight simulator facility, and the modes of operation considered.

3. ATC FLIGHT SIMULATOR DESIGN CONSIDERATIONS

3.1. Modes of operation

The design of an airline flight simulator is a very complex and costly project even before the hardware aspects such as cockpit instruments and visual and motion systems are taken into consideration. The cockpit of such a simulator is an exact replica of the aircraft cockpit and the instruments work under all operating conditions in the same way as those in the actual aircraft, providing the crew with reliable information which determines the control action they take.

The main criterion for the design of an aircraft flight simulator for Air Traffic Control purposes is that the pilot-operator should be able to control the simulator in such a way that the flight profiles resulting from the "qualified crew - actual aircraft" combination can be reproduced with a high accuracy in all the flight phases relevant to the ATC exercise concerned. Further requirements are detailed on the basis of Figure 3.1., which depicts the functional diagram of a single aircraft simulator in a typical next-generation Air Traffic Control simulation environment.

The ATC system under examination is shown schematically on the left of the diagram. Its basic source of information is the radar system, wich interrogates the flight simulator for position data. The principal interface between the ATC system and the aircraft is the radiotelephone link between the ATC controller and the pilot-operator. A possible second link is the automatic digital air/ground data link between the ATC system and the pilot, or a direct link with the aircraft systems. The ATC system can therefore operate in two modes: ATC-1 and ATC-2, depending on whether such a data link facility already exists. The aircraft simulator facilities are shown on the right of the diagram.

If the flight simulator facility is to become a practical tool in the perfomance of ATC experiments of the type described above, the following constraints on its design require to be taken into consideration:

- The operator-simulator interface should be independent of aircraft type. This will reduce the required familiarization time and, operationally, has the advantage of greater flexibility in that any aircraft can be allocated to a given pilot-operator position in the ATC simulation exercise.

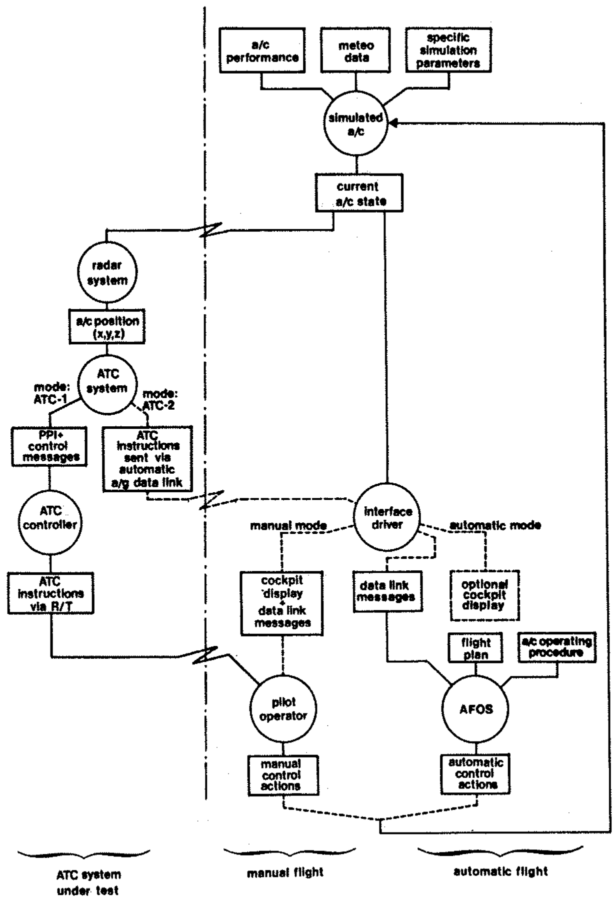
- In addition to "manual" operation by a pilot-operator, an "automatic" mode is also necessary in order to reduce the manpower required during a full-scale ATC simulation. However, the simulator should also be able to react appropriately in the automatic mode to ATC directives generated by the traffic management system under examination.

- The specific aircraft performance should be integrated into the flight simulator program in a modular manner so as to reduce to a minimum the time required for the implementation of a new aircraft type.

- An Air Traffic Control simulation exercise involves the simultaneous presence of many aircraft in the control area. Consequently, the computational load of a single aircraft simulator on the computer system should be kept to a minimum.

- Whenever possible, standard available hardware should be used for man-machine interfaces.

So far, the more general aspects of flight simulator design have been discussed. Specific requirements in respect of the various modes of operation are detailed below.



Schematic simulation operation
Figure 3.1

3.2. Manual operation

In order to enable the pilot-operator to fly several different aircraft types without extensive training, the use of primary flight controls, e.g. a control stick, must be avoided, and the pilot should interface only with the automatic flight control systems, such as the autopilot, autothrottle, etc. This implies that a wide range of automatic equipment will require to be available on any aircraft type modelled, regardless of whether the said equipment is available in the actual aircraft. Furthermore, the layout and presentation of the instruments on the cockpit display will need to be independent of aircraft type. Nevertheless, the set of flight controls and instruments should as a whole be sufficiently realistic to allow a qualified pilot to fly the simulator in an ATC experiment at his own discretion for the purposes of providing expert opinions.

A broad description of the "cockpit" in terms of display screen layout and flight control options offered in the manual mode of operation is given in Section 4.

3.3. Automatic mode

As is shown in Figure 3.1., the pilot operator is replaced in the automatic mode by an 'Automatic Flight Operating System' (AFOS). This module selects the appropriate flight modes in the same way as the pilot. The AFOS takes decisions on the basis of the aircraft's current status (e.g. as indicated to the pilot-operator on the display screen in manual mode), the flight plan and the standard aircraft operating procedures laid down by the airline or aircraft manufacturer. This procedure can be overruled by Air Traffic Control instructions received from the ATC centre via the automatic digital air/ground data link.

The automatic mode offers the same control flexibility in terms of possible flight paths as that afforded by the manual mode and therefore reproduces the same degree of realism in the flight profiles generated. In this mode, operation of the flight simulator can be completely independent of a pilot-operator, yet react consistently to ATC messages. Accordingly, automatic mode is used in an Air Traffic Control simulation exercise primarily to generate 'background' traffic which may be affected by decisions taken by the traffic management modules.

However, it must be understood that, in the automatic mode, the perturbations caused by pilot reactions are eliminated. Moreover, the manual mode provides the pilot-operator with more flexibility to deal with an adverse situation. For example, if a pilot feels that he is a little too high on base leg, he can quite easily remedy the situation by extending flaps and/or landing gear slightly earlier that he would if he were following the standard extension procedure. Higher levels of automation will also result in the standardisation of flight profiles, thus eliminating another perturbing element from the simulation exercise which occurs in actual Air Traffic Control.

3.4. Semi-automatic operation

Although the manual and automatic modes of operation of the flight simulator are referred to above as being independent, it should be pointed out that they may also be combined in order to automate manual operation further. For example, during approach and final descent, the Automatic Flight Operating System may be asked to apply the standard speed reduction and changes in aircraft configuration schedule automatically. Many of the functions which require an operator when the simulator is flown in manual mode can in fact be automated where necessary. This has the following advantages:

- A pilot-operator needs less training to perform a standard flight.
- The actual operator-simulator interface can be considerably simplified in terms of display complexity and possible input.
- One pilot-operator could "fly" more than one aircraft simultaneously, thereby reflecting more closely the present structure used for the organisation of full-scale real-time ATC simulations.

In this mode of operation, the impact on the ATC experiment of perturbation caused by pilot reactions is rather less than in the case of basic manual mode.

3.5. Fast-time operation

During system development, specific flight profiles are often required in order to study rapidly the impact of certain parameters or operating procedures on flight time, fuel, cost, path, etc., and to compare the results obtained using various types of aircraft and other air traffic aspects.

This information can be readily obtained from the flight simulator facility. When the simulator is operated in "automatic" mode, "real-time" can be easily accelerated to produce "fast-time" results. Obviously, this is of considerable benefit during the initial planning of a real-time Air Traffic Control simulation or the subsequent analysis of the results, since the profiles generated in "fast-time" mode are fully compatible with those computed in real time during the actual simulation exercise.

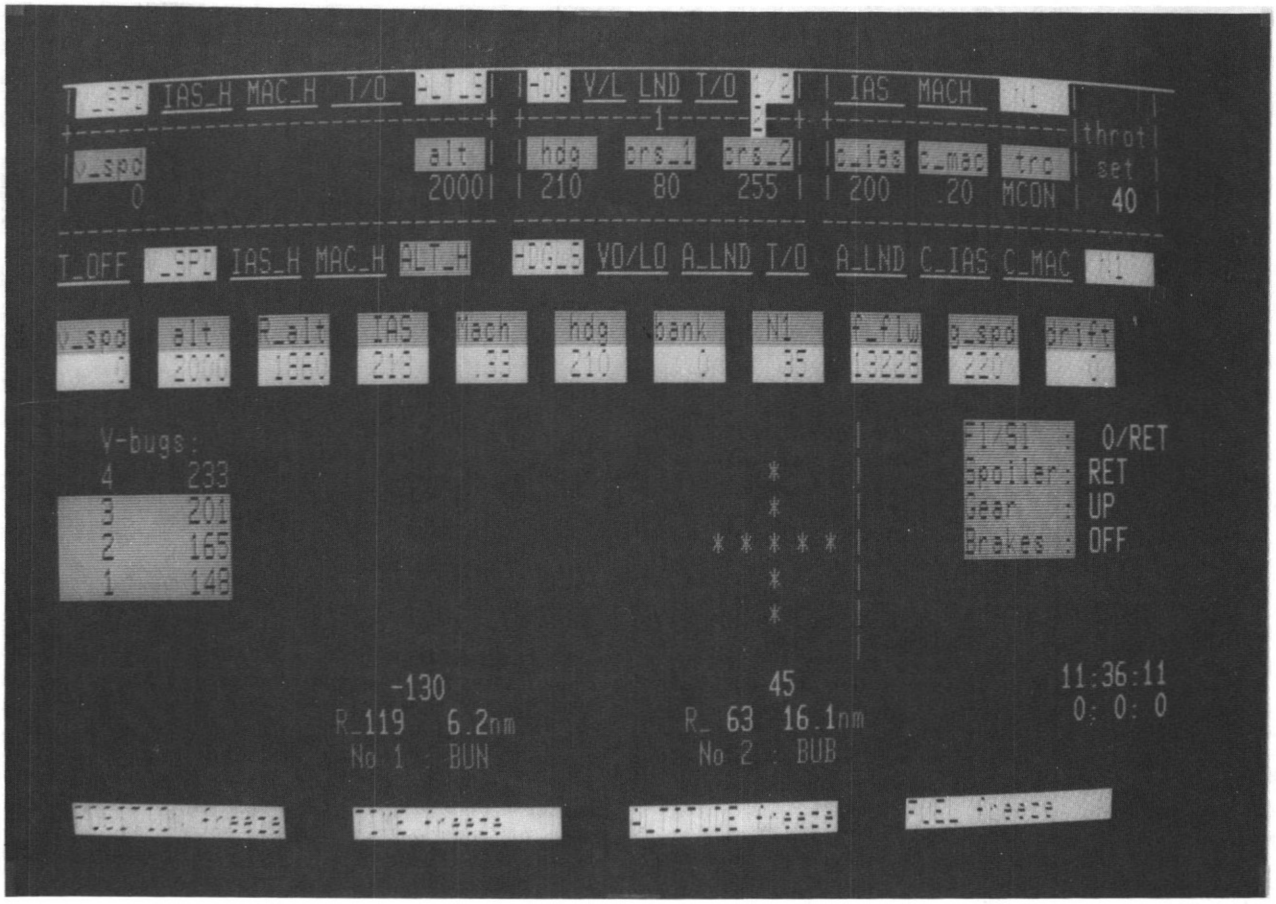
4. THE COCKPIT

The "cockpit", which constitutes the interface between the pilot or pilot-operator and the flight simulator, is a standard alphanumeric computer terminal. It will be described in a subsequent report; the following paragraphs outline only some of its essential characteristics.

4.1. The cockpit display layout

The cockpit display layout can best be discussed on the basis of Figure 4.1., which shows what appears on the screen when the simulator is initialised.

The top and bottom lines are not directly associated with the operation of the aircraft. The first line constitutes the data area reserved for Air Traffic Control messages received via the digital air/ground link. They contain the ATC clearances issued during the flight. The last line on the display pertains to the specific operation of the simulator, e.g. position freeze, altitude freeze, etc. These functions are particularly useful for the evaluation of aircraft performance and during system testing.



"Cockpit" display layout
Figure 4.1

The middle part of the display contains a row of flight instrument indicators. From left to right: vertical speed, pressure altitude, radio altitude (i.e. altitude above ground level), indicated airspeed, Mach number, aircraft magnetic heading, bank angle, engine performance parameter, N1, instantaneous fuel flow, ground speed and drift angle.

Between the ATC message area at the top and the row of flight instrument indicators, there are the three groups of basic flight control functions and Flight Mode Annunciators (FMA) for pitch, navigation and engine throttle respectively. The first line of each group indicates which function has actually been selected. The middle part is taken up by the controls which set specific flying speeds, altitude and courses. Below these, and just above the instruments, are the FMA's, which serve to indicate the functions being performed by the autopilot.

Below the flight instruments on the left is a type of bar display for the various speed bug settings, and on the far right the selections for the airframe configuration, such as flaps/slats, speed brakes, landing gear and brakes. The Horizontal Situation Indicator is displayed in the middle above the navigation receiver selected.

Real time and simulation time are displayed below the airframe controls.

4.1.1. Altitude control

Pitch control may be used to define the progress of the aircraft in the vertical plan.

The possible selections include "Constant Vertical Speed", "IAS Hold", "Mach Hold" and "Altitude select". A function not normally available on an aircraft is provided, viz. "Automatic Take-Off". Two numeric inputs are available, one to preset the vertical speed and the other to define the altitude at which the aircraft will level off if "Altitude Select" has been switched on.

The FMA, shown in bright reverse video, indicates the autopilot function being performed. The low-intensity reverse video mode indicates that the associated function has been "armed", i.e. the case of the "Altitude Select" function, the autopilot will automatically level off the aircraft when approaching the preset altitude.

4.1.2. Navigation control

This section deals with the control of the aircraft's lateral movements. The autopilot can be directed either to fly a constant magnetic heading or to intercept and follow a specific radial of a VOR or localiser. Two navigation receivers are available. The pilot can select from "Heading", "VOR/Localiser", "Auto Land" or "Auto Take-off" modes. The "1/2" switch is used to swith the navigation receiver connected to the autopilot. Preset settings are available for heading and VOR radial selection.

The output of the two navigation receivers is permanently displayed in a three-line section on the lower part of the screen. The first number indicates the difference between the selected radial and current heading. The second line shows on which radial from the beacon the aircraft is flying and the actual DME distance to the beacon. The third line gives the identification of the selected station.

The Horizontal Situation Indicator is displayed above the selected navigation receiver. It depicts "graphically" the aircraft's position with respect to the selected station radial. If the station is a landing aid, a horizontal bar is also displayed, indicating the aircraft's position in relation to the glide slope.

4.1.3. Throttle control

The engine throttles may be controlled manually via the keyboard, or automatically using autothrottle functions. The number in the "throttle setting" area indicates the selected percentage of the maximum thrust that can be generated on the basis of the selected operating mode of the "thrust-rating computer" (TRC), shown just to be left of the throttle setting. Typical TRC modes are "Take off / Go Around", "Maximum Climb" and "Maximum Continuous".

4.1.4. "Speedbug" display

In an actual aircraft, the airspeed indicator has several markers which the pilot presets to remind him of various critical speeds related to the aircraft's operation. The pilot has been provided with a more or less identical feature by the addition of two-bar-type display. When the actual airspeed is below one of the preset values, the value is displayed in low intensity. When the IAS is close to the selected value, it is displayed in high-intensity flashing mode, and when the IAS exceeds the value, the display mode switches to reverse video, thus constituting the "bar".

Since the number and organisation of the speedbugs often differ from one aircraft type to another, and in view of their extensive use by the pilot, this is the only part of the display which changes according to the aircraft type that is being simulated.

4.1.5. Airframe configuration

The status of flaps/slats, speed brakes, landing gear and brakes is displayed in the airframe configuration area on the lower right-hand side of the screen. When the devices are retracted or off, the status is displayed in high-intensity normal video. When they are extended, the status is displayed in high-intensity reverse video. During the period of transition from one status to another, the display is dimmed to low intensity.

4.1.6. Basic automatic functions

The simulator may be flown entirely in manual mode in all flight phases, using "Manual Throttle" to accelerate and decelerate, "Heading" for lateral control and "Vertical Speed" and "Altitude Select" to define the vertical profile. However, during take-off and approach and landing the workload is high, in particular for the inexperienced pilot-operator. To facilitate matters, additional "Automatic Take-off" and "Automatic Landing" functions have been included in the basic flight control functions.

5. EXAMPLE FLIGHT

Since the final part of a flight is the most interesting from an operational point of view, the approach and landing phase of an aircraft flown manually to Brussels National Airport is shown as an example. The recorded ground track, the vertical flight path and the speed profile of the flight are given in Figures 5.1. (a) to (c) respectively. Two pictures of the cockpit display screen are shown in Figures 5.2.(a) and (b). The positions from which these pictures were taken are marked "1" and "2" in Figure 5.1.

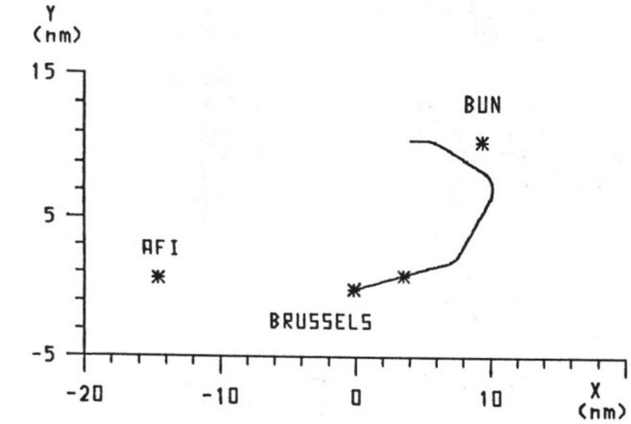
During the flight, the engines were controlled by autothrottle, and the approach and landing phases were performed using the auto-land option. Figure 5.4. shows a situation where reduced speed necessitated the extension of the slats (below 233 knots IAS, see speedbug indicator). The Horizontal Situation Indicator shows that the aircraft had yet to be aligned either with the localiser or glide slope.

Figure 5.5. shows the cockpit display with the aircraft in landing configuration and stabilised on the glide slope.

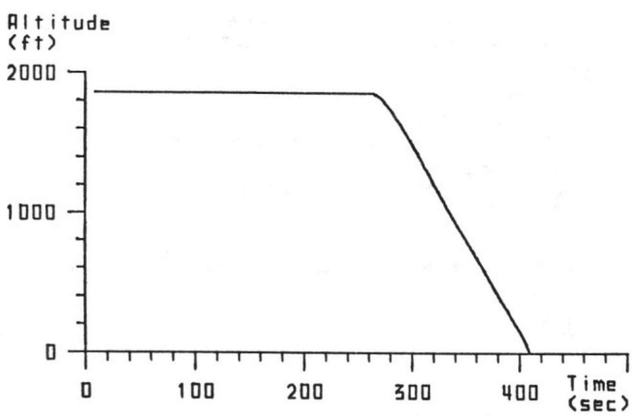
6. AIRCRAFT PERFORMANCE

6.1. Basic assumptions

Aircraft behaviour requires to be simulated in particular during the initial and final phases of flight, which include several acceleration/deceleration phases and associated changes in power setting and airframe configuration. The method used to ascertain aircraft performance is based on earlier work on flight profile calculations (Ref. 3), particularly the Integrated Flight Prediction System (IFLIPS), carried out by the General Directorate of EUROCONTROL.



(a)



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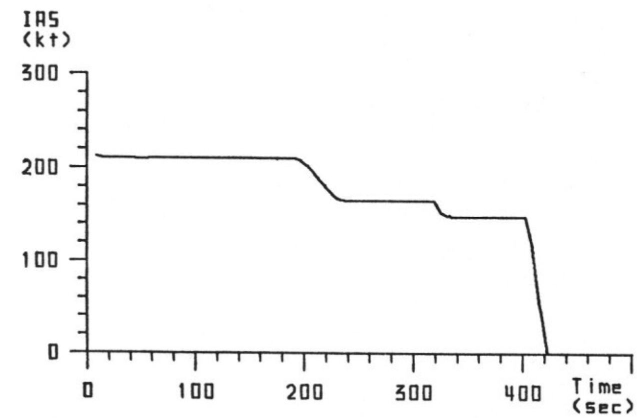
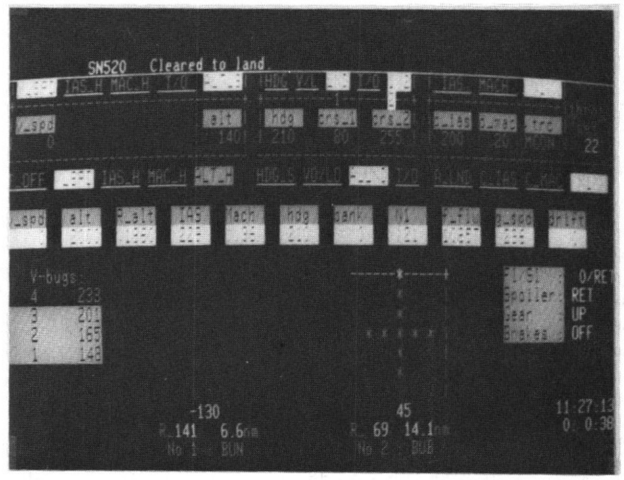
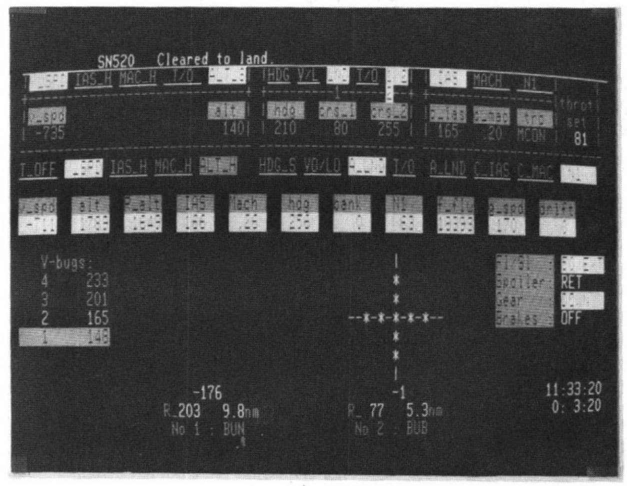


(c)

Example flight
Figure 5.1



(a)



(b)

Cockpit display for example 5.1

Figure 5.2

6.2. Availability of basic data

The cooperation received from the aircraft manufacturer in the course of our work has always been very positive. Nevertheless, it was noticed that requests for aircraft performance data, including detailed information on aerodynamic polar and specific power plant characteristics, can give rise to difficulties. To solve this problem, a method was developed to derive the necessary information in some equivalent form from integrated paths that are readily available.

Accordingly, it is felt now that the basic information required to use the flight simulation facility described in this paper can be obtained in a form suitable to generate simulation results of high quality.

7. CONCLUSIONS

An aircraft Flight Simulator Facility (FSF) has been developed. It is specifically designed to assess the next generation of 4-D Air Traffic Control procedures.

Such assessments require highly realistic trajectory data, particularly with regard to the initial and final flight phases. During the development phases, various requirements arise in respect of flight-path generation, but the results produced must be consistent. To this end, the flight simulation facility provides several modes of operation, viz:

- Two levels of manual operation. At Level 1, the pilot-operator has access to all basic flight instruments and autopilot functions available in the aircraft modelled and the simulator can therefore be operated as in real life.

  Level 2 is specifically geared to the application of the facility in a large-scale real time Air Traffic Control simulation, where, for practical reasons, one operator has to cope with several aircraft simultaneously. At this level of operation, all standard aircraft operating procedures are automated.

- An automatic mode, in which the flight simulator may function independently of a pilot-operator, but is nevertheless able to respond to ATC directives received via an automatic digital air/ground data link.

- A fast-time mode for parametric studies, exercise planning and post-simulation analysis.

Compatibility with current real-time Air Traffic Control simulation facilities was ensured by using a standard computer terminal as a man-machine interface, the "cockpit" layout being adapted accordingly.

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