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THE AUTOMATION OF AIR TRAFFIC CONTROL

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"What a f---ing system!
Send 'em all to the same place
and then expect us to stop 'em hitting."

A controller, Summer 1987

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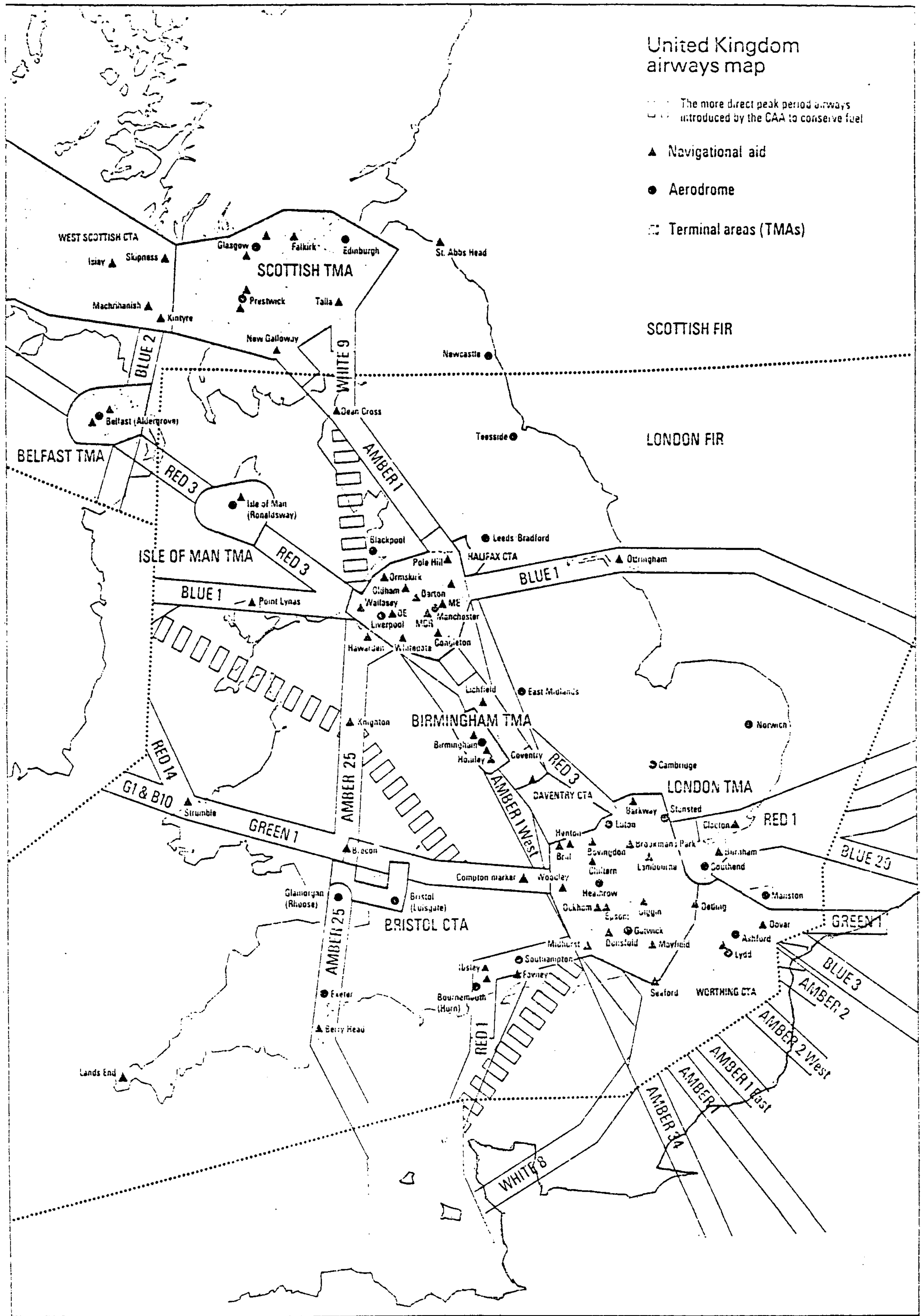
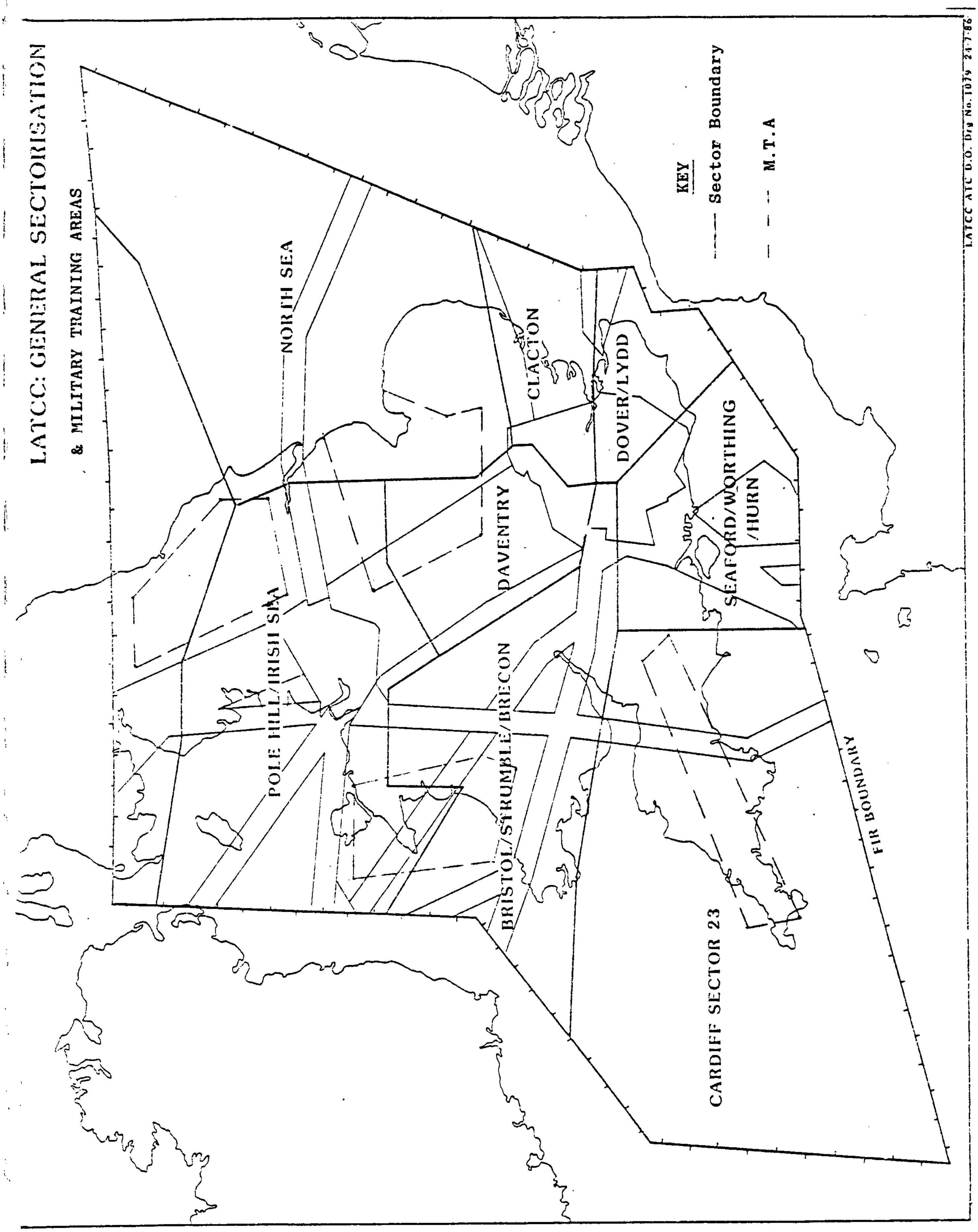
Needless to say, there are many others not mentioned, but to all, many thanks.


United Kingdom airways map
The more direct peak period airways introduced by the CAA to conserve fuel
Navigational aid
Aerodrome
Terminal areas (TMAs)
WEST SCOTTISH CTA
SCOTTISH TMA
Glasgow
Falkirk
Edinburgh
Islay
Skipness
St. Abbs Head
Prestwick
Talla
Machrihanish
Kintyre
New Galloway
SCOTTISH FIR
Newcastle
BLUE 2
WHITE 9
Belfast (Aldergrove)
Dean Cross
Teesside
LONDON FIR
BELFAST TMA
AMBER 1
RED 3
Isle of Man (Ronaldsway)
Leeds Bradford
Blackpool
ISLE OF MAN TMA
HALIFAX CTA
Pole Hill
Ottringham
BLUE 1
Ormskirk
Oldham
Barton
Point Lynas
Wallasey
Liverpool
Manchester
MCR
Congleton
Hawarden
Whitegate
Lichfield
East Midlands
Knighton
BIRMINGHAM TMA
Norwich
Birmingham
Honiley
Coventry
Cambridge
RED 14
AMBER 1 West
DAVENTRY CTA
LONDON TMA
G1 & B10
Strumble
AMBER 25
Barkway
Stansted
GREEN 1
Luton
Clacton
RED 1
Henton
Brookmans Park
Brecon
Bovingdon
Burnham
BLUE 29
Chiltern
Lambourne
Southend
Compton marker
Woodley
Heathrow
Manston
Glamorgan (Rhoose)
Bristol (Lulsgate)
Detling
BRISTOL CTA
Epsom
Biggin
Dover
Gatwick
Ashford
Midhurst
Dunsfold
Mayfield
Lydd
Southampton
Ibsley
Fawley
BLUE 3
Exeter
Seaford
WORTHING CTA
AMBER 2
Bournemouth (Hurn)
Berry Head
AMBER 2 West
RED 1
Lands End
AMBER 1 East
AMBER 1
AMBER 34
WHITE 8

MAP 2


LATCC: GENERAL SECTORISATION
& MILITARY TRAINING AREAS
NORTH SEA
CLACTON
DOVER/LYDD
SEAFORD/WORTHING /HURN
DAVENTRY
POLE HILL/IRISH SEA
BRISTOL/STRUMBLE/BRECON
CARDIFF SECTOR 23
FIR BOUNDARY
KEY
Sector Boundary
M.T.A
LATCC ATC D.O. Drg No. 1079 24-7-86

A glossary of abbreviations is appended

SECTION 1

INTRODUCTION

The steady and accelerating growth in air traffic over the last fifteen years or so have placed a growing burden on air traffic services in the UK. What was a vital but largely invisible occupation as far as the general public was concerned has been the regular recipient of disquieting news coverage of near misses and reports of the alleged failure of the Civil Aviation Authority (CAA) and National Air Traffic Services (NATS) to maintain the quality of their service as the capacity of the ATC system is stretched. It is now also the subject of a Parliamentary Inquiry. Such criticisms have been unfair in some respects, and at best partially informed. Reports about declining morale and the increasing pressure that the service is under occur within a very particular 'industrial relations' context of disagreements over staffing levels and working arrangements (see Section 5), but are given a more pronounced edge with increasing traffic densities. Within this context, however, the general tenor of these reports has some substance.

Little of this public and political prominence existed when we began our research. Our principal research aims were the following:

(1) to analyse the social organisation of ATCO work;

(2) within this, to analyse the working practices and knowledge-in-use of ATCOs;

(3) to focus upon the implications of organisation, practices, knowledge and attitudes for technological innovation in ATC;

(4) to use these analyses to contribute to the completion of an automated monitoring and planning assistant for ATC - *Cassandra;*

(5) on this basis, to throw some light on the problems to do with the design and architecture of man-machine systems;

(6) and, finally, as a longer term aim, to develop connections between sociology and the artificial intelligence aspects of computer science by supplementing or, where appropriate, substituting a psychological with a sociological perspective on the nature of human activities, skills and competences.

In view of the recent notoriety of ATC it is as well to point out that we had no brief to inquire into morale, work loads, staffing requirements, and so on; issues of some delicacy in negotiating access to London Air Traffic Control Centre (LATCC). In the event, however, such issues could not be avoided, though we have tried throughout to maintain an independent and detached stance.

The software for the 'Cassandra' system, designed to monitor and warn of aircraft 'conflictions', was completed by Dr Craig in 1987 (Craig, 1987)[1]. At the time of our fieldwork, however, NATS was preoccupied with reacting to the Monopolies and Mergers Commission and private consultants' reports recommending more efficient use of manpower, with attempting to devise accurate measures of ATCOs' workloads, and with a shift to new methods of TMA sector control (see Section 3.6 below). All of these - together with the public spotlight on safety considerations alluded to above - meant that more adventurous longer-term innovations had to be placed 'on the back burner' while these immediate problems were tackled. Thus, although we found ourselves relatively well placed to attempt to pursue our original questions, the practical context within the CAA had changed in such a way that this was not immediately possible. In order to cope with this while sticking closely to our original research objectives we decided - with the advice of the CAA, NATS and LATCC - to focus our research on technological innovation on the case of the development and implementation of the 'RD3' radar system. This investigation provided us with rich material to illuminate the interactions between human competence and technological provision as well as identifying the features of the controllers' occupational culture relevant in affecting their response to technological innovation. In particular, it reinforced our view that the problems of specifying an expert system lie not only in coding the

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[1]Dr Craig left Lancaster, and the research team, for a post at the University of Warwick in 1986.

expertise and specifying the knowledge base it is supposed to model, but in including the full context of the 'tacit' working knowledge deployed by those who use the system as a day-to-day feature of their work. Although RD3 was not the kind of 'intelligent' automated ATC system of the kind envisaged for the future, it did anticipate some of its features and provided us with the opportunity to look at issues involved in human-machine interaction.

1.1 THE RESEARCH PROGRAMME

Our initial interest in ATC arose out of a series of studies of decision-making in complex environments (Anderson et al, 1987) and the choice of ATC reflected the growing importance of two aspects of these investigations: the speed and ease of handling decisions in the context of 'information rich' resources, and the relative lack of fit between formal models of decision-making processes and actual working practices. It is the latter aspect which stresses the importance of 'tacit' knowledge in making complex systems, such as ATC, work. The concerns are, therefore, located in the academic issues pertaining to sociological and psychological accounts of work routines and decision-making.

In addition, it was our contention from the outset that understanding the effectiveness, as well as the consequences, of technological innovation requires investigation of the social context in which that innovation is introduced. Although many accounts of the effects of technology have focussed on the relative powerlessness of occupational groups to resist for long the imperatives of innovation, especially in modern industrial society, our study enables us to look at the effects on a highly skilled, essential and 'irreplaceable' workforce of new technologies, including automated assistance in decision-making. Air Traffic Control Officers (ATCOs) are members of a distinctive occupation. They are few in number, concentrated primarily in one major centre, London Air Traffic Control Centre (LATCC), experience a long period of training, licensing, and acquiring a skill that is not significantly transferable, either between industries or between employers. All of this, as we shall see, encourages a strong sense of occupational loyalty and identity. Moreover, ATCOs, as experts in ATC, are, on the face of it, in a strong strategic position vis à vis management and unlike occupations whose strength tends to vary tactically with levels of unemployment, economic demand, and so forth. The particular and very visible relation to public safety also lends the workforce important strategic resources in any conflict with management.

Two further distinctive features of the organisation of air traffic control deserve to be highlighted. There is, firstly, the 'professional' character of ATC work. This manifests itself partly in the training, certification, and formal specification of the work; but also in the fact that nearly all ATC management is drawn from the ranks of qualified ATCOs: features they share with other 'self-governing' professions - law, medecine, academia, etc. We argue that this gives a very particular character to the process of management and to 'industrial relations', in ways which both enhance and circumscribe management power, knowledge and effectiveness. Secondly, the CAA is a 'semi-state' body, and has therefore experienced the swings of climate, expectations and funding that have charatcerised the changes in state-organised activity over the last two decades. Many of the CAA's current predicaments can be traced to the particular state/regulation/commerce nexus which it occupies. These various organisational aspects are discussed in Sections 4 and 5 below.

Given our research aims, it was decided that the main methods of data collection would be interviews with air traffic controllers at various grades, and the staff who service and manage them; extended periods of fieldwork and observation of the task of ATC in practice; and recordings of sequences of ATC work for subsequent detailed analysis. The two research officers, supplemented by the principal investigators, undertook extensive periods of fieldwork beginning September, 1986 through to October, 1987, mainly at LATCC, complemented by periods at the Manchester ATC sub-centre. In addition to the ethnographic work, interviews were undertaken with controllers, managers, and development staff at both sites, and with researchers at RSRE, Malvern, the training centre at Hurn and with some CAA staff. Periods of fieldwork covered both slack and busy periods. Audio and visual records of actual controlling work and its associated work activities were gathered, and some transcripts of the automatic recording were provided by the CAA. Throughout, the intention was to unobtrusively gather as much detail as possible about ATCO work and its environment, the practical aim of the research officers being to become as proficient as possible in ATC as the limited time and circumstances allowed. The materials so gathered, along with reports from various sources including the CAA, RSRE, published and Conference papers, etc. form the empirical basis for what follows.

A word or two is necessary about the character and tone of this report. First, the ethnographic method employed tends to a more discursive style of reportage than more quantified research. However, it is our contention that the adoption of a more quantified style would not have provided us with the necessary richness of material. Second, we realise that our work has relevance for very different audiences, some of whom will know very little about ATC, while others will know a great deal more. Accordingly, we have tried to strike a balance between exposition of background material essential to understanding what ATC does and how it works, with the more analytical material. Third, in some sections we make extensive use of quotations culled from interviews and conversations with various grades of personnel. These are intended mainly as illustration, with the context providing for the typicality of the views expressed in the particular quotation used. We have only minimally edited these quotations. Fourth, and finally, we emphasise that this is continuing work. The fieldwork was compressed into a single intensive funded year, hence most of the research time was taken up with fieldwork and the analytical work has largely had to follow this pace, so this report represents very much a first run through the materials. Work is continuing, both on this research project and the one following on from it (undertaken by Dr Anderson with funding from Manchester Polytechnic). Our main vehicle for the findings of the research will be in published papers, and the Committee will, of course, be informed when these result.

Section 2 of the report provides a reasonably detailed account of the ATC system and, in addition, discusses relationships between civil and military operations, mainly from the point of view of civil ATC. Section 3 focusses on technological developments and innovation in ATC, the major social factors influencing its character, and the perceived need for automated assistance. We also discuss at some length the case of RD3 and its reception by controllers; an example which provided some insights into the occupational culture of controllers. Finally in this section we review the new CCF system projected for London TMA by 1995.

In Section 4 we review the 'semi-state' location of the work of the CAA, the 'professional' character of the work of ATC, and some aspects of the management structure. These are then used in Section 5 to cast further light on industrial relations and on the receptiveness of ATCOs to various kinds of technological change.

Sections 6 and 7 report more directly on elements of the occupational culture, working practices and the interdependence of skills of controllers, highlighting the teamwork character of work within a discretionary system of work organisation. Section 7 is where we make a preliminary attempt to describe controlling skills and activities as sequences of self-organised working tasks.

We should stress that although much of this report is concerned with operational controllers, ATC is, of course, more than these, important as the ATCOs are, and includes all the service and management personnel who make the work of ATC possible.

SECTION 2

BACKGROUND TO AIR TRAFFIC CONTROL IN THE UK

In order to grasp much of what follows as well as to appreciate the enormous complexities of the ATC system, it is necessary to have some general idea of what the current system does, and how. In this section of the report the characterisation of the ATC system is very much a generalised one dealing with its basic lineaments and its broad principles of operation. There are, however, important differences in detail with respect to different sectors of the airspace. We begin with a review of the early history of ATC.

2.1 A BRIEF EARLY HISTORY

The period between the two World Wars saw a dramatic increase in air traffic and made it imperative that movements in airspace be controlled and regulated. A rudimentary service to guide, advise and control aircraft was introduced in 1920. Thereafter, more elaborate and effective 'rules of the air' were devised (Field, 1985; Whitnah, 1968). A network of airways was gradually drawn between the major hubs of traffic obliging aircraft using these routes to follow procedures designed to maintain separation and minimise the possibility of air collision. The system of control that evolved was known as 'procedural control'.

The basic feature of this method was the requirement that pilots of aircraft submit flight plans to the air traffic control authorities prior to their departure. These plans contained the name and type of aircraft, its departure point and destination, time of flight, route, expected altitude and speed. By comparing plans controllers could judge the likelihood of more than one aircraft flying in the same airspace at the same time. In such an eventuality all but one plane would be instructed to alter their position. It was crucial to the system that all aircraft, once airborne, conformed to the filed flight plan. This pre-radar system worked by pilots radioing in at specified navigation points enabling the controller to compare progress with the flight plan filed. In this manner controllers could ensure the safety of each flight - barring, of course, certain contingencies. The method, though vastly enhanced by radar and computer technology, is still at the heart of the management of airspace today.

'Sectorisation' of the airspace proceeded apace during the Second World War with the establishment of Flight Information Regions (FIR) each controlled by one centre, located in London, Preston and Prestwick. Within these regions some airspace was given over to exclusive military use, some for controlled civilian flying and some for non-controlled flying only, known as Visual Flying Rules (VFR) airspace. Control of traffic in controlled airspace was divided into sectors which could be further divided, or 'split', into 2, 4, or 8 parts, a single controller being responsible for each (Broadbent and Voss, 1976).

During the 1940's developments in primary radar supplemented procedural control by enhancing the ability of controllers to survey and direct traffic in transit. Primary radar produced a 'blip' on a screen representing objects in airspace. Controllers identified which 'blip' represented which aircraft by directing pilots to manoeuvre in specific ways and correlating this with the movements of the 'blips'. Once identified controllers had to memorise which 'blip' belonged to which aircraft. Later some radar screens were set horizontally to enable markers, or 'shrimp boats', to be placed over identified 'blips' and moved along with them (Broadbent and Voss, 1976; Field, 1985)[1]

In the early 1960's secondary radar technology became available. This system enabled an aircraft to transmit data to radar centres, the most important being the aircraft's call sign and its height. This information was displayed in data blocks on the radar screens beside the primary radar 'blip'. Controllers no longer had to ask an aircraft to identify itself by changes in direction nor have to memorise the identification of the 'blip' itself. All of this was now achieved automatically by the secondary radar system.

The most recent innovation with radar came in the 1970's with the computer processing of radar signals. This meant that data could be selected, rejected, screen images enhanced, and other information over and above that provided by primary and secondary radar displayed on the screens. In addition, and somewhat earlier, the processing of Flight Progress Strips (FPS) was computerised. Computers calculated (a) when an

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[1]There are still controllers around who remember using the 'shrimp boat' system.

aircraft would actually arrive in a sector on the basis of route, speed and wind and, (b) which sector a plane would traverse and where. FPSs were then printed for controllers responsible for each of the sectors of airspace through which an aircraft would travel.

Among the more important organisational changes in the management of ATC was the setting up of the CAA. The CAA was brought into being by the Civil Aviation Act of 1971 and consolidated by the 1982 Air Navigation Act. The CAA itself was the brainchild of the Edwards Report (Command Paper 4018, 1969) which argued that a single agency was necessary to bring coherence, uniform safety standards and efficiency to the various air traffic activities. ATC and other regulatory bodies were to come under CAA control while accident investigation, in order to provide a degree of independence, would be the responsibility of the Department of Trade.

The CAA has a board of 12 appointed by the Secretary of State. It is an independent agency funded by the government but raising revenue from charges to users of the service, and its statutory purpose is to ensure safety, expedition and efficiency in the management of air services. It discharges the UK's commitments to the ICAO, established as a result of the 1944 Chicago convention on civil aviation.[2] In 1983 the CAA employed about 7,400 staff, approximately 75% of whom were involved in National Air Traffic Services, or NATS, work.

NATS was set up in 1961 and taken under the umbrella of the CAA in 1971. As a division of the CAA it has its own organisation and is headed by a Controller who is, alternately, military or civil. The Controller has a place on the CAA board but only as technical advisor. Under the Controller are three divisions headed by 1) the Deputy Controller, Operational Control and Planning; 2) Director General of Telecommunications (Engineering, Technology, and Maintenance); 3) Joint Field Commander responsible for the day-to-day running. These 3 along with the Controller form the management committee of NATS.

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[2]Despite the ambitions of some of its member states the ICAO has failed to replace individual agreements between states with the result that there are a plethora of such agreements specifying the details of international flying. These arrangements often differ, albeit in minor points, and add to the complications of international ATC. See discussion in Section 4.

Of the remaining workforce the largest group are the ATCO's including the training grade ATCOs and supervisors. These make up 27% of the total. The majority of these personnel are GCE A Level school and college leavers.[3] Air Traffic Control Assistants (ATCAs), who handle the bulk of the flight strips, meteorological and other statutory records, such as take-off and landing logs, make up about 10% of the total. Air Traffic Engineers (ATEs) handle installation, maintenance and repair and make up 26% of the total workforce. There are plans to bring in qualified personnel from outside to reduce 'inhouse' training costs. Other staff include management and reserch staff, teleprinter operators, telephonists and communications officers, and other support staff. Over the years, however, there has been a gradual decline in the numbers of personnel despite the increasing number of air traffic movements.[4]

As part of these organisational and technological changes LATCC was nominated as the main ATC centre, with a subcentre at Manchester airport which employs the CAA to provide ATC services.[5]

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[3]However, a recent report in The Independent, April, 25th, 1988 suggests that in order to recruit additional, and much required, controlling staff, the educational qualifications are to be relaxed.

[4]However, despite earlier recommendations that the number of ATCOs be reduced, an increase is now projected. But see also previous footnotes.

[5]Manchester has its own Air Traffic Zone (ATZ) and TMA and related approach services providing *en route* service for traffic beneath flight level 10. Some of those we talked to expressed doubts about the purpose of the Manchester centre and suggested that its existence owed more to political exigency than technical need. As far as the latter is concerned, all ATC services could easily be provided by LATCC. In fact, the FDP system at Manchester is driven by the LATCC computer.

2.2 THE CURRENT ATC SYSTEM

UK airspace is divided into 4 main categories [see Map 1]. Beneath FL 5.5, and outside the special rules around airports, is uncontrolled visual flying rules (VFR) airspace. Aircraft fly through this airspace without benefit of ATC, except for the relaying of weather reports on request. Between this level and FL 245 can be either more VFR airspace or controlled airspace.[6] The latter consists of flight corridors and Terminal Manouevring Areas (TMAs) where such corridors converge. In upper airspace, that is above FL 25, all traffic is controlled. Traffic within controlled airspace is obliged to maintain contact with ATC, obey its instructions and carry transponders which 'inform' the radars of the call sign of the aircraft and its height.[7] Both these items are displayed on the ATC radars alongside the blips and, along with other information, on the flight strips [see appendix 1 for details of flight strips].

Traversing these categories of airspace at various levels from the ground is military airspace used for training excercises, in-flight refuelling, and live firing [see Map 2]. Civilian aircraft are prohibited from entering these areas at certain times of the day and whenever they do so it is at their own risk. Military aircraft flying in this airspace are not always under the direction of military ATC, but may be flying on VFR.

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[6]Note that flight levels are expressed in 00's of feet. The measurement of these levels is based on air pressure which, of course, varies. ATC deals with this by each FIR having daily adjusted air pressure levels to enable pilots to calibrate their instruments accordingly.

[7]The call sign is a scheduled designation. But, in addition, each aircraft has a unique 'squawk' number, rather like a car registration plate, that is issued by the FDP/RDP computer when the aircraft departs. A call sign, on the other hand, is a flight number and, as such, renewable by aircraft flying the specified route at successive times. 'Squawk' numbers can be arranged to also indicate to ATCOs, for example, that the radio has failed, there is a hi-jack, among other information.

The four areas of airspace are under the control of, respectively, the civil and the military arms of NATS. Each is organised differently, and has its own technology and staff. As the airspace becomes more crowded the proportion of airspace allocated for military purposes is a bone of contention for many civilian controllers. The fact that most military airfields are in the east and many of the larger military airspaces in the west, such as Wales, the Lake District and North Lancashire, necessitates that military aircraft fly across the busiest en-route sector in the UK, Daventry, and this does not help matters. Also, civilian controllers indicated little respect for military pilots and their ability, or inclination, to follow instructions. Civil-military liaison in ATC is effected at the suites by the assistance of an RAF controller [See sections 2.3, 2.4].

Civilian ATC provides two services. First, a responsibility for all controlled airspace ensuring that all aircraft using this space are adequately separated from each other. The internationally agreed distances are, laterally, 5 miles[8] and, vertically, 1,000 ft in the airspace between FL 30 and FL 290; above FL 290 the distances are 10 miles and 2,000 ft. On aerodrome approach the distances are 3 miles laterally and 1000ft vertically. Second, it is obliged to provide an advisory service for all aircraft flying VFR but this does not include radar coverage nor is the organisation responsible for aircraft separation.

The airspace itself is divided into sectors with separate ATCOs responsible for each. LATCC has twelve sectors, and the *'en route'* sectors (see below) are divided into two, each half dealing with one direction of flow. Each sector has its own console consisting of two 23" horizontal radar screens, and two smaller vertical screens, computer printout and input stations, telephones and R/T for communicating with other controllers and with pilots, and sometimes closed-circuit monitors showing panels of flight strips at other sectors [see appendix 2 for suite layout]. The radar screens display the entire area of the sector and some of the neighbouring sectors. The scope and centre of the radar can be adjusted as desired by the ATCO. Radar contacts are displayed as 'blips' along with the call sign and height of the aircraft. Some radars can also

[8]Aviation uses nautical miles. All references to mile distances refer to nautical miles.

display vectors as smaller blips following the track of the main 'blip'. Examples of radar displays are shown in Appendix 3. The radars are 'synthetic' in that they are under computer control which processes the 'raw' signals for the screens. The computer itself is an IBM 9020D purpose built for ATC and can, in addition to the information already noted, also display on screen maps of the sectors, boundary lines, beacons, coastlines, airports, etc.

Sectors are of two types. *En route* sectors are those between major junctions of the airways and, normally, have few airports beneath them, such as Daventry, the *en route* sector located between London and Manchester. Consequently, the bulk of traffic is *en route* to somewhere beyond the sector. Terminal Manoeuvring Areas (TMAs) are sectors at the confluence of major airways and over busy airports. For example, all airspace around London and a large proportion of the Home Counties up to FL 13 down to FL 5.5, descending down to FL 2.5 at or around aerodromes, is designated as London TMA. Once in-bounds reach one of the six stacks around London TMA they are normally handed over to their respective aerodrome control, primarily, Heathrow, Gatwick, Stanstead and Luton.

All aircraft using controlled airspace must submit flight plans indicating route and destination, which are used to create the Flight Progress Strip (FPS). This strip indicates, among other information, every navigational marker along an aircraft's route and is printed for each aircraft in advance of it approaching each marker. The strip is printed by the computer and given to the ATCO who places them in racks immediately above the radar screens. The strips enable a controller to gauge how many aircraft are due in the sector, where they are bound and when, and the strip can be used to record any instructions given to the aircraft, such as to descend to a particular FL, change course to a specified heading, change speed, or ascend to a particular height. It is the combination of the strips, radio and radar information that constitutes the 'information base' from which the controller works [see Appendix 4 for sample extracts of controller-pilot communication].

The majority of aircraft travel through a sector only for an average of 20 minutes at a time, though normally there is a steady stream of traffic. On busy *en-route* sectors there can be up to 30-40 planes an hour. However, it is important to note that there are daily, seasonal and sectoral variations in these figures. For navigational (and also historical) reasons, aircraft follow much the same routes between airports, and these routes are not only few in number but concentrated particularly around London which has 4 major airports, Heathrow, Gatwick, Stanstead, and Luton. Recently, the STOL (short takeoff and landing) port in London's dockland, and Biggin Hill, which is now a business commuter airport, have been added. In addition, there are a half-dozen ancillary aerodromes.

The speed of the modern jet aircraft means that ATCOs have to make decisions quickly to maintain adequate separations; decisions that, regularly and routinely, have to deal with various departures from standard profiles, such as failures to achieve expected heights and pilots mishearing instructions.[9] However, since the bulk of air traffic does fly standard routes, this means that controllers can become familiar with flight patterns and expected difficulties and can, at any period, achieve a maximum flow rate of, perhaps, 9 or 10 aircraft simultaneously through the sector. The rotation of controllers around positions for which they are validated aids familiarity with neighbouring sectors and their problems, as does their knowledge and experience about aircraft performance, airline company instructions, and so forth.[10]

The procedures, requirements and details of the system are embodied in *The Manual of Air Traffic Services, Vols. 1 and 2* which is regularly amended in its details.

The above is a brief outline of the main elements of the ATC system in use in the UK and elsewhere (some variations from this which are of importance to the future development of the UK airspace system will be noted below). In general terms the aim of controlling is to ensure the safe and efficient movement of aircraft. The first is achieved by ensuring

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[9]However, as we shall discuss later, even under 'ordinary' controlling conditions ATCOs have a great deal of discretion as to how they handle the traffic. By no means all departures from what we call here 'standard profiles' are due to 'troubles' but, on the contrary, may be manifesting 'good controlling'.

[10]Controllers are extremely knowledgable about, for example, aircraft performances; information which is routinely provided for them. But, more importantly, this information is also used in controlling itself in, for example, 'stack jumping' (see section 6.4).

that aircraft are surrounded by an envelope of space, the second by directing aircraft to follow the shortest available route. Necessarily there is occasional conflict between these two aims, and it is up to controllers to maintain the first by sometimes compromising on the latter using the procedural framework of the Air Traffic Control system. These are, however, treated as minimal requirements, with the controller able, and needing, to use discretion in coordinating aircraft.

This discretionary character of the ATC system is important to bear in mind. The implementation of the rules of control consist in working within them with respect to a particular configuration of aircraft at any one time; a configuration that may be, as it were, 'typical' but which may also display 'untypical' and unpredictable characteristics. For although the bulk of air traffic follows predictable routes, the controller must continually attend to that configuration, and its unfolding, as a matter for him/her to deal with in whatever manner is appropriate in meeting the requirements of, particularly, safety but also expedition. So, although most controlling is accountably done 'in conformity with the rules', there are occasions when departures from these rules are in evidence for reasons of safety and expedition.[11] Although there is a limit to the total number of aircraft a controller can handle at once, it is the configuration of those aircraft which is the more important feature attended to in controlling. Roughly speaking, the more complicated that configuration - with cross-overs, planes ascending and descending, changing direction, and so on - the more difficult is coordination. This is one reason why, for example, London TMA controlling is more difficult compared with, say, Maastricht in Holland which mainly deals with *en route* traffic.

This account of ATC continues with a section on the 'other side' of NATS, the controlling of military aircraft, which is, given the very different objectives of military flying, procedurally rather different.

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[11]As said earlier, such departures are not always, or even most often, provoked by crises of one sort or another. Many of them are regarded as characteristics of 'good controlling' and, in this respect, display the skill of controlling within a discretionary system.

2.3 MILITARY ATC

Military controlling is different in important respects to civilian controlling.[12] Whereas the latter is organised to maintain the safety of regular flows of traffic on certain routes, military control is designed for the coordination of a few aircraft across vast areas of airspace. The reason for this has to do with the character of military flying, the great bulk of it done under VFR at the discretion of the pilot. When controlling is required it is mostly to facilitate the conjunction of aircraft rather than their separation, for in-flight refuelling, formation flying, interceptions and so on. For these purposes, aircraft travel from their respective bases in the UK and meet at some prespecified point. It is the controller's task to effect a conjunction between the aircraft at the specified point in airspace. Once in sight of each other, it is the pilot's responsibility to maintain adequate separation. This is very different to civilian flying where it is unusual for pilots to see other aircraft at close hand because they are nearly always well separated.

Sectorisation is of no benefit to military controlling. Instead aircraft are divided among controllers on the basis of what each group of planes intends to do. Thus, planes on in-flight refuelling excercises will be controlled by one controller, aircraft on a low-level excercise by another. Each controller will only work for the duration of the excercise and could, at different times, be controlling different kinds of excercise.

Instead of a small area or sector of airspace, radar screens used by the military display either half of all UK airspace divided by a line between Anglesey and the Wash. Since there will be many dozens of aircraft in these areas at any one time, most not under the jurisdiction of the controller, only those aircraft under control will have data blocks displayed beside the 'blips' on the screen. All other signals will remain as 'blips'. The data blocks show the 'squawk' code of the aircraft and its height. The code specifies which radar centre has control of the plane, such as London or Eastern, and which radar console is being used for the purpose. This latter information allows the controller responsible for any aircraft to be contacted.

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[12]It is sited in a separate operations room at LATCC.

Military radar screens are only 18" in contrast to the 23" diameter screens used by civilian controllers. Since military controllers can often find themselves controlling aircraft at opposite ends of the airspace, and thus opposite sides of the screen, it eases their ability to survey all aircraft under their control simultaneously.

Adjacent to the radar screens are electronic flight data display systems. These are based on the flight plans common to all flying and display the flight strip for any military aircraft.

Most often military controllers will be responsible for two or three aircraft at any one time, although they have a limit of five. This partly reflects the fact that flying excercises requiring control normally involve only two or three planes, and partly due to the belief that restrictions on numbers is necessary due to the complexity and unpredictability of military controlling. This is in contrast to civilian controlling where, because the great bulk of aircraft follow established flight paths, and are hence more predictable, larger numbers of aircraft can be handled at one time since the attention that has to be devoted to any one of them is reduced. In military flying pilots do not normally follow the regularly used airways, though they do make use of navigational beacons and markers, but tend to fly through empty airspace at their own discretion.[13] Also, military flying is subjected to all kinds of contingencies to which civilian flying is not, such as weather and the relatively greater unreliability of military aircraft, because of their greater complexity, compared with civilian planes. Further, in military flying, although the controller is nominally in charge, in practice his/her role is advisory, with the pilot's decisions taking priority.

However, although there is a separation of the military and civilian functions in the organisation of ATC and in the organisation of the airspace, clearly aircraft using the respective systems do have to be coordinated, mainly because most of the military airfields are sited on

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[13]Military aircraft can fly regular civilian airways and when doing so come under the control of civilian ATC. However, since they are often bound for military destinations they can sometimes generate problems for civilian controllers. For example in-bounds to Upper Heyford descend across and through descending and climbing aircraft out of LTMA.

the east of the British Isles with military flying zones located predominantly in the west.

2.4 JOINT CIVILIAN AND MILITARY OPERATIONS AT LATCC

Aircraft under military control enter controlled airways in two ways: either via the London Joint Operations unit (LJO) or via military control. The LJO unit at LATCC is a squadron of military controllers whose function is to assist the coordinated movement of military aircraft through the controlled airspace around the airways. They work within the civilian operations room at LATCC using the same consoles as the sector controllers. On some consoles additional radar screens and RT equipment has been fitted to facilitate LJO functions.

This adjacent positioning makes it easier for LJO personnel to coordinate with civilian controllers in choosing routes for military planes through civilian airspace. These routes are selected and allocated by the sector controller, or the sector chief, and it is the responsibility of the LJO officer to ensure that the aircraft follow these routes. The LJO takes control of the military inbound just before it arrives at the sector boundary, controls it through the sector and then relinquishes control as soon as it departs. The civilian controller does not speak to the military aircraft throughout the operation. Some sectors are, of course, more prone to 'crossovers' than others. The ones most affected are those running up the spine of England dividing East Anglia and the West Riding from Wales and the Border country, which stand astride the routes military pilots have to traverse in 'going to and from work', as it were.

The LJO unit is a recognition that difficulties can arise as a consequence of military aircraft wanting to traverse civilian sectors. As said earlier, the most important reason for such problems is the fact that a large proportion of military flying necessitates crossing civilian airways in directions that go against, conflict or generally contrast with the bulk of the flow on these airways. In the same way that a car wishing to cross a busy dual carriageway at 90° causes traffic problems, so too does a 'crossover' require more controlling work than an aircraft flying routine routes. 'Crossovers' reduce the capacity of the sector, causing delays that may not only make for complications later, but prolong the time a controller has to deal with what can be a complicated configuration of traffic. In addition, and again as mentioned earlier, the complexity of military aircraft means that they are more vulnerable to failures and emergencies than are commercial ones and if such an emergency occurs in civilian airspace, as with all emergencies, this would take priority over all other traffic and be the source of yet further complications. Civilian ATCOs report that military pilots appear to make proportionately more navigational errors than commercial pilots; mistakes which can ruin controllers' plans for the resolution of a configuration problem.[14] ATCOs also report that military pilots are sometimes unfamiliar with busy radios, mishearing commands, failing to attend properly, and lacking brevity and clarity in their own transmissions. They often ask repeatedly to change direction (whereas civilian pilots normally wait to be told), ask for explanations of control commands and even dispute the necessity of such commands; all activities which can take up limited RT time.

These particular differences in attitude probably reflect the relationships pilots have with their own respective controllers. As explained earlier, most military control effectively functions as an advisory service and rarely involves as many aircraft as civilian controlling.

Taken as a whole the relations between the civilian and the military arms of NATS are good, especially through the LJO system. However, differences in attitude, training and controlling practice do, sometimes, make for friction. Sector controllers are not always happy about aircraft passing through "their airspace" without being in direct contact. Although LJO personnel will direct aircraft whichever way the controller desires, delegation is, nonetheless, a slow and complicated way of working. Sector controllers become less confident that they have complete control of "their sector" and having confidence is an important element of their ability to work effectively. Also, when a military plane does start travelling in the wrong direction or at the wrong height, it is not immediately clear whether it is a mistake - and, if so, who is responsible and should be directed to take remedial action - or whether there is a good reason for the manoeuvre. Quite often LJO controllers find

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[14]It is important to point out that many military pilots are on navigational training sorties, often flying solo, whereas civilian pilots are not allowed to fly any route until they have familiarity with it as a co-pilot.

themselves squeezed between the demands of the sector controller and the pilots, unable to satisfy the former by being unable to control the latter. Military pilots, meanwhile, often show little idea of the complications their journey is causing. They cannot hear RT instructions to other planes, since they are on a different frequency, and rarely see other aircraft. To them the skies are empty and the LJO controller often comes across, as one pilot put it, as "excessively safety conscious".

As a whole, however, LJO controlling is successful. Though their physical proximity to civilian controllers sometimes makes them an easy target for blame when matters get difficult for the civilian controller, they do become familiar with both sides, military pilots and civilian controllers, and learn that diplomacy does much to sustain amicable relations between the two sides of NATS.

2.5 CONFLICTS BETWEEN CIVILIAN AND MILITARY CONTROLLING

Conflicts potentially arise when a plane under military or civilian control transgresses the boundaries of the other's airspace. Fortunately, very few of these lead to any incident. Nonetheless, there are problems, mostly relating to transgressions of military controlled aircraft into the controlled airspace of the civilian system. Although there are occasions when civilian traffic enters military airspace, they rarely cause problems because of the relative emptiness of that airspace. By contrast, civilian airways are busy for most of the day, occasionally reaching capacity, and it is inevitable, therefore, that military transgressions into civilian airspace result in more potential conflictions than do civilian entries into military zones.

Transgressions, especially military into civilian airspace, illustrate the contrasts between the priorities and the methods of military aviation and civilian controlling independently of the LJO system; differences reflected in the distinct ways in which air traffic information is presented to controllers, the character of that information and the practical decision policies that flow from this information.

Most military aircraft flying their filed planned routes do not cause real difficulties for civilian controllers, apart from those mentioned above, though they do significantly affect the workload:

R: The military crosses that there are dashing around the place, I mean you might say, 'Oh, it's nice and quiet this morning, isn't it', and the civil traffic is rushing through, and one military aircraft will come along and he can absolutely cause chaos, just one, by just going across.

Such "crossovers" are dealt with by LJO controllers. It is the *ad hoc* entries that cause the most difficulties. Whatever the reason, such as weather avoidance, error, or such, the official policy is for the military controller to contact the relevant sector controller and request an entry, and to coordinate a flight path that avoids conflictions. In practice, however, contact is not always made because military controllers judge from the information available to them that there is little risk and to ask the civilian controller for confirmation of the entry would only serve as a distraction since it would be accepted in any case.

However, from the screens military controllers use it is not always clear just what the traffic situation is in the region affected. Also, errors in radar signals and in the display of video maps on the screen indicating the boundaries of controlled airspace can result in an aircraft being indicated as outside the boundary, when on the larger screens of the civilian controllers it appears within it.[15] Further, on military screens, only aircraft under military control have data blocks displayed; the rest, including civilian aircraft on the airways, are shown as 'blips' only. Without such information it is much more difficult to calculate any potential conflict. For example, it is not possible to separate aircraft by height unless their respective heights are known. Military controllers do not always have the time to survey other sectors given that military flying is much more unpredictable in character than civilian. In any case, surveying other sectors would require them to grasp and understand on their own a situation for which several controllers are required.

Accordingly, in the absence of military controllers contacting the relevant civilian controller in the case of a transgression, it is open to the civilian controller to make the contact by reading the 'squawk' number of the threatening aircraft. However, this does not necessarily ease the situation since, for reasons already mentioned, military control is often slow in locating and dealing with the problem.

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[15]Of course, the reverse also happens, that is, a plane looks to be outside a boundary on the sector screens and inside on the military.

In addition to these considerations of the tension between military and civilian ATC in terms of practical procedures, there is also another set of tensions at the level of the system as a whole. In an airspace as confined and crowded as that of the UK, the reservation of large tracts of airspace as military zones places blocks on the rational development of the system. The perception among many ATCOs is that several such areas either are not really necessary to the military at all, or are only sometimes needed and could be made available at other times - to cope with weekend peaks of charter traffic, for example:

> R: I think our major problem is the way our airspace is organised. We are hamstrung by our joint responsibility with the military. I think we are virtually unique. ... There are definite chunks of airspace where we are not allowed to go, and we are stuck with the airways system. In practice that means that if you go outside the airway you are in bandit country, and the military say if you go outside the airway you are in our bit, that belongs to us, and we say it's impossible to organise direct routing unless they give us the airspace back at the weekends and bank holidays and things like that. If we could operate as the French do where we could, say, direct from one point in our airspace to to the other, it would make it much better, much more efficient from the aircrafts' point of view as well.

And again:

> R: One of my pet frustrations is the North Wales MTA which affects us, the fillet that goes to the east, the little triangle to the east of Amber 25, and that piece above Amber 25 needn't be there as far as I can see. I am told that the reason for it originally was because of Little Rissington, allowing them access to the MTA so that they could climb and go supersonic, and they needed the whole of that airspace to do it with the Gnats that they had. But Little Rissington has been closed for many many years but someone is hanging on to that airspace, I can't say that in the last ten years I can remember seeing aircraft using that space as high level fighters, so why they hang onto it is purely political, I'm sure, but it's a bloody big inconvenience to us. If we didn't have to keep descending and climbing aircraft as we do to avoid these military areas it would be much easier for us. Our job, it would actually reduce the pressure by about 30% on

the man controlling the Bristol area ... .
As another ATCO put it, such conflicts can only be resolved, 'virtually at Cabinet level', and they feel that, politically, the military will always prevail in such contests.

2.6 CONCLUDING REMARKS

An important observation to make at this juncture, and one that anticipates the next section, concerns the evolved character of the ATC system. The current system has nearly a 60 year heritage and, as a result, an inertia of adaptation which, though suited orginally to the character of air traffic and the load it placed on the system, has, in recent years, found itself subjected to loads it was never designed for. Though this is perhaps to put it over-strongly, the present routes, including the division between civilian and military air space, follow a pattern which the Romans would have found familiar. Certainly it is one which road and rail users would have little trouble in recognising since the these kind of routes connect the major urban areas. And, given the origins of the ATC system, this is no surprise in that it grew up in a period when flying was largely conceived as an extension of travel over the ground, if only because the technology of the time required the ground as a resource for navigation and, in emergency, succour.

So, seen within a wider context, the significance of technology in terms of what it can do, needs to be understood within a legacy bequeathed by historically shaped options. In other words, the radical, not to say revolutionary, potentialities of technology, such as radar, can often be inhibited, or so it seems with hindsight, by the legacy of past arrangements. So, within the ATC context, and it is not unique in this by any means, the tendency is to incorporate innovations within existing arrangements rather than begin anew by redesigning the whole system to make more 'effective' use of technological innovation. This is exaggerated, for ATC, by its continuous character - air movements cannot be 'switched off' while a completely new system of routes and procedures is introduced - and by the very proper emphasis on safety, which privileges incremental over revolutionary change. This is not, therefore, a complaint against the unimaginative policy of the ATC services, but merely to point out the importance of understanding origins in order to understand the present shape, and problems, of ATC.

More particularly, and as part of the legacy, there is no doubt that the division of the airspace into military and civilian districts does restrict the space available for civilian controllers to organise their traffic. And although, from time to time, amendments are made, these are, on the whole, relatively minor adjustments. The fact remains that as far as civilian controllers are concerned, what is to them a huge 'no go' area is seen as making their job, in an area of ever increasing traffic loads, more difficult than it need be. They also recognise that there is little that can be done about it under the present system.

Another part of the legacy lies in the distinctive patterns of military and civilian controlling which are also reflected in the rather different kinds of information available to the respective controllers. While in their own domains the adequacy of this informational presentation is not a major issue, it is at the interface where difficulties arise and have to be resolved by liaison between controllers.

SECTION 3

TECHNOLOGICAL DEVELOPMENT IN ATC

ATC is a technologically rich environment which has, over the years, incorporated many of the innovations in radio communication, radars, and computing. Much of the work of controlling requires the use of complex and sophisticated machines providing the resources for controlling decisions, and also connecting the operational decisions of the controller with aircraft and with fellow controllers. The technological richness is reflected, too, in the large research and development support maintained by the CAA and other organisations dealing with both the technical and the human aspects of ATC.

In this section of the report we want, first, to review the recent background to developments in ATC technology at LATCC; second, to discuss the impetus behind the perceived growing need for more automation in ATC; third, to examine a case of technological innovation at LATCC in terms of the response of controllers.

3.1 BACKGROUND TO THE DEVELOPMENT OF ATC TECHNOLOGY

Worldwide there is considerable diversity in technologies, controlling procedures and development plans for ATC. In part these differences reflect the unique characteristics of each Flight Information Region (FIR), but also the individual responses of national ATC organisations. Nonetheless, the American Federal Aviation Authority (FAA) has two main advantages which have resulted in its systems tending to become the model, in varying degrees, for other countries. First, the sheer size of the US airspace requires 22 centres to service it, whereas France, the largest airspace in Europe, has 3.[1] This has enabled the US to standardise systems, and thus reduce unit costs, making them both readily available and relatively cheap. Second, US airspace is also the busiest in the world generating massive reserves to finance research and development, tending to make FAA authorised designs the most advanced available.

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[1]The bulk of air traffic in France is *en route* traffic to destinations in the Mediterranean, the Middle East and Africa.

NATS over the past 3 decades has relied very much on FAA developments. In particular, a US system devised in the late 60's, known as the 'Mediator System', was bought entire for LATCC (known as LATCC Development Step 1), and became fully operational in 1974, and is still the basis of the centre's system some 14 years later [prior to this the system was, as reviewed in section 2.1, based on 'primary radar data' and a fairly limited FDP computer system, Hermes]. The Mediator System was designed to satisfy the requirements of an entire ATC centre and included furniture (that is, radar screens and frames, known as 'suites'). An IBM 9020D provided combined RDP and FDP functions.

At first, the FDP subsystem had a mixed reception. In its initial form assistants (ATCAs), who attended the input and output functions, were located in a separate room from the controllers. This resulted in delays, confusion and was generally an inefficient utilisation of the system. Only when sufficient 9020 input positions were placed adjacent to operational positions was this problem solved. Though the system was not ideal, it did improve the FDP service and work continues in simplifying and exploiting it.

Step 2 of the plan was intended to update the computer facilities and replace the FPSs with vertical electronic flight data strips. This was postponed largely because of the long lead time for development. An Interim Sector Update (ISU) was designed and installed in 1975 in the form of a touch sensitive display, but, subsequently, with keyboard and VDU using a Myriad computer interfacing with the 9020D. This enabled an ATCA to update the computer with information about changes in flight plans and programmes and, to some degree, obviated the need for an entirely automatic updating system.

Step 3 of the LATCC plan was intended to be a joint FDP-RDP (Flight Data Processing - Radar Data Processing) system implemented on current suites. The reaction of controllers, however, meant that only a limited version was eventually proposed for the current centre and, instead, plans were advanced for the complete system to be built in a new operations room utilising 2-man (Executive and Support) suites with vertically mounted radar and flight displays. Subsequently, however, attempts to modify the 9020 system to meet the current increased demands on the UK ATC system, in particular to meet the different needs of civil and military operations, have resulted in delays to the programme for implementing the FDP-RDP system. In 1976 a decision was taken to use a limited form which would be unaffected by the LATCC sectorisation procedures and which could, therefore, be introduced in the current operations room in a relatively short space of time. This would, it was thought, have the advantage of familiarising controllers with this kind of system. In addition, a new Mosaic Radar Data Processing System (MRDP) and automatic tracking facility, called RD3, was introduced. For the sake of brevity, and a usage consistent with controllers' own terminology, we shall call the combined FDP and RDP system and the mosaic radar system, RD3.

To understand the character of technical innovation in ATC, its consequent effects on such matters as working practices, as well as the sheer difficulty of making decisions about technological needs for decades ahead, it is important to recognise two overriding constraints. First, the system cannot be 'switched off' but must maintain its standard of operational efficiency while innovations are implemented, assessed and learned. This means that the strategy followed to date has been one of 'incremental innovation', changing parts of the system in such a way as to retain the integrity of the whole. This is, in fact, the way in which the system has evolved over the past 60 years, or so. Second, and related to the first, is the overriding importance of safety, a consideration which reinforces the need for incremental change which, at the same time, retains elements of the 'old' system as 'back-ups' in the case of failure.

What has provoked a serious problem for this strategy in the last few years has been the failure to keep pace with traffic loads. In significant respects, ATC is 'consumer driven' in that NATS has little control over the traffic loadings placed on the system. This is determined, though imprecisely, by a number of factors: airline demand for routes, local noise abatement regulations on take-off times and frequencies, aircraft design, the demand for foreign holidays, the impact of fuel prices on airline practice, the need for airlines to use expensive equipment to their fullest extent, independent initiatives such as the London STOL airport, and so on; few of which NATS themselves can influence in any direct way. Moreover, it takes a great deal of planning time to reconcile all the various interests, legal requirements, consultative procedures, and more, that can be involved in any changes in technology, procedures and airspace utilisation. Indeed, such are the complex interactions of the factors determining traffic loads and the difficulties of estimating any one of them without a large margin of error, that despite best efforts it has proved extremely hard to project future demand with very much accuracy. Projected traffic loads for 1990 were, for example, exceeded for the UK in 1983. As a result, since the overdemand for ATC services came relatively suddenly, leaps in technology become, or are seen as, more urgent than the incremental strategy can be expected to deliver.

3.2 THE NEED FOR AUTOMATED ATC

However, it would be quite wrong to suppose that the CAA, its various research arms and NATS itself have been unaware of the growing need to revise the ground-based, tactical, manual control ATC system to handle the anticipated increase in air traffic movements. The problem, from the point of view of getting the technology right for the time when it is needed, was that the increases in traffic came earlier than projected. From the late 1960's, and certainly by the early years of the 1970's, the realisation that automated assistance for ATC would become necessary was widespread. Indeed, the ICAO had, in 1972, specified criteria for the automation of ATC, namely, that it was justified,

> "a) when any particular ATC functions or processes are becoming too burdensome or time consuming to be carried out efficiently by human operators alone;
>
> b) when it becomes certain that substantive improvements with regard to regularity and expedition of operations cannot adequately be maintained without automation while maintaining the required level of safety."

(International Labour Organisation, 1972, p. 88)

It has been evident for some years that the existing system, dividing the airspace into sectors and allocating these to human controllers, would need revision in order for the airspace to handle many more air traffic movements. By the late 1970's, when automated ATC options and technology came to be seriously considered, the Department of Industry (1977) estimated that in Europe, by 2000, air traffic movements would have increased by 2 to 3 times (a large margin of error it is worth noting). An earlier forecast by the FAA for the US, (1975) predicted that take-offs and landings would, by 1987, double and *en route* traffic handled by FAA ATC be 2/3 as high as 1975 levels. The limit to the existing system is the human controller and the capacity he/she can cope with safely (Crawley, Spurgeon and Whitfield, 1980, p. 2; Department of Industry, 1977). In other words, it is the workload limit of controllers which determines the capacity of a sector. An apparent solution to capacity problems is to subdivide the airspace into a larger number of smaller sectors. However, this problem is exacerbated by the fact that as the number of sectors increases, so too do the coordination and handover elements of the workload, so that the potential gain is negated. UK airspace has now reached the limits of this intractable interaction effect. Moreover, this option would incur increased staffing costs as more controllers would be required to staff the additional sectors.

A further important factor influencing the need to consider automated ATC systems, especially from 1975 onwards, was the rising cost of fuel. The more loaded and difficult to operate the manual ATC system becomes, the less expeditious is the movement of aircraft, as the need to maintain safety more frequently conflicts with and over-rides the attempt to maintain an efficient flow of traffic. For the aircraft, and ultimately the airline, this means increased fuel consumption, and increased costs, since it finds itself less able to deploy optimal speeds, heights and manoeuvres.

In the 1970's, then, in the UK, the USA, and elsewhere, a number of ATC systems concepts were explored as possibilities for the future shape of ATC.

The RSRE, involved in systems research and design for the CAA for nearly 20 years, proposed two concepts. The earlier, Computer Assisted Approach Sequencing (CAAS) was developed to assist ATC in the intermediate and final approach areas for Heathrow as a means of increasing its capacity. The system got as far as feasibility trials but was abandoned soon after, although by that time it was clear that considerable revision would have been required (Crawley, Spurgeon and Whitfield, 1980). The system offered computer generated decision making concerning the required flight path that an aircraft on intermediate approach should follow so that it arrived at the landing threshold at the optimum distance behind a preceding aircraft. Despite its abandonment, what was clear was that such a system would require human controllers to maintain active involvement since the computer would be unable to handle all situations adequately (Fearn, 1975).

More recently, the RSRE developed Interactive Conflict Resolution (ICR) which used the computer in a much more supportive role in decision making than CAAS and, in this respect, was much more a 'computer assistant' to the human controller. ICR, developed for *en route* traffic, applied trajectory prediction for aircraft for up to 20 minutes ahead. This information could be requested by the controller and, it was argued, help his/her ability to predict future traffic configurations, including possible conflicts, and so 'buy time' for suitable solutions. The controller could also use the system to search for conflicts, again up to 20 minutes ahead, and be automatically warned by the system of such possibilities. In interactive mode the controller could also validate a proposed flight path for any possible conflicts (Ball, 1976). Yet, despite the fact that the computer monitored traffic, detected conflicts and had the potential to suggest solutions, the controller was left to make the final decision.

A more general study of automated ATC systems was carried out in the USA under the auspices of the Transportation Systems Centre between 1971 and 1973, and designed to examine the feasibility of proposed systems that could cope with traffic demands beyond the 1990's. The Advanced Air Traffic Management System (AATMS) was predicated on assumptions about new flight deck, navigational and communications technologies, the most important being an advanced transponder which would send data to the ground in response to interrogation, automatic data links for routine messages between ground and air, and greater freedom for an aircraft to choose its route (Jenney and Lawrence, 1974; Crawley, Spurgeon and Whitfield, 1980). The biggest change proposed by this system was from an airspace centred approach, based on sectorisation, to a traffic centred approach in which aircraft are allocated either to a computer or to a human controller depending on need. Though the human controller would retain overall regulatory and managerial responsibility for critical operational tasks, he/she would have far less involvement with the direct and continuous control of aircraft.

A more modest approach to improving the ATC system for the future was the development of Intermittent Positive Control (IPC), an automated ground-based collision avoidance service for aircraft (McFarland and Horowitz, 1974). The system would act independently of the controller and warn a pilot of proximate traffic and traffic in potential conflict. The controller would also be warned that one of the aircraft under his/her control is in potential conflict.

One of the distinctive features of the concepts such as those reviewed is not so much that developments in computer technology make them more than just idle contemplations, but that the total automation of ATC, in the foreseeable future, is not seen as an option.[2] Moreover, the overriding concern of safety, along with the fact that no ATC system can be 'switched off' while fundamental system changes are designed, tested out and learned, means that any automation of ATC would have to follow the standard pattern of innovation, namely, one of incrementalism.

The upshot of these conditions is that any automated system would have to achieve a suitable balance between the human operator and the machine: a principle endorsed by the ICAO in its original guidelines for the automation of ATC (International Labour Organisation, 1972). As a result, "There seems little doubt...that the human controller will continue to play a major role in ATC for the foreseeable future, probably well into the next century" (Crawley, Spurgeon and Whitfield, 1980, p. 8).

3.3 AUTOMATION AND THE CONTROLLER

Of course, there is no doubt that automation, however incremental, would have effects on the work of the ATCO; a realisation expressed by a concern for the effect on job satisfaction and, through this, operational efficiency. The considered opinion was that it would be unwise to relegate the controller to simply a monitoring function or reduce his/her activities to routine data entry and retrieval within a highly automated system. Morale and efficiency, it was felt, depend upon the excercise of skill, judgement and experience (ATC Systems Committee, 1975).[3] Our own work also confirmed the 'perishable' nature of key ATC skills - see Section 4 below.

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[2]Whether it is seen as an unnecessary option, in being extremely costly, or whether uncontemplatable because of doubts about the public acceptability of a totally automated system, is unclear.

[3]As Crawley et al (1980) point out, and as many studies have confirmed, the relationship between job satisfaction and worker performance and/or productivity, is neither clear nor consistent. Although job content, as defined in terms of repetitiveness, does show some relation to job satisfaction (Walker and Guest, 1952; Hertzberg, 1966) as does absenteeism and turnover, the multidimensionality of job satisfaction is clearly an important consideration in investigating its effects.

Hopkin, who interviewed ATCOs during the CAAS trials, realised that automation could have serious effects on the job satisfaction of ATCOs despite the fact that many of them could see its advantages. Many of them, too, felt that they would be reduced to helping the computer rather than receiving assistance from it (Fearn, 1975). Later, Hopkin made the general point that "Automation, when introduced in a man-machine system, entails that the system, and all parts of it, are assessed in machine terms, since no other terms can be used" (Hopkin, 1975).

However, even though automated systems are on the agenda, and under development, the reality is that the pace of technological development in ATC is still very much an incremental and piecemeal one. Nevertheless, this is not to say that issues of job satisfaction, morale, effectiveness, and so forth, are irrelevant, nor that the study of existing controlling work is redundant. For one thing, and as most experts in this field are at pains to stress, for the foreseeable future ATC will be a man-machine affair and devising a suitable 'symbiosis' of these two elements will be crucial (Crawley, Spurgeon and Whitfield, 1980).[4] This is a problem of deciding the 'architecture' of ATC systems; that is, how the tasks should be divided between controllers and computers given that the latter would have some decision-making capacity. One additional constraint on this is that the computer would have to produce solutions that the ATCO would come to in order to sustain a suitable matching of the performance of man and machine.

But deciding what kind of man-machine system will work, and for how long in terms of the demands made upon it, is hard to determine. What is more certain, and this is perhaps one unavoidable drawback of this approach to innovation, is that the incrementalism which is a feature of technological innovation in ATC means that the shape of the man-machine relationship already owes much to the existing system. It owes much in the obvious ways that the personnel needed to man any system, new or old, will be existing ATCOs, and it would need to be usable by them, and to be compatible with key elements of the existing system in order to maintain operational safety and efficiency. In practice, of course, since

[4]Indeed, much of the ATC organisation sponsored research on the human factor in controlling is predicated on the need for adequate job design in relation to automated systems.

fundamental innovations in the way of automating the airways are only on the horizon, any efforts in this direction will need to be 'added on' to the existing system. The more strategic consequence of this is that thinking about the problem of the man-machine relationship is in terms of enhancing the existing system, especially with regard to what the human operator requires in order to become more efficient. However, as the case we will now discuss illustrates, determining the shape of this relationship is not an easy task.

3.4 THE CASE OF RD3

A key feature in the introduction of any new technology into ATC operations is the attitude and response of controllers themselves. As we pointed out earlier, they are the factor in the ATC system which most determines the amount of traffic that can be handled and so they play a key role in the acceptability, or otherwise, of any technological change. Controllers [see sections 6 and 7] are highly skilled at what they do, carry a great deal of responsibility and exhibit a strong pride in their craft of ordering the airways safely and expeditiously. Further, as a number of studies in various countries have shown, rates of overall job satisfaction among ATCOs is high, especially due to the challenging nature of the work (Grandjean, Witzka and Kretzschmar, 1968; Kennholt and Bergstedt, 1971; Singer and Rutenfraaz, 1971; Smith, 1973; Clark, Quinn and Lacey Scott, 1973). As far as performance is concerned, over the years, despite increasing traffic flows, outdated equipment and increasing pressures to cut costs, the safety record of UK ATCOs is impressive. There has never been a mid-air collision involving British civil ATC since its inception as an organisation.[5] As far as records are able to determine, the UK has the best record in this respect in the world.[6] This strong corporate pride among operational controllers, while leading to a highly motivated and responsible work force, also gives rise to an unwillingness to take technological and other innovations 'on trust'. Systems must be demonstrably safe and trustworthy to controllers, before they are

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[5]On average there are 3 air crashes per week in the UK, none of them attributal to ATC error. Source: Danger and Distress Unit, LATCC.

[6]A number of countries do not supply figures.

acceptable. As we discovered, cynicism and conservatism toward new technology and operational techniques is a strong element in the occupational culture of controllers despite the fact that they work in a technologically rich environment. This feature also affects management-workforce relations. Yet at the same time, many ATCOs are eager for the 'right kind' of technological enhancement and reorganisation. This ambiguity is explored further in Section 5; but many of these factors are illustrated by the controllers' reaction to the RD3 system.

RD3 was a synthesis of, on the one hand, available software and, on the other, new hardware and radar technology and, as such, was not a dramatic change in controllers' technological environment. Nevertheless, as far as management saw it, RD3 offered a number of advantages: a version was already in use and so controllers had a degree of familiarity with its operations; the combination of FDP and RDP will almost certainly form the basis of future ATC technology and RD3 would introduce controllers to its principles; it would dramatically change the type and source of information available to controllers and so enhance the performance of ATCOs; and, since it was to be introduced on existing furniture, controllers would be able to switch in and out of the system as preferred using the old and familiar system as a backup [for technical details of RD3 see appendix $ and Working Paper 1].

3.4.1 RD3 In Practice

There was, therefore, every hope that the system would improve the working environment of controllers and, by making extra information available, ease the expedition of controlling. However, controllers were, at best, indifferent to it and, at worst, positively hostile to RD3. It was not, in the main, seen as its designers intended, that is, as a forerunner of future developments using present technology, but as an innovation that was irrelevant, badly conceived and difficult to operate. A survey NATS conducted some months after the introduction of RD3 presented a dismal picture. Less than 10% of controllers returned the questionnaire and nearly all of these were controllers who preferred not to use the system. Our own interviews and conversations with controllers confirmed the problems mentioned in the survey to do with difficulty of accessing information displays, their irrelevance, problems with multihead radars and the increased likelihood of conflicts using it, the unreliability of the technology, inappropriate sectorisation, that it was confusing and time-consuming in layout and operation, and the general difficulties of using RD3 within a Mediator system. The few advantages noted referred to vector lines and the Direct Routing facility. Another survey of RD3 usage found that this varied between sectors and times of day. On the Hurn sector, for example, it was used for over 50% of the time whereas on Daventry, a notoriously busy sector, hardly at all. In sum, the system was held to be untrustworthy, so much so that one watch (there are 5 operational watches at LATCC) temporarily banned its use.

The story of the reception of RD3 by controllers is instructive since it told us a great deal about the character of controlling work and the occupational culture in which it is embedded. In particular, it highlighted an important attitude which underpins controllers' effective work, and one that is difficult to overestimate, namely, the ability to assume that the technology can be trusted. Although most controlling work consisted of an interplay between flight strip information and radar displays, vital to this was their confidence that what they saw on the screen was an accurate representation of movement in airspace.[7] Cognitively, the screen is a technological representation of a slice of sky and the relevant events occuring within it. The orderliness of the screen stands proxy for the orderliness of the sky [see Section 6] and controllers need to be confident that this is maintained routinely. However, this trust is fragile. Distractions, any doubt in the information to hand, undermines the controller's confidence in 'what is being seen'. 'Thinking twice' about information before them has to be avoided, and as far as RD3 was concerned, the bulk of controllers felt that, in particular, the multihead radar assimilation displays were not trustworthy.

A number of controllers expressed the view that RD3 displays did not feel as 'firm' as ordinary displays. Close examination and comparison of RD3 with non-RD3 displays suggests some grounds for this lack of 'firmness'. 'Blips' on the non-RD3 screens are refreshed every few seconds and, due to the screen material, leave an incandescent trail. The Data Blocks alongside each 'blip', derived from computer processed transponder signals, moved simultaneously with the 'blips'. Controllers, therefore, got used to the rhythm of signal refreshment. On RD3, however, 'blip's and

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[7]Strips come into their own in the case of computer failure.

Data Blocks moved at different times mainly because the latter were not derived from transponders but from computer memory activated by the transponder signal. The general effect was to give the impression of much more movement on the RD3 screen; an impression, so to speak, that the system was 'unsure' of itself due to its unrhythmic character.

This feeling of uncertainty was reinforced by the fact that with multihead radar assimilation, controllers did not know which radar was being used. Though the system was designed to give the 'best choice', most controllers had preferences. Some did not like the clutter low coverage radars generated preferring ones with longer range. In any event, all were familiar with the advantages and disadvantages of particular radars, knowledge irrelevant to interpreting the signals processed by RD3. Further, the assimilation of information from different radars for display on a single screen could, occasionally, compound inaccuracies in the display of the aircraft's position. In addition, on RD3 signals received from beyond the radar's accepted limits of accuracy were displayed with extended trail markings to denote the signal's possibly inaccuracy, information which was unnecessary since such signals were only to estimate likely traffic and not for immediate controlling purposes. The extended trails were another irregularity on the screen and, since they could be large enough to obliterate other signals, were an additional distraction.

The fact that RD3 was not functioning on all sectors at all times impeded familiarisation with the system since even a controller willing to use it would have to use non-RD3 displays on other sectors. Since familiarity and trust are essential features of ATCO work, the tendency was to 'switch out' of RD3 to revert back to a known and trusted system. In addition, the frequent unserviceability of RD3 further inhibited opportunities for familiarisation and discouraged trust. But, perhaps of most importance, was the consequence of computer breakdown and the loss of all data. The age of the computer, the immense complexity of the systems driving it, the difficulties of service and maintainance, meant that breakdowns were not uncommon.[8] With ordinary radar, on the other hand, only FDBs were computer processed while the primary data went directly to the screens. Although ATCOs on RD3 could switch back to ordinary radar, there was a lapse of approximately two minutes before the screen activated.

Finally, apart from the lack of trust ergonomic factors also played their part. The positioning of the MEP made easy access to telephones impossible, the board was difficult to understand and use, input instructions were cumbersome, and so on. As one ATCO put it, "At busy periods you don't have time to hunt for badly placed buttons...Nice toy if you've got the time".

However, this lack of ease compounded by poor ergonomics was not the whole story. Of considerable importance was the inappropriateness of RD3 for the different types of work on sectors during busy and quiet periods. RD3 could only be adapted when controllers had the time, that is, during quiet periods. It was based on a system designed to be used by one controller and (possibly) one assistant. Ancillary functions were either done by FDP/RDP computers, by the controller, or minimised by airspace utilisation procedures which reduced coordination requirements. By contrast, the older mediator system necessitated so much coordination that one individual on the suite had to devote most of his/her time to that purpose alone. The FDP computer under this system required at least two, often four, workers per sector, and was centred around a type of controlling so demanding as to massively restrict the controller's capacity to perform any other function. RD3 was designed as an individual-based system, the mediator team-based.

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[8]It seems that the primary difficulties were with the outdated power supply equipment and with the software. As is often the case, the original software was no longer maintained by the personnel who had designed and implemented it with the result that some of this essential knowledge was lost, to the detriment of the operational efficiency of the system. In addition, that the computer was being asked to perform more and more tasks was a further handicap. A number of computer technicians expressed the view that the software is in "desperate need of a spring clean".

3.4.2 Mediator Teamwork and RD3

Mediator team work allowed controllers to concentrate solely on controlling; that is, maintaining separations, controlling ascents and descents, etc. The coordination of traffic between and with neighboring sectors, preparing flight strips, etc. was largely done by assistants and, where circumstances demanded, by crew chiefs.

Ensuring that the right strips were placed in front of the controller at the right time was one of the basic tasks of the teams. Strips were taken from the printer, sorted into various categories and located appropriately in the bays in front of the controller. Strips would be printed for every aircraft that came through a sector and for every important navigation point it would have to cross[9] [see Appendix 1 for details of the strip and section 6 for a more detailed consideration of the strip and the work associated with it]. The strips would be separated on the basis of general direction, fitting westerly in yellow, easterly in blue holders, for example. Computer eta's would be corrected as necessary, and updated for other sectors. Finally, the strips would be placed in the correct sequence, usually the sooner, the lower, and in appropriate columns. Once finished, the strips were taken and collected by the assistants. In addition, ATCAs liaised with neighboring sectors, acting as intermediaries between controllers, and any agreement was marked down on the strips. They also drew to the attention of controllers any 'procedural conflicts'[10] by moving strips slightly out of position.

A key member of the team was the sector chief who attended to unusual or difficult traffic to minimise its effect on the bulk of the traffic flow. The chief also kept an eye on all strips for any potential conflictions. At busy times, most of their time was taken coordinating with unusual traffic, such as trying to find an unused flight level, or 'bridge', and liaising with neighboring sector chiefs. In addition, the chief has the ultimate responsibility for the running of the sector and

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[9]There were normally 3 - 4 such points each side of a sector. The FDP computer would estimate the eta for each of these points and print a strip shortly before.

[10]That is, where 2 aircraft were expected to cross a navigational marker at the same time and height.

the authority to instigate flow restrictions on incoming traffic, even to the extent, though rarely used except in dire emergency, of turning all traffic away.

The site of the activities of the team's work is the flight strips. By noting down on the strips only relevant details, all members of the team are able to see 'at a glance' the state of the sector, and provide the controller with all the information he/she needs for coordination activities. The aim of the team is to minimise distractions for the controller so as to expedite safety and efficiency. Non-standard flights, particularly, were a distraction since they required more controlling attention. Teamwork, then, enabled controllers to maximise the time they spent on dealing with the bulk of traffic and, since it maximised the traffic capable of passing through the sector, was a productive method of working even though more expensive in personnel than RD3 was intended to be.

Accordingly, to achieve more than this RD3 would have had to replace some aspect of the functions of the team so as to increase capacity still further or provide additional facilties. It did neither. It could not, for example, automatically update FDP information nor display it for all who needed it. Nor could it deal, in the way that a chief could, with non-standard traffic. The new facilities it did provide were not easy to use nor relevant to the type of work done. For example, though vector lines were easy to access they were not used at peak periods since, at such times, decisions tended to relate to short distances, and they cluttered already full screens. In any case, controllers could do without them. Similarly, the direct routing facility had no relevance at busy periods since there were just too many aircraft in the air to allow for direct routing.

At slack periods, however, when there was not enough work for a full team, RD3 did prove useful, particularly in respect of vector lines and direct routing. The former enable controllers to make judgements about potential conflictions much earlier and also enabled them to use extra airspace to bypass the 'long corners' of standard profiles. The latter gave controllers an accurate idea of where a direct routing would actually take a plane and enabled them to meet such requests from pilots more effectively. Among the few controllers who did use RD3 frequently, this was the facility most cited as helpful, particularly in checking that aircraft on parallel headings did not drift into one another due to improperly aligned giros. This use of the facility can buy for the controller about 4-5 minutes with respect to the planes concerned.

No other RD3 facilities were used to any considerable degree. But it is also essential to point out that often the motive for using the facilities noted was that it gave controllers something to do; something that kept them engaged on the controlling task. It was for this reason that the team was dismantled when things were quiet to make sure than when on duty everyone was busy and concentrating. As one chief put it: "a busy controller is a good controller, a bored controller is one you cannot depend on." And it was the busy-ness that gave controllers an "eye for what's happening, using his pencil to get an accurate heading...he can do that more quickly than inputting, and punching questions into a keyboard" [Watch Supervisor]. In other words, the controller's own ability to see 'at a glance' what is happening and needs doing, is an ability that made the RD3 facilities largely redundant. As another controller expressed it: "I mean we know an efficient abacus operator can outperform a calculator any time".

3.5 CONTROLLERS' WORK AND TECHNOLOGICAL INNOVATION

The scepticism of controllers concerning RD3 is, of course, not the only instance of technical and other innovations treated with this response. Other examples include changes in procedures relating to the height of the LTMA ceiling, its boundaries, in STARs (Standard Arrival Profiles) and SIDs (Standard Instrument Departure Profiles) and the introduction of entirely new procedures in relation to minor airports, such as Southend and Southampton. These have often failed to improve controllers' work (in some cases they made the situation worse) largely because they were not based on an accurate characterisation of that work. The Processed Radar Display System (PRDS) introduced on some sectors at the beginning of this decade provided information on radar screens at the finger touch request of controllers. But it bore no relation to controlling work, was difficult to use and would sometimes distract controllers from their main coordinating tasks. What controllers require is that designers base their proposals on what ATCOs call 'real controlling' rather than a second-hand version culled from manuals or constructed from disembodied characterisations of ATC tasks.[11]

It is also quite clear that many controllers feel that those responsible for designing and ordering new equipment ignore the views of those who will have to operate it. One frequently-told story relevant to this was the discovery that the furniture for the new operations room was an "ergonomic disaster", a conclusion came to after the equipment had already been purchased. Another was the decision to go for a computer control and data system without strips before asking controllers whether or not they could do without them.

It is important to point out, however, that there were differences of opinion on RD3, even though the most of the controllers we spoke to were against it. As we have said, it was the younger controllers, particularly, who were more likely to use it and see its benefits. A few managers and a few Chiefs also felt that the controllers' resistance to RD3 was "simply because its a little different", pointing to the conservatism of controllers which makes it "difficult to get new equipment accepted" before it is out of date. Some also pointed to the failure of management to sell RD3 properly, to build up the confidence of controllers instead of introducing it too early before its reliability had been proved.

The ambiguity of innovation is very real for controllers as well as managers. Controllers are aware that the system is reaching its limits of capacity and that new technology is needed if ATC is to remain safe and efficient. However, for them at least, so far they have little faith that the necessary developments will either arrive on time or be suitable to enhancing the work of controlling.

3.6 TRAFFIC GROWTH AND PLANS FOR THE FUTURE

At its simplest present controlling techniques are a fusion of the formal and the informal; a balance of constraint and creativity. However, there is a limit to the extent to which the techniques can produce a safe and efficient air traffic system. As the airspace fills, it becomes more complicated to coordinate and exhausts controllers. As it is

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[11]What we have in mind here are the kind of studies which specify a job in terms of a number of discrete tasks. This point will be taken up further, and in more detail, in sections 6 and 7.

controllers do not work for periods longer than two hours at a stretch and, even during these periods, try to ensure that they are not working at peak levels for all of this time.[12] To some extent, this is taken account of by the 'flow rates' which restrict the number of aircraft allowed into any sector per hour; a rate known as the sector capacity.

It is the sector capacity, tied as it is to what can reasonably be expected of a fully trained and experienced controller to cope with per hour (or that can be handed on to a neighbouring sector without swamping it), that is the 'block' in the system, and the attraction of automated systems which would remove this 'block'. Sector capacities, at present levels, can be seen as a restriction on the growth of air traffic for to increase them very much further would break the system. However, from controllers' point of view what is important is that the move toward capacity restricts the creativity that is possible in controlling and, at the same time, removes one of the major sources of job satisfaction and pride among controllers. The complexity of configurations as the system reaches capacity makes it necessary to fly according to standard procedures since controllers do not have the airspace, the RT time, or even the cognitive capacity to devise other ways of maintaining separations and flow. Resorting to standard procedures further clogs the system requiring even more concentration and effort on the part of controllers. Ultimately, sector capacities are reached more quickly.

Up to the summer of 1986, it was unusual for any sector to reach capacity and flow rate controls were only ever introduced on a temporary,

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[12]Some of the resentment expressed by ATCOs at recommendations to alter shift working patterns and declare a number of them redundant was in response to the perceived failure to understand the rhythm of concentration and recuperation needed for controlling; a failure, in short, to understand the demanding nature of the job. It is true that it can appear that while on shift controllers have a great deal of 'free time' and, therefore, that the operation is overstaffed. Against this has to be set not only the concentrated nature of controlling but also the need for adequate backup. Local management, of course, as ex-controllers themselves know this, and also know that there is some flexibility possible in rostering arrangements. There is more on this in Sections 4 and 5.

short-term basis.[13] Many ATCOs, and managers, felt that the UK service had been 'disgraced' by this step and felt that "now we are becoming the poor man, air traffic wise, of the European system". Significantly, most put this down to inadequate equipment rather than to a decline in competence, and also to the lack of flexibility induced because "more than half of our airspace isn't actually available to us". Traffic levels have, however, increased so much that it is now necessary for longer-term flow controls. LTMA is the most overstretched sector of all. For the first time, the UK's ATC system is a source of permanent constraint on the amount of traffic in the airspace and not just on the way traffic flows through it.

3.6.1 CCF

The anxiety of controllers and management about safety and the pressures on the CAA and NATS from air users and the Government to increase air traffic have led to thoughts about new systems, especially in connection with LTMA, and for *en route* sectors updated some time in the near future. These new systems of controlling, while allowing for increases in traffic, will radically alter the role of the controller, the skills required and the opportunities for creativity.

At the present time TMA airspace is divided into sectors each the responsibility of one or two controllers. The procedures as laid down relate generally to controlled airspace use and specifically to individual sectors, and, while complex and extensive, still afford considerable freedom in the available courses of action for a controller and yet provide a basic and dependable order in the sky. However, although it is the workload limit of the controller which is the main detriment to maximising the flow of traffic through the system, it is important to remember that this constraint is within the particular way in which the airspace is organised. In particular, the division of the airspace into civilian and military zones is, for civilian controllers at least, a major source of frustration, mainly because it inhibits their ability to organise direct routings and adds to the problems of coordination by the

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[13]At the time of the research, many ATCOs expressed worries about the next summer, since though they were working, at busy periods, for only an hour and half without a break, the work was so intense that they were not recovering adequately at break periods.

need to make sure that civilian traffic does not stray into "bandit country". In other words, this legacy has a major bearing on the way in which the traffic load problem is approached. No doubt, if the system was designed from scratch in the light of the current performance of civilian aircraft, it would look very different.

Under the new proposals the amount of airspace or sector under each controller will be far smaller and traffic will flow only one way. Instead of dividing the TMA into 5 sectors, and making all traffic within these the responsibility of a single controller, in the new system each controller will only be responsible for one-way 'corridors' of space. There may be up to 16 such 'corridors' in LTMA.

For example, all inbound traffic to Heathrow from the south and south eastern approaches (currently the Dover/Lyd sectors) will have to join a single route which will lead them all directly to Heathrow. This 'corridor' will have a ceiling, base and sides and will take aircraft through a large part of their descent. The corridor will be divided into sections, each under one controller who will make sure that the aircraft remain within the boundaries and at a speed which maintains adequate separation between traffic in the stream. This 'speed control' will become the basis of coordinating and sequencing aircraft into airports rather than the present hold and stack procedure. The aerodrome approach controller will be placed in the same operations room as TMA to ease coordination. It is this which gives the name to the system, the Combined Control Facility, or CCF: a system which has been in use in the USA for some 10 years.

It is intended that all main routes to and from terminals within the TMA will be corridor based. The system will necessitate more extensive and stricter SIDs and STARs. However, what is interesting about this change, and immensely relevant to the strategy of innovation, is that it adopts a very different set of preferences than those reflected in RD3. In the latter case, the solution was seen as a matter of providing the controller with more information, information which, as it turned out, was redundant, whereas CCF even removes the need for some of the standard information currently made available under the sector and mediator system. Inevitably, this will have major consequences for the role of the controllers, the levels of skills required and their position within workforce-management relations.

3.6.2 Changes in the Controller's role and its consequences

Whereas within the present TMA structure the controller has a crucial role, requiring great concentration often under considerable pressure, in the new system this will change to a more supervisory, less interventionist mode. No longer responsible for traffic flowing in all directions and various speeds, he/she will be more like a railway signal box man, timing and watching the speeds of aircraft as if they were trains running along the same track. His/her task will be to prevent aircraft catching each other up or flying off the track into another corridor of airspace. Inevitably this system minimises the opportunities for creative controlling and a reduction in the skills required for controlling. To this extent it is a form of 'deskilling'.[14] As one controller summed up the widespread feeling about CCF:

> "...if you are just sitting there and you have to do a given thing to an aeroplane, (until) the sector is going to be handed over to someone else, you may as well get a machine to do that, because I think most of us get a lot of satisfaction from being original...It would become even more of a sausage machine."[15]

There are several consequences of this change. While the impact of controller error will be minimised, it will make system failures more manifest. Controllers' work will be simplified, and so, arguably, less likely to lead to mistakes. However, the system, both airway procedures and technology, will become more complex and more vulnerable to failure.

Second, using the skills described earlier is an important aspect of the controller's job, highly prized by them and from which they derive a great deal of satisfaction (Crawley, 1982). It is one way in which their professionalism is displayed. However, the reduction in the range and character of the skills required under the new system means that controllers will be more readily replaceable. At the present time a controller must be well versed both in the procedures and the range of practical techniques, both formal and informal, on sectors that expedite

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[14]The sociological literature on this is extensive, initiated by the work of Braverman (1974).

[15]The analogy with a sausage machine is not inappropriate since CCF can easily be visualised as a series of intertwined sausages in the sky.

the safe and efficient coordination of air traffic (the discussion of 'stack jumping' [see section 5] illustrates how and why detailed knowledge and practise in the use of that knowledge is necessary). With the CCF system training could be shorter and achieving practical competence, despite there being more formal procedures to learn, quicker. Obviously, such a system will weaken the position of controllers vis a vis management. However, as one Watch Manager observed, the lack of keenness for CCF will be more pronounced among the older controllers:

> "He's done donkey's years of having a bit of freedom but the new controller who is brought into the system...won't know any different, so the new chaps would not be against it. You slowly get rid of the prejudice, or whatever you like to call it as people retire".

Third, controllers will be able to deal with more traffic and, hence, be more productive. The price, however, is that, on present evidence, they will be doing less satisfying work.

The main reason controllers are prepared to accept the new system despite the kind of scepticism we have noted earlier, is that traffic demands necessitate it. Controllers, perhaps more than anyone else, are aware of the risks and hazards of the present system and realise that its limits have been reached. Further, because of experience with previous attempts at innovations, designers and managers are going to considerable lengths to involve controllers in the design and implementation of the system. A committee of TMA controllers reports on and makes proposals about the procedural aspects of CCF. The design itself and its new upright consoles placed side by side in banks in a new operations room, will be introduced gradually so that faults and improvements can be tackled step by step in the light of operating experience. Controllers will use the new suites under existing TMA procedures in order to resolve ergonomic and other problems. Approach controllers will not be introduced until all TMA controllers have become familiar with the system, all teething troubles overcome, and, even then, Heathrow, Gatwick and Stanstead controllers will only be introduced one group at a time.

All of this, though methodical, prolongs the time taken to implement CCF. It is estimated that from now it will be another 5 to 6 years before it is fully operational. As the system is already reaching breaking point, much depends on the attitude of controllers who are becoming increasingly resentful. Many feel that the system is too late and that the delay before its introduction will take too great a toll of controllers' energies and even, conceivably, the lives of air travellers.

3.7 POSTSCRIPT ON RD3

Since writing the above, very recent discussions with some of LATCC's senior management have indicated that there are moves to make use of RD3's confliction warning system. Controllers are going to be required to make us of it. This was prompted by a 'near miss' in Lydd in January 1988. In current circumstances, management feel that it is ill-advised to have a confliction warning system that is not being used until operational experience has confirmed whether or not it is an "improvement which makes things worse".

As far as the confliction system itself is concerned there are already a number of problems they need to resolve. At present there is no control over the timing of when the warning goes off, and when it starts flashing it is not only visible to the ATCO concerned but also to the ATCO in the next position. In addition, as yet there is no input to the computer, so the system cannot be turned off.

The Lydd incident itself seems to have been due to "communication failure" in that one controller did not know that an aircraft had been sent down to a level in use. However, the position involved had not been used for 5 years, and so the ATCO was unfamiliar with it. The union now wishes to regularise the situation so that if positions are opened regularly then it has to be ensured that controllers are allowed to become familiar with them.

3.8 CONCLUDING REMARKS

It would be easy to conclude that RD3 was a major mistake, especially in hindsight, and mistakes there were. However, given the complexity of the ATC system itself, anticipating what is needed in order to enhance its traffic carrying capacity is not straightforward, given that there are options not all of which are equally available. Increasing civilian airspace, and so decreasing the military, is, for example, one option not available. Also, given that it is the controller's ability which places a limit on the flow of traffic through a sector, it was perhaps natural to assume that providing the ATCO with more information would improve his/her performance and/or ease the pressure. However, as we shall illustrate in Section 6, much of the work of an active controller is 'buying time' and if much of the time bought is expended on operating a poorly implemented technology, then there is no gain.

Further, RD3 failed to give due weight to the experienced and trained knowledge controllers acquire in being able to see and work out, almost 'at a glance', what is happening and what is required: a talent that largely obviated the need for the kind of information RD3 was capable of delivering.

SECTION 4

THE CONTEXT AND MANAGEMENT OF ATC

4.1 ATC IN THE CONTEXT OF STATE-ORGANISED PRODUCTION

The initiation and reception of technical and organisational change do not arise in a vacuum, but are conditioned by their context and circumstances. Part of that context of the activities of NATS within the CAA lies in is its characteristics as a 'semi-state' body. Recent sociological literature concerned with theories of the state has increasingly emphasised its relative autonomy. Evans et al. (1985), for example, express a commitment to the complexity and variety which real state systems are likely to reveal, and to empirical studies through which to reconstruct an understanding of 'the state' and state relations. They cut through aspects of the 'autonomy debate' by claiming that, 'heuristically, at least, it is fruitful to assume *both* that states are potentially autonomous and, conversely, that socioeconomic relations influence and limit state structures and activities.' (1985, p. viii). We should note the 'Janus-faced' character of the state in the two distinctive aspects which it presents: an outward-directed one in which states face - and compete with - each other in a 'state of nature' (de Jasay, 1985) as nominal equals; and an inward face which they turn to their own subjects/citizens. Both of these are relevant in considering the functions of the CAA.

For our purposes, we are mostly concerned with the ways in which state-organised *production* - that is, those activities where the weight is on the production by the state of goods and services, rather than on the production of regulation and policy - has been changing. It is therefore pertinent to consider how those activities compare in their organisation to the production of goods and services by private capital and what similarities and differences exist in the restructuring of those activities (Shapiro, 1988). At first sight the competition that characterises relations between private capitals is formally absent in the state sector since, even where there is a direct private alternative available which may strip the state of 'market share', this will not automatically generate a crisis of profitability. Hence the key mechanism of 'creative destruction' (the engine of restructuring) is absent

(Schumpeter, 1939).

However, when looked at in detail some of the differences in these processes are mitigated. For large companies with diversified production and extensive internal (national or international) transfers, it will often be far from clear excactly what the profitability of a particular unit is, even though it may be far clearer in a generalised sense that profitability is the goal. Further, for such companies, the market for many products may be far from perfectly competitive, and mechanisms for price and profit regulation may abound. So, when faced either with a crisis of profitability for the overall organisation or with a rigorous management, such organisations will seek analytical tools and measures of a 'secondary' character with which to establish the value or the deficiencies of a particular unit. There is, therefore, a substantial 'institutional economics' that enters into the relation between the profitability and the restructuring of major capitals. Such organisations may often seek ways to 'mimic' a market rather than experience it directly.

There is some similarity between this and the reorganisation of state production. Fiscal crises generated by state expenditure - or political crises of commitment to state expenditure - will prompt a search for economies and 'efficiency'. These too will often take the form of seeking to mimic a market by inventing and applying rules of measurement and of performance. Restructuring will occur, therefore, but it will tend to be 'lumpy' rather than continuous and to take on a 'theoretical' or 'pseudo-professional' character - e.g. by commissioning consultants' reports and attempting to copy strategies adopted in the private sector. It will also be difficult to monitor the implementation of such strategies, as can be seen from current attempts to devise 'performance indicators' for the public sector in the UK. There may be 'demonstration effects' between capital and state in either direction: how to establish independent cost-centres, or how to break a militant union. Another feature of such 'indirect' criteria for success is that, to the extent that they are arbitrary, they can be rapidly and frequently changed. Public and large private organisations may, therefore, be forced to jump through a succession of hoops reflecting the philosophy of the day.

A significant current example is the prominence of discussions of flexibility and the 'flexible firm' in academic, management *and* official literature. Some have argued (e.g. Pollert, 1987) that this literature has a very slender empirical and theoretical foundation, and slides imperceptibly between description, prediction and prescription. It is claimed that the notion of flexibility originated in officially-sponsored research and was enthusiastically taken up and promulgated at the highest levels within government; that it has been tested first in areas of state employment; and that it is now being promoted to private industry as 'best practice' in terms of manpower management.

There are other distinctive features of state production which may be relevant. Firstly, national states will not normally consider strategies that directly shift production outside their territories, and this excludes a significant part of the repertoire of strategies available to capital. Secondly, states can also award themselves special legal regimes for production. The most obvious example of this is the state monopoly. Even where 'privatisation' is attempted extra-competitive regimes may persist - e.g. the crucial determination of 'common carrier' charges for communications networks, or the 'inflation-minus' formula for Telecom charges. Thirdly, states may also intervene in their own labour processes by suspending some citizenship rights for some employees. They may also exempt themselves from certain statutory or common law requirements, e.g. planning consent for public utilities, or legal liability. Fourthly, states will be more prone to direct political (e.g. electoral) considerations in reaching restructuring decisions, such as relocations. And fifthly, the very production activities in which the state engages (and changes within these) will similarly respond to political considerations rather than market opportunities.

The relationship of the CAA to the state is complex. Firstly, NATS is a joint civil-military service, united at the top, split operationally in terms of civil and military ATC, but with various semi-formalised mechanisms for coordination and conflict resolution between these wings. Some of the tensions to which this gives rise are discussed elsewhere in this report, but this context brings an irreducable 'state' element right into the heart of ATC operations. This is reflected in the high security that surrounds it and in the fact that the main UK ATC centre - LATCC - is located within an RAF base. ATCOs were formerly civil servants and, though this status has been formally severed for some time, it remains endemic to the salary, pensions, grading and organisational structures of the service.

Secondly, the CAA exercises several of the regulatory functions of the state in connection with air transport. In the *internal* of its Janus-faced aspects it is responsible for licensing new aircraft, airfields, pilots, airways, categories of airspace, the allocation of routes, etc. It is not to be expected that the state will ever relinquish these regulatory functions, regardless of the extent of moves towards the privatisation of state services. In its *external* aspect, the state negotiates (and competes) with its peers over the international regime of air transport and the allocation of routes to (now, overwhelmingly national) carriers. Although the UK is currently in the vanguard of moves towards deregulation, this is partial in that some controls are likely always to remain (e.g. pertaining to safety or security); and the state will never surrender the principle of its *sovereignty* over such matters, unless it is to transfer aspects of its sovereignty to supra-state bodies such as the EEC. The current situation is complex and rather messy. For some functions (particularly charges to users) the UK operates through 'Eurocontrol' (a consortium of European ATC agencies). There is also an International Civil Aviation Organisation (ICAO) founded after the 1944 Chicago convention on civil aviation but, despite the ambitions of some of its member states, there has been little progress in replacing individual agreements between states. There is, therefore, a plethora of such agreements, specifying the conditions for international flights. Regardless of political climate, therefore, the state will always require some kind of 'expert arm' in relation to aviation; though this could, of course, take many different organisational forms.

Thirdly, it is very much in the character of ATC in an airspace as small as that of the UK that it must be organised by a single body. Although it is conceivable that, for example, SCATCC (the Scottish ATC centre) could be separated off, this would account for only a very small proportion of air traffic movements. NATS therefore has a rather irreducible monopoly character. It does not follow from this that it must be organised within the state; but it does mean that any privatisation would be complicated by special arrangements to take account of this monopoly character, and would always remain controversial. NATS is in the position of being able to cover its costs by charging fees to its direct users - the airlines, and other pilots making use of its services. For the airlines, ATC charges represent a small component of their operating costs, although, following the decision to move towards 'full cost' charges in the 1970s, these (together with aerodrome navigation charges) grew to account for approximately 10% of direct operating costs (Hislop, 1980; Ambrose, 1984). On the other hand, the provision of an effective and efficient ATC service is of the greatest concern to airlines, since this greatly affects both their direct operating costs, and their marketing through the quality of experience that their passengers have in flying with them (whether there are long delays in taking off, lengthened flying time resulting from circuitous routes, long uncomfortable periods circulating in the stacks prior to landing, etc). Hence, while airlines have a strong material interest in the details of the ATC regime, the cost of the service is probably the less important aspect of it.

The CAA has, then, reflected since its inception the changing self-conception, organisation and activites of the state. It was very much a product of the climate of burgeoning 'quangos' of the Labour administrations from 1964. It typified in many ways that style of interpretation and realisation of the 'mixed economy'. Its purpose was to provide coherence for a field of state regulation and administration, and to impose order, control and leadership on the activities of the private sector. As such, its cost or 'cost-effectiveness' was not a matter of very great concern.

Much of this has changed from the mid 1970s, particularly in the period of Conservative government since 1979. This is not, however, a simple 'rolling back' of all of the activities of the state. Some areas, particularly those to do with the military and with social control, have been strengthened, and various local state functions have been centralised. NATS, with its military and security aspects, has stood to gain from these developments. However, suspicion and hostility has focussed particularly on those institutions within the state designed to regulate and control the activities of the private sector. The 'enterprise economy' is no longer seen as requiring the firm guidance of an avuncular state. In a related move, the notion of 'consumer sovereignty' has meant that those parts of the state exercising a monopoly in the provision of goods or services have come under particular scrutiny. Here, therefore, the ATC service is vulnerable, and was considerably shaken when it found itself referred to the Monopolies and Mergers Commission in 1983 for a report as to whether it was operating 'in the public interest' in the exercise of its monopoly.

The MMC report focussed on the financial accountability of the CAA, and its recommendations were concentrated in three main areas; that the procedures for accountability should be improved; that the methods used to assess the merits of new procedures and new equipment should be reviewed; and that the utilisation of manpower - the largest single component in NATS costing - should be critically examined. This last recommendation was based on the finding that private companies providing ATC facilities at smaller aerodromes, such as Exeter and Liverpool, appear to do so at lower cost. This report, and a subsequent report by a firm of management consultants (both, incidentally, the subject of some anger and derision within the organisation for what was perceived, from the shop floor, as the cursory manner of their investigations) recommended that the system of rostering staff - particularly their distribution between busier and quieter periods of the 24-hour cycle - was wasteful, and that significant savings could and should be made. We argue below that this context is important both for developments in industrial relations and for the introduction of new technology. In effect, the change in the 'state regime' being applied has produced a particular kind of squeeze on NATS, in the shape of costs via staffing levels. Though undertaken 'in the interests' of consumers, it is arguable that it may benefit them where the felt need is least, but create problems where that need is greatest: in the quality of the service.

4.2 THE MANAGEMENT OF ATC

4.2.1 Morale

We have already stated that it was no part of our purpose to inquire directly into manning levels, morale or management style. However, it has also emerged very clearly that we cannot understand developments in technology, or the routine achievement of safety and expedition as a collective procedure, without taking account of some aspects of these matters. A striking and, to us, unexpected finding was the marked 'stand-off' between 'management' and 'shopfloor' in NATS, and the lack of much in the way of understanding and sympathy bridging them. Though most of those we interviewed formally, or spoke to informally, expressed the opinion that morale among controllers has reached a low ebb, it also seemed to us that this distanced relationship was of much longer standing. It is, indeed - as in many workplaces - symbolically represented by the spatial arrangement of NATS, both locally: with managers on a separate floor of a separate part of the building from the 'bears in the bear-pit' doing the controlling; and nationally, with higher management, but also research and other ancillary services, seemingly a world away at CAA headquarters in Kingsway. (This is not to say that there are no good reasons for these locational arrangements; but that they nevertheless feed the strong sense of division.) If this was unexpected, it was because we were also aware that ATC could be counted as a partially-autonomous, credentialled and licensed occupation with a strong and self-contained occupational culture; that the work offered considerable job satisfaction; and that the pay and conditions were relatively favourable. How, then, had such estrangement built up? An initial approach to the question can be made by considering the extent to which the institutional arrangements in which ATC is embedded can be described as those of a 'profession'.

4.2.2 ATC as a profession

There is a variety of perspectives on 'the professions'. At its most benign, professionals are seen as trusted custodians of esoteric knowledge and complex skill; as altruistic and universalistic servants of the public need, who place vocation above self-interest and observe an ethical code of service; and as exercisers of legitimate and charismatic authority. Not surprisingly, the members of professions themselves often espouse this kind of view. As Freidson points out (1983, p.19), other observers are less sanguine. Economists have focussed on their closed, monopolistic, exclusionary labour market, and other restrictive economic practices. Political scientists have emphasised their features of privileged private government of themselves and, often, of others. Those concerned with policy have criticised their narrow, insular and often self-serving vision of the 'public good'. And sociologists, while picking up these other perspectives, have also studied their institutional organisation, their everyday battles over the allocation of resources and of tasks, and their relation to political and economic elites, to the state, and to the class and market system (Larson, 1977).

Despite a considerable history, studies of the professions have made only limited progress towards a coherent analytical conception of their subject. It is difficult even to agree on the defining features of the mediaeval 'status professions' (Elliott, 1972) of law, medicine and the clergy, let alone those of the many newly formed or reorganised middle class occupations which have sought this status since the nineteenth century. Indeed, Friedson (1983, pp. 22-26) argues that 'the professions' are not a general phenomenon, but one specific to particular societies - Britain and the USA - in a particular historical period. This usage has little application in continental Europe or in other industrial societies: professionalism is an 'Anglo-American disease'. Hence, he claims, an analytic conception of profession is unattainable, and should be substituted by the study of *occupations* and the full variety of distinctions and processes that obtain within them. The study of professions survives, then, but relieved of the broader generalisations and conceding their changing, intrinsically ambiguous, empirical, localised and historically limited character. This includes the study of the institutional and organisational arrangements through which some occupations seek to improve their security, autonomy, conditions of work, income and prestige; but also the arrangements through which *other* groups and interests may contest such moves, whether as existing professions seeking to preserve their prerogatives, or as employers or clients seeking, in their turn, to control the terms and content of the jobs they wish to have done (Freidson, 1983, p.28).

Following this spirit, we can inquire into the particular characteristics of ATC work as an occupation, and the managerial consequences that flow from them. Appropriate headings for this include recruitment, training, accreditation, working practices, and promotion and career.

4.2.3 Occupational characteristics of ATC

Recruitment

Historically, the most significant source of recruits for ATC was ex-servicemen, particularly from the RAF. Both the military discipline and the familiarity with flight procedures (though not necessarily as air crew) were seen as particularly relevant. There remains a distinction in the occupational culture of ATC between those with service backgrounds and the more recent 'civilian' recruits, which compounds generational differences. Some linked this to low morale and discontent within the profession:

R: I mean, these controllers that are in this unit have got to bail out management who have failed to perform, it's as simple as that, and they've got big troubles I can tell you because I think that the chappie of today won't take perhaps what my generation would.

I: Why not?

R: Because they are a different animal altogether, I know a different animal when I look at my kids. I think there's a different awareness, a different sense of loyalty, a different sense of discipline, and a different sense of service. I'm not talking about professionalism, or professional service, but a difference in *providing* those services ....

And again, in a different interview:

R: I didn't join a union myself and I think a lot of ex-service people are certainly non-union or have a dislike of unions. I came into this job to do the job, and as far as I'm concerned ... I feel that management is there to manage and I'm here to do the job, and if they say, 'You do it that way', I do it that way, and if I don't like doing it I get out and go somewhere else, and this is my philosophy in life. ... A lot of the young guys coming in ... they've got no feel for the job, they just come in as a job, and obviously they are looking to go somewhere. And they are dis-chuffed with the way things happen and it causes low morale. I think service background guys, which we are getting less of now, I think they are ... a completely different animal.

These views, it should be noted, did not prevent this interviewee from later voicing a string of scathing criticisms of management failings.

For the civilian entrant, education to 'A'-level standard is the minimum requirement, though there has recently been some graduate-level recruitment. In terms of educational pre-requisites the job can be seen as roughly equivalent to that of a laboratory technician or a nurse. Within the nuances of the British class-related education system, therefore, ATC as an occupation is unable to aspire to the 'status professions'. There is never any shortage of applicants.

Training

The details of training procedures change from time to time, but typically involve up to two years of study and practice at the College of Air Traffic Control at Hurn near Bournemouth. The work involved is complex and should be thought of as a form of 'higher education', though the precise level of the qualification is harder to specify. Since this credential is an absolute requirement for entry to the occupation, it clearly has the potential to operate as an exclusionary market shelter and hence as a vehicle for professionalisation. However, there are also limits to its capacity to work in this way since the skill and credential acquired, though exclusive, is also non-transferrable. There is in effect a monopsony purchaser of ATC skills. Management, rather than a collegial professional body, retains control over training and recruitment; but, as we shall see, ATC management is largely made up of ex-ATCOs. This aspect of the occupation's professional character therefore remains essentially ambiguous. The training is very rigorous and a substantial proportion of recruits fails to complete it successfully. This failure rate has grown recently and the selectors are having great difficulty in finding aptitude tests with better predictive powers.

Accreditation

Training is by no means the end of the accreditation procedures for ATCOs since they are required to be 'validated' - that is, assessed and licensed - for each sector of airspace that they are to work. These are not 'once-and-for-all' validations, but must be regularly renewed and maintained by spending the specified number of hours actually working that sector. It is the ATCO's responsibility to ensure that his/her validations do not lapse and to take the initiative in prompting the rosterings necessary to achieve this. This can, therefore, be seen as an attribute of professional responsibility and autonomy, though it is again ambiguous in involving a far more rigorous standard of continuing assessment and licensing than most professionals subject themselves to. There are, in addition, annual competency examinations. These are not token or ceremonial procedures but are taken seriously by candidates and assessors. Autonomy is also reflected in the assessment and licensing by 'peers' (senior colleagues) that is entailed in validation - though, again, as much on behalf of the organisation as on behalf of the profession.

Working practices

There is much detail on working practices throughout this report, and this section is concerned only with their 'professional' attributes. It is very clearly the case that the occupation involves a specialised, codified and formal body of knowledge, contained in the volumes of the Manual of Air Traffic Services and in other documentation. Though highly elaborated, extensive, and completely uninterpretable to the layman, this clearly does not compare to the volume and open-endedness of legal, medical or academic bodies of knowledge. It is also less clear that the body of knowledge is under the control of the members of the profession, but is imposed from above (albeit by ex-ATCOs), and the changes that this involves are often resented:

> R: We are conservative animals, basically. Change is difficult to cope with as well, it requires an awful lot of effort on the part of the controller. The controller wants to know exactly where he is, what he's dealing with, and how to deal with the problems. Whenever a change occurs we are changing the rules, it becomes another philosophical hurdle the controller has to cope with, a case of when he's busy, will he remember the change, will he remember how to cope with it? If it's a change in procedure, it's an extra amount of stress.

Anyone familiar with mainframe operating systems can sympathise with this: it can often seem easier to learn an entire new operating system than to internalise a minor change in one procedure.

One cannot fail, after a period of observation and discusion with ATCOs, to be impressed by the genuinely and unremittingly demanding and complex nature of the work. This emerges in three main ways, in addition to the description of the tasks themselves. Firstly, there are the strong anxieties that some ATCOs express at having to try to cope with past and future peak loads. This can be understood when it is considered that the work load in confliction resolution and avoidance is generally taken to increase as the *square* of the growth in traffic movements (Hislop, 1980):

> R: There was so much traffic down there, coming up and down and crossing, you couldn't provide a vertical separation as they were coming into this lot because all the levels were taken up, nor could you provide procedural separation because there were too many of them, we just had to take that traffic from that

sector ... and everything had to go round. I can assure you the chappie on the right was watching that little bit, I was looking at all the inter-liaison and the rest, and the chappie on the left was doing his bit, there was no way that any one of us knew everything that was going on on that sector because it was so bloody busy, no-one could have done it, it was so busy, and it was aggravated by a lot of problems outside our area. ... In fact Concorde didn't get up above 240 until it was out because there were 25s and 26s and 27s and 28s, and they had to lace through it. I don't want to see a day like that again, it was not air traffic control, no-one can say it was AT control; it was held together on the expertise of the three of us that were in there. We came to 2.25 to hand over to the afternoon team and [they] came in, two plus a chief, the three of us stood back from that scenario at a quarter to three with the other three in situ, it had taken 20 minutes to hand over. That sort of pressure, for me, that's not air traffic ....

I: What month was this?

R: This was August if I remember, ... but I've never seen anything like it. Took it down to ops downstairs and said, 'Have a look at this, analyse it because this is ridiculous', never did hear anything about it. X who took over from me, he said it didn't stop, it went right the way in the split format until 9.30 that night, that's a hell of a lot of traffic!

And again, from a senior crew chief:

I: Do you think morale is really low at the moment?

R: I'm not very happy with it. My own morale went down considerably last year. ... I think we had a real beating last year and the traffic increased a lot and we were, personally, I was hanging on by my fingertips an awful lot last year ... and when you are on a busy sector and you are just trying to scrabble on to stay with it - you can't do it, you can't do what you should be doing. And that's not good enough, that's not safe, I don't think. This was the situation last year and prediction figures show that there's going to be an increase this year ... so I'm not looking forward to it at all.

Secondly, there is the concern that ATCOs express, both for themselves as individuals and for others on whom they are dependent, with the necessity for constant practice in the specific tasks and skills involved in a particular job or position. This is because their ability to do it rapidly fades, even for a more 'junior' task such as 'working the wings':

> R: One of the problems is of course that when, the more skilful, the more tasks people are able to do as controllers, the less duties they do on the wings, and then of course they lose all their skills, they are very conscious [of this], and most of them, when they don't find it easy to do the wings any more, don't actually like doing the wings, and ... because of that they tend to get rostered even less for doing the wings and it can cause a bit of a problem. Their facility with the computer completely goes, which is not surprising with such a difficult computer to use, if you don't do it all the time you forget all the criteria that you've got to apply ...

And thirdly, there is the concern expressed by many ATCOs about the problems of age. It seems to be widely accepted that it is difficult to cope with the pressures and to achieve the necessary level of concentration, speed and decisiveness much beyond the age of 50:

> R: It's a fact that recently we've had quite a few cases of people beginning to slow down certainly at 50, definitely at 55, and even 45 we've got people beginning to slow down.

And again, speaking of a particular sector:

> R: It's a big sector, yes. It was always big geographically, but it wasn't very big on movements. It was known as the geriatric sector, all the gentlemen went down there and worked.

And again, from a respondent himself senior in age and position:

> R: There have been one or two exceptions, and very few, who have been able to remain efficient controllers up to the age of 60, but the majority are on the decline from the middle 40s.

It is sobering to consider that the intrinsic demands of the job are such that ATCOs are losing faith in their colleagues' capacity to perform it dependably beyond their mid-40s.

Overall, then, the work of ATC involves materially extremely complex and demanding skills; it is carried out - as we have emphasised - collectively rather than individually, but in relatively autonomous work groups who control and direct their own activity. Yet it is governed by an extensive body of rules imposed, at least in part, from above; and it is subject to constant management surveillance and recording.

Promotion and career

The career structure in ATC has a number of distinctive elements. Firstly, the opportunities for promotion are rather limited. Many of those interviewed remarked that the work basically consisted in controlling aircraft 'on the tube' [radar] and that there was nowhere in particular to go:

> I: What do you think of the career system?
>
> R: There isn't one as far as most of us are concerned, a lot of them accept that, I accepted that when I took the job. ... I'm not the type of person who wants a job where I am necessarily in charge of a lot of people, because that tends to be an office job away from where you can do the controlling, ... I'd rather control airplanes than manage people.

There is also a hierarchy of positions within 'active controlling': ATCO I, ATCO II, crew chief, deputy watch supervisor, watch supervisor, watch manager. Even here, though, several respondents seemed genuinely uninterested in any move away from what they saw as direct controlling:

> I: ... do you think there is generally a problem with the career structure?
>
> R: There is no career structure, I mean I am now, apart from my salary going up, the chances of me getting promoted are very slim. If I look for promotion I can't think of anything more boring at the moment than sitting out there being a chief. Being told what to do, virtually, by people that are junior to me. I have to say I enjoy doing what I'm doing at the moment.

This view was, of course, contested by crew chiefs themselves, who elaborated in detail both the interest and the increasing complexity and importance of their tasks.

This perception of there being 'nowhere to go' in terms of promotion and career stems in considerable part from a peculiarity of the 'civil-service-type' pay structure. ATCOs succeeded in negotiating a substantial allowance - worth upwards of £2,000 - in recognition of the shift work which they all must do. This allowance is lost if ATCOs move to a regular desk job, so a move into management and administration means a drop in pay. Hence, this move is interpreted as a demotion rather than a promotion, and is generally spoken of as something that happens when 'something is wrong': when an individual is no longer willing or able to continue with active controlling, perhaps because they have failed a medical, or have suffered a loss of confidence:

R: Most people realise that there has to be a differential between shift work and non-shift work, but the differential at the moment is far too large, most people can't afford to lose £3,000, £3,500 per year, plus all the extra travelling expenses involved in going to work at CAA House, for example; I certainly couldn't. Because everyone who lives down here has got a massive mortgage and that amount makes all the difference. So they tend to get people who have lost their licence on medical grounds, ... or they have had enough of the ops room and can't stand it any more and go into an office.

I: And they are not really the people who should be there are they?

R: No, you need people who have the motivation to say, 'I want to do something, therefore I must go into an office on the administration side', but they don't do that at such a large financial disadvantage.

We have no way of assesing whether this really affects the 'calibre' of management and administration; but, true or false, it undoubtedly affects the esteem in which they are held by the 'shop floor'.

Despite this, it is nevertheless claimed - indeed, almost taken for granted - that only ex-practicing-ATCOs have the knowledge and capacity to 'manage' ATC:

R: ... there's no other way of doing it, you can't have a management structure entirely divorced from the operations side, you've got to have the operational experience somewhere before you go into the office job.

This conforms to some degree, therefore, to the model of a 'self-governing' profession. Yet, no doubt for the kinds of reasons discussed above, these managerial 'colleagues' soon come to be disparaged:

R: ... others, I think, they would use the excuse that they want a career to get out of the ops room because they find it - they find it a bit hot in here and so they think, 'This isn't for me', which is fair enough. ... this is what frustrates people, when they see people making lots of decisions and they know darn well that their actual operational experience is very little, and this does get frustrating. ... It's easier to take decision-making from people at the top you respect, it's hard to take it when you see the decisions being made by people who,

> when he was here, he didn't half struggle a lot! You know, he couldn't cope with this, now he's telling us to do it, you know.

However, others also made the reverse point: that those with little aptitude for management, administration or systems work used the notion of a practical, operational vocation as an excuse for disregarding a 'career'.

4.2.4 Structures of management

What emerges from this review of some of the occupational characteristics of ATC work is an amalgam of some aspects of the classic attributes of a 'profession' - credentialied entry, autonomy and self-regulation in work, a notion of vocation and of service, and a codified body of knowledge - with many of the classic attributes of a bureaucracy. In this it clearly reflects its origins in the civil service (and in military service) - the archetypes of a developed, hierarchical and rigid bureaucracy. Although at first sight an odd combination, Dingwall reminds us, drawing in turn on the work of Parsons, that the capitalist economy, the rational-legal social order (bureaucracy) *and* the modern professions are all contemporary developments (Dingwall, 1983, p.3). Bureaucracy and professionalisation, then, can be seen as sharing many features - functional specificity, the restriction of the domain of power, and universalism - with only the minor, alleged distinction between self-interested and altruistic motivation dividing them (Dingwall, 1983, pp.3-4). However, this overview, systems approach to these institutions does not necessarily coincide with the experience of being a member of a 'professionalising' occupation within a bureaucratic framework.

This helps, perhaps, to set a general context for relations between 'workforce' and 'management' in ATC. The combination of bureaucracy and hierarchy with the 'professional' specificity and distinctiveness of the occupation help to account for the distanced, 'us-and-them' climate. At the level of experience, the 'professionalism' challenges the legitimacy of the 'bureaucracy', and competes with it for control over the organisation and development of the task. This finds institutional expression in the salience of the public-sector unions to which the majority of ATCOs belong. Yet, the hierarchy too takes on a distinctive character as a result of being largely composed of (ex-practicing) 'fellow-professionals'. The main differences one would expect are a continuing orientation to the notion of 'service' and hence to the established working practices through which that notion is realised, and an attempt to generate or maintain a 'collegial' sense of self-government and of consensus within the ranks of the occupational group. This contrasts with the position in industry in which hierarchy and conflict are much more clearly institutionalised, both between workers and management, and within management through an ideology of personal advancement, competition, success and failure. Of course, this 'industrial' mode also has its own peculiar consequences, such as the 'Peter principle' of continued promotion to the level of incompetence, and the disincentives for collective work.

It does not follow that management in ATC will be static, conservative, or resistant to all change; but it does make it likely that some *kinds* of change will tend more than others to generate conflicts for individual managers between their administrative and professional identities; and, indeed, real conflicts with their 'professional colleagues'. An interesting consequence is that each 'side' of the divide tends to see itself as dynamic but its counterpart as conservative. We were frequently warned, when seeking initial contacts and access for our work, that we would find ATCOs a profoundly conservative, 'practical' bunch - meaning that they were both resistant to change and suspicious of 'outsiders', 'researchers' or 'investigators'; hence that we might well find them hostile both to ourselves and to our interest in technological change. We found just the opposite: that after very brief explanation, ATCOs, both individually and through their union representatives, were dying to tell us all about their work, what was wrong (and right) with it, and how it should be changed. The results of these conversations, together with the context of the institutional arrangements described in this section, form the main basis of the discussions of industrial relations and of attitudes to technological change which follow.

SECTION 5

INDUSTRIAL RELATIONS AND THE ACCEPTANCE OF TECHNICAL CHANGE

5.1 INDUSTRIAL RELATIONS

We argued in the previous section that the combination of the changing 'state' context of NATS and the professional and bureaucratic features of the occupation of air traffic control together inform labour-management relations. Management, we argue, finds itself squeezed between rapidly shifting expectations of performance and cost-effectiveness, and a critical workforce; and constrained further by shared notions of a professional community. The events that brought this relationship to a head, and brought air traffic control out of obscurity, started with the attempt by management to act on the recommendations of the Monopolies and Mergers Commission and consultants' reports on more efficient manpower utilisation. They proposed changes in the rostering arrangements designed to align staff availability more closely with the peaks and troughs of demand for ATC services, and so bring about manpower savings. This brought into focus differing perspectives on the nature of the job of ATC, and hence of the 'proper due' of those who do it:

I: It's also useful, the nature of the shifts gives you a lot of [free] time..?

R: They try to make us work for our living, and there are others thinking that we don't already. I firmly believe that we do work for our living adequately as we go now. The reason that our safety record is good is because we *need* that relaxing time, we need not to do more than two hours on radar without getting a break, we need to to have the ability to go early after you've been hit between the eyes by tons of traffic for the morning duty, you don't need to be told that you must stay on, you must do eight hours. We are very efficient in our way of handling traffic, ... we shift it, we are extremely productive, therefore don't keep piling the pressure on. It's not a job where you must work 37 hours a week come hell or high water, because then I think safety will be compromised. I go home after a morning duty knackered and it's not unusual for me to go to bed for an hour or two, and it's not because I've been up the night before! ....

I: Well, there have been some controllers who have said, well, in a sense one of the consequences of the shift system is that there is a mis-distribution of labour. Other forms of shift system, perhaps breaking off the shift system so you have teams instead, to ensure that you have the bulk of labour say between 6.30 to 10.30 in the morning. Or slightly different arrangements.

R: Well, that argument leads on inevitably to the fact that they are trying to get 36 hours or whatever it is, whatever figure you want, they are trying to extract the last hour out of us. I am saying that I firmly believe that that is potentially very very dangerous.

In similar vein, a very senior controller elaborated his views on the balance between safety and efficiency in a changing climate - offering, incidentally, a fascinating sidelight on the interpretation of technology:

R: I think they feel it's not the same ... freedom in which to get on with running our own ATC system, we are more and more being ruled by the accountants, which is happening in lots of jobs, airlines are suffering from it as well, ... which is really being looked at as a commercial enterprise now rather than part of the civil service as it used to be. OK, we've possibly wasted a little bit of money in the past, but you've got a safe and efficient service for the travelling public and if you do try and screw it down too tightly on a commercial basis you are going to erode safety a bit. This is what worries them, that they are going to be too cost conscious, try and run it with too few controllers and make them accept longer hours on a busy tube, and possibly accept a bigger slice of the air traffic, a larger sector ... . I can draw a parallel between that and a crash that happened in Spain, at Madrid, you remember the DC9 that taxied on to the runway in front of I think it was a 727 or another DC9 taking off, and they collided ... taxied out of thick fog, it got lost and couldn't see which turning he was on and he blundered onto the active runway. ... He'd have been behind the aircraft that was waiting to take off, so the ATC naturally cleared him to taxi to the waiting point and cleared the other one for take off. The other one took off and this thing was on the runway and it killed a lot of people. The accident investigators blamed, the one section, blamed Madrid airport for not having aerodrome surface radar. So that caused the accident. Well, with some, equipment you haven't got can't cause an accident! The accident was caused in this chap being forced to taxi in conditions where he couldn't see where he was going and the tower couldn't see where he was going. It was the commercial pressure of getting that airliner on its way; he didn't want to go, apparently, in those conditions. And those are the sort of ideas that get in their minds and they think they are going to be cut down, screwed down, held down in salary... . 'Is it difficult to recruit controllers? No, it isn't', is the view I've heard expressed by one of our senior people on the administrative commercial side of the CAA, 'if you put an advert in *Flight* you are snowed under with applications'. Right, so we are paying them too much. A simple equation. Keep cutting it back ... until you get down to the level where the resignations or lack of recruits balances out what we want. Fine, but then, and we've noticed recently that the staff that are volunteering are not quite so good as they used to be ... . You've got the ne'er-do-wells then applying for our jobs, and even if you are still snowed under with the rush of recruits, you've probably got 12 bad ones out of which you've got to pick 2, instead of perhaps 6 bad ones and 6 good ones.

It is clear, then, that the immediate and obvious response to a threat to the terms and conditions of work is to focus on the consequences for safety. Viewed purely as an industrial relations strategy, it patently has promise (though, as we emphasise below, it is certainly not purely a strategy). This is not at all to say that its success is assured; sometimes 'shroud-waving' is effective in securing public support and additional resources, but at other times it is not. Crucially, it depends on being able to make a credible link between the general claim and 'real cases' of actual or impending disaster. Probably the critical factor in this case was the way in which a succession of 'air misses'[1] were harnessed for this interpretation, and largely succeeded in turning the thrust of the attack away from ATCOs and back on to the CAA itself. The CAA and government ministers struggled in vain to insist that statistics showed that the incidence of air misses was falling, and hence that air travel was getting safer rather than more dangerous (an interpretation strongly contested by some controllers). ATCOs had succeeded in engaging the concern of the media, and hence in securing a framework of interpretation of these incidents consistent with their perspective. Against this the unsung air misses of previous history counted for little. And indeed it is true both that any air miss is a legitimate cause for concern; and that a crisis of safety in air transport makes a better story than the absence of one. A further implication is that the media adopted the mode of treating complaining ATCOs as 'responsible professionals' in giving their accounts credence over those of management, in contrast with the mode applied to other groups of workers (cf. Philo et al., 1977).

However, although 'playing the safety card' may function successfully as an industrial relations strategy, this would be a very poor interpretation of how this contest arose. Rather, the 'attack' on manning levels was understood by ATCOs as emerging from an already existing context of poor relations, poor communications and an absence of understanding by management of conditions 'at the sharp end'. There were dissatisfactions with loading, with the technology, with airspace organisation, to some extent with pay, and hence with morale and atmosphere. The proposals on manning therefore appeared as the 'last

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[1]An 'air miss' occurs when there is a failure to maintain the regulation separation standards, and this is noted and reported by the pilot(s) concerned. The equivalent, if noted and reported by air traffic controllers rather than pilots, is a Mandatory Occurrence Report (MOR). Since the appropriate separation is usually five miles horizontally and 1,000 ft vertically, an air miss or MOR need not be a particularly close encounter. Since an air miss (but not an MOR) results in the automatic suspension of the ATCOs and pilots involved, there are institutional pressures to avoid declaring one. Whether or not passengers have witnessed the incident is said often to be the deciding factor.

straw' and intensified a genuine sense of crisis and of frustration. It appeared as though, in the face of all these serious grievances, all management could think to do was propose staff cuts. This view was expressed by a senior crew chief:

I: There's certainly a lot of camaraderie isn't there?

R: Very good, yes. This is one of the things that distresses me now because it's been torn apart. Our guidance from up above is nil.

I: And that's having an effect on the camaraderie, do you think?

R: It's putting us perhaps more together here in a way, but it's unfortunately, it is now making people dig their heels in and say, 'Buggered if I'm going to do that! When they don't even think anything more of us up in HQ than that!' That is a bad state for a start. That's one thing that is happening, and sure this is why my attitude is like this now.

I: What do you think of the career of the controllers?

R: Ghastly!

I: Is it?

R: Yes. ......

I: You see that's one of the things I think some of the younger contollers don't appreciate, they go on about the money and all this stuff, but I feel like saying to them, look, you've got a job you enjoy, most people don't have jobs they enjoy quite so much.

R: Yes, that is very true. I've been very thankful for that. It's just that I'm not enjoying it now, not so much last summer, and having nasty thoughts about this year.

Several controllers made the connection between the demands now being made of them and the recently announced refunds of ATC fees to the airlines:

R: Most of them are seeing other people outside, who they live next door to most of the time, with their company cars, extra money for this, that and the other, people who work for British Airways getting their guaranteed shares, selling them straight away and making £16,000 profit. You live next door to somebody who does that, half the money that we make they give back to them at British Airways!

I: I heard about that.

R: Giving money back, things like that, it's the final straw.

Many of the dissatisfactions centred aound the state of equipment, and this is taken up in the second half of this section. Others, as above, were connected with pay. Some made the comparison between themselves and airline pilots:

R: And the salary now, personally I would like to see a break in the link with the civil service, I would like to see an Air Traffic salary, not a civil service salary.

I: It seems odd, dosen't it?

R: When I started in this job, the salary for the job I was doing, I was quite pleased, I thought it was quite good. Now, if you compare our salaries with pilots, they have kept going up and we've been held down with the civil service. Although it's a good salary, I don't think it's a good salary for the job we are doing.

I: Everyone makes the analogy with the pilots, actually.

R: Well what else can you make an analogy with? They are the closest thing.

Some of the most significant discontents, however, centred on what was seen as poor, or even absent, communications between management and shop floor, and the failure of management to get a coherent grip on the organisation of the airspace and its procedures:

R: Well, I think the younger controllers are going to have to hack it, I think the problems that are coming up now are mainly problems of default of management in the past. And indeed the present, if you want.

I: Such as?

R: Such as development schemes which have gone astray, wildly astray, and it didn't have to. It's alright saying with hindsight, but that's not true because 15 years ago when they were going down this avenue there were many vociferous people like myself who said, 'You are going down the wrong way, you should be doing this, you should be doing that', you didn't have to be a genius to see that, you just had to be a practicing, practical controller to see what was needed.

Similarly, from a crew chief:

I: So how is it going to become, will it be more effective management in the sense of more single-minded management?

R: Well, effective management. An effective management can only be achieved with consultation, with understanding of what the other guy's problems are, there's no point in bringing in people who are going to dictate, ... they really have to speak to the guys. They can't work in isolation, if they work in isolation we will waste another 10–15 years.

And again on the subject of planning and communication, but more in sorrow than in anger:

R: I came in to be an ATCO and that's all I wanted to be, I didn't want to go into an office to do any paperwork. If it came to planning, that kind of thing, I'd be interested, but only if it took place say at this unit, or where the job actually takes place; and I feel that's one of the big problems that we are having at the moment, the planning side, and what has been removed from the actual workplace, as it were. I know there have been attempts to get LATCC Development here but it doesn't seem to have worked, headquarters still has the overriding say.

Not everyone, of course, is so uniformly condemnatory of management. As one crew chief put it:

R: Once you take people out of the job to do an office work job .... then the instant you take them away from the operational work they are no longer actively in practice, but provided they've been in the job operationally for a reasonable amount of time beforehand then they will always have that operational experience behind them, and I think it's that that counts. I think it's very unfair to criticise people who go into offices simply fcr going into offices, they still have a lot of operational experience to offer, you get a lot of that [i.e. crticism] at LATCC. The people who are working now are very critical of the office people, but I think the office people generally do a good job.

Another crew chief, who had himself done a stint of several years in administration, could illuminate the structural differences in perspective:

I: How important do you think it was ... leaving the ops floor for a couple of years?

R: I found it important, ... it gave me a good experience, possibly made me more tolerant of the organisation because I was part of something broader, I learned the difficulties of changing procedures. ... The operational controller tends to be very demanding, he looks at his very narrow little sphere of things - why can't such-and-such a thing be changed, it would be so simple to have a route going where the aircraft want to fly. ... Going into staff work enabled me to find out that there is a big life outside the Ops room at LATCC, lots of other people involved, not just in aviation, but demands on airspace go beyond the aviation requirements. So I learned how to pursue change, or how plans are changed against other people's requirements. .... You will probably hear the moans and groans about the TOIs that come out, they are flawed some of them, they are not really what the Ops room wanted, but the whole origin of the change started way outside LATCC, and in some cases outside the AT environment.

Yet despite this perspective, this same individual strongly endorsed many of the criticisms:

R: Morale is pretty poor at the moment, people in the Ops room feel as though they are in the 'mushroom club', which is the usual way of describing it - kept in the dark and fed manure every so often. .... It's the feeling that nobody understands us, communication with management is regarded as being very poor, the recent press exposé I don't think has done anyone any good. I'm sure you've been told that CAA have announced to the press that they spent, I don't know how many million pounds on refurbishing us, but on the Ops room floor the impact is nil, in terms of actually making the system easier to work, more efficient, increasing the capacity, there's been no impact. So, it just heightens the feeling amongst controllers that management are quite happy to con the press, they are trying to con us, they want us to work for - I think most controllers are convinced if management could get us to work for less money, that's their premier aim: more work, less money. Management see the Ops controllers, largely, as grossly overpaid and grossly underworked.

Of course, everyday work and everyday contacts continue despite these problems. Indeed, some arrangements, such as the LTMA working party in which managers, planners and controllers are working together on the details of CCF for the London area (see Section 3.6), are tending in the opposite direction, to forge better links in some areas. Nevertheless, the *malaise* is real, and lurking in the background is the spectre of the Reagan administration's successful battle with air traffic controllers in the USA. Here, striking controllers were defeated, and all were dismissed, by a combination of tactics: using military ATC to cover for striking civilian controllers [it can be seen from our account of the systematic differences in the nature of military and civilian controlling in Sections 2.3 to 2.6 how disturbing a prospect this would be in the UK context]; bringing forward the deployment of automated assistance; reorganising the airspace along more routinised and less discretionary lines, as with CCF; and reducing the scope of ATC coverage. Many argue that the relatively poor safety record of ATC in the USA is a direct consequence of these moves.

5.2 THE ACCEPTANCE OF TECHNICAL CHANGE

It can be seen, therefore, that changing circumstances meant that the whole issue of technical change and automated assistance for ATC functions had become much more controversial by the time we embarked on our fieldwork than we had originally anticipated. Despite this, we found that the views expressed by ATCOs did not, for the most part, amount to a simple rejection of technical or organisational change, or an automatic, conservative adherence to the current system. Indeed, much of the criticism levelled by ATCOs at management centred on what they saw as their *failure* to grasp the changes taking place and institute appropriate responses. As one controller put it:

R: As far as the equipment goes, I feel that people are so unhappy about what we've got at the moment, that the Continent has leapfrogged ahead in terms of what they've got to use in the way they handle the traffic. But we've got this system from the USA, which was the best available at the time but that was in the early '70s, and if management sits on their laurels and say 'Isn't this great!', we can produce traffic down towards France and we can just keep on piling it down until the French ring up and say, 'Look, we can't take any more because we can't cope'.

> But now I think we've got into a disgraceful situation, we've really gone backwards. Now for the first time this year we had to say to the Europeans, 'Look, we just can't cope with the traffic that you are going to offer to us, you've got to restrict it at your end'. It was a proud boast until last year that there were never any restrictions created by us ecxept in conditions of bad weather ... but now we are becoming the poor man, air traffic wise, of the European system .... which is a kick in the teeth for the people who are actually operating it.

Many controllers reiterated both of these themes: that the UK was falling behind, and the pride taken in not previously having needed to introduce routine flow controls. Another controller, however, explained how this was not purely a matter of 'pride', but related to the practical ineficiencies of flow control in operation:

> R: Flow rates are so horrendous, it doesn't mean, even if they are quite sensible, say you've got 20 airplanes, which is what an airport can handle, if you give out flow rates, five to Maastricht, five to Paris and five to somewhere else. But they don't [split that way], fifteen all want to come from the same direction, it's sod's law. When we did that about five years ago when ... there had to be a flow rate, and we were well under capacity, we only had half the slots full. But because we only gave the French seven slots an hour into Gatwick, the French gave sort of four to Italy, two to France and one to Greece, and Greece had sort of four or five airplanes which all wanted to take off to go to Gatwick, but the first one got an hour delay, the second one got two, and some bloke at the back got five hours delay; [and he] gets on the phone to his Company at Gatwick and they get through to air traffic, and they say, 'Well, there's nothing in the hold'. Flow rates work like that, they really delay everything that's going. It's a really inefficient way of working.

The issues of technological change and reorganisation of the airspace are, therefore, quite closely intertwined. Technological aids can help to realise the theoretical capacity of a given airway system, but they cannot independently increase that capacity. That is, technological aids for ATC address the capacity of the controller, not that of the airway system. As the former is reached, it prompts a reconsideration of the latter; which in turn may have implications for new kinds of technical support for controllers. As one crew chief put it:

R: They've talked about the capacity of the London TMA for years and years but it doesn't really matter, the governing factor is the landing rate, and there is no point bringing more and more airplanes into the TMA and stacking them up - it's just filling up the airspace with airplanes going nowhere. The sooner we get some sort of system - whereby we hold out at a high level and, you know, start off with some sort of manual system while bringing them in to fit the landing rate, and then computerise it - the better. .... Although the majority of controllers are looking at new and more modern equipment rather than systems and flow management, most people travel around and they see what Maastricht has got in the way of equipment, and they see what the French have got and all their equipment, and what they've got in the States: a lot of people tend to think that is the answer, and they would be much happier, morale would even be increased if we got a new computer; but when it comes down to it, you've still got to separate airplanes in exactly the same way, no matter what equipment you've got. What we've got at the moment is perfectly satisfactory, providing it keeps working, to do the job. It's the system and the flow management, as far as I'm concerned, that need the big overhaul.

And, from another crew chief:

R: The way we utilise airspace in the UK is not - we don't do it in the best manner. The users tend to be very entrenched in their demands and we are not practical about it, and all the equipment under the sun won't increase our ability to put a finite number of aircraft through a particular chunk of airspace. So if we are in the business of moving more airplanes we must change the airspace. It does mean we will need to use *more* airspace for ATC purposes, it doesn't mean that we will need to use it *exclusively* for ATC purposes. So we are into shared use, but that in itself will build in problems for us because it will be - we will have to make it very clear to controllers when he can and when he can't use a particular piece of airspace. And the changes, the day-to-day changes like that are very real problems for us, it's actually remembering or having access to the information. That's one thing we are very poor at in LATCC is actually presenting controllers with information. We have these maps up on the suites, but very often the important information has to be retained in the head. I think, for the most part, we retain far too much information in the head, that's when errors occur because we will forget at the vital time, and we all find one of the most difficult things is not to regress to a previous procedure or a previous piece of information.

We can see from this how important it is to consider technological change within the appropriate strategic context, and not simply as a replicator of current functions. The overall objectives of a concern - setting aside the complication that these will usually be *contested* rather than consensual, both within and beyond the organisation - may be furthered by a range of methods, of which technology is just one. The proposal voiced above - and echoed also in the interviews quoted in Section 4.2.3 - has the effect, on the one hand, of downplaying technological change as the most significant current frontier for increasing the capacity of the system; but, on the other hand, entails proposals about the quite different kinds of technological assistance that would *really* be useful if such airspace changes were introduced. Another controller made the same point with respect to the current system:

R: The equipment, it should be reliable. It's not just the reliability side of it, when you see information, we are often asked for bits of information, we get information on our little TV screens, like Heathrow weather and so on, very occassionally we get other information, but most of it you have to pick up yourself, you get frequencies displayed on scraps of paper all over the place...

I: Or chalked on strips...

R: Yes, if you hunt around enough you'll find it! It's not very - it's not a very practical means. Whereas you can have superb information retrieval systems where you can press up a few numbers and you get a big index; you can dial up the track structure, instead of us having a bit of paper with a bit of plastic over the top of it, which keeps getting lost down the back of the sector, and with our tracks written on with chinagraph. You just punch a button and you can see it beautifully in glorious colour, it's all very pretty and easy to read, that's the important thing.

And, similarly, from another controller:

R: Obviously an equipment update would be very important. The equipment, as you have no doubt been told by lots of people, is on the blink, and there are a lot of systems available to help us, it's just a question of finding the money somewhere. The technology is way, way in advance of any systems we are likely to get in the next five to ten years, I think. But the data that we are expected to know, I think, also poses a big problem. We are expected to carry far too much data in our heads and we are expected to update ourselves, as you know. We live off the evidence of our eyes, and to be able to read and digest a lot of these yellow pages every week that you come to work is asking a lot. And in my case, whatever new information I manage to digest is probably pushing something else out at the other side. And there are systems available whereby an awful lot of data we are meant to know could be actually available at the push of a button. There might be - for danger areas the military have got, I don't know, hundreds of pages, and instead of having to look on the danger area map and trying to remember which danger areas are active today, and up to what level, you can just press a button; and the same with an awful lot of other information that we need, like changes to arrival routes when they change the BOR, or something like that. It's an enormous amount of stuff to try and carry in your head, and I think it's asking rather a lot to expect people to cope with as much information as we have to - I mean that would be a big improvement. Other countries have equipment like confliction alert and things like that, but without having actually used it it's hard to know how effective it would be, because one is often setting up situations where the airplanes would be in conflict, but you are actually in the process of climbing somebody through on the TMA or something. You wouldn't really want buzzers going off all the time if you are in control of that situation and, for instance, you are just turning the airplanes onto the same heading, or something like that.

Whatever one may make of this 'displacement' theory of memory, the message is clear that a database system would be a technological aid that would really engage these controllers' problems as they currently see them. And, almost in the same breath, we can see that a technological aid which would seem an obvious boon to an outside observer - a system to warn of impending conflictions - strikes the controller as fraught with difficulties in its real context. Indeed, the more complex the environment - the planned 'tunnels in the sky' CCF system for the London TMA, for example[2] - the more likely such a system would be to give 'false warnings'. That is, the more it is needed, the less reliable it would be, and in this it mirrors our observations on RD3 in Section 3.4. What the controller is really saying is that, although he keeps an open mind, he is sceptical of the capacity of such a system to really adequately incorporate the full context, and distinguish an impending confliction which is the result of a genuine lapse from one which is just an artefact of 'doing the job'. If, on the other hand, the system *could* cope with this context - by assuming, say, that airplanes would indeed follow their CCF 'tunnels' - then how would it be able to predict the occassions on which this would *fail* to occur and so instantly give rise to a very serious hazard? Human controllers *attempt* to do this by picking up minutiae of 'behaviour' that convey to them a vague sense of unease - a 'feeling in my water' as one senior controller put it. The problems of 'computing' such understandings remain formidable.

The above quotations, and many others like them, show that ATCOs are prepared to accept and indeed demand new technology that is 'appropriate'. Sometimes these demands are unrealistically ambitious, as in the following controller describing the system he has been advocating for more than ten years:

I: What do you think of RD3 at the moment, then?

R: Well, it's a useless bit of -

I: Some of the controllers use it, though.

R: Well, some use it because it's there, it's a nice toy, but it has no real function at the rate at which we are working now. No controller working a sector can possibly be fooling around with inputs and all this sort of thing. And I could see that happening. What I wanted to do, I wanted to go down the road where, instead of having RD3 quite the way they have it, I

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[2]See Section 3.6

wanted automatic, everything to be automatic for this, so that instead of having to input with your fingers, taking your eyes off .... I wanted it done on voice, so that as you spoke the input took place automatically. ... I said, now the Americans are putting in a lot of effort, all you've got to do is bide your time and sooner or later there is going to be a breakthrough, that's what I was after. I think to work out a system, with increasing traffic flow, it doesn't matter how many innovations you put into any system, the speed at which the traffic is developing is always offsetting any improvement you get in technology. So you had to make a really rash, far-reaching decision and go for it. My system would have done that, everything you said went automatically along to the Chief, so that if you told an airplane, 'Speed 121[3], descend flight level 170', the computer took it up from your voice, put it in a down arrow on the call sign, flight level 170, and everything was there. Everybody around you new what you were doing, you didn't - I mean, I was working on the system where the strips have gone, disappeared, everything was automatic. OK, now if I wanted to co-ordinate a level from one sector to another, the minute I said, 'Speed 565, maintain flight level 350, your routing is', and told him, the computer takes it up, it says, he's routing via the Park [Brookman's Park], so its going to Red 1; it starts tapping out the information on the next sector, they can see a light flashing. Then, say there's a Speedbird coming up at 350, there's a Danair at 310, there's something coming up at 240; accept, I'm looking for an acceptance, so it's flashing - into the computer, even if it's an assistant, you say, these three are accepted through flight level - at these flight levels through Brookman's Park, get a green light at the other end, all done by computer, no nonsense, no eyes diverted off the tube or anything, everything is done and you don't lose concentration for what you are doing. That's what I wanted.

Despite this, many controllers spoke of themselves as being conservative regarding technical or organisational changes, and some

[3]i.e., confusingly, 'Speedbird 121'; i.e. British Airways Flight 121.

blamed this for the current state of the equipment:

I: What do you think of the technology that's available at the moment?

R: Dreadful, absolutely dreadful really. I think we are living in the dark ages, and I think one of the reasons for that is that controllers are generally are very conservative people and very resistant to change. And because that resistance makes itself felt, it's very difficult to get new equipment accepted, and when it is eventually accepted it's already out of date, I think. I suspect that there's an awful lot of new technology available to us pretty well now which isn't used, simply because the controllers wouldn't accept it.

Others are, more straightforwardly, satisfied with the equipment they have:

R: Well, I don't think the equipment is as bad as people make out .... I don't really see, under the present system of operating, that the equipment could be that greatly improved.

And again:

I: What do you think of the technology you've got here at the moment?

R: It's old, but it works. .... I'm a great believer in that, if something works, leave it. Why change onto this new equipment that they've put in now, this new equipment, we've no idea what benefit we are going to get from it; basically, I don't see why we're changing.

To make it more confusing, the conservatives and the advocates of radical change are, very often, the same individuals. For example, the following is from the same interview as the preceding passage:

R: The morale is low for various reasons, and I think a lot of people feel that management isn't doing what they should be doing, and the development - the improvements aren't going forward as they should be going forward, not keeping up with the build-up in traffic, basically. That TMA change is another one, a lot of people think the controllers are against change, and I think that is wrong. I think a controller who has been there for any length of time can look at a change that's mooted and they can personally say, 'No, that's not going to work, done like that, that won't work'. That's the sort of change they are against, what they want is a structured development that is going to work; an overall picture, somebody who is doing the development, to take everything into context and think what's happening and actually suss it right through from the beginning and bring it in. Those sort of changes they *will* accept.

This passage illustrates the paradox, but also indicates its resolution. The problem is that the job of controlling is always 'more than it seems'; and so the real practical effects of a proposed technical or organisational 'improvement' - whether it actually helps or hinders - are very difficult to predict. Hence the ambiguity with which controllers both embrace and reject innovation. They fully understand the depth of their dependence on technology and on particular organisational arrangements, and perceive both the need and the opportunity for these to be improved. But they are sceptical of the forms that such changes are likely to take, and they mistrust the extent to which the whole context of their work will have informed such proposals. Given what hangs upon their work, their caution is surely justified:

R: They tried, I think, to bite off much more than they could chew. They were far too ambitious, they tried to take a huge leap ahead onto a completely new operating system. I think they would have been much better off trying to evolve it stage by stage, and if they found at one stage it didn't work, they could always fall back to the next one. A good example of the way they manage these projects is recently when they were testing furniture for the new operations room and they did a trial down at the evaluation unit at Bournemouth, and they obviously send people down there to check the system out. And at the end of the evaluation they said, 'What do you think about this?', and they said, 'Well, not much, it's ergonomically a disaster, you can't input if you are looking at the radar because your arms aren't long enough to reach the touch-sensitive screen, and this sort of thing, if you push your chair back beyond a certain point you bang into someone else who is sitting behind you'. And they said, 'Oh, we didn't realise that, but to tell you the truth we've actually ordered all the equipment', and they'd made the decision to buy it before they'd actually evaluated it.

Hence, the system is not to be trusted, even in the simpler aspects of its innovations.

It is undoubtedly the case that the reverse of this also applies: that the 'simple' and 'obvious' demands for improvements made by practicing controllers often fail to take account of the 'full context' of the system as a whole, its nuances, competing pressures and constraints. There is, for example, an extensive mythology about 'the Computer' and its failings, as one of those responsible for its support remarked:

I: Do you think the controllers know enough about the IBM? Or appreciate its nature?

R: I don't think the controllers on the operations room, who work in shifts, have got a good picture of the problems we have been having with the 9020 in the last two years. They think it's a - and I think that's natural, that they are presented with a product, we are a support group, so to them it's immaterial if it's the 9020 hardware failing or the power supply failing.

I: It's the same difference to them, isn't it?

R: Yes, you know, and I think really it's a matter of communication, where there is no-one - I've tried to go onto the floor and communicate, now it's nearly impossible when you've got the number of ATCOs, and the number of changes, for me to know them all and to get my message across.

The situation is not truly reciprocal, however, in that it is part of the task for management and operations staff to ensure the appropriateness of innovation, whereas ATCOs may have a keen interest but no corresponding obligation. In this, the peculiarities of the 'profession' and of the managerial structure which, we argued, go to create a particular context of industrial relations, also work to 'condition' the attitudes of controllers to technical and organisational change.

5.3 CONCLUDING REMARKS

In sections 4 and 5 we have tried to broaden the understanding of technical change in ATC by considering more of the context in which it occurs. We have seen that the nature of the task of ATC is not static, but can vary with the state regime and the commercial environment that is applied to it, as well as other changing external circumstances. Technological innovation is only one way, albeit an important one, in which the organisation can respond to such pressures.

This has two different kinds of implications for technical change. Firstly, the nature and timing of proposed innovations, and the reception that they receive, will be a product of these contexts as well as of the 'objective' properties of the schemes themselves. That is, the external contexts will usually generate, and certainly mould, the 'problems' for which technological change may be proposed as the 'solution'; and the nature of professional and managerial relations within the CAA will both further shape technological innovation, and influence its acceptability.

Secondly, the 'success' of technological innovation must include a measure of its integration into its professional and managerial context. It is accepted that the total automation of ATC is not on the immediate agenda. It is also largely accepted that a system which attempts to use controllers as 'monitors' for machine systems is dangerous, since the capacity to perform effective ATC work is highly perishable and requires constant reinforcement. This means that any technological innovations will have to 'work with' the social and organisational context of NATS largely as they currently are. It is, therefore, not enough to function as a 'fix' for technical problems; changes must also satisfactorily 'affix' themselves to the network of social relations they will encounter.

SECTION 6

THE SOCIAL ORGANISATION OF ATC WORK

It has been our conjecture from the inception of this project that the effects of technical change cannot be understood independently of the social context in which that change is introduced. This is the case because any technical system has a history involving the development of working practices, sets of understandings, the creation of different interests surrounding that technical system, and it is within this context that any proposed change to that system will have to find its place.[1] In this respect, ATC is no different to any other occupational group even though, as we have said before, it is a 'technologically rich' environment. As we saw with RD3, proposed technological changes, for many different reasons, can provoke resentments, strategies of resistance, fears of deskilling, challenges to morale, and so forth, responses which are by no means unreasoned or unjustifiable from the point of view of controllers.[2]

In this section of the report, we want to bring to the fore (1) the way in which existing ATC technology is dependent for its safe and efficient use upon working practices not specified in the manuals, (2) discuss some key elements of the occupational culture of ATCOs and its effects on their ability, as a group, to control their work situation. Some of these themes will be developed a little more fully in the

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[1]We need to note here that we are not subscribing to any technological determinism. Indeed, it is arguable that the distinction between the technology and its associated working practices is not, and cannot be, a hard and fast one. In other words, the specification of a technical system ought to include the specification of the working practices. However, and for reasons we shall discuss later, the latter task is only beginning.[See section 7]

[2]After all, the Luddites did have a point. Though this remark is not intended in any way as a reflection on the attitudes of controllers. It is, however, to recognise that there are different, and reasonable, points of view with respect to the effects of technological change.

following section.

We have already alluded in this report to the team character of much ATC work both in reference to the organisation of mediator suites and to that of the operations room at LATCC. It is a notion related to the discretionary character of ATC in which the choices a controller makes in dealing with a particular configuration of aircraft is very much up to the individual ATCO working within parameters specified in the manuals.[3] It is our claim that the idea of 'teamwork' provides a powerful pointer toward the characterisation of the social division of labour in the organisation of ATC work as 'seen from within'. We need to note here that as a moment-to-moment activity, controlling is done without central direction. That is, it is not, in its practical aspects, a hierarchically organised or orchestrated set of activities in which individual controllers respond to some central direction. By doing what they do, moment by moment, as a set of decisions and tasks, the overall pattern of traffic flow is achieved as an ordered, predictable and understandable pattern that can be dealt with as such by controllers.

The importance of this point of view on the social organisation of work is that the design and implementation of complex systems, especially if grafted onto existing systems, need to be adaptive to the character of the work they are intended to enhance. In which case a description of that work and its organisation is a vital first step since this is the context in which, for example, systems have to prove themselves. Whereas the psychological studies which tend to predominate in ATC have focussed on the 'cognitive skills and capacities' of controlling to the neglect, we argue, of the social organisation of controlling work. From a sociological standpoint our aim is to describe this social

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[3]Though as we shall see later, just recognising what the parameters consist in is a practical, and on-going, matter for controllers as they work. Also, it is interesting to observe that in systems appellage the distinction between 'open' and 'closed' systems is overly crude. 'Discretionary systems', like ATC, and, indeed, most human social systems, display a combination of flexibility and order that is the product of individual units within the system making decisions within some overall framework which fails, as it must do, to give in detail the actions required.

organisation as the accomplishment of those doing that work 'there and then'; as, to put it another way, the social organisation of competences.

One of the main conclusions arising from Weber's pioneering work on bureaucratic organisation (Weber, 1947) has been the 'discovery' that the formal specification of the duties of officials as enshrined in the charter of the organisation fails to recognise the 'informal' dimension of behaviour.[4] This distinction between the 'formal' and the 'informal' character of formal organisations has remained a key one in the sociological study of organisations (but see Bittner, 1965). Although the operational character of ATC is only minimally bureaucratic, it is, nonetheless, a rule-governed system.[5] However, as we pointed out earlier, these rules are minimal requirements, though strict in their consequences, which offer considerable discretion to the ATCO in dealing with a sector's traffic. The implication of this is, of course, that the rules as embodied in the *Manual of Air Traffic Services* tell only part of the story of what ATC work consists in. The remainder are the practices learned by controllers in training, through 'shop talk' with fellow controllers, and through their own experience of controlling.

6.1 A REVIEW OF RESEARCH APPROACHES TO JOB SKILLS

The skills of ATCOs have long been of interest to the CAA and its research divisions, and other national and international organisations, prompted especially by a need to develop objective measures of 'workload' to assess stress, system capacity, and for the evaluation of new systems in terms of skills and amount of concentration required to

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[4]Of course, Weber well knew about the 'informal' aspects of bureaucratic behaviour. His 'ideal type' conception of bureaucratic organisation was misleadingly taken by many scholars as intended to describe the actual organisation of bureaucracies. In fact, the 'ideal type' was a methodological device designed, among other things, to identify the formal and informal aspects of such organisations.

[5]By 'operational character' we are referring, in the main, to the organisation of work within LATCC. Of course, as part of NATS and, further, the CAA, ATC is within the ambit of a formal organisation. However, our point here concerns the organisation of controlling work.

operate them. Much of this work embodies the Human Factors approach to discover the human limitations and possibilities with respect to information processing capacities in order to arrive at an optimum allocation of tasks to man and machine. Interest has also been shown in work stemming from industrial applications of job design within the framework developed by Lawler and Porter (1967a and 1967b) and Vroom (1964). Lawler argued that it was the intrinsic rewards deriving directly from task performance that enhanced expectations on the part of the worker that valued outcomes were dependent on effort (Lawler, 1969). Enriching the content of a job was more likely to make an employee feel that he/she was accomplishing and achieving something through his/her effort, and that his/her skills were valued. Hackman and Lawler specified a conceptual framework designed to discover which job characteristics resulted in intrinsically motivated employees (Hackman and Lawler, 1971) after noting that despite many years of job design research, little was known regarding its effects and effectiveness. As far as they were concerned, earlier studies had lacked a systematic conceptual/theoretical basis, suitable measures of job change and depended far too much on case studies rather than experimental research.

In Hackman and Oldham's (1980) Job Characteristics Model, five 'core job' characteristics, that is, 'skill variety', 'task identity', 'task significance', 'autonomy' and 'feedback from job' are related to three psychological states, described as the 'causal core of the model', namely, 'experienced meaningfulness of the work', 'experienced responsibility for work outcomes' and 'knowledge of results'. The model predicts that if a job is high on all five 'core job' dimensions, then job satisfaction, instrinsic motivation, quality of work will all be higher than a job with lower motivating potential.

The above is only a brief summary of the model which has, in any event, been developed further by including, as 'moderators' between job characteristics and outcomes, 'knowledge and skill' and 'work context' (Hackman and Oldham, 1980). However, for our purposes, further details are not important (see Crawley, 1982, pp. 95-107) for summary of work using this model). Suffice it to say that while research has lent support for certain aspects of the model, there have been anomalies found and its effects are not always in the directions predicted. There is also some dispute about the relevant measures of the dimensions and the statistical techniques appropriate to expressing the model formally. Crawley (1982), who used a variant of the job design approach in a follow up study of controllers' reactions to automated assistance, found that, generally, ATCOs would be responsive to such assistance, especially if traffic densities were to increase, if restricted to routine tasks, such as route planning, sequencing, choice of stack levels, while wishing to retain the more dynamic, skilful and satisfying tasks, such as expediting the flow of traffic in the TMA by use of levels and headings, for themselves. These tasks, together with those where safety is directly concerned, such as crossing clearances or allocating conflict free levels to traffic entering the sector, ATCOs want to keep under their control.

The important point however and, as Crawley (1982) points out, one of the major inadequacies of the job design approach, recognised to some extent in the revision indicated above, is that it focusses on the characteristics and content of individual jobs to the relative neglect of the wider organisational context and the consequences on this that any job enrichment might have. Crawley goes on to conclude that "Unless the effects of redesign are considered on...all related parts of the work system, negative effects on the surrounding system may attenuate the positive effects of job enrichment" (Crawley, 1982, pp. 105-6). Of course, more global approaches to work study and design have a long pedigree, though without much direct benefit of sociology, particularly in the sociotechnical systems approach pioneered by Trist (Trist et al, 1963; Trist, 1971). Mumford (Mumford et al, 1972) has also developed a diagnostic tool to quantify the degree of mis-match between the individual and the job in terms of five types of exchange relationship between employee and employer described as implicit contracts. Each contract represents the degree to which certain kinds of employee need is met within the work situation and are 'knowledge contract', 'psychological contract', 'support and control contract', 'task contract' and 'ethical contract'. Like the sociotechnical systems design approach of Trist, and others, it takes regard of the wider setting as well as job characteristics, though it has yet to be tested systematically.

From our point of view, the drawbacks of the approaches just reviewed is that while there is a recognition of the importance of social factors in addition to psychological ones, what these social factors might be, let alone how they relate to job characteristics and working practices, is poorly articulated. Global characterisations tend to be used with little idea given as to how they relate to particular instances and examples of work.[6] This is compounded by what to us is a premature effort to quantify the properties and dimensions specified in the absence of any clear understanding of what is being measured and what metric is appropriate.[7] [See Section 6 for discussion of working practices].

More directly concerned with the practical aims of ATC, interest in ATCO skills has hitherto been largely concerned with measuring mental workload; an aspect of ATCO work that can easily be made suitably dramatic, as the following summary of the skills involved illustrates. The ATCO has to

- visualise objects in 3-dimensional space using a 2-dimensional screen as proxy with its indications of location, direction, height and speed of movement;

- project the future positions of these objects;

- plan the desirable movement of these objects to accord with highly situation contingent specifications;

- persuade the human operators of these objects to follow requests for movement;

All of these in conditions which directly affect a large number of lives at any one time as a continuous effort without pause, in which each decision is taped and open to later scrutiny, involving high speed objects that can behave unpredictably and precipitate a "highly dangerous constellation of events." (Shaw, 1979).

Investigations of mental workload particularly are intended as investigations of the limits and thesholds of cognitive capacity as they are likely to affect the level and safety of operations under specified

[6]This is not simply a feature of the kind of studies reviewed but is endemic in much of social scientific theorising. See, for example, Sacks (1963); Garfinkel (1967).

[7]This is an overbrief summary of what is a long, detailed, difficult and disputed area of social science methodology. But see Cicourel (1964), Phillips (1971) for examples of this point of view.

conditions. One major conclusion of such studies is that although in significant respects computerised and semi-automated systems enable ATCOs to handle increasing traffic efficiently and safely, they also enhance the weaknesses of the human operators in the system. Evidence from accident case histories suggests that efforts to reduce the workload of controllers and pilots by eliminating many of the manual and clerical tasks to enhance their judgemental role, can result in a "lessening of the margin for error in some circumstances" (Danaher, 1980, p. 544).[8] Automation tends to shift the human role to that of monitor, a task humans do not do well, and, as a result, in the event of equipment failure there is a question mark against the capacity of controllers to escalate their performance to cope with such an emergency. Indeed, Whitfield suggests that it is the ATCO who is the restrictive element in the system and it is his "traffic handling capacity which sets the ceiling on sector performance" rather than limitations of airspace. procedures or equipment (Whitfield, 1980, p. 2).

While much of the literature recognises that 'workload' has not been defined with much rigour, effort at constructing measures of capacity are usually a combination of workload as a set of task demands and as effort. By using mathematical models and calibrating empirical evidence obtained by subjective ratings in either field or simulated situations, it appears that the number of aircraft under simultaneous control gives a rough but realistic indication of workload (Whitfield, 1980; Sperandio, 1978; Hurst and Rose, 1978; Posmooij, Opmeer and Hyndman, 19 ; Hopkin, 1979; Parker, 1987)[9] While this is, indeed, a practical measure that is both effective and relates strongly to what controllers understand and see as posing difficulties for them, as Hopkin notes the variety of activities in which a controller is involved - scanning radar displays, talking to pilots, other controllers, annotating flight strips, planning ahead, anticipating problems, liaising, up-dating, removing out of date information, and so on - makes it difficult to "express all of this task in any single measurable dimension". Indeed, Hopkin goes further querying

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[8]Danaher is speaking of the United States, but there is every reason to believe that the conclusion is generalisable.

[9]Hurst and Rose conclude that "peak traffic" is the "most generalisable as well as the most potent" index of workload.

whether mental workload is a single measurable dimension at all or, at least, one which is "of any practical use" (Hopkin, 1979) Hopkin is also less sanguine about the efficiences claimed about the replacement of, for example, speech functions and a greater use of semi-automatic information displays actually enables the controller to devote more time to decision-making and problem solving. "In practice, such replacements never lead to demonstrable changes in the amount or quality of decision-making or problem solving"' as RD3 illustrates (Hopkin, 1979, p. 382).

From our point of view, much of this research into workload has much the same problems as the job design approaches reviewed earlier in being overly individualistic and psychological ignoring, that is, not only the teamwork aspect of ATC work we mentioned earlier, but also the way in which the nature of the controlling task varies with the coordinating problems ATCOs face rather than simply the number of aircraft they have to deal with. As Sperandio's work suggests, while the controllers' behaviour is "modified according to the number of aircraft they had to deal with simultaneously", workload is not a simple linear function of the number of aircraft. Controllers alter their strategy by reorganising his/her system of cognitive information. A smaller and smaller number of factors are taken into account as traffic increases treating "each aircraft as one link in a chain whose characteristics remain stable and not as an independent body moving in free space among other independent moving bodies" (Sperandio, 1978, p. 195). He goes on to suggest that there are a sequence of progressive changes in operating methods, corresponding to different strategies adopted successively by controllers to delay the overload theshold. Workload is not an 'all or nothing' phenomenon on both sides of some limiting theshold. Our own research suggests that the image on which much of the workload inquiries are based with its emphasis on the cognitive capacities and skills of the individual controller is radically wide of the mark in providing adequate descriptions of controllers' work. We have already mentioned the important role of teamwork both in respect of the ways in which other members of the sector suite assist in dealing with tasks to enable the controller concentrate on coordination and in the ways in which coordination itself is done to ease potential problems for those on neighboring sectors. There are, too, strategies of the kind mentioned by Sperandio used to facilitate controlling; practices which are an informal aspect on controlling and which transform it into an art rather than a slavish adeherence to rules and procedures laid down. To illustrate the ways in which controllers adapt and develop their own *ad hoc*, though consistent, techniques we will deal with 'stack jumping'; an aspect of LTMA controlling where the pressures of traffic and its complexities necessitate considerable creativity on the part of ATCOs.

6.2 LTMA CONTROLLING

The LTMA sector covers the airspace above London and much of the Home Counties (see diagram 1). For controlling purposes it is divided into North and South sectors (see diagram 2), each of these capable of being subdivided further into East and West for LTMA North, and West, South West and East for LTMA South. The primary concern is to separate outbound traffic leaving Heathrow and Gatwick climbing to their requested levels, from inbounds descending to airports. Inbounds are sent to one of several holding points where they circle until space is available for landing approach. These holding points are known as 'stacks'. Heathrow has 4, Lambourne, Biggin Hill, Ocham, and Bovingdon, while Gatwick has 2 at Mayfield and Willo. The number of aircraft in each stack and the number of stacks in use varies according to how busy the sector is. As the airspace fills, planes are held at higher and higher levels in the stack separated from the one beneath and above by 1000' on each side. As planes leave the bottom of the stack, all planes above are directed to descend one level. A spiral emerges with planes joining at the top, leaving at the bottom.

This procedure has the advantage of transforming a varied flow of aircraft from many directions into a consistent, predictable stream that airports can handle. TMA controllers have only to direct aircraft to the top of the stack while approach control, situated at each airport, takes the planes for landing. The regular stream of departures has to be separated into the various routes. The TMA controller receives traffic from the main airports and must direct it safely around the inbounds before allowing them to turn onto their designated routes, specifically, around or over the stacks.

There are sets of procedures for both these tasks and within LTMA sectors the most important of these relate to the standard profiles of aircraft into and departing from the airports and the related stacks. These procedures are specified in the manuals and specifically relate to:

1] Standard Instrument Departure Profiles (SIDS) which consist of exact details of the trajectory of outbound traffic and are designed to satisfy noise abatement requirements and ensure that no conflict develops with inbound aircraft following their own respective procedures (see diagram 3).

2] Standard Arrival Procedures (STARS) designed to coordinate traffic into a regular flow for approach. These separate inbounds from outbounds. As with the SIDS, the STARS reflect the destination and route of the aircraft. So, for example, a plane bound for Glasgow will have a Daventry SID to lead it onto the correct *en route* sector.

3] Between LTMA sectors and neighboring sectors are agreements about levels at which aircraft are to be handed over (see diagram 4).

We will concentrate on 1] and 2] of these procedures.

The standard procedural flight rules are, however, not always the most expeditious way of controlling nor do they necessarily ensure safety. The STARs and SIDs are complex and, in many ways, restrictive because they have been designed to weave traffic through every other traffic route and be of such minimal performance requirements that any aircraft can follow them. This can often mean a delay in getting a plane to its most efficient cruising level and speed, prolongs the flight so increasing fuel consumption and require considerable piloting work as well as some discomfort for the passengers. In addition, they require more controlling work since the aircraft is in the sector for longer using up valuable airspace, RT time and controller attention.

Accordingly, controllers regularly make use of other techniques; techniques that are also taught to controllers and seen as essential elements in professional competence and controlling skill.[10] The techniques avoid delay, help reduce strain on controllers by reducing traffic and can increase safety by reducing the time an aircraft remains in a busy sector. One of these techniques is known as 'stack jumping'; that is, climbing an outbound aircraft over an inbound, either in the holding stack or those descending to the stack points instead of sending the plane beneath the stacks and to the outskirts of the TMA sector before allowing it to climb, as with SID profiles.

6.3 ILLUSTRATION: A DAVENTRY SID FROM GATWICK (see diagram 5)

This is for an aircraft from Gatwick heading north. The first *en route* sector is Daventry. If the aircraft has to take off in a westerly direction, according to the SID is must fly up to 6000' beneath the base of the stacks and remain at 250 knots. Second, skirt east away from the aircraft coming off the stacks onto final approach. Third, recommence climb once it is well to the north side of the TMA before climbing to 11,000' and exiting the sector. An aircraft on this route will be controlled by both TMA South and TMA North controllers.

Characteristic of many such procedural routes, it delays an aircraft, forces it to fly low and slow and adds distance to its journey. It also involves 2 controllers and clutters up the airspace. Although the aircraft is theoretically safe from inbounds, there may well be other aircraft wanting or needing to fly through that airspace, such as 'puddle jumpers' (light aircraft) or, when the outbound has reached the eastern part of the TMA and turning north, outbounds from Luton and Stanstead. Further, if the airspace is crowded, the mere fact that a plane is on RT frequency adds to the controller's workload. SIDs are not a 'no-work' option and 'stack jumping' is one way of clearing aircraft from the

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[10]As said, the ATC system was designed to give the controller as much freedom as possible. However, one consequence of this might be that if there were to be a case of litigation, it is the controller who is sued rather than the organisation if it could be shown that the controller used informal rather than formal techniques. Controllers certainly believed this to be the case and incorporated this into their attitudes toward their responsibilities. "The buck stops with me when I make these decisions", as one controller expressed it.

airspace.

In 'stack jumping', although a plane will have to keep its speed down during the initial stages of the climb (a noise abatement requirement), the controller can assess whether there is enough space for a 'jump'. Simply, this is a question of the location of inbound aircraft under the controller's direction and those already in hold and under approach control. A 'jump' is basically climbing a plane up in front of and over inbound aircraft in hold points or approaching them. For example, there may be two planes circling in the Biggin Hill stack, one at 7000', the other at 8000'. An outbound Daventry would only need to climb, or 'jump', to 9000' before, or by, Biggin Hill to be safely clear and continue a rapid climb to exit TMA before it has even reached TMA north side. In this way the plane will have 'jumped' all the inbounds under TMA North control and will, almost certainly, be allowed to continue climbing to its requested cruising altitude in the relatively empty sector above TMA much sooner than allowed by the SID.

'Jumping' is, however, a complex series of judgements. Previous outbounds have to be considered in case they are slow and could be in the way of faster subsequent aircraft, or too many, or in such a pattern that there is no 'hole' to 'jump' through. There may also be other problems occupying the controller. Added to these is the fact that the speed of modern aircraft is such that there are often only moments to decide whether a 'jump' is on. For this reason it is rarely practised by new controllers or those who have been off duty for some time. 'Stack jumping' is a delicate dance in the sky and much be practised to succeed.

The advantages are considerable; it ensures that the aircraft is out of the sector's airspace as soon as possible, frees RT time, avoids involvement of TMA North controller, gives the plane to *en route* controller earlier which can ease the situation with inbounds, enables the plane to reach efficient operating height and speed quicker, and, since a simpler trajectory, eases passenger comfort. So keen are some pilots for the opportunity to 'jump', they offer 'good climb rates' to controllers on their first contact with TMA controllers on their initial climb out of the airport. Many aircraft are not capable of the climb rates required for a 'jump' and by informing a controller that they have the ability increases the likelihood that if a 'jump' is possible they will be given the opportunity to do so.

There are, however, limitations. Apart from the need for quick assessments of the situation, the most troublesome limitation is the failure of aircraft to achieve their directed climb rates. There may be various reasons for this, but it has serious consequences. A controller may be depending on the outbound to climb in front of an inbound or plane in the stack and if the outbound's climb is too slow, the two aircraft may come close to confliction. Other problems relate to the bifurcation of control between approach control and TMA control. Occasionally one or the other of these direct aircraft through the other's airspace without coordination, that is, without explanation. Although in normal circumstances this procedure is quite safe, on others it can lead to conflicts. For example, a TMA controller may not 'jump' an outbound completely over the stack but, instead, take it around the middle of the stack over the normal flight path of aircraft between the bottom of the stack and final approach. However, on occasion an approach controller may have to take an aircraft not from the bottom of the stack but from midway.[11] In cases such as these, one or both aircraft have to be redirected immediately.

6.4. IMPLICATIONS OF 'STACK JUMPING'

Competent controlling requires considerable skill not all of which is specified in the manuals. Some of these, such as 'stack jumping', are sector specific in that they require intimate knowledge about an experience of a sector, the type of aircraft regularly using it, their performance, traffic requirements, the limits of certain techniques, an awareness of what attention the controller him/herself can give at the time, and more; knowledge and experience which has to be applied regularly and routinely to be effective, smooth and crisis-free. Stack jumping, as we have seen, requires exacting assessments of the spatial positioning of aircraft and where they are likely to be in a few minutes time; assessments which must be determined 'at a glance' and executed 'immediately'. As we mentioned, controllers new to TMA, or those who have been away for some time, will not 'stack jump' as readily as those more practised because they cannot be certain of the quickness and correctness

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[11]There are various reasons for this including reducing an already severly delayed flight, vortex problems, or availability of parking slots at terminals.

of their judgements. 'Warming up' is necessary. Having to think which aircraft can climb at the necessary rates would take time, for example, so all the necessary and relevant factors must be adjudged 'at a glance'; a consequence of experience and regular use.

The actual nature of controlling is not to be found in the manuals; these are intended merely as compendiums of rules and not an accurate representation of that work.[12] It is not possible to construct the nature of controlling work from these resources. Not only are some skills sector specific, there are also adaptations of procedures done for the sake of safety and efficiency. Indeed, it is arguable, and many controllers do argue, that without such adaptations controlling would become extremely difficult and, possibly, hazardous. However, the busier TMA gets the less flexibility controllers have in what they can do with the aircraft. Basic procedures have to be resorted to, that is, keeping aircraft to standard outbound routes and levels. With 'stacks' the main difficulty is that "once you get a stack building up, they are not just aircraft flying in a straightline and then coming off and getting into Heathrow. They are going into a point and then going into a holding orbit. And these orbits can vary in size depending on what the, how the pilots navigate around a holding pattern" (Controller, TMA). Yet, and this is indicative of the kind of pressure the current ATC system is under, modern aircraft are wanting to fly non-standard routes, but this becomes increasingly difficult, ironically, as traffic loads become greater.

'Stack jumping' also gives some insight into the character of discretionary systems, such as ATC. In these, the rules of operation, as stated in the *Manuals,* do not exhaust, as we have said, what the work consists in. Though they specify the general parameters, these are neither fixed nor determinate of controlling work. Indeed, as we shall argue later, the rules, like all rules, have an indexical character to them in that they have to be used in particular circumstances 'here and now', with 'this' configuration of aircraft, and so on (Garfinkel and Sacks, 1970). Further, whatever else controlling skill consists in, it is not exhaustively described, if described at all, by the generalised categories provided by job design approaches or the over-cognitivised psychologically

[12]The procedures, however, do have a quasi-legal status in determining responsibility when things go wrong.

inspired models. Although 'monitoring', 'communication', 'tasks', 'decision', 'judgements', and so forth, are clearly specifications of activities that controllers engage in, as categories they tell us very little about the character of controlling work *as controlling work*. 'Stack jumping', for example, involves all of the above, but is not recoverable as a controlling activity from such descriptions. We shall return to this point below.

6.5: THE TEAMWORK CHARACTER OF CONTROLLING

At the beginning of this section, and also in connection with the discussion of RD3, we have referred to the teamwork character of controlling work: a dimension whose significance has largely been missed in much of the existing research on ATCOs. It is this feature that we intend to highlight in this sub-section of the report.

There are two initial points to make, both of which we will amplify below. First, teamwork is visible in the organisation of the suite positions and the duties of the working personnel. Second, it is visible, too, in how ATCOs do the work of controlling and, in this sense, is a feature of the working world which they themselves orient to as part of that work. It is this latter aspect which we particularly concentrate on in this section.

6.5.1 The Organisation of Suite Positions

The general duties and responsibilities of the personnel manning a suite are specified in Part II of the *Manual*. Normally, that is when traffic is relatively light, a sector suite will consist of two controllers, one responsible for either side of the sector, that is, West or East or North or South; the Chief who is in overall command of the sector and who coordinates with other Chiefs on other sectors; an Assistant Controller, the 'wing man', who is a validated, or validating, controller whose task is to process flight plan data, search and provide information about requested coordination levels and generally assist the active controller; an assistant who processes 'strips' and services the IBM with information updates.

The suite itself, as described before, consists of two horizontal radar screens displaying the relative positions of aircraft in the airspace; access points to and printers for the FDP computer which prints strips giving details of the flight plans of each aircraft flying through the sector; direct telephone links with all other sector suites, neighbouring ATC centres and main airports; and discrete radio channels for each controller. Headsets and associated microphones are used for both radio and telephones.

During busier periods, sectors may be split according to the busy-ness and/or complexity of the traffic. Sometimes this can be a 4-way or a 5-way split involving 6-7 people using one radar screen, each controller taking responsibility for a route within the sector. Occasionally, 'man-and-boy' splits are used in which another validated controller is asked by the active controller, or by the Chief, to 'listen in' and help out as circumstances dictate. Also, 'bandboxing', when two sides of a sector are controlled by one ATCO, instead of the normal two ATCOs, on one console under the supervision of a Chief and with the help of another ATCO or 'wingman', occurs when sectors are 'light', usually at night.[13]

Most of the above procedures are specified in the *Manuals*, though there are departures from these. Some sector splits, for example, are based on the Chief's judgement and choice but are, though regular and routine, not yet incorporated in the *Manuals*. TMA South-East is sometimes additionally split with a controller assuming responsibility for in-bounds and out-bounds to and from Gatwick to Clacton. This is necessary because of the complex problems of ensuring separation between Gatwick in-bounds and out-bounds from traffic routed Dekling and Dover to and from Heathrow. Bristol-Strumble sector, at the junction of Amber 25 and Blue 39, is also sometimes split by height level with different controllers responsible for traffic above and below nominated heights.[14]

So, the pattern of position organisation around the suite is designed to service the coordination function of the active controller, and in this respect is organised very much as a team. Suites are, as we have just mentioned, linked together by telephone and the layout of the operations room at LATCC is an analog of the division of the airspace which is divided North and South of the Thames, so that the 'working

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[13]Very occasionally, 2 sectors may be 'bandboxed' together when there is hardly any traffic. Such occasions are becoming rarer.

[14]Management have objected to this practise.

world' of ATC is known and usable as a working environment that is organised, and understandable, as one which is very much dependent upon 'what others do'.

6.5.2 The Team as a Feature of the ATCOs Working World

Of course, the formal organisation of the suite tells us only a small part of the way in which controlling work is organised. Teamwork, as an element of a 'working division of labour' within the ATCOs working environment recognised and oriented to by controllers themselves, includes much more than the recognition of the formal roles around the suite, within the operations room and the wider organisation. In the sense in which we discovered it, it is a 'commonsense construct' that is a vital part of the occupational culture of ATCOs, and very much something which plays a large part in the ways in which they do the business of controlling[15] [See also section 3.6]. What it includes is a strong sense of interdependence among controllers that their work has consequences for the work of others, as others' have for them, and a sensitivity to the limits and the abilities of colleagues: both important elements in maintaining the generalised 'trust in the system' without which its operation as a discretionary system would be impossible. This is not to say that controller's are unaware of particular faults and troubles with the system. On the contrary. An essential part of their trust in the system is knowing about just such things and, in this respect, is part of their practical competence and knowledge as controllers. As we saw in the case of RD3 [See sections 3.4, 3.5 and 3.6], this can reach such proportions that what is perceived as 'untrustworthy' technology is effectively rejected.

In other words, for ATCOs 'trust in the system' is not a matter of having a generalised 'trust in the system' but is experienced as a reliance on particular features of the working environment, such as radar screens, flight path data, that others are doing their jobs, and so on;

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[15]The notion of 'commonsense construct' used here draws upon the ethnographic tradition of studies of occupational culture as part of the 'actor's point of view'. It is not used in quite the way in which the idea of commonsense appears in ethnomethodological work (See Garfinkel, 1967).

that is, knowing that the things they have to deal with as part of their practical day-to-day work are operating in a 'trust-able' fashion. For them, as a working experience, the generalised 'trust in the system', to call it that, is built up out of very particular features of their working world, as is the team character of the work itself which is sustained, in detail and locally, by a myriad of activities.

The team character of the work is enhanced by the formal organisation of suite units and watches. But there is also a tendency for a horizontal structure of affinity to develop by function. For example, in the canteens, during rest periods, controllers do tend to sit with other controllers and assistants with assistants. A controller explained this as follows,

"...because what happens is the controllers, the longer you are a controller the less you do with assistants, the more radar time you do, so when you are doing the radar you mainly work with controllers, and what happens is you work with controllers, so you know them better...and when you go to the canteen you sit with your friends who know you best, which are the controllers, and the assistants, they do the whole of the room, and so therefore they work with each other a lot, they maybe work with say the controller once every six months or something like that, so therefore they don't know the controllers on the social side so much..."

However, this is not, it is important to point out, a rigid caste-like division, and there are variations between watches in the practise.[16] Nevertheless, it is one important means by which experience is shared, through 'shop talk', between persons performing the same job within the system, so providing some strong sense of 'shared understandings' about controlling work.

But this 'shared understanding', to call it that, does not necessarily lead to an identicality of work routines. Differences in 'controlling styles' are common and orientable to by controllers, and knowing such differences is an ingredient in knowing how to do the work of controlling as a practical, day-to-day task. However, differences between controllers, though many and varied, are frequently organised, for

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[16]Some controllers referred back to the days when most controllers had military backgrounds, suggesting that status divisions between ranks was once more pronounced than it is to-day.

controllers, around the the criteria of age and/or experience.[17] As one Watch Supervisor, whom we have quoted before, remarked,

> "The older controller can measure things, he has an eye for what's happening, using his pencil to get an accurate heading...Its taken twenty years to develop the skill".

There is a premium given to experience as a necessary, though not sufficient, quality which marks off the 'good' controller from the 'indifferent'.[18] Experience is perceived as important, too, in enabling controllers to *control* their respective sectors: taking the sector "by the scruff of the neck", as one respondent put it. He went on, in connection with the growing request of pilots for non-standard routings,

> "...a lot of youngsters, I don't know how they view a pilot, as some sort of mystical figure or whatever, some people do. And they tend to, they don't want to say no and they give the impression that, well I'm not quite sure what impression they want to give, they don't want to say no for whatever reason. They don't want to have to say...hold, hold at Clacton...they want the things to be all going on. There are occasions on a sector when there is so much traffic when one of the best methods of sorting it out is to pull a couple of aircraft ahead of the whole bunch of traffic that you've got there and put them in the holding...and there's a gap behind to put them in. You will find the younger controller won't do that, I don't know why, I don't understand it myself, someone said to me it takes experience...they don't want to, they don't want to inconvenience people that are

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[17]The reason for formulating the relationship between age and experience in this way is that the relationship, as a feature of controllers' occupational culture, is not a simple linear function where age=experience and is interchangeable with it. What 'age' means, what 'experience' means for ATCOs, in terms of the consequences they have for performance, for example, or what can be expected in the way of an ability to handle high traffic densiities is, as we shall see, variable.

[18]We should stress here that the difference between the 'good' and the 'indifferent', as expressed here, is within an overall very high standard of competence.

flying".

So, experience is a notion controllers use as part of knowing how colleagues are likely to deal with the work, and the ability to get the sector by the 'scruff of the neck' is all part of experience at controlling: "you must control your sector because of the safety of it, you cannot allow it to get out of control". Another controller summed up the point: "...90% of air traffic is getting the pilots to know, to have the confidence to do exactly what you tell them, so if you try to do it as if you are reading it out, it doesn't work...".

Of course, the value of experience is, no doubt, one of the occupational myths typical of all occupations though, again undoubtedly, it has more than just a basis in practise. In the absence of firm, 'objective' criteria to measure controlling aptitude, experience, in the sense of knowing that colleagues have been "there when the blood starts falling out instead of sweat", as one controller graphically put it, is a 'trustable' substitute. This is illustrated by the honesty with which a number of controllers involved with training responded to questions about how they knew when a candidate was ready to go solo. One Chief involved with training for about twenty years expressed the typical sentiments as follows:

> "...how do you say, this lad he knows what he's doing, he knows all the rules, he's doing everything right, how do you say he's ready to go solo? I have no criteria. How do I know whether he can handle an extremely busy sector, I don't know what his limit is, neither does he really. So how do I say, yes, this man is ready to go solo? The only criteria I can use is, if this chap is the sort of bloke who realises he's getting toward his limit, he will turn round and say somebody help. Now if he can do that, he's a go because there are people who won't do that for personal pride whatever. Human nature being what it is, there are, particularly the younger chaps, they won't do it, and they go over the top and they've got to be rescued, but if he is the sort of person who knows the system and who has demonstrated that, he knows what he's doing, he can handle the aircraft, the only criteria I can use is...is he the kind of chap who would say, I'm getting near to limit...this is the question that has to be answered before that man can go solo. Nothing is laid down, its entirely up to the individual instructor, to say yes, this man is ready to go...there are no guidelines".

There are guidelines, of course, to do with the the extent to which a candidate controller masters the principles and practices of controlling. But, equally, there is the guideline provided by experience in judging whether or not someone else has the qualities to know when help is needed and to call for it: in short, recognise that the system is trustworthy to the extent to which individuals within it know that *their* failure can have repercussions on others within the team.

However, age-cum-experience does not always ensure the same valued response throughout every point of an ATCO career. Some doubts were expressed, both by controllers and managers, that from the middle forties onwards an operational controller has reached his/her peak. Certainly, with only one or two exceptions noted by respondents, the common view is that few controllers have been able to remain efficient up to the age of 60. However, this is not a fear that controllers of this age band are becoming dangerous, but more a feeling that with increasing pressure of current traffic loads controllers who have reached this sort of age become a potential weakness in the team and must be accomodated in some way. A Watch Manager stated the point as follows:

> "...round about 50 I think would be enough at a place like this or Heathrow, I would say...There's certain sectors go extremely busy occasionally and that is too much for a man of 50, I think. Generally speaking, I know some will keep going, others will come sooner, so its very hard to say all controllers will cease to be competent at age 51 and a half...How you do it I don't know, whether its retirement early or whether they are moved into an office or whatever, well, you haven't got enough offices to put them all in!"

But in the absence of any such policies on this matter (and it would be quite wrong to infer that all controllers, or even the majority of them, in this age group are declining in competence), what happens is that anyone whose ability is judged to be "in decline" is "carried" - mainly by not rostering them on busy slots[19] - otherwise they would have to be stopped by declaring them incompetent and this most controllers and managers are reluctant to do. This, again, reflects the strong sense of the team, its loyalties and the importance of knowing the limits of one's

[19] A strategem which does not always work, by the way.

colleagues.[20]

'Trusting the system' and the teamwork predicated on this, is manifestly a matter of 'relying on others to do their job', and this despite variations in style and competence between individual ATCOs. And one of the most important facets of teamwork around the suite is knowing when and how to assist the active controller. Many controllers, in talking about their work, mentioned that one of the most valued abilities of colleagues was their understanding of 'what was going on' without the need for much, if any, explanation. Chiefs, particularly, are rated in terms of this quality.

Most controllers, and Chiefs, regard the role of Chief as crucial since he/she is the only person in overall command of the sector, whereas sector controllers themselves concentrate on their own section of airspace and the tasks that need doing there. It is the Chief who is required to acquire an overall picture of what is going on. However, and possibly because the role is seen as so crucial, opinions about Chiefs, their styles and abilities, are sharply etched by controllers. Although these were voiced 'about Chiefs in general', it is clear that the views are drawn very much from personal experience. Controllers rely on Chiefs, though not necessarily specifically, as another pair of eyes seeing the whole picture and a check that the controller is not making mistakes. But this rather vague expectancy on what Chiefs should be doing is, nonetheless, a demanding one. As one Chief expressed it,

> "...a Chief who doesn't take an active interest is worse than no Chief at all...because unless he's maintaining an active interest and continually updating himself as to what is going on, what the traffic flow is doing, and all the rest of it, he can't act efficiently and effectively" (Int. 13)

However, precisely because the Chief is required to take an active

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[20]This decline of competence with age has to be kept in perspective. We are talking about a relative decline from a peak and in no way implying that controllers past the age of 45, or so, are in 'past it'. From our conversations and interviews with controllers, though age is clearly a dimension used as a criterion when talking about controller types, the cases when age seriously hampers performance, and requiring "carrying", are very few and far between.

interest but with minimal participation, there is a widespread recognition, both by controllers and by Chiefs, that the job is prone to boredom. One Chief, a newcomer to LATCC, felt that there was a tendency for Chiefs who had been at LATCC for some time to "lose interest", "operate the sector automatically", because they know the traffic pattern so well. But, with current traffic densities this is "not good...because you get out of the loop and its not easy to get back into the loop again". Many ATCOs expressed a reluctance ever to contemplate promotion to Chief, largely because of the supervisory, "inactive" character of the job. As one controller summarised the view,

"I think if I was a Chief, job satisfaction would go way down, if I was. Its a bit like doing the 'wings'...even though what you are doing is necessary, and you are doing it properly, its the fact that you are not actually having a direct input into what the aircraft is doing...We call it in fact a wee man with a green pen. That's all he is."[21]

Having said this, however, there is no doubt that the role of Chief is a delicate one to do well. From our materials it appears that one of the prized qualities of a Chief, a quality appreciated by both controllers and Chiefs themselves, is not simply their knowledge of the competence and the style of the controllers under their supervision, but an ability to *use* that knowledge without fuss and undue interference. In desribing their work, a number of Chiefs mentioned the importance of knowing which controllers could be relied upon to "get on with it" and which "need help and guidance". Effectively, what this means is that Chiefs need to encourage controllers to trust them "to take the non-routine jobs" so allowing the controller to get on coordinating the bulk of the traffic. Another Chief summarised this as follows,

> "...they don't have to keep prodding me as the Chief to do things, they can just, they know that things will be done as and when they are required, but they can rely on me to take on the non-routine jobs that may crop up at short notice...I regard myself as the director of the suite, and also the general factotum if you like, its up to me to foresee problems for the sector controllers, and solve the problems

[21]The reference to the pen here has to do with the practise of Chiefs having a different coloured pen to that of the controller with which to mark the strips.

> before it ever gets into his hair".

Chiefs have to recognise, as we have said, the differences in style and technique; differences which are not simply between individuals but also between watches.

> "If you've sat in on an odd watch as I did at first, the first thing you've got to learn is the way they've been doing it. You've then got to reverse that until you get to the point where you think it is right and its rather a difficult phase...but you wouldn't believe the lack of standardisation between one watch and another. I didn't believe it until I saw it."

Among the differences mentioned included dealing with levels and holding, and practices to do with separating aircraft well in advance or leaving them on current headings to see how things develop, and so on. Once again, though, there is the familiar, but not to be underrated, appeal to the value of experience in knowing when to intervene or "let things go".

But effecting this trusting relationship between Chief and controller is, of course, a two-way street in that the controller needs also to know how the Chief works and what he/she expects. And much of this is culled from interaction that is unspoken consisting, for example, in the movement of a strip to one side to "catch the Chief's eye" and "if they know their job properly, they will have a look at it...to realise what's required". This does not always happen, of course, and to this extent serves as an example of the source of some of the disgruntlements controllers expressed about Chiefs.

6.6 THE INTERDEPENDENCE OF ACTIVITIES

The discretionary character of ATC means that the fragmentary tasks of individual controllers do, moment-to-moment, have to achieve a unity that results in the predictable, expeditious and safe flow of traffic through the airspace. However, as we have said, the source of this unity is not imposed centrally, except in the sense that the *Manuals* and the technology provide both constraints and resources for doing the work, but by an interdependence of controllers' practices,[22] which is the team character of controlling work.

Though the ATC system itself can be, and is, described in a number of different circumstances, in CAA literature, by management, by controllers, in the interviews we conducted, in the design specifications of the technology, and more as totality and as a formal scheme of operations, these accounts constitute 'global summations' (Bittner, 1965). As such they give a thematic unification to the activities of controllers, codifying them as a structure within which they are located, and providing an overall sense of them as activities organised to some clear and determinate end.

However, 'from within' the experienced working world of ATCOs and the activities they do in that working world, such depictions of ATC serve as a 'transcendental presence' (Bittner, 1965). The work, the fragmentary tasks involved in controlling, moment to moment, are not encountered as a coherent, integrated totality, but as a stream of differentiated and discrete tasks to be performed. In this respect, teamwork, from the point of view of the ATCO, is egological in its determination in an environment which is saturated with information.

The principle of egological determination refers to the way in which the organisation and accomplishment of practical activities associated with any position around, say, a suite is encountered as a structure of 'decisions-that-I-can-take' or 'actions-that-I-can-do', and those that others deal with. In processing an endless stream, getting things done, means doing 'what I can do' and passing on tasks so others can do what they do. So, teamwork is an interdependence of egologically sited activities (Anderson, Hughes and Sharrock, 1987).

However, this egological structure of activities is open to to review, though not always so reviewed, as is illustrated by the often delicate relations between Chiefs and ATCOs as to which are 'the-actions-

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[22]We are struck by the metaphor of the 'invisible hand' Adam Smith used, over two centuries ago, to characterise the way in which the social order was produced by the activities of separate and discrete individuals, each pusuing their own self-interest (Smith, A. 1976). The problem of social order, of course, remains central to sociology (Parsons, 1963; Garfinkel, 1967).

I-can-take' and which are 'actions-the-Chief-ought-to-do'. Nonetheless, the principle does provide, routinely and regularly, a solution to the problem of task coordination by its reliance on 'what others know' without the need for explanation. A Chief's drawing attention to a flight strip by pulling it to oneside in the rack is normally sufficient to call that strip to the attention of the controller so that he/she can embed any necessary action to do with the flight into the stream of tasks already in process.

The teamwork nature of this interdependence of activities works to the extent to which it is associated with a structure of relevances. At its baldest, controlling work requires that whole areas of the operation of the system are not, at the time of doing the controlling work, practical matters of enquiry. A controller, for example, need not be, indeed cannot be so concerned, whether the work on another sector is particularly difficult just now as an abstract matter of enquiry. There is a practical working assumption that others are 'doing their job', and though the details of this could be made available for the tasks 'here and now' they are unnecessary.

An important point about the organisation of work and the interdependence of activities is that the activities are highly visible to controllers, mostly 'at a glance', in locally provided, known in common, ways. We have already remarked upon how much of the interaction around the suite is unspoken but yet, to those 'in the know', highly visible in terms of what is required by way of action. For example, for any particular controller, work on a shift consists in a continuous processing of, making decisions about, 'blips' and their associated data blocks, as they stand proxy for the aircraft moving across the airspace. Controlling these movements, by instructing the pilot as appropriate, becomes a task to be completed and then passed on to someone else. However, one of the most striking features of this process to the naive observer of suite work is the degree to which exchange transactions between controllers are minimised, or even non-existent. The latter are referred to as 'silent handovers'. The achievement of a 'silent handover' is evidence of the routine working of the system. 'Blips' visibly appear in the right place at the right time and in the right sequence with the right codes attached to them.[23] This is 'evidence' of routine performance of their task by someone else making their work unproblemmatic to you. Thus, while the coordination between controllers is an issue and one which, by and large, ATCOs see as complicating their work when telephone contact has to be made, there are ways in which 'repairs' to failed 'silent handovers' can be made. However, it is the pervasiveness of the 'silent handover' which is both evidence of and dependent upon the visibly proper deployment of competence by the controllers concerned.

6.7 CONCLUDING REMARKS

Although the division of labour is a notion much celebrated in sociology as a basic axiom of its theories of social organisation, few studies have looked at it as a feature of a 'working world', oriented to by members of that world and used by them, as a resource, for organising the activities and the sense of the working environment. In the context of ATC, especially at 'the face', the interdependence of activities is a key feature as is the notion that controlling work is very much teamwork. Discretionary systems such as ATC, though this idea is, we suspect, generalisable beyond this to many kinds of organised work activities requiring the use of human judgement in the execution of general principles or rules, require a sense of teamwork in order to sustain an acceptable level of operating efficiency.

Arising from this, and in light of previous discussions of technological innovation, it is hard to overestimate the role of controller team work as of major importance in getting the technology to cope with the demands made upon it by the ATC system. This is not so much a point about the failure of technology to match up, which it often does, but with the fact that the technology, as it evolves, has to be made to work within a particular and changing environment. In ATC, it works, we might say, because of the dedication, experience and effort of those who work it.

The general point arising from this is that given the long lead times conceiving, designing and evaluating complex technologies, once introduced adaptations are inevitable since circumstances have changed,

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[23]'Right' in this context means in correspondence with the 'standard practices' in force.

often radically. Again, these are adaptations that must be done by human operators learning how to use the technology within changing circumstances to do the day-to-day work required. Nowhere is this problem more evident in LATCC than with the computer where, due to staff changes over the years, the new demands increasingly made upon it, and so on, its history of adaptations mean that the current capabilities of the machine are an unknown quantity. The reliance of human operators to work on despite this is a matter that would need to be taken seriously in the design of any more automated ATC system.

SECTION 7

THE PICTURE, TACIT KNOWLEDGE AND CREATING ORDER IN THE SKIES

In this section of the report we intend to develop some themes and issues arising from the preceding sections, particularly those to do with the characterisation and development of controlling activities as a sequence of steps. It is here that we move toward the production of a qualitative description of air traffic controllers' work as an achieved arrangement of tasks.

7.1 'THE PICTURE'

The local culture describes a controller's orientation to the configuration of traffic on the sector and the likely problems it poses, as 'getting the picture'. It is clear that this is no detached description but one used and understood within the controller's culture to refer to various practices in controlling work, such as, for example, the regular practice of an incoming controller spending anything up to 10 minutes watching over the shoulder of his predecessor to 'build up the picture' before taking over the position. An important part of this is "looking about 5 to 10 minutes ahead all the time...sometimes a little further than that", in order to get an idea of the actions that need to be taken 'now'. As one controller described the process at some length,

> "...the kind of checks you do is check your information which is your strips which will show you whether an aircraft is in there or not, and that means then that you don't have to look all over the radar...it would be an impossible job to sit and look at the radar and look at all the different blips and try to avoid them by putting the aircraft into blank spaces on the radar, so you've got to have this information to tell you what traffic is coming into and going out of your sector. From your strips...you can find out whether or not there is a possible confliction...and what you can do about it, you then go to your radar and look for that particular aircraft and see where it is in reference to the, the outbound from Heathrow, for example, and you want to climb it, to see where it is in relation to that. Then you decide what you're going to do with it, whether you are going to go up underneath it, whether you are going to wait until

its gone past it, whether, if its on your frequency whether you can put them on parallel headings and then you can climb it up to the other aircraft levels. Same as with the inbounds, its the same sort of thing".

So, 'building up the picture' is integral to the task of controlling: finding out the things to do 'now' by 'scrolling' the current state forward to see what it might be in a few minutes time. And this requires a complex interplay between, mainly, strips and radar as information sources. 'Loss of the picture' is a reason for worry, and knowing when this is likely to occur is an essential part of 'knowing one's limits' as to the amount of traffic one can cope with.

"I'm not quite sure what my limit is - I can only tell you when I'm approaching it...Now if you can do that a little bit before you really reach that limit then obviously its going to help you on the sector..."

This particular controller went on to describe such a situation:

"...all their aircraft falling down in the morning into Heathrow and into Gatwick, and you can split the sector, split the downbound flow between two controllers...The problem with the downward sector, is that you've got climbs out of Manchester, climbs out of Castle Don, climbs out of Birmingham, all going south, at the same time as you've got southbound traffic into Heathrow, coming into Gatwick, descending amongst that. You also at times have traffic coming up through the west side going to Birmingham, or Castle Don which is straight into the teeth of all this downward flow and on the east side of the airway you've got climbs and outs and so on of Gatwick, Luton, Stanstead and you just physically haven't got the space to - no matter what kind of system you can dream up on the spur of the moment...where experience comes in, its recognising the fact that this is likely to happen again from your strips and doing something about it. And it may mean...blocking certain levels and saying sorry I can't accept any traffic at this level, you'll have to hold them back...otherwise the sector just explodes...nobody knows what the hell is going on".

Of course, with increasing traffic loads, more and more ATCOs are claiming that maintaining 'the picture' takes more and more effort and 'losing the picture' a more frequent anxiety.

The point about the 'picture' is that the ATCOs transactions with aircraft are not only in a serial order, but in a developing sequence such that current moves are dependent on those which have previously been made and which must not only anticipate but contribute toward the production of future situations. The ATCOs work in ensuring the safe coordination of traffic in a sector, such that decisions about a single aircraft are made in relation to the disposition of others, requires a continuing state of awareness of the ongoing development of the traffic.

7.2 SOME CURRENT RESEARCH ON THE 'PICTURE'.

The controller's 'picture' has been of interest to ATC researchers for some time (Whitfield, 1979). Its potential significance was first appreciated during investigations on Interactive Conflict Resolution, a computer-assistant which extrapolated air traffic situations to aid planning for controllers (Whitfield, Ball and Ord, 1980). This interest led to the development of various techniques to illuminate aspects of the 'picture' as a mental model, or 'internal representation', and its relationship to measures of workload (Jackson and Onslow, undated). The idea of the 'picture', best summarily characterised in Whitfield and Jackson's words as the "overall appreciation of the traffic situation for which they are responsible", recognises that controlling work has a subjective dimension to it in the sense that a controller has to think and make decisions about the situation before him/her and, it is argued, that this process is characterisable as the matching of a 'picture', or mental model, with the information on screen, from R/T, or from strips. What is also important is that the idea recognises that controlling is not simply a matter of unreflectively applying rules but a matter of applying rules with respect to an ongoing configuration of traffic; in short, a matter of interpreting, or making sense of, what is going on 'now'.

The importance of the 'picture' is emphasised by the possibility of computer assistance and the consequent reduction of the ATCO to 'supervisory control'. And, since such changes will almost certainly involve major alterations of controlling strategy, not to speak of the risks that this may provoke through, for example, boredom, the examination of the 'picture', it was felt, would provide further understanding of air traffic control skills essential to the design of automated systems more adequately adapted to human capacities.(Whitfield and Jackson, undated; Hopkin, 1979(a) and 1979(b)). Results based on interviews with controllers suggest that though they often find it difficult to describe the 'picture' verbally, certain themes did emerge as important ingredients, such as, establishment of the 'picture' before taking over, the value of experience in handling information, the division of traffic into 'foreground' and 'background', and planning and prediction (Whitfield and Jackson, *op.cit.*). Further studies using the Verbal Protocol Technique (Bainbridge, 1974; Rasmussen and Jensen, 1974), where an operator is asked to give a running commentary describing his/her sequence of thought and action prior to taking over a position, which is recorded and analysed, provided the following counts of 'protocol elements':

- strips were the predominant elements in establishing the 'picture'. Expected aircraft are not yet on radar and strips alone contain the detailed information about each flight;

- radar was mentioned much less frequently, and then often in conjunction with information provided by the strips;

- 'mental activities' inferred, such as time check, memory reference, predictions, calculation, decisions were small in frequency;[1]

- search activities prior to reference to the strip or to radar were relatively infrequent.

Further analysis of the 'strip category' suggests that controllers appear to use route information frequently when thinking about aircraft and obtaining a general sense of the traffic situation. The next most important one was flight level, then beacon time, though other categories do play a 'significant' role at times. However, it is noted that there are variations between protocols even though the most frequent procedure when taking over a sector is to examine the flight strips in time order. Departures from this included exploring potential conflicts first, inserting a new flight strip and considering that first, overhearing R/T, among others. Also, some controllers apparently organise

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[1]Though the authors of the report state that this could be an artefact of this study.

their 'picture' in terms of inbound and outbound flows for various airports relying on their knowledge of typical routes and procedures, while yet others organise it in terms of flight levels. Some also focussed the 'picture' on unusual and non-routine flights.

From our point of view, this emphasis on the 'picture' as a mental model of the situation with which the ATCO must deal and which can be specified in terms of definable boundaries, and its relationship to fairly abstractly conceived mental operations such as searching, remembering, deciding, and so on, is to decontextualise what is a local account of the work of ATC offered by, and for, controllers. One of the instructive features of the admittedly provisional research summarised earlier was the variation noted in the organisation of the 'picture' as reflected in the ways in which controllers described the process of 'building up the picture'; a variation which could, in large part, be due not only to variations in practice by individual controllers but also to the particularities of the traffic being dealt with when the recordings were made. Moreover, simple frequency counts of activities tells us very little about the significance of the activity in the process of controlling a particular configuration of traffic. That flight strips were the most frequent element cited in establishing the 'picture' should be no surprise since these contain the necessary detailed information about flights and are crucial to making the radar intelligible, as the quote used earlier illustrates. In other words, consulting flight strips is not an action controllers 'happen' to do most frequently as a source of information they are most comfortable with. Rather, they do so because they are competent in the work of controlling and 'know' that strips contain the information they need in order to read the radar 'properly'.

In sum, then, the approach neglects the fact that reference to the 'picture' is offered by controllers in a way that is related to the practicalities of the work they do, and the tasks they have to perform in doing that work, *then* and *there.* Instead the decision-making process is conceptualised, in the approaches reviewed here, as involving the matching of a particular traffic configuration with a mental model or representation, 'the picture', and in light of this making the necessary decisions. The work of controlling is viewed in terms of a system of 'internal representations' appearing as a sequence of cognitive operations, and it is the objective of research to map the organisation of the operations.

In the following sections we introduce an alternative conception of the 'picture'.

7.3 SOCIOLOGICAL APPROACH TO SKILL AND ACTIVITIES

The last two decades or so during which sociological attention to skill concentrated mainly on the extent to which various occupational groupings have become prone to processes of deskilling, occasioned by Braverman's (1974) seminal work, have recently raised questions about the social construction of skill and the tacit knowledge used in skilled work of all kinds (Wood, 1987).

In this vein, a more direct form of sociological inquiry into skill as a form of knowledge rather than simply an interest in the causes and consequences of the changing distribution of skilled occupations, has begun to draw upon the sociology of knowledge and sociology of science traditions.[2] The immediate impetus for many of these studies was to challenge the philosophically dominated view of scientific knowledge in an effort to make scientific knowledge amenable to sociological investigation (Barnes, 1977; Bloor, 1976). While many of the claims vis a vis philosophical views of science were misdirected, the approach has stimulated a wide ranging interest in the social organisation of science, not only in the networks of social relations that sustain or inhibit the growth of scientific knowledge (Collins, 1974; Mulkay et al, 1975), but also in the factors which shape the form and content of particular scientific theories (MacKenzie, 1981; Shapin, 1972; Knorr-Cetina, 1987).

An important feature of this tradition is the recognition that much of what scientists know, and therefore much of scientific practice, depends upon "a body of knowledge which is informal and partly tacit" (Ravetz, 1971, p. 103). Like a craft, acquiring the skills of scientific work is a matter of apprenticeship, interpersonal interaction with peers

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[2]The published work on this is voluminous, but see Barnes (1974), Barnes and Edge (1982) for representative selections.

and, generally, acquiring the culture (Collins, 1987a).[3] Collins goes on the draw a useful, if, in his own words, an 'oversimplified' distinction, between "algorithmic" and the "enculturation" models of knowledge. The former holds that knowledge can be transmitted to members of society in discrete bits capable of being written down, codified and counted. The latter, on the other hand, stresses "socialization, not verbalization" as the way in which knowledge is transmitted, with much more emphasis on the 'tacit' character of knowledge. This distinction surfaces in the recent interest the sociology of scientific knowledge is showing in Artifical Intelligence, or AI (Woolgar, 1985; Collins, 1987a and 1987b).

The claims of AI have caused considerable excitement in a number of disciplines concerning the extent to which computers can be designed to model human thought processes. The claims that they can be so designed is a view which leans toward the 'algorithmic' model of knowledge. Those, however, who argue that this is not a plausible aspiration lean toward the 'enculturation' model. (Dreyfus, 1979). However, although these debates within and about AI are of considerable interest, from a sociological point of view, their resolution is not of any immediate concern[4]. What is of concern, as it is in this project, is the way in which computers with some 'decision-making' capacity relate to the working practices and skills of those who use them.

One area of AI which is especially pertinent is the 'expert system' or 'Intelligent Knowledge Based System' (IKBS). The idea, in brief, behind such systems is that a body of knowledge is extracted from experts and stored to be used and retrieved in answer to some problem posed, either by an 'end-user' or automatically triggered by some

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[3]Collins also draws attention to another important feature of the modern sociology of scientific knowledge, one which has its roots in the philosophy of the later Wittgenstein, (1953), that even the theoretical work of science is best thought of as a 'skilful' activity (Collins, 1974; Bloor, 1983). The idea that 'mental life' in general is the excercise of human skill has been usefully exploited in sociology by Coulter (1979 and 1983).

[4]This is not to say that they are irrelevant, simply to point out that their resolution is likely to be a long way off.

automatically detected state of affairs. However, such systems can be designed and made to work[5] to the extent to which the knowledge encoded in the system is explicit and codifiable enough to be programmed. Collins (1987a, p. 24), for example, suggests, albeit tentatively, that those whose professional competence "rests on stores of condified information - such as solicitors and medical specialists - will be more easily replaced than those whose expertise is less tidily organised - such as barristers and general practitioners".[6] The parallel with ATC, conceived as a rule governed system, albeit a discretionary one, are obvious. As *Cassandra*, designed by Dr. Craig, shows, ATC systems can be modelled with many of the key decisions being 'taken over' by 'intelligent machines'. Of course, this is a far cry from developing a practical version of such a system.

But, what the studies of scientific work have shown is that even highly codifiable knowledge depends for its 'use-ability' on further understandings that are not themselves part of the formal knowledge scheme.[7] In this, of course, the 'end-user' of expert systems is crucial. The extent to which an 'end-user' needs to be expert in the knowledge programmed in order to use the system clearly has a bearing. So, too, does the extent to which use depends not so much on a specific expertise in a body of knowledge but upon 'common sense knowledge' which is not itself modelled within the system as in, for trivial example, the knowledge of the QWERTY keyboard is for computer users. Once again, what becomes important are the wider cultural competences involved in use of the expert system.

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[5]Though their performance is arguable.

[6]But, elsewhere, he points out that though expert systems may become useful aids to those already skilled, there are many difficulties to resolve before clear answers to the questions here can emerge (Collins, Green and Draper, 1986).

[7]One reason, Collins argues (1974, 1987a) for using ethnographic modes of research in order to grasp the processes by which knowledge is acquired and transmitted. "Participant observation...may, oddly enough, be of direct relevance to the new breed of knowledge engineers." (1987a, p. 26)

The 'wider cultural competences' referred to above are not so much other areas of specific skill, though they can be those, but the more mundane, everyday skills acquired by virtue of becoming a competent member of society. As Suchman (1987) observes, the mutual intelligibility that is achieved in our everyday interactions, mostly with effortless ease, is always the product of *in situ* collaborative work. Further, an essential aspect to this work includes the resources for making sense, gaining understanding and, as part of this, remedying troubles in understanding as a fundamental feature of its organisation. Every occasion of human communication is "embedded in, and makes use of, an unarticulated background of experiences and circumstances. Communication...is a real world activity in which we make use of language to delineate the collective relevance of our shared environment". She goes on to conclude her study of human-machine communication as follows (Suchman, 1987, pp. 180-181)

> "The initial observation is that interaction between people and machines requires essentially the same interpretative work that characterizes interaction between people, but with fundamentally different resources available to the participants. In particular, people make use of a rich array of linguistic, nonverbal, and inferential resources in finding the intelligibility of actions and events, in making their own actions sensible, and in managing the troubles in understanding that inevitably arise. Today's machines, in contrast, rely on a fixed array of sensory inputs, mapped to a predetermined set of internal states and responses. The result is an asymmetry that substantially limits the scope of interaction between people and machines".

Though this asymmetry clearly poses problems for designers as well as for users, what is also clear is the need for an adequate base of descriptions of "situated human practices", to use Suchman's phrase, in order to amplify the 'enculturation model' referred to earlier.

In this respect, and stemming from a rather different though not divergent sociological tradition, ethnomethodology, as the examination of the ways in which persons make their activities "visibly-rational-and-reportable-for-all-practical-purposes i.e. accountable" (Garfinkel, 1967, p. vii) is assuming some importance. The ability of persons to recognise what is happening as "just that kind of thing", "typical", as "routine", as "predictable", as "not going to plan", and so on, is crucial not only to the employment of skill, but also in the conduct of more mundane activities in our daily lives, such as conversing which is, incidentally, one of the more developed areas of this branch of sociology.[8]

Interest has also been shown in the structure of practical reasoning in the production of courses of action; that is, reasoning as it occurs in natural settings.[9] Lynch (1985) has examined the practical, 'taken-for-granted' reasoning involved in laboratory technicians' ability to produce photographs of brain tissue lesions appropriate for experimental work; an ability treated by technicians as a basic competence, so basic that to include mention of it in more formal accounts of scientific work, such as in scientific papers, is considered superfluous and irrelevant, but which remains, nonetheless, an essential, if tacit, element in the more formal characterisations. Other contexts looked at include astronomy (Garfinkel, *et al*, 1981), mathematics (Livingstone, 1987), truck tyre repairs (Baccus, 1987) accountancy (Harper, 1988), medical consultations (Sharrock and Anderson, 1987), legal settings, (Pomerantz, 1987, Atkinson and Drew, 1979), business decision-making (Anderson, *et al*, 1987), police interrogations (Watson, 19), among others.

By contrast, mental modelling approaches do not treat as particularly problemmatical the question of what it is social actors are doing when they perform certain tasks. In these, action is seen, for example as job design approaches tend to do [see section 5.1] in rather gross characterisations that are, putatively, regarded as the response to certain psychologically based 'need dispositions'. This, from our point of view, overly simplifies situations of choice as they are encountered by those who make choices, underrates the knowledge available to decision-making agents, and ignores the socially organised features of the environment within which the choice is to be made. While such models lead

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[8]See, for example, Button and Lee (eds), (1987), Atkinson and Heritage (eds), (1984). Further, some interest is being shown in this form of analysis in studies of cockpit interaction. See, for example, Goguen and Linde (1983); Linde (forthcoming); Linde (mimeo).

[9]In contrast, that is, the formal models of reasoning as developed in logic, mathematics, game theory, and so on.

to generalised pictures of action, what is not clear is how they relate to particular cases, particular skills and competences as used and understood by those doing a specific job, such as controlling aircraft: in short, its quiddity (Garfinkel, *et al*, 1981) What is lost is the realistic character of the situation in which practical decision-making takes place. It is to avoid this that we sought to look at controlling in detail, as it takes place.

The most elementary objective of this approach is a concern to describe decision-making as a step-by-step matter involving the sequential ordering of social actions as a means to achieve a given end. So, ATCO work becomes not so much the accumulation and construction of an 'internal representation' but the production of an observable state of affairs at the console; this being done not by a sequence of inferred cognitive operations but by a succession of *witnessable* social actions done so that their recognisability is evident to those 'in the know'. As we have remarked before, the visibility of actions, and therefore their 'witness-ability' is a key feature of social action. Within the operations room at LATCC, for example, among those familiar with it, what a controller is doing is visible by looking at the strips, the screen, listening to the talk, and so on, *because* of its visible familiarity to those doing the work involved. The incoming controller, in 'getting the picture', does not routinely have to interrogate the outgoing controller to determine what is happening but simply sits and observes the strips, the radar and the talk, and, from these resources, is able to determine what the active controller is doing and why.

Of course, not everything an ATCO does is intelligible in this way. There are occasions when the activities of a controller are puzzling even to the most acculturated of observers. At such times interrogation might be necessary. But these are exceptions rather than routine occasions.[10]

7.4 OBJECTIVITY AND SUBJECTIVITY IN THE SOCIOLOGY OF WORK:

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[10]It was for this reason that we required the research officers to become as acculturated in the practices of controlling as possible in the time available. And it is on the basis of their observational familiarity with the moment-to-moment work of controlling, we venture the analysis here.

Technology: action with + through it:

TECHNOLOGY AS CONSTRAINT OR RESOURCE

One issue which we need to address, though briefly and more in the way of making our own methodological intentions as clear as we can, is one endemic to the human sciences, namely, the relationship between the 'objective' and the 'subjective' dimensions in the determination of social action.

In the sociology of work this typically appears in the characterisation of technology as a putative determinant of action, attitudes, even life chances. For us this kind of issue needs to be treated methodologically rather than philosophicallly or meta-theoretically, acknowledging that the problem of relating the 'objective' to the 'subjective' results more from an impoverished way of describing human activities and competence than from overly generalised metaphysical difficulties about the problem of cause and its relation to the explanation of human action.[11] Accordingly, rather than beginning with, say, the assumption that technology is an 'objective' factor which may, or may not, be determinatively related to conduct and attitudes, our objective here is to describe the technology from the 'actor's point of view'; that is, the technology as it is known to those who work with it.

In this respect, views taking technology as an 'objective' phenomenon, with dimensions and properties unknown to those who use it in their work and exerting constraints on their conduct of which they are unaware, are at best premature. This is not to claim that the actor's point of view is omniscient. Far from it. What is does mean, however, is that descriptions of the technology in the usual highly abstract fashion of much research in this area is insufficient in being very 'thin' descriptions indeed (Ryle (1973), Geertz (1977) and, incidentally, no more 'objective' than describing the technology *as it is for those who work it.*

Further, from the actor's point of view, the technology does not necessarily appear as a *condition* of action, but, as it is for ATCOs, more an instrument by which they do their work. And it is with technology as an

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[11]This is, of course, an enduring problem in the philosophical branches of sociology; a problem which has both theoretical and methodological consequences. It draws upon more general philosophical issues, of course. See, for example, Ryle (19), Winch (19), Taylor (19).

instrument, perhaps sometimes unwieldy, sometimes intractable, variably adequate, that is our concern. Thus, to talk about technology from a 'subjective point of view' is a concern with technology, in this context, as the controller's instrument for carrying out the work of controlling with an attentiveness to the ways in which the controller gets the instrument to do the work. In other words, the technology cannot be treated as having a fixed material structure about which actors can do nothing, so to speak, but recognising that those who work the technology confront it in terms of those things 'something can be done about', 'those things that cannot be altered', 'those things that can be modified in the longer term', 'those that can be managed and manipulated "now"', and more. That is, experientially knowing the differences between these kind of conditions involved in working with the technology as an instrument and not something that is as immutable as some theories, sociological and psychological, would lead us to believe.

As we discussed in connection with the teamwork character of ATCO work, the 'front line' status of the ATCO at the suite means that activities are organised 'around' him/her - the egological principle of the division of labour within LATCC - such that other activities, such as repairing the technology, must be done without interrupting the flow of that work in which other matters must be 'held off' when he/she is busy, and so on. Matters will be organised in terms of relevances which range from 'anybody's business', to 'none of my business', to 'mine and yours', 'nobody's but mine', and more. Again as we said earlier, the ATCOs activities are embedded in a more or less definitely known division of labour, such that the controller can presume that others, outside the domain of his/her awareness, are going about their work in ways that ensure the routine provision of the resources necessary to his/her work and that failures will show up in detectable ways.

This was illustrated [in section 2.5] by the routine 'troubles' arising from the relationship between civilian and military controlling. From the point of ATCOs civil-military conflicts are a routine 'trouble', one about which, in the immediate term, nothing can be done but is, for the civilian controller at least, a product of 'obvious' features of the arrangement of the airways, the relation between military bases and practice areas, between the social types 'civil pilot' and 'military pilot', and of the conditions of work and capacities of military controllers. Military planes will, on occasion, cross civilian routes causing problems for civilian controllers, and this cannot be prevented. So, what has to be done has to be done within these constraints. That civilian controllers feel that these transgressions ought to be resolved by military controllers or by LJO personnel, is a feeling which also recognises that, given the constraints mentioned, there is nothing that can be done except deal with the matter as effectively as possible 'in the circumstances'. It is this attitude which manifests the controller's sensitivity to the location of his/her activities within the division of labour. In this particular case, of course, for civilian controllers matters which 'ought not to be any of their business' become 'theirs' to be taken care of as best as they practically can.

Of course, issues about tasks which legitimately fall to the controller and are his/her 'proper' work, are connected to, though not in any fixed fashion, to what we might term the 'reciprocities of ordinary life', such as 'doing things you don't strictly have to do in order to make other people's work easier', 'doing things to help them out', 'doing things you don't have to do because of their incompetence, inexperience, age, paucity of resources', and so on: all of which are important features reflected, again, in the teamwork character of controlling. Similarly, there are issues here, immensely relevant within the local culture, to do with supervisory work and the conditions under which, and the ways in which, Chiefs, among others, can intervene and in doing so be seen as 'reasonable', 'intrusive', 'offensive', 'questioning my competence', and so on.

Using the technology as an instrument means that anyone doing so is not just using it to 'figure out what is happening now' but also coming up with solutions as to 'why that is happening', working out what it is about the instruments and the organisational setting that enables a user, at the work site, to 'work out what is happening'. That is, from the point of view of working with the technology, controllers have to address, as practical matters bound up with their work, 'what the equipment is supposed to do', 'what it can do', 'what it can't do', 'what it takes to get the equipment do what it is supposed to do', 'the troubles it can make for you', and more.

Examples of this kind of process abound, though cases of discrepancies in the information provided by the three primary sources - strips, radio and radar - are adequate to illustrate the point here.

7.4.1 Dealing with Information 'Troubles'

An important activity within controlling work is using information derived from strips, radars and radio. However, this process does not deal with each of these sources as distinctly separate items of information, but as being mutually determinative as to what each means. What each source of information means is reflexively determined by the sense made of others. This mutuality is premissed upon 'learnt through experience' knowledge of controlling. These interpretative practices, and the commonsense reasoning they embody to make sense of these resources, are not only not described in the manuals, but could not be; they are, in short, tacit features of controlling activities. This can be illustrated by cases where there is an inconsistency in the information provided by one, or more, of the main sources of information.[12]

The mutual determinacy of strips, radar and radio is reflected in the ways in which discrepancies in the information are dealt with. Strips, as mentioned earlier, state when a plane is due to arrive in a sector. Failure of an aircraft to appear on the radar screen at the time stated, or failure of the pilot to contact the controller at the appointed time, is not normally treated as a reason for the controller to think that there has been an accident or that the strip is spurious, that the aircraft never existed or that there is a technical malfunction in his equipment. Routinely, a controller in a situation such as this, will assume that the radio and radar are functioning normally and that the strip should be set aside until further information clarifies its status. Controllers know, in other words, that there are many 'good reasons' why an aircraft does not arrive at the time indicated on the strip.

Another and similar type of situation are the cases where radio and radar contact is present but no strip for the aircraft is available. The controller does not request the aircraft to circle until a strip appears but, rather, works on the assumption that radio and radar are correct and that there should be a strip (but for various reasons this is

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[12]These example cases are based on witnessed instances even though here they are discussed in a generalised and abstracted fashion, as 'vignettes'.

unavailable)[13]. Similarly, in the absence of radio contact with an aircraft for which there is both strip and 'blip', the controller routinely assumes that, for example, the pilot has selected the wrong frequency from the previous sector. So, in this case, strip and radar are assumed to be correct, there being a range of routine reasons for the absence of radio contact.

Finally, and for the sake of completeness, in the absence of a 'blip' but where there is both strip and radio contact with an aircraft, the routine response is to request the pilot to check the aircraft's transponder rather than conclude that the pilot has made a navigating error and is flying elsewhere (i.e in such cases, strip and radio are used to determine and identify the radar information).

There are other occasions when there is neither 'blip' nor data blocks on screen. This is normally treated as a radar system fault necessitating switching to another system which is capable of displaying the target.[14] Once again, controllers treat the status of the information (or lack of it) provided by each resource as subject to verification or determination by information provided by the others.

The mutual determinacy of strips, radio and radar means that each is 'made sense of' by what the others indicate; a process of sense making that, for most of the time, is 'at a glance' and reflects what Garfinkel identified as a salient feature of commonsense practical reasoning, namely, its 'documentary method' (Garfinkel, 1967). It is this which makes 'what is happening' transparent. That is, that on the basis of the information the resources provide and what experience about aircraft doing-these-sorts-of-things-in-these-typical-ways, a controller can 'recognise' or 'know' where a plane will be in the future - in controlling terms a matter of a few minutes away - and, hence, where it will be vis a vis all other aircraft in the sector. It is this ability to make

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[13]Precisely what the reason is is not normally of immediate relevance for the controller at that time. It is sufficient that he/she 'knows' that there are standard reasons for the absence of the strip. That is, the strip's absence is not a matter for inquiry at this time.

[14]There are several radars servicing the processed radar system which can be selected from the consoles.

transparent what is happening on a sector which is the quiddity of controlling work. Controllers make practical assumptions about what each datum represents or indicates on the basis of, among other things, the predictable ways aircraft fly and in so doing, can judge whether the absence of one or other resources represents a serious problem or not.

In short, controllers respond to the technology and its operation in 'sensible' and 'rational' ways predicated on the motivations induced by the need to 'know what the technology can do as part of my work'. In this sense, the workings of the system as 'known' yields determinate causes for occurrences.[15] The important point is how the technology appears as an element in working practices is very much a matter of dealing with the kind of practical issues we reviewed earlier.

7.5 TECHNOLOGY AS A REPOSITORY OF SUBJECTIVITIES

The perspective on technology as an instrument we are outlining here can be summed up in the phrase, 'technology as a repository of subjectivities'. What this points to is the ways in which, briefly, social actors' conceptions of what the technology can do, will do, will not do, can be made to do, and so on in all the myriad of fine details involved in these, is integral to 'working with technology'. So, in the context of ATC, the suite becomes not so much a material object the performance of which is governed precisely by the technical specifications which its design incorporates in the machinery, but an organisation of things which a controller needs to do his/her work, 'serving up information when needed', 'giving information that is not needed just at the moment', 'providing facilities that are useless', 'telling me what needs to be done', and so on; meeting, in short, to a greater or lesser extent the practical needs of the ATCO as experienced in 'doing the work of controlling'. In this respect, conceptions of problems, ways of dealing with them, of likely exigencies, of efficiencies, and so on, are part of the technology-as-experienced by those 'doing work' with it. And a key element in this is working with the information that is available, reading

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[15]Of course, and especially in complex discretionary systems such as ATC, what are diagnosed as 'routine' faults may, in the end, turn out not to be so. This, if one likes, is the price paid for systems of such flexibility.

and evaluating it. This is the kind of activity that anyone familiar with the work will be able to know without saying or describing. Working with the strips, the R/T, the radar is the routine 'stuff' of controlling and the 'bottom line' feature of the ATCOs task is the continuing consultation of these resources.

By way of illustration we shall deal at some length with the use of a key element in suite technology, namely, the flight data strips.

It is at this point that describing the 'work of controlling' in the density of detail that is necessary to capture both its delicacy and its routine, day-to-day flavour raises problems of exposition as well as analysis. Accordingly what follows, as with much of what has gone before, is very much an abridged version of such descriptions culled from field notes, interviews, and tape recordings of controllers at work.

7.5.1 Flight Data Strips

Flight Data Strips, or simply 'strips' as they are known, are pieces of paper about one inch wide and eight inches long that specify information about the flight path of individual aircraft[16] [see appendix 1]. This includes the aircraft name or "call sign", its departure and destination point, its preferred route and height, speed, and the type of aircraft. In addition, the e.t.a to certain navigation points in the sector is printed on the left handside of the strip beside the abbreviation for that navigation point. Each sector will have three or four key navigation points, strips being printed for each point for each aircraft. The strips are placed in racks, or 'bays', just above and behind the flat radar screens. Strips are printed some ten minutes or so before an aircraft is due to arrive at the point. These strips represent the aircraft at each stage of its journey trough the sector. As each point is

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[16]Pilots are required to submit flight plans to the relevant ATC authorities before they begin their flight. These plans include the pilots own estimated time of arrival at the navigation points in the journey. This information is processed by a purpose designed computer along with additional information, such as wind speed, to predict more accurately when the aircraft will arrive at these points and, hence, which sector strips should be printed for by the computer and at what time.

crossed so the respective strip is discarded by the controller.[17]

These strips provide the 'template' for what is and will happen in the sector. They are the material instruments that controllers attend to and use in their work. Yet the strips do not determine the sequence of actions of controllers in the sense that what comes along a production line determines what a production line worker has to do next, rather the controller has to organise the strips so that they can become an instrument that helps organise, and so make possible, controlling work. Strips are 'manipulated', 'glanced at', 'taken heed of', 'ignored', 'revised', and so on. And not just when they are first placed on the racks, but continuously all they time they are in use. The end result of these activities is that, at any moment in time, what the strips indicate and create is the sequence of controller actions that results in the achievement of order in the skies. Thus, management of the strips constitutes a large part of the work that underscores controlling competence.

This can be discovered by looking at the precise detail of using the strips. We shall be looking at how strips are attended to when they are first placed on the racks, then how they are used when 'live' and finally how they are finished with. In this manner we shall be able to build up a 'thicker' description of 'working the strips'

7.5.2 Working the Strips

Strips are placed in racks in front of the controllers. As already suggested the controller does not treat these as determinants of his/her behaviour, but rather as a resource, among others, that can be used to organise the controller's activity. The controller, naturally and without reflection, takes it for granted that the strips have been placed in the 'bays' for the reason that an aircraft is due which is his/her responsibility. Beyond this practical assumption nothing more is needed to justify giving it attention; the strip is part of his/her work and this is sufficient to give it relevance. The next step is to order the strips in ways that reflect the work that needs to be done.

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[17]The strips are in fact colllected and used to calculate the cost of the ATC services. The agencies responsible for each aircraft are charged accordingly.

Planes fly through a sector in a sequence reflected in the succession of times aircraft are estimated to pass the various navigation points. The controller uses these estimates and the navigation point to order the strips in the racks so that the next plane due in at any point is at, say, the top of the rack, the one which will be last to arrive at the bottom.[18]

This ordering enables the controller to get a clear idea of what decisions he/she is likely to have to make in the near future. Ordering the strips, shapes the controller's attention in terms of what is likely to happen in the sector, for example, with respect to traffic densities, with respect to standard traffic patterns, but also toward any special problems that need to be anticipated.

Special problems that need to be taken into account and include such things as two aircraft estimated to reach the same point simultaneously and at the same height. Although this may well be of no immediate concern, controllers mark out such 'problem' strips by partly lifting them out of the rack. In this manner when the strips become 'live', the controller will have already prepared them so that they indicate to the controller how they need to be read, specifically and 'at a glance', in relation to *that* potential problem.

These actions are not related to the real time events 'in the sky' as represented on the radar screens, since, at this stage, the aircraft the strips refer to are not yet the business of 'this' sector controller. The actions just described are very much preparatory. Though subsequently the strips may come to be seen, in as yet unforeseen and unpredictable ways, as in need of revision, supplementation or may, indeed, turn out to be correct what the business of the controller at this stage is, is ordering the resources such that what he/she may require from them is available in 'useful' ways. To use a phrase made much of by Heidegger, it is an activity of making the strips come to be "at hand".

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[18]Some controllers put the latest at the bottom. It depends entirely on what is preferred by the individual controller. Nonetheless, assistants, who provide the new strips, need to be aware of this preference so that they can orient their activities to ensure that they sustain the preferred order when placing new strips in the racks.

In fact the bulk of time estimates are fairly accurate and so ordering the strips in time sequence usually turns out correct and, hence, a 'useful' way of ordering the strips. The controller will know immediately where a needed strip is, whether he/she should take account of any special features in relation to it (i.e., in respect of those circumstances that the controller thought worthy of being 'marked out') and so on.

Working the strips, or making them 'at hand', continues once they become 'live'. Typically a strip becomes 'live' on the receipt of a radio message from the respective plane when it enters the sector. The controller selects the appropriate strip and moves it down the rack to the 'live' strip section: 'live' and pending strips being separated by a strip designating the navigation point being used.

The 'live' strip is not placed in just any position among the already 'live' strips. As with the pending ones, it is placed in sequential order: for example, the latest being placed at the top of the bay. Thus, as strips are added to the 'live bay', a flow emerges, new entries at the top, old and finished strips exiting from the bottom. This order reflects, and helps organise, the fact that controlling decision making is a sequential matter. So the latest addition to the sequential order will not be finished with ordinarily until ones beneath, hence before it, have been finished with.

Not only are strips moved in this manner when they become 'live' but they are also colour marked to indicate that the controller moved it into the 'live bay' and not one of the other personnel able to do so. Sector chiefs, for example, and assistants who prepare the strips may replace strips with more up to date ones giving more accurate pending times or revised requests for flying height or destinations, and so on. In being unmarked the controller can see 'at a glance' it is a strip that needs to be attended to and its implications 'taken on board', and, once done so, marked accordingly. Any command given to an aircraft is marked down on the strip. This has a two-fold function: it ensures that the resources are accurate and up-to-date and that this information is readily 'at hand', and a physical confirmation of what the controller has done to date. As a controller remarked, the strips "are like your memory, everything is there..."

Finally when a plane crosses the navigation point represented by a strip the controller does not just throw it away but puts a cross through it. This is especially important on those strips which represent the last point through which the aircraft pass in the sector. The controller puts the mark through the strip when he/she directs that aircraft to contact the next sector controller. In other words it is a physical mark to demonstrate that the controller's work has been properly completed and indicates that the strip has not 'just' been thrown away.

Thus, strips play a key role in enabling controllers use the radar quickly and effectively as 'good technique'. As a controller said, "You've got to have a complete picture of what should be in your sector and what should be in your sector are on those strips". He went on to describe their use:

> "It's a question of how you read those strips...an aircraft has called and wants to descend, now what the hell has he got in his way, and you've got ping, ping, ping, those three, where are those three, there they are on the radar. Rather than looking at the radar, one of the aircraft on there has called, now what has he got in his way? Well, there's aircraft going all over the place, now some of them may not be anything to do with you, it could be above or below them, your strips will show you whether the aircraft are above or below, or what aircraft are below you if you want to descend an aircraft, and which will become confliction...you go to those strips and you pick out the ones that are going to be in conflict if you descend an aircraft, and you look for those on the radar and you, put them on headings of whatever, you find out whether those, what those two are...which conflict with your third one, it might be all sorts of conflicts all over the place on that radar, but only two of them are going to be a problem, and they should show up on my strips."

7.6 THE PICTURE AS A SEQUENCE OF WORKING TASKS

Newcomers to the suite cannot see there what the experienced controller can, though they can, very quickly, be given sufficient guidance as to how to see on the screen what the experienced ATCO is seeing. They can see this at least in the sense in which they are shown where the outlines of the coast are, the flight lanes, the major airports, the 'blips' which represent the aircraft, how the data blocks identify the flight and its height. Similarly, the strips: their left to right arrangement can be shown, what the letters and the figures in the cells refer to, what the coloured marks mean, and so on. However, none of these things can be apprehended in the fluent way in which the controller does. The ATCO, of course, does not just see a series of identifiable units and patterns of movement, but also the history and likely future of these units and patterns and, furthermore, can see that these are not only a coherent and coordinated series of movements, but how they come to be coherent and coordinated.

It is this quality which is sought by the notion of the 'picture'. In vernacular terms, the 'picture' refers, among other things, to the controller's capacity to 'keep it all together'; to see and give coherence and organisation to the patterns of aircraft movements under varying conditions. As indicated earlier in this section, to date the marked tendency has been to treat the 'picture' as an 'internal representation', the controller taking time to sit observing his predecessor's work, observe what is going on and, through this, build up a sense of 'where things are' and, both generally and specifically, what is happening on the sector. At a certain point the incoming controller takes over and, presumably, begins to work in terms of a synthetic appreciation of the information available putatively matching his/her 'internal picture' with the developing information from screen, strips and radio.

However, again as we pointed out earlier, our own research effort has been directed at viewing the 'picture' from a slightly different angle. Our interest in the ATCO is not so much as an information processing device, so to speak, but as a worker and, hence, an interest not so much in the ATCO as a cognitive machine but in the ATCO as someone working out the organisation of a set of tasks. To repeat an earlier comparison: ATCO work is not like that on an assembly line in which a recurrent sequence of steps has to be followed through, but one in which the work consists of putting the tasks to be done into a sequence of steps that can be followed through. Any current transaction between an ATCO and a pilot, or any other member of the team, is not an isolated one but part of a developing sequence whereby current steps are built upon previous ones and shaping subsequent ones.

There is a temptation to interpret ATCO work at the level of the screen.[19] The screen, which stands proxy for what is happening in the sky (and, indeed, for the ATCO this is, in important ways, just what it is) compels attention. But from the point of view of ATCO work, the screen, along with the strips and the radio, is a display of 'things to do'. The work site at the suite is, at its crudest, a display of 'how much work I have to do', 'how busy things are', 'what is going to happen in the next 10 minutes', and so on. The 'picture', on this point of view, can be conceived as the ATCOs analysis of the developing situation of the 'things done so far' and the anticipated future development of a schedule of tasks. A sight of the number of strips building up on the racks gives an idea of the number of planes that are there or shortly to arrive. Of course, the strips must be looked at more closely and this requires an organised interplay between what the strips 'say' about what aircraft are scheduled to enter the sector, and how, and what flights they are, when, and so on, and what a 'reading' of the radar indicates. This may involve looking for particular strips, removing one for an aircraft that has not turned up, moving a strip down for an aircraft that has arrived early, write a new heading or descent indication, etc..

Thus, as Whitfield and Jackson found, it is natural to make a contrast between 'background' and 'foreground' considerations which recognises not only the dynamic variation in the focus of the ATCOs attention, but also the tie between those matters now at the centre of attention and those which, though not focussed upon, are present to the awareness, matters against which currently focal considerations are developed.

At this stage of the research we are examining episodes of air traffic control in what might be seen by psychologists as a form of protocol analysis [see section 7.2] resembling the running analysis of chess situations and moves, to identify the detailed considerations that enter in at any point in time. Though one can accumulate, as we have

[19]As we ourselves did at first. However, as an aside remark here, there is a strong suspicion that the metaphor of the 'picture' owes more than a little to the most salient feature, to the outsider at least, of the suite, namely, the radar screen. However, as we have tried to show, from the point of view of the work, the radar is simply one element in the information resources required for controlling work.

elsewhere in this report, a collection of matters which make up a generalised portrayal of air traffic control, but it is not possible to understand how these things systematically collect together unless note is taken of the ways in which they interdigitate in the step by step, moment to moment work of controlling, the ways in which ATCO's identify and respond to the relevant considerations at the appropriate moment. The only way to work toward a systematic examination of these is through the detailed study of protocols, and some initial exploratory work on such protocol material that we present the following is based.

It is notable that those whose skills are being studied are often most comfortable in relaying those skills to outsiders by giving a running commentary on some episode of that work, and, for researchers, an effective way of eliciting data. Though such running commentaries are often used as a means of yielding data which may subsequently be reconstructed and reorganised to reveal, say, decision making structures, or psychological dispositions, in our case, the protocol is closer to the phenomenon that we are aiming to investigate. We are interested in the work of air traffic control as a moment-to-moment exercise and as one in which the course of reasoning is, to a large extent, exigency driven; that is, responsive to particular occurences as comprehended in the context of an unfolding pattern. Thus,the controller is not dealing with the catalogue of considerations which over the course of time enter into ATC work but is dealing,at any point in time, with those which are relevant and salient now.

From the point of view of understanding how the picture is acquired, what the ATCO is doing and how he/she understands the information being received, the importance of his/her extended familiarity with the sector in which he/she is working cannot be underestimated, since it is this which enables the controller to know the sector as a structured whole, equiping him/her with ready ways of organising prominent features of the work.

The ATCO will readily detail the character of the sector in which he works. It has identifiable features, not least its embeddedness within the system of sectoring U.K. airspace, thus providing it with adjacent sectors and interfacing constraints. The sector itself will be known in terms of air traffic generating and directing features, such as the presence of airports, the disposition of air lanes, the location of beacons. It will be known also in terms of the typical patterns of traffic movement and the variation of these by time and season, in some respects down to the specificity of the direction, timing and idiosyncracies of particular flights. The ATCO who is taking up a position is, thus, not in the position of having to contrive a model for the current distribution of traffic but, rather, is concerned to absorb that traffic, insofar as it can be so absorbed, to the known and standard traffic patterns for the sector. The first thing to see is where things stand relative to the pattern of this-sector-at-this-time-of-day-at-this-time-of-year-under-these-conditions.

Thus, a sector will possess a number of what we can call 'gross structural features', such that, for example, it is adjacent to the sector including Heathrow, and that, therefore, Heathrow will be the destination or origin of the great bulk of traffic in the sector. The majority of aircraft will either be wanting to descend into the airport or to ascend from there. The traffic in the sector will be distributed within its structural arrangements, and the controller will, thus, be able to anticipate that the work he will be doing will have a definite character; that it will involve, say, (more or less) receiving and maintaining a more or less aligned succession of planes all requiring descent into Heathrow. This is likely to involve, initially, achieving the segregation of inbounds and outbounds from that airport. Of course, such patterns will be prevailing ones, and there will be traffic which does not fall into such a standard flow but which will thereby be treated relative to it. Thus, one aircraft will be treated as part of the standard pattern of descent whilst flights seeking to cross its path will be 'individually routed around them'. The ATCO is ad-hocing but doing so within a structured setting which can be counted on to provide the controller with certain predictable features, allowing him/her to read the needs and intentions of pilots and other ATCO's. Such structurally generated task requirements will also engender the expectably problematic features of the work, as, for example, the presence of a 'traffic focus' (i.e. some locale on which ATCO's may centre the headings of a number of planes) will ensure that there will be planes which will potentially come into confliction.[20]

Examining the way in which the ATCO does his moment-to-moment decision-making is rather like analysing chess situations and moves. Because the ATCO is focussed at any point in time on a particular next move, he/she is also going to be concerned with where the aircraft is now and what its developmental possibilities are, as well as with how these interlock with the developmental possibilities of the other 'pieces', or aircraft, along with a concern that there is nothing outside the range of possibilities that are being considered which might have bearing. The difference between ATC and chess, however, is that there is no 'unified' problem situation but, within the overall structure of the sector, localised problems. Thus, an ATCO may have traffic converging on one focus and the task of organising traffic in another part of the sector into shape for handover into the next. This involves looking for traffic converging on a particular point to see if it is separated by levels, while elsewhere concerned to see if outbound and climbing traffic can be got onto a single heading and vertical separation, or, alternatively, to keep them on parallel headings because there is not the time, given the speed of movement, to achieve the vertical separation.

Rather than thinking of the situation as one which involves a pictorial representation of the state of affairs up in the sky, it is better to think of it as a display of task requirements. This is how the ATCO is looking at it, to see what needs doing, and so at any point in time there is 'stuff' which is already dealt with, or which will take care of itself, 'stuff' which now, or soon, requires the ATCO's intervention, and things which are coming along. Thus, situations are treated as more or less problematical, such that it is not the existence of a traffic focus which provides the problem since the aircraft involved are likely to have been cleared and to be safe, separated by height and so on. The problem begins if any of them require moving. It is at this point that coordination with other controllers might be required. Thus, there is looking for movements of planes which, if continuing on present headings

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[20]Perhaps one important 'non-technical' feature about near misses is that they will occur 'out of the blue', where the controller least expects them. It is in places where conflictions might be expected that measures are taken well in advance to avoid them.

and at present levels, would get into conflictions. There is also looking for planes which are on routes that are now coordinated with other planes and but which will now have to be rerouted, and then there is the problem of those presently coordinated planes which are not under 'my' control, but which another controller might alter, to mention but a few of the possibilities.

The ATCO is not, of course, contriving new solutions for each case, but is generally following standard ways of organising regular patterns of traffic flow. Within these there are what we might call 'nominal' conflictions and a differentiation between things done for practical effectiveness and for 'procedural reasons. Thus, if a controller is attempting to bring down inbounds and ascend outbounds in broadly the same direction and are going to have to cross each other's routes, then he/she wants to achieve height separation at that point. But, in such a case, a confliction becomes possible, but is it one that can resolve itself before is represents any serious difficulty. In the same way, if descending aircraft in sequence, it can be judged that by the time a second is to be sent down the first aircraft will have cleared the relevant level before the second arrives so that separation by levels is maintained. Accordingly, for practicality's sake, it would be possible to start an aircraft down before a precending one has cleared the next level down. However, for procedural correctness' sake, the controller would hold the current back until the previous has actually cleared the next level down.

A great deal of ATCO work is segregating the problem areas from each other, where this can be done. Thus, there are problems of coordinating among eastbound departures to align them on height separation, but the controller tries to isolate those problems from those of coordinating eastbounds and westbounds by putting them on parallel tracks, where this is possible. Accordingly, it is necessary to be somewhat wary about describing the activities the ATCO is engaged in as 'problematical'. Many things are notionally so, in the sense that standard technique for dealing with it means there should not be any problem; that if planes are descended, say, in a stepwise fashion, then there will be clearance at a point where inbound and outbound routes cross. What will be genuinely problematical are situations which cannot be dealt with in standard ways. For example, a plane which has given the wrong identification, has apparently misunderstood some message and is not responding on radio is problemmatical in this sense. It would be wrong, therefore, to give the impression that the ATCO is trying to bring the traffic into a unified coherent pattern according to some plan.

The perennial variable for the ATCO's decision-making is time. The issue, at bottom, for the ATCO is, "how busy am I?" A 'glance' at the strips confirms this. Seven or eight indicate a relatively quiet time, some twenty or so signify 'busyness'. One of the features of 'busyness' which seems to present a serious problem for ATCO's is whether they are in unrelieved contact with planes, with pilots calling in and the ATCO giving out instructions. The ATCO wants the flow of work to be uneven, with periods of relative quiesence to look around the screen and strips, or do some planning ahead.

The big constraint on their work, then, is the need to get round the calls, do the talking, to leave themselves time such that any plans they might have for traffic development can be implemented, the right people talked to and enough instructions given. The extent to which they are busy and will have time, then, will depend upon the exigencies, upon the given conditions of planes turning up and the extent to which they do so in problematic ways, such as being behind schedule, displaying the wrong call sign, with the transponder out etc.. But the ATCO seeks to manage the circumstances so as to maximise the amount of time available to make decisions. As we have mentioned a number of times in this report, ATCOs do not merely aim to get air traffic through safely but also aim to effect 'good controlling', and this is a matter of dealing with traffic efficiently. So, for example, of the three broad ways of controlling climbing and descending aircraft on the same heading, by parallel, vertical and speed control then, generally speaking speed control is dispreferred. Time can be bought to assess situations at the price of slowing down a plane, that that the aim is to buy yourself as much time as possible but not to do this at the expense of the next controller or of the pilot. Thus, in the case of planes ascending and descending in different directions, if things are quiet, then the controlling will be done by coordinating with the next controller, by actually talking to him. But as things get busier then the time taken up by talking, not to mention the problem of coordinating the talking so that the two controllers are not distracted,[21] - "he's got six aircraft yapping away and he ain't going to answer you" - gets to be such that seeking to provide a continuing descending and ascending movement for both planes is difficult but, better to preserve the continuing climb of the outbound and bringing the descending plane down in a two step operation. So, if there is a standard separation at the point of convergence, whereby the inbound will be under the outbound, then the inbound will, under the uncoordinated arrangement, be brought down to a level well above that at which the outbound will cross.

The giving of instructions and the management of the traffic are interrelated in terms of the stepwise construction of the traffic movement. Thus, with the example just given, it is a matter of whether a plane is to be brought down in a single movement from the level at which it enters the sector and that at which it leaves it, whether it will be brought from thirty down to eleven on a single instruction so that, for the Heath Row Approach it will be at the level required for final approach, or whether the plane will be brought down from thirty five to twenty, then taken down from twenty to eleven (or whatever height the stacks are receiving). It is possible, therefore, to give a pilot instructions 'early' so that he can be offered the opportunity to get down from thirty thousand feet to eleven thousand before he reaches the Lambourne beacon and to begin his descent when ready. This kind of operation will be done when the situation is relatively quiet. Allowing the pilot do this will mean that many levels will be nominally occupied until the pilot begins his descent. In quiet periods this may not matter because the ATCO does not need them. When things are busier, however, the controller will want to get the aircraft down in such a way as to maximise the number of available levels.

There is also the simplication of problematic situations to buy time, such as bringing an aircraft across a traffic route, say, taking a Gatwick inbound across the Heath Row inbound line. This can be dealt with by taking the inbound well under the level, taking it right down so that there is massive clearance between them. This means that the controller can pay this flight less attention save to confirm that the plane is going

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[21] In fact, controllers quickly have to learn to listen to two conversations at the same time.

right down. Another way of buying time is to expand the forewarning by skewing the radar display to one side, looking at the vertical display, or at the next ATCOs screen to obtain a wider coverage and see as early as possible where any of 'your' flights might be. There is also working out how much time one has got with respect to planes by working out flying time on the screen. Some ATCO's, for example, can take a certain distance between two places as representing (say) three minutes flying time for a jet and can use that distance to multiply for how much time they have got, as a rough but accurate enough practical measure.

7.7 SOME CONCLUDING REMARKS

What we have been trying to do is treat the ATCO's work not just as a matter of manouevring the aircraft in an ordered way through the sky, though this is the point of the work, but of managing the work such that the organisation of tasks enables him/her to effect the manouevring. It is not, then, a matter of whether the ATCO has thinking time, and how much of it, but of trying to organise things so as to provide him or herself with thinking time; to maximise that with respect to the work to be done and, also, trying to set things up so that when there is the least thinking time, there will also be the least to think about. The exigencies of traffic flow, of course, dictate in a gross sense whether the ATCO now has more, or less, thinking time. The occasions which the ATCO's really dislike is when they have very little thinking time and are coping rather than controlling. Nonetheless, at each level of busyness, they try to maximise the thinking time available. This, involves, too, the workings of the 'norm of reciprocity' or, as driving instructors would conceive it, 'showing consideration'. As was mentioned in connection with teamwork, so ATCO's try to arrange things which best suit themselves, within the constraint that this should not make things more difficult for a 'receiving' ATCO than need be. So trying to achieve vertical separation and alignment before the boundaries of one's sector is done to save the receiving ATCO the trouble of doing that, given that the receiving ATCO may have other things on hand.

It is when one begins to get down to this level of 'thick' (Geertz, 1977) description, and the above is only a beginning, that one can begin to see the very fine judgemental work, and its organisation as a set of tasks, involved in controlling. To the extent that the notion of the 'picture' has oriented researchers to the skills and knowledge of controlling, we suggest that seeing it as a sequence of working tasks holds some promise. For one thing, it emphasises the 'visibility' of the work to those others who have also acquired the skills and so can see 'what is happening'. To this extent it emphasises, too, not so much knowledge which is tacit, except from the point of view of highly formalised models of knowledge, but taken-for-granted and understood 'at a glance' by those knowledgeable in the skills and tasks of controlling.

From the perspective of AI such knowledge is difficult to model. The 'picture', as we understand it, is a dynamic, unfolding organisation which can change, moment-to-moment, and, accordingly, posing immense difficulties, at least for the present. This is not to say, of course, that ATC is not capable of much further automation that at present, including elements of 'intelligent systems'. However, it is unlikely that such systems could be developed, or useful, within the present system of ATC since, as is commonly known though with varying significance, the controller, and the skills he/she employs, is crucial. It is, undoubtedly, the weakness in the system, but without it there would be no system. Moreover, within the present arrangements it is also hard to see to what extent additional information, such as RD3 tried to provide, would be of very much benefit. What ATCOs generally lack is time rather than information; time in which to organise their tasks steadily and effectively. Time which is becoming in shorter and shorter supply as traffic loads increase. Of more promise, though to the detriment of the skills of the controller, are rearrangements of the airways, such as CCF; rearrangements which make it possible to increase traffic loads by restricting flexibility.

SECTION 8

GENERAL CONCLUSIONS

In this last section we want to hazard a few general conclusions arising from the research. We do, however, stress, as we said in the introduction, that this is very much a first run through the materials and experience we have gained.

What has become clear is that in complex systems, such as ATC, in which technological developments take many years to design, evaluate and implement; in which changes in procedures require various forms of consultation; in which the demands made upon the system are difficult to predict with the kind of accuracy that does not frustrate planning; then, at any point in time, the system as it stands will be a compromise between the ideal and the disastrous. It will, in other words, represent what can practicably be achieved.

In such a situation more onus is placed on the human operators to keep the system working by 'cobbling' it together so that the system can meet the demands placed on it. So, although the controller is often referred to as the 'weakness' in the system - though in the context of some putative standard of what traffic loads the system is, in principle, capable of bearing - it is also clear that given the inevitable compromises involved in the system's historically determined shape, without the controller's ability to patch things together, the story would be very different. Controllers are no Luddites nor technological conservatives, though they can be awkward, highly vocal in expressing their disgruntlements, critical and independently minded. Their sense of teamwork, high level of competence at what they do, and, above all, tremendous pride in and sense of responsibility about the service they deliver, enables them to perform their craft *despite* all the increasing pressures on the service.

We referred to the incrementalism that has, over the years, characterised innovation in ATC; an incrementalism that has been overtaken by, mainly, the burgeoning demands for air services. Although, perhaps because of the pressures, automated systems begin to look more and more attractive, it is doubtful whether they will prove to be, in the short and medium term at least, the *sufficiently dependable* panaceas hoped for.

Hence, it is difficult to see any sensible alternative to such a strategy given the safety considerations of ATC: an ATCO used as a 'machine monitor' rapidly ceases to be an effective ATCO at all. The CCF system represents a rather different approach to the problems of traffic loads, namely, redesigning the airways so that they are simpler to control in requiring fewer coordination tasks. This, of course, changes the technological parameters in ways that are now being explored in some detail by the CAA.

The implications of this research for the social context of 'expert systems' are various, even though at this stage difficult to specify exactly. One feature, however, which is to our mind important is the need for caution in describing the knowledge such systems will work upon. Knowledge which is codifiable without need for background interpretation is a ready candidate for such systems, but whether the knowledge meets even these minimal standards can often be an arguable matter. The fact that most 'expert systems' tend to be designed and used by those already expert in the knowledge often conceals the tacit and background resources necessary for proper understanding. Also - as we have tried to do in the last section of this report - describing in detail what an ATCO knows and what his/her activities are points toward the extremely rich possibilities, but difficult challenges, for those in AI with ambitions to model human capacities. It is in this context that generalisations are hazardous without a clear idea of what the parameters are, and it is in this field of man-machine interaction where, because so much basic research needs to be done, they are particularly dangerous. No more so than where automated and advanced information processing capabilities are introduced with what we have dubbed 'discretionary systems'. Though modern technology is capable of processing vast amounts of data at high speed, it is not clear in every case, or even most cases, that what will improve efficiency - itself not always clearly definable - is more information. As we illustrated in the discussion of RD3, the tacit skills and competences of controllers made the additional information RD3 could provide largely redundant, even accepting the lack of ease with which the system could be interrogated by users.

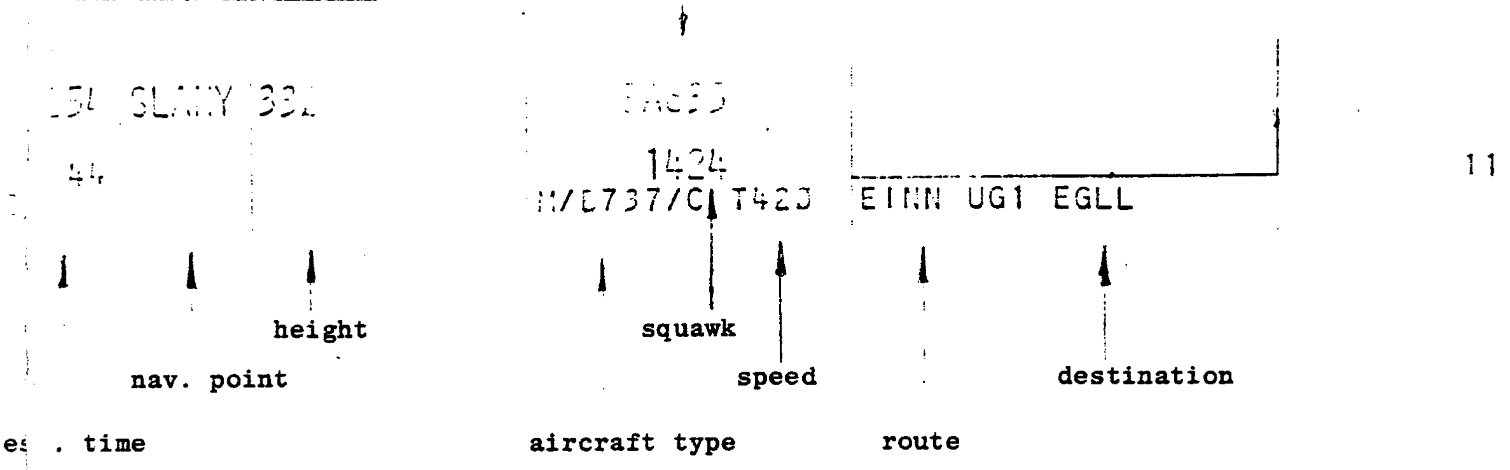
For the foreseeable future ATC will rely to a considerable extent on trained human judgement, with all its tacit features, even though the work of controllers may well become, from their point of view, less interesting and satisfying. As we said in the body of the report, consistent with many studies of job satisfaction and productivity, the relationship is simply not a clear one but dependent on so many variables within the work situation, and outside. But more important within the context of ATC is that although new arrangements of airways, such as those proposed under CCF, may reduce coordination tasks, and hence remove some of the pressures on controllers, it is precisely this kind of challenge that, for many ATCOs, makes the job worthwhile. Moreover, the concentrated attention required for controlling also means that when emergencies arise they can respond quickly because they are 'warmed up'. Ironically, making the job easier may also make it more boring and so potentially more dangerous in some situations, because controllers will find it much harder to 'raise their game'. This may be overdramatising, not to say oversimplifying, matters though it is a concern expressed by a number of researchers in ATC. Automated systems change the role of the human operator and, as part of this change, in assuming a more supervisory stance the human operators lose their 'edge'. This only becomes apparent in emergencies provoked by the failure of the automated system or, indeed, of any of the 'subsystems' feeding it. With airways close to capacity, very little needs to go wrong to cause pandemonium - something such as the failure of r/t communications to an airplane or, more mundanely, the failure to use it correctly by, for example, a pilot switching to the wrong channel. Of course, the problem of maintaining an 'edge' for use in emergencies is a routine problem for many emergency services, such as the Fire Brigade, military organisations, to mention but two examples, and it may be that an ATC of the future will have to learn from them.

We have said that ATCOs, while far from straight-forwardly conservative about technical and organisational change, are distinctly hard to please. In the body of this report we hope to have cast a little light on why this is. Our core concern has been to explore the *collective, social* character of the work of controlling, and we have argued that many, though by no means all, of the deficiencies of existant and prospective technological innovations flow from the failure fully to recognise this. Controllers mistrust that the design of innovations will take proper account of the *full context* of their work; and this pessimism is frequently justified. This context can be specified on at least two levels. Firstly, the minutiae of the tasks of controlling rest on an elaborate interpretative context of 'situated actions'. And secondly, at a broader level, the task of ATC is set in a changing context of administrative, organisational and professional relations. The 'success' or 'usefulness' of technical change is dependent, among other factors, on its sensitivity to and congruence with these contexts. This is a complex relation, and may entail projects that appear less ambitious but have a greater value in depth. Such projects must certainly engage the detailed involvement - albeit subjected to critical scrutiny - of practicing ATCOs. Despite the difficulties, technological innovation has always taken place - few controllers would seriously wish to 'turn the clock back' to a previous system - and will certainly continue to do so. Our claim is that their prospects of success can be much enhanced through incorporating these new elements in their design and evaluation.

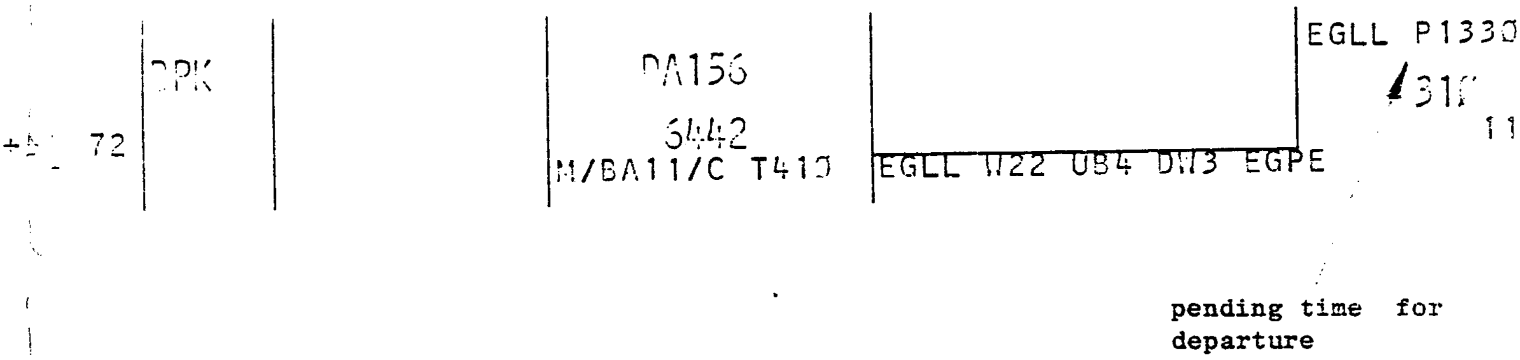
APPENDIX 1

FLIGHT DATA STRIPS: ILLUSTRATION

xample one: En route



xample two: Heathrow departure



xample three: Controller markings/aide memoir

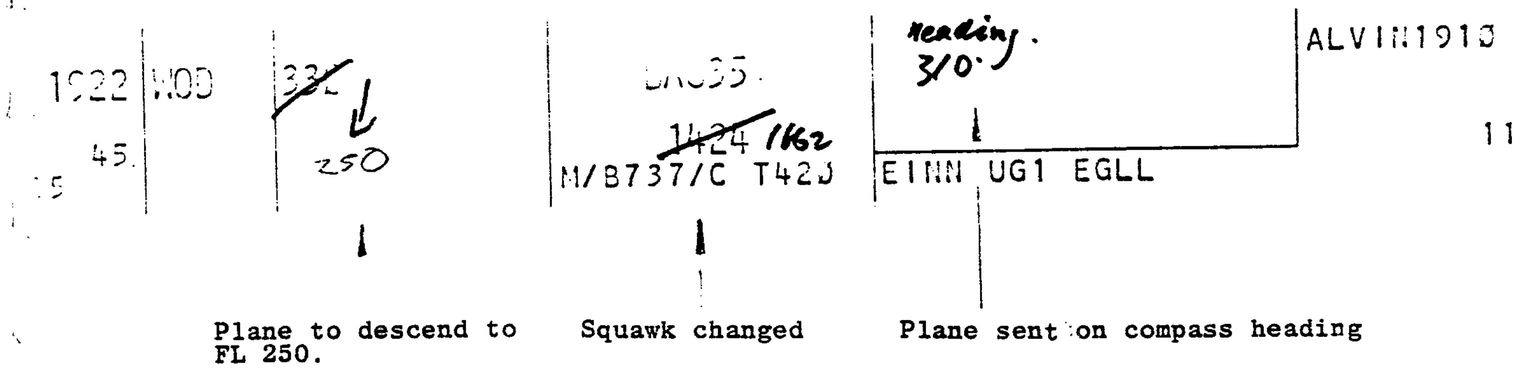
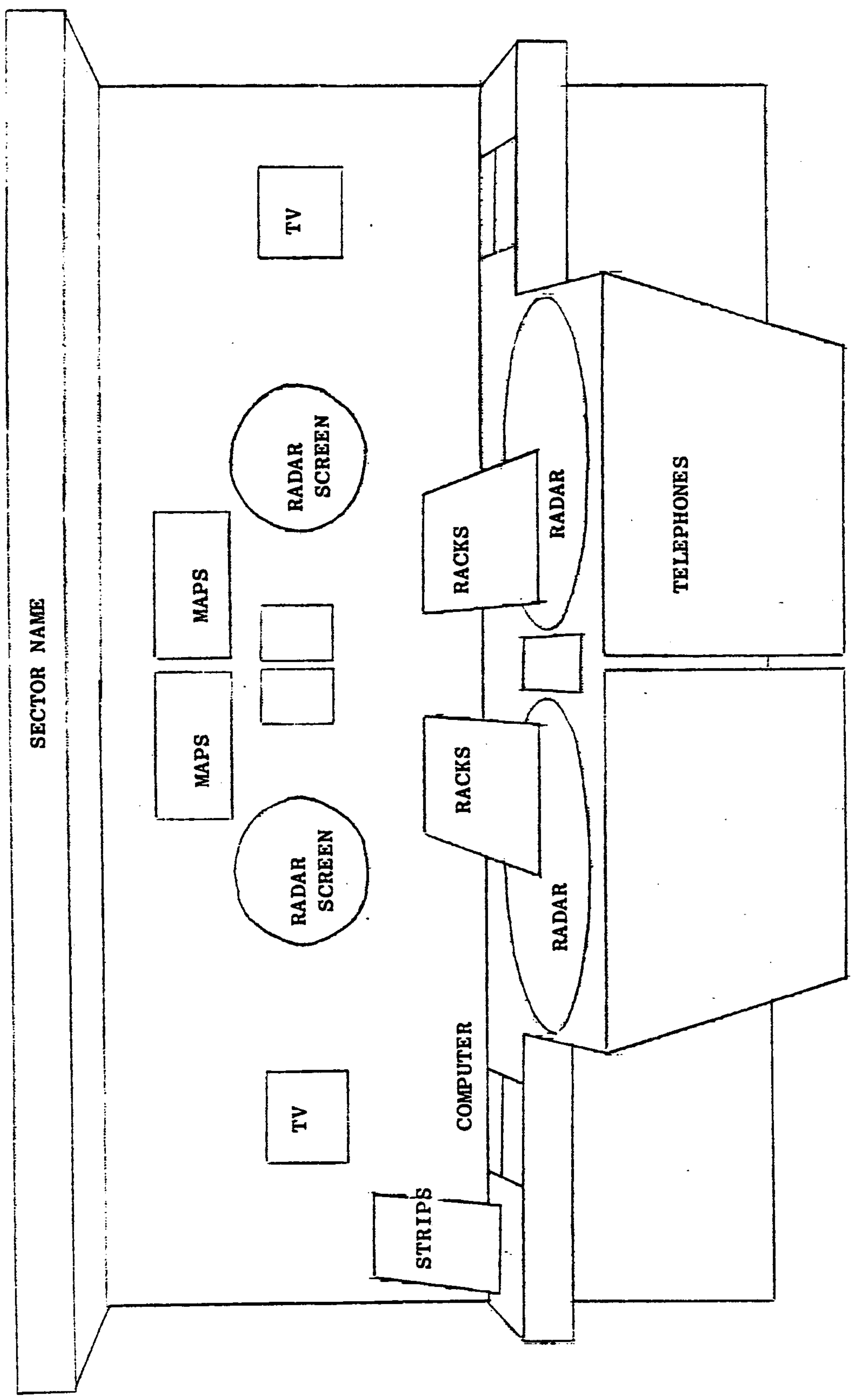


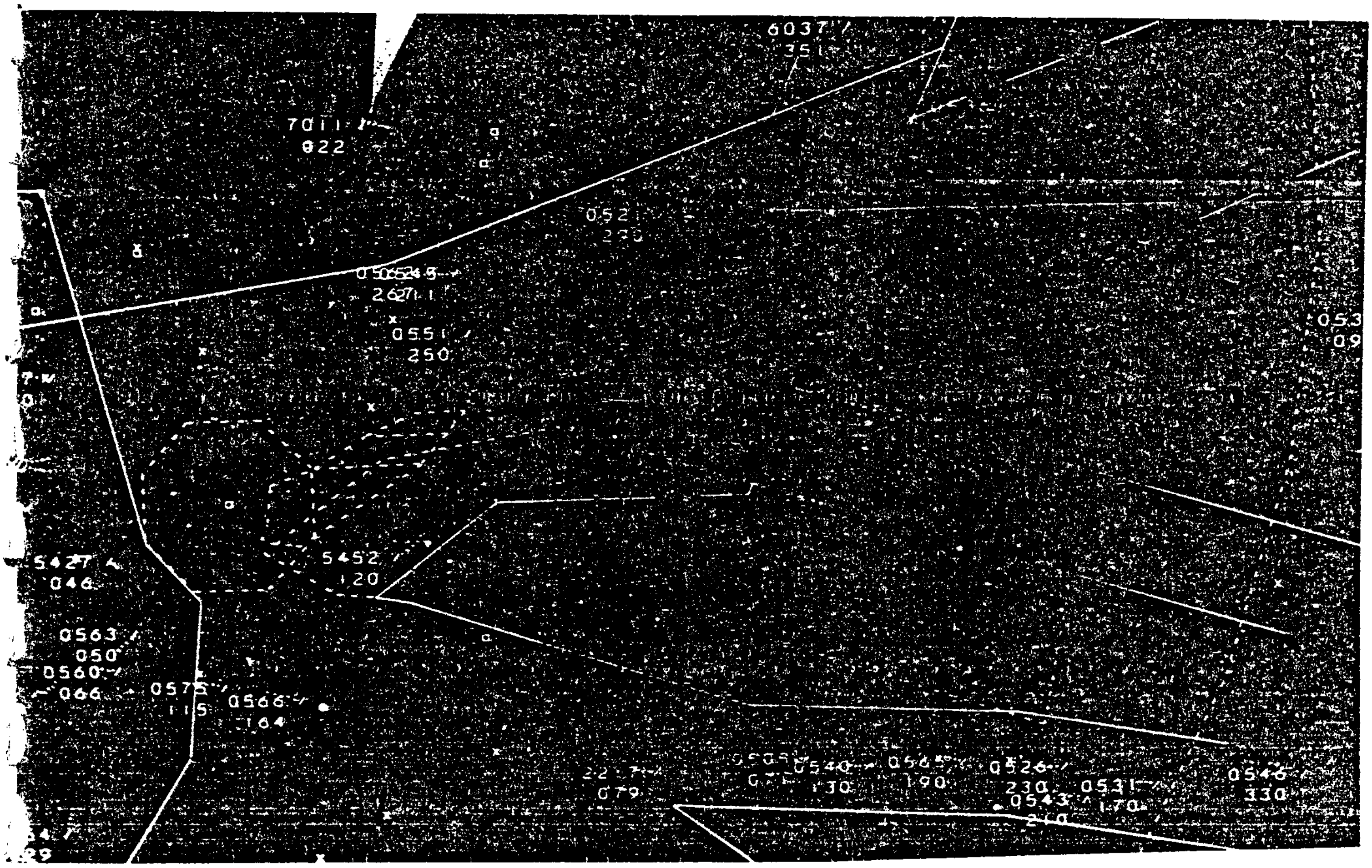
DIAGRAM OF A TYPICAL SECTOR SUITE AT LATCC/MANCHESTER SUBCENTRE



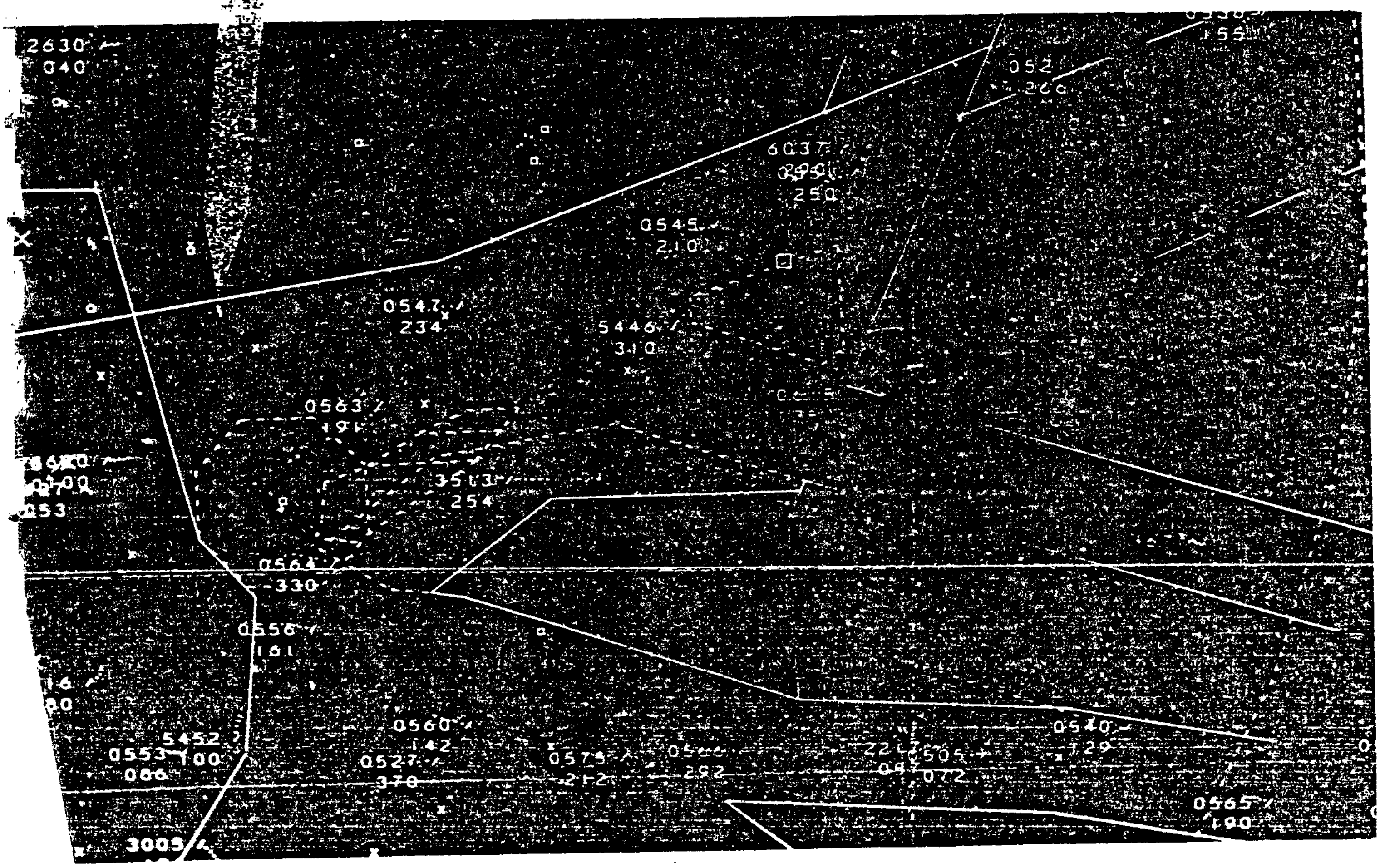
APPENDIX 3

THE RADAR DISPLAYS

A Military 'squawk'



A non-converting target



APPENDIX 4

A SAMPLE OF TALK ON THE SUITE

NOTES

Clacton Sector West Controller's radio transmissions (r/t) written in **BOLD CAPITALS.**
Respondent written in *ITALIC CAPITALS.*
Explications written in Underlined Lower Case.
EAST is Clacton East(Outbound) Controller.
CHIEF is the Clacton sector chief.

	WEST CONTROLLER	**RESPONSE**
TIME 8.50.00.		
50.34	**SCANDINAVIAN FIVE ONE FIVE ROUTE DIRECT TO DETLING.**	
50.42		*SK515."ROGER DIRECT DETLING SK515."*
	[East talking to chief.] [About the state of T.M.A.] [West sums up.]	
51.05	"You've got to learn to work under pressure, Paul."	
	[A request from the phone]	
51.14	"if you like,"	
	[In response to phone.] [Telephone conversation in progress.]	
51.20	" o k ".	
51.49	**SK515 CONTINUE DESCENT NOW TO FLIGHT LEVEL ONE ZERO ZERO ONE FIVE MILES BEFORE DETLIMG.**	
52.00		SK515 *"ROGER LEVEL ONE ZERO ZERO TO BE LEVEL FIFTEEN MILES BEFORE DETLING SK515".*
52.04	**KYOU**	
	[East talking] [Strip sorting]	
53.11	"thank you, Sandy." [to assistant.]	
53.22	"Ferry 201................. .... is ferry 201 past?"	

EAST: " Oui ".

53.27 **AIR FERRY TWO ZERO ONE CONTINUE WITH AMSTERDAM ONE TWO FIVE DECIMAL SEVEN GOODAY.**

53.34 *BAF201 " ONE TWO FIVE ER SEVEN GOODAY".*

53.44 *CHIEF; " How's he with the 89692. "*

53.51 *EAST: " Gotta go to ninet...*

53.58 *EAST: if you go to 19 and make sure he misses, then...."*

55.06 " Scandinavian going the ??? "

55.21 **SK515 WHAT'S YOUR PRESENT HEADING.**

55.25 *SK515 "DING TWO TWO FOUR ZERO SK515"*

55.28 **ROGER TURN LEFT HEADING TWO TWO ZERO KEEP YOU CLEAR OF THE DANGER AREA.**

55.33 *SK515 "ROGER HEADING TWO TWO ZERO SCANDINAVIAN FIVE ONE FIVE "*

[Strip sorting]

55.47 **SPEEDBIRD SEVEN TWO THREE YOU CAN TURN ER FOR LAMBOURN DESCEND WHEN READY TO FLIGHT LEVEL ONE FIVE ZERO.**

55.56 *BA723 "ROGER RECLEARED WHEN READY LEVEL ONE FIVE ZERO AND TURNING DIRECT FOR LAMBOURNE SPEEDBIRD ER SEVEN TWO THREE.*

56.04 *LH038 "GOODMORNING LONDON THIS IS LUFTHANSA ZERO THREE EIGHT LEVEL THREE FIVE ZERO."*

56.08 **LUFTHANSA ZERO THREE EIGHT GOOD MORNING STANDARD ROUTING TO LAMBOURNE LANDING RUNWAY IS ONE ZERO LEFT.**

56.15 *LH038 "STANDARD TO LAMBOURNE FOR ONE ZERO LEFT LUFTHANSA ZERO THREE EIGHT."*

56.31 "He's slow shifting this stack"

56.33 *CHIEF: " Right ".*

56.34 " He's pretty slow shifting this stack "

56.37 *CHIEF: " how many's he got then,two"*

56.38 "He's got 14, he's a well er er 14, he;s just left 14, I thinks it's One Three Six "

56.48 *CHIEF: "Ok, I'll go and have a look when he gets to Longsands "*

56.56 *CHIEF: " How'd he get there? "*

57.00 " He went up there , now he's turning down there again"

57.02 *CHIEF: " Right ".*

57.04 " he's obviously crossing at right angles ... and doing a good job"

57.06 *CHIEF: " Be warned "*

[Talk about SK515]

57.10 **SCANDINAVIAN FIVE ONE FIVE ER RESUME YOUR OWN NAVIGATION NOW DIRECT TO DETLING.**

57.15 *SK515 "DIRECT DETLING SCANDIN-AVIAN FIVE ONE FIVE ."*

57.42 *SEDEV "LONDON SIERRA ECHO DELTA ECHO VICTOR GOOD MORNING LEVEL THREE FIVE ZERO MAIN-TAINING,"*

[Already analysed strip and position and ready with squawk; Note only plane on Amber 37.]

57.46 **SIERRA ECHO DELTA VICTOR GOOD -MORNING SQUAWK FIVE FOUR FOUR SIX STANDARD ROUTEING TO LAMBOURNE LANDING ONE ZERO LEFT.**

57.57 *SEDEV "SQUAWK FIVE FOUR FOUR SIX STANDARD ER ROUTING LAMBOURNE LANDING ER ONE ZERO LEFT SIERRA ECHO VICTOR".*

58.04 **SCANDINAVIAN FIVE ZERO FIVE CONTACT LONDON ON ONE TWO EIGHT DECIMAL FOUR GOODDAY.**

58.11 *SK515 " ROGER ONE TWO EIGHT FOUR GOODAY SCANDINAVIAN FIVE ONE FIVE."*

58.14 " Oh dear! "

58.17 **SIERRA ECHO DELTA ECHO VICTOR CONFIRM THE SWQUAWK FIVE FOUR FOUR SIX.**

58.20 *SEDEV "FIVE FOUR FOUR SIX SIERRA ECHO VICTOR."*

58.21 " Got it! "

58.22 *CHIEF: " That lufthansa going to come to you "* [To East]

58.26 **ROGER THANK YOU GOT IT NOW**

58.29 *EAST: " Yeh well,"*

58.31 *CHIEF: "he's looking for 21, he'll come to you at 37 "*

[Transmitter switched by *SEDEV* to acknowledge.]

58.35 " Have you got any dirty knees Den, thirty three's ".

58.37 *CHIEF: " No, You're going upto 31 on him."*

58.38 *EAST: " There's a 33 here "*

58.39 *EAST: "That's Swiss Air going up to 33"*

58.41 "Yea....hh--s, at Gabbard"

58.45 "OK down to 31 ... with the Sierra Echo Victor"

58.48 *EAST: " OK !"*

[Echo Victor is from Amber 37 he is cutting the outbound lane]

58.47 **SIERRA ECHO VICTOR DESCEND TO FLIGHT LEVEL THREE ONE ZERO**

58.58 *EAST: " Right the Swiss Air coming South "*

59.00 *SEDEV " LEAVING THREE FIVE ZERO FOR THREE ONE ZERO SIERRA ECHO VICTOR."*

59.00 *CHIEF: and this one coming down to thirty three's too"*

[East controller changing over;
Description continues in background]
[Chief interrupted by the phone].

59.26 *SEDEV " RADAR SIERRA ECHO VICTOR CONFIRM ER OUR ROUTEING IS ER VIA GABBARD CLACTON."*

59.34 **SIERRA ECHO VICTOR NEGATIVE ROUTE ER PRESENTLY ON A RADAR HEADING OF ER TWO THREE ZERO**

59.42 *SEDEV " O K RADAR HEADING TWO THREE ZERO SIERRA ECHO VICTOR."*

59.45 **ROGER REMAIN ON THAT HEADING TO INTERCEPT RED ONE SOUTH INTO LAMBOURNE.**

59.50 *SEDEV "ECHO VICTOR THANK YOU."*

APPENDIX 5

TECHNICAL DETAILS OF RD3

RD3 was a system that combined Radar Data Processing (RDP) with Flight Data Processing (FDP) through the central 9020D IBM computer. Neither of the two sides of the combination could work separately since they were dependent on a common core of data. The RDP and FDP functions are described separately before dealing with their interdependence.

Radar Data Processing:

Unlike bypass, where only one radar is processed at a time, RD3 processes signals from all available radars which are produced as a composite, or 'mosaic', picture of the airspace. To achieve this the computer divided the sector's airspace into a grid of 16 nm squares forming columns of airspace upwards from the ground. These are called Radar Sort Boxes (RSBs).

Each RSB was serviced by at least 4 radars, depending on the number available. The radar providing the best cover was designated as the 'preferred', the next best the 'supplementary', with the remainder forming a reserve. So long as satisfactory data was received from the 'preferred' this was the one used. If a response was not received but available from the 'supplementary' radar, data from this would be processed. In other words, the intention was to provide controllers automatically with the 'best' radar choice in any RSB, removing the need for them to select different radars for different areas.

Flight Data Processing:

By comparing the past movements of targets with flight plan intentions, the IBM was able to predict, or 'track', where an aircraft would be at a certain time. The objective of this facility was to enable the system maintain the unambiguous identification of targets. As soon as a target was correlated with a track, the computer, using calculated velocity and flight plan data, would predict ahead by setting up search areas where it could expect the target again.

As a result, RD3 could deal more effectively with 'multi-response radar problems', such as splits or reflections, than previous systems. It was especially effective in dealing with aircraft flying very closely to their flight plans. But even for those that did not, the computer used previous actual flight data to predict an aircraft's direction.

Information Available:

One consequence of combining FD and RD processing systems was the change in and expansion of information available to radar screens. The displayable data can be separated into 3 broad categories;

1) essential data for controlling aircraft, such as radar targets, data blocks, maps, over which controllers had powers of selection;
2) information to assist in the compilation of messages to the computer;
3) lists of information, including the state of various selections or actions of the controller and other flight data of relevance to the radar task.

More specifically, the controller was able to select any of the following:

1. Data Blocks on all secondary surveillance radar
2. The first or second lines of the Data Blocks
3. The orientation of Data Blocks relative to their targets
4. The position of individual Data Blocks
5. The target symbols for all non-tracked primary data
6. Any or all of 5 different types of map information
7. The geographical position on which the display is centred
8. The range of the display area
9. The length of the leader lines connecting targets to the Data Blocks
10. The size of the velocity vector lines predicting and indicating the direction of a target
11. The number, or size, of plot histories

As well as these facilities, GMT was displayed as were warnings of emergency conditions, system failures and display overloads. There were other facilities available to controllers, but the ones mentioned were those most likely to be used in regular operational conditions.

Using RD3:

Associated with every screen were various control panels and devices enabling the controller to select both static (eg, maps) adn dynamic (eg. radar targets) information.

The *display control panel* consisted of 8 rotary switches, the most important of which were:

1. selection of multi-radar head assimilation or controller selection of radar.
2. selection of scope or range if display between 30-250 nm.
3. shift Data Blocks either north, west, south or east of target.
4. to extend history marks for each target from 0 to 5 nm.
5. to adjust length of leader lines.
6. a 5-position switch controlling the length of the vector lines associated with radar targets from 0 to 4 minutes flying time.

There was also a trackball for each screen situated at the front of the centre console which generated a mark on the screen; a mark used by the computer to determine where information should be displayed, or to which datum was being referred to in a request.

An additional display control panel of some 42 keys, all backlit but not all serving a function, was used to call up information displays. If nothing was selected, nothing was displayed. The displays were of 2 types, 'static' and 'dynamic'. The most important of the former were 5 types of maps denoting, respectively, reporting points and airfields, airways and associated danger areas, special routes and centre lines, coastlines, and geographical reference lines. Controllers could shift the centre of the display, and thus all the maps, by moving the trackball. The most important of the 'dynamic' data were target histories which could go up to 5 scans of the radar head, and 'see only' targets at particular altitudes, targets with Secondary Surveillance Radar transponders, targets 'squawking' selected codes, primary data, or any selection of these. In addition, the controller could choose the number of DBs displayed (up to 3), but other information, such as 'squawk' codes for emergency, radio off, hijack, and fire, were displayed irrespective of pilot or controller intentions. List displays could accept any list of aircraft codes for display, and was mainly used for aircraft in hold when the flight plan was frozen and reactivated when the aircraft left hold.

The final item, and the most complex, was the Message Entry Panel (MEP), This enabled controllers to communicate with the RDP and FDP systems. It consisted of 60 keys arranged in 3 blocks on the centre console. All but numeric keys were backlit. Nearly all the keys had some function and those serving similar purposes were as close together as possible. However, because of the need to give strength to the panel, the keys had been arranged in 3 blocks resulting in the separation of some groups of keys. For example, 2 of the alphabetic keys were placed away from others on the bottom of the left block. One of the symbol keys was placed on the opposite side to the rest, between editing keys, and even the latter were split, 5 at the top and 2 at the bottom of the right hand block.

Using the MEP:

All messages had to begin with a declaration of message type using the 17 keys specifically for this purpose. When selected, the rest of the keys would revert to alphabetic functions. Messages could relate to the following:

changing the position of the DB
insert a temporary level on the hold list
reposition the display of the tabular list
display the intended route of the aircraft
modify, delete or add to the flight plan
originate or change or add to a flight plan
activate a flight plan by entering departure time
request a discrete SSR code for a specified flight
initiate, modify, terminate or cancel hold on a particular flight
remove from the system all flight data relating to an aircraft.

Once the message was declared, the controller would then have to input the message. Messages had to be constructed in a certain order, composed of specific elements, some of which could not be used in the same message. An example of a message is as follows;

Elements: First the message function of declarattion (eg. ALEV - assigned level

- text = flight level = 200 = assigned by ATC = ATC
- flight indicator, that is, aircraft in question = either by call sign, computer identification number (written on every strip), by use of trackball coordinates, or by assigned SSR code.
- message enter = press enter key on MEP, or if trackball coordinates used, then trackball enter key

The above is a simple message. If incorrect in any way, then the message was rejected and the process gone through again from the beginning. Message input was displayed on the radar screen and terminated at the acceptance of the message.

GLOSSARY OF ABBREVIATIONS

ATC	Air Traffic Control
ATCA	Air Traffic Control Assistants
ATCO	Air Traffic Control Officer
ATM	Air Traffic Movement
ATS	Air Traffic Services - a generic term applying to flight information, air traffic control, approach control and aerdrome control.
CAA	Civil Aviation Authority
CCF	Combined or Central Control Facility
DORA	Directorate of Research and Development. The DORA technique refers to a system of calculating sector capacity.
eta	estimated time of arrival
FAA	Federal Aviation Authority. The US equivalent of the CAA.
FDB	Flight Data Block
FDP	Flight Data Processing
FPS	Flight Progress Strips
FIR	Flight Information Region
LATCC	London Air Traffic Control Centre. This is situated at West Drayton and is reponsible for all the main air traffic routes in the UK. Some subsidiary controlling is done at Manchester and Prestwick.
LTMA	London Terminal Management Area
MTA	Military Training Area.
MEP	Message Entry Panel
NATS	National Air Traffic Services
RDP	Radar Data Processing
RSB	Radar Sort Box. Used to organise the display on RD3 radars.

RSRE Royal Signals and Radar Establishment, Malvern. The CAA keeps a small research group there looking into systems of ATC.

RT Radio Telephone

SID Standard Instrument Departure

STAR Standard Instrument Arrival Procedure

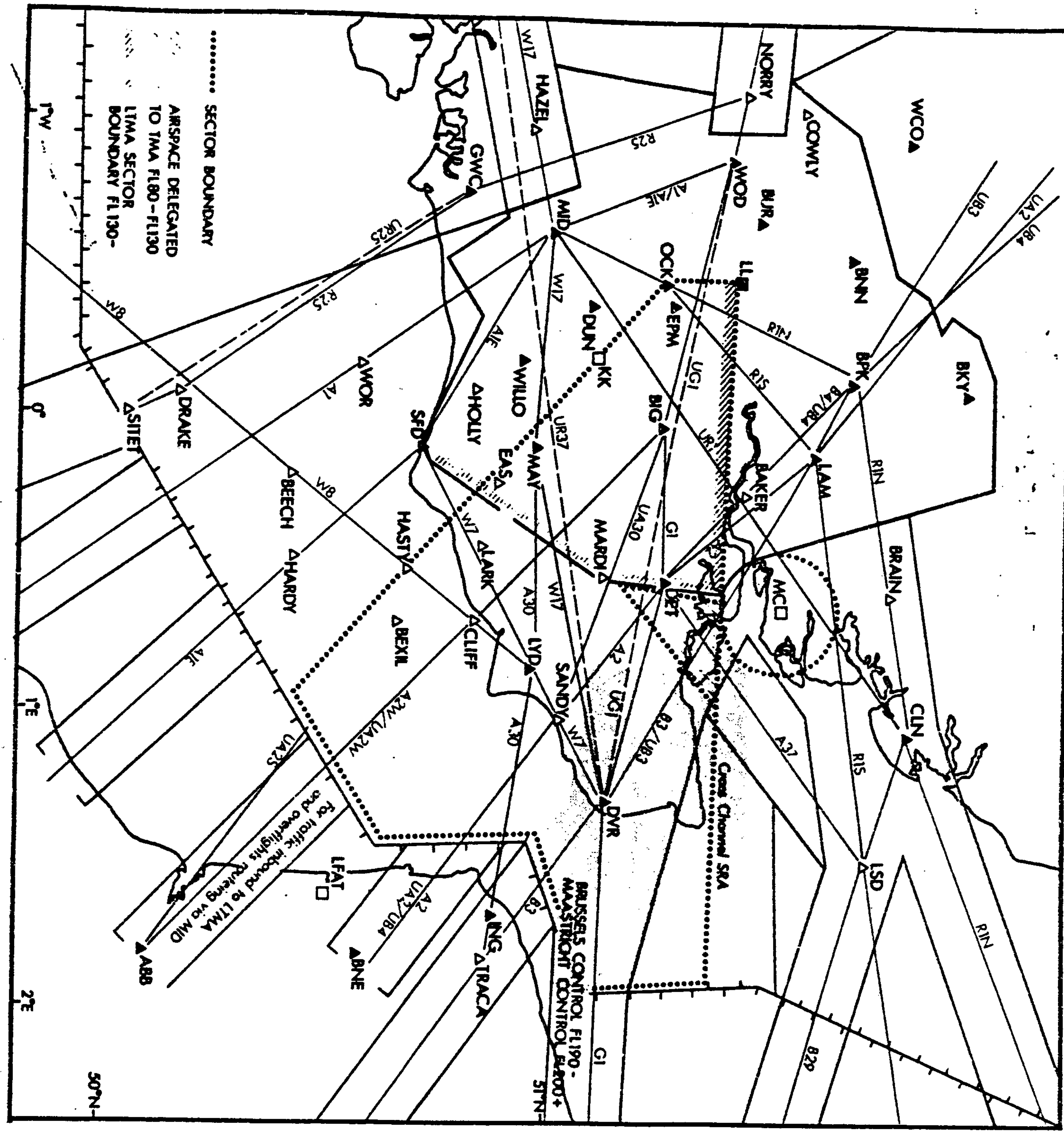
TMA Terminal Management Areas. These are sectors at the confluence of major airways and above busy airports.

TOI Temporary Operations Instruction

VDU Visual Display Unit

VFR Visual Flying Rules

DIAGRAM ONE



SECTOR BOUNDARY
AIRSPACE DELEGATED TO TMA FL180-FL130
LTMA SECTOR BOUNDARY FL130-
1°W
0°
1°E
2°E
50°N
51°N
WCO
NORRY
COWLY
WOD
BUR
BNN
BKY
HAZEL
GWC
MID
OCK
EPM
DUN
KK
WILLO
HOLLY
SFD
EAS
MAY
BIG
LAM
BPK
BAKER
MARDI
DET
MC
BRAIN
CLN
LSD
HASTY
LARK
LYD
SANDY
DVR
CLIFF
BEXIL
WOR
DRAKE
SITET
BEECH
HARDY
LFAT
BNE
ING
TRACA
ABB
Cross Channel SRA
BRUSSELS CONTROL FL190-
MAASTRICHT CONTROL FL200+
For traffic inbound to LTMA and overflights routeing via MID
W17
R25
UR25
A1/A1E
A1E
A1
W8
UG1
R1N
R1S
B4/UB4
UB3
UA2
UB4
UR37
W7
A30
UA30
G1
A2
B3/UB3
A37
B29
A2W/UA2W
UA25
UA2/UB4
B3

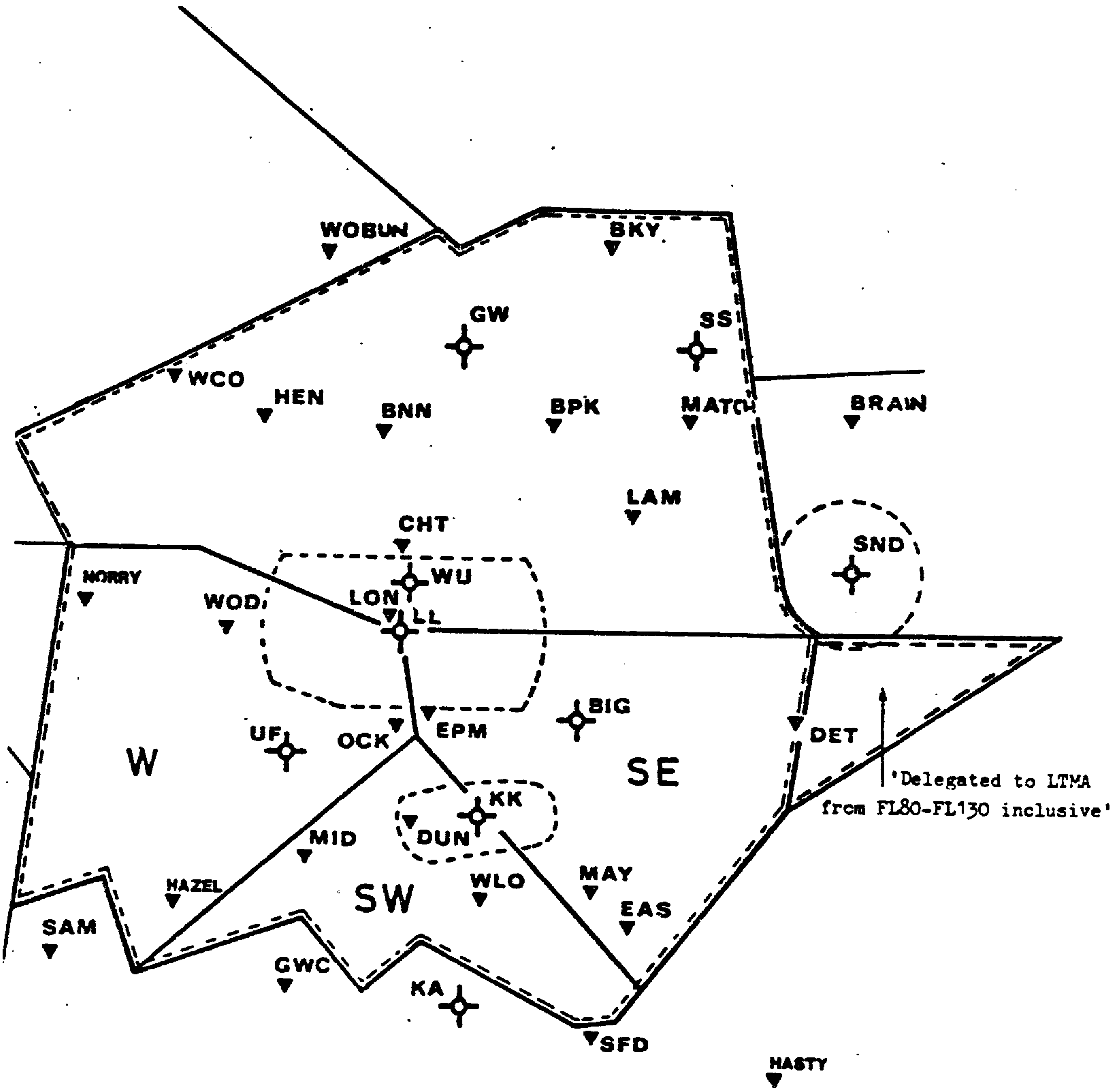
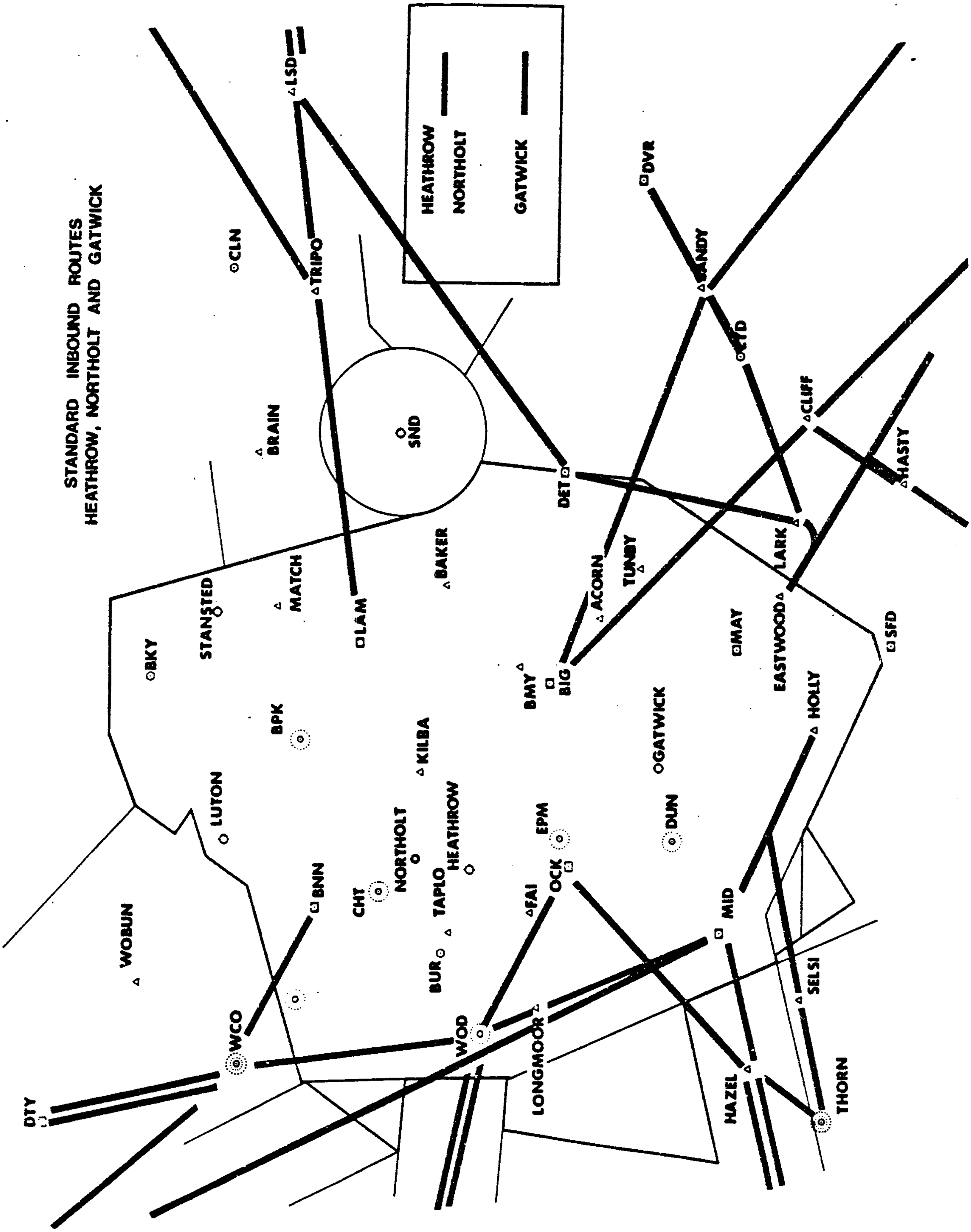

WOBUN
BKY
GW
SS
WCO
HEN
BNN
BPK
MATCH
BRAIN
LAM
CHT
SND
NORRY
WOD
WU
LON
LL
BIG
UF
OCK
EPM
DET
W
SE
'Delegated to LTMA from FL80-FL130 inclusive'
KK
MID
DUN
HAZEL
MAY
WLO
SW
EAS
SAM
GWC
KA
SFD
HASTY

DIAGRAM THREE

MANUAL OF AIR TRAFFIC SERVICES Part 2



LONDON AIR TRAFFIC CONTROL CENTRE

DIAGRAM FOUR

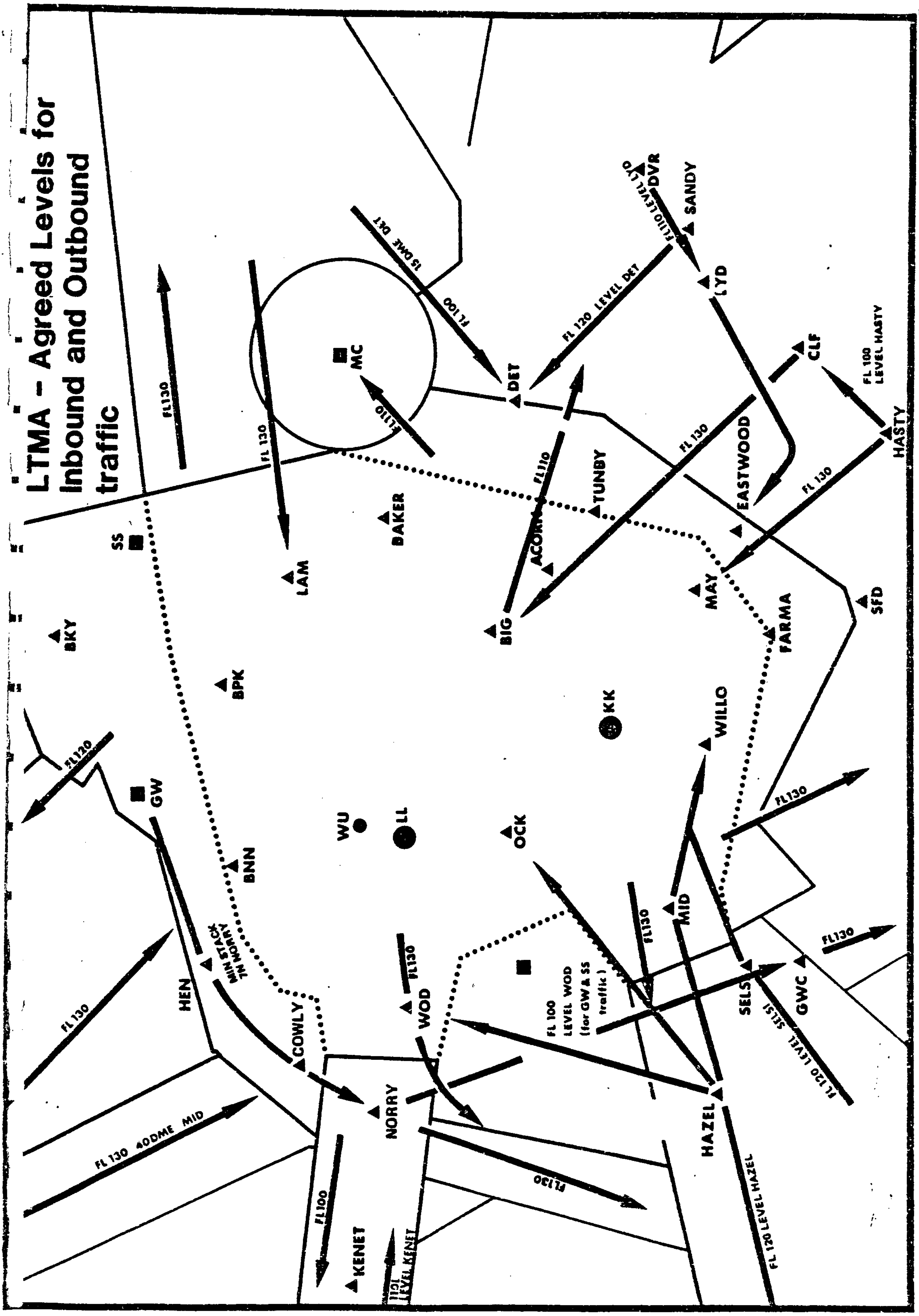


DIAGRAM FIVE S.I.D. FOR DAVENTRY

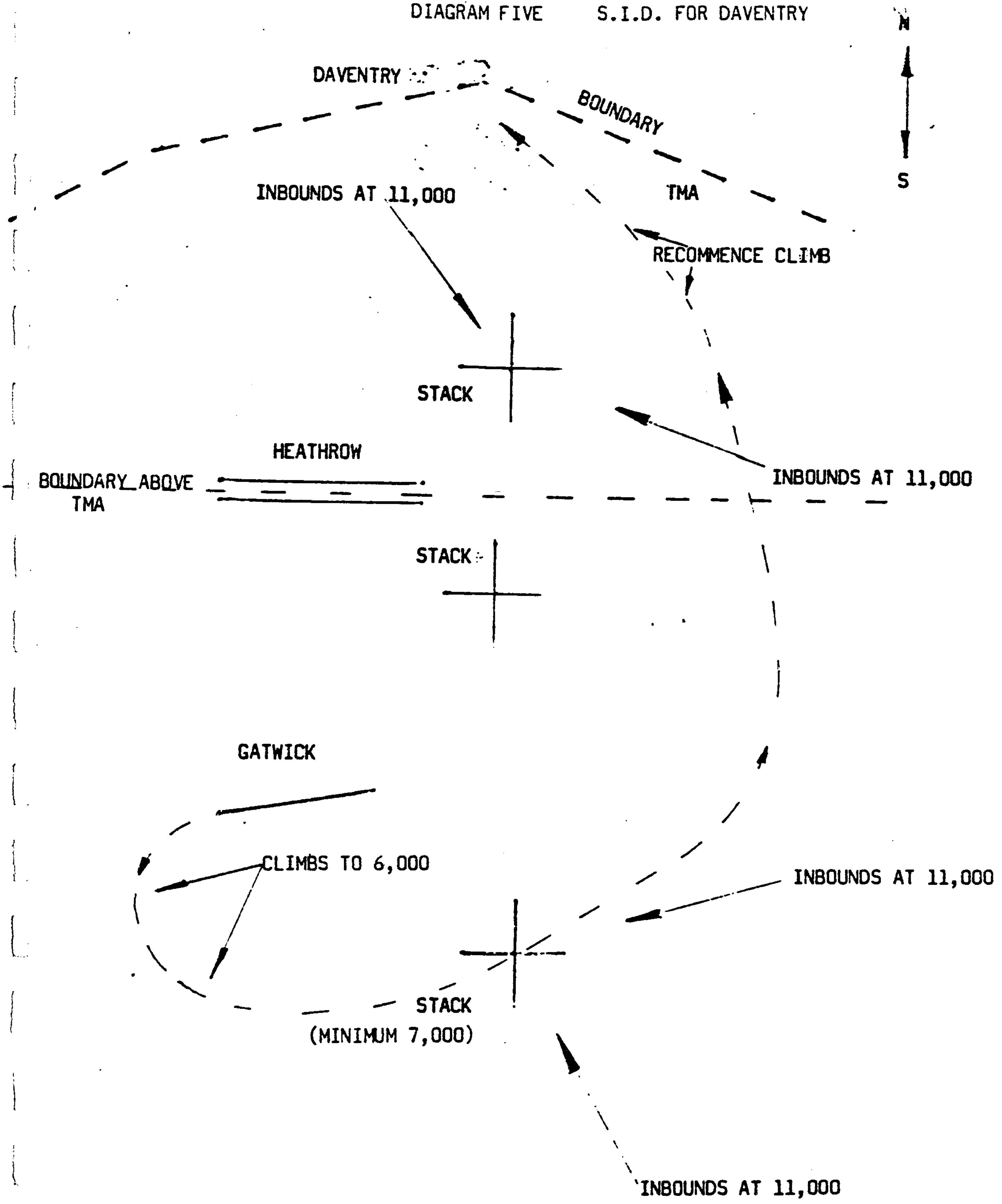
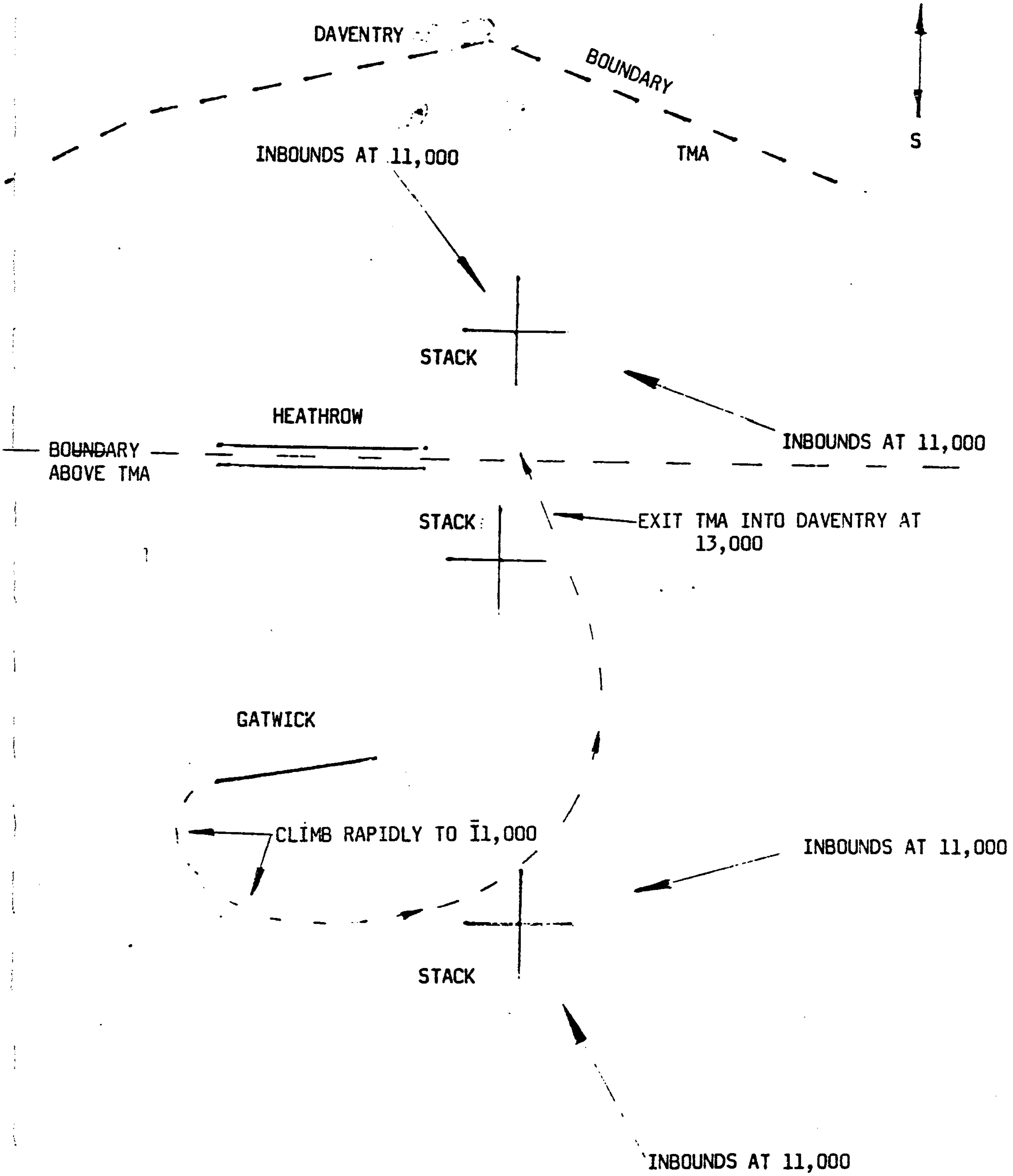


DIAGRAM SIX STACK JUMPING A DAVENTRY



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