The Air Traffic Kludge

Hugh DAVID

R+D Hastings, U.K.

Abstract Air Traffic is a 'Kludge'. Antiquated methods are linked to state-of-the-art devices, and 'work-arounds' devised to keep going. There has never been a systematic analysis of Air Traffic as a whole. Analysis shows that the archaic controller-aircrew link is the weakest link in the system. The answer, however, is not to introduce specific technical innovations, but to examine the system as a whole, and to use knowledge of human (and computer) capacities to provide a safe, humane and economic solution.

Keywords. Air Traffic, Kludge, System Analysis, Radiotelephony

1. Introduction

The traditional Air Traffic Control (or Management) system is a 'kludge'. A kludge has been defined by Granholm (1962) as 'an ill-assorted collection of poorly matching parts, forming a distressing whole'. Kludges are 'workarounds', quick-and-dirty solutions, clumsy, inelegant, difficult to extend, hard to maintain yet effective and quick solutions to a problem. The Air Traffic system, a classic kludge, was never designed, but grew by adapting elements from mostly military sources to maintain an evolving service. The trouble with kludges is that, although they work, no-one really understands how they work. No-one understands where the risks lie, no-one knows how close to the edge things are and no-one dare make changes because they don't know what will happen if they do. Moreover, in a very large, bureaucratic organisation, there is no-one really interested in stirring up trouble, because they know that the organisation will react by punishing them for pointing out the problems.

2. Background

Proposals for collision avoidance rules and customs controls were made as long ago as 1914. "What is suggested is that, with some modifications, the laws of the sea should be adapted to the air." (Grahame-White et al, 1914).

The air traffic control system developed steadily between the two world wars, with the availability of R/T (radiotelephony) (1930) supplementing the flag and pyrotechnic signals (Very Lights) originally applied. The United States generally took the lead in this period, providing designated air routes based on visual signals. Originally, these were huts with code letters painted on their roofs, supplemented by bonfires or searchlights on request at night. Radio beacons, transmitting Morse code identification on pre-defined frequencies were also introduced.

In Europe, the German Lorenz company developed radio-based blind-landing systems in the 1930s, which were extended into bombing and navigation aids during the Second World War (1939) After the Second World War, military radars were converted to civil use (1945). Initially, these were used to help control in the relatively congested areas around airports. ICAO, (the International Civil Aviation Authority), founded in 1947, began the process of international standardization necessary to cope with the increasing quantity and variety of civil international traffic A standard vocabulary was also established (1948), which provided for all routine ATC operations. A standard form of Flight Plan (FPL) was also developed (1948). This provided all the necessary

information about the intentions of the flight, from the type of aircraft, including the route that the flight was to follow, expressed in terms of airways, which themselves were defined by beacons. Most flights follow the airways. A few may be allowed to follow direct routes, if there is not much traffic.
The 'strip' was developed from the Flight Plan. Usually, one strip is provided for each sector. The strip contains the identification of the flight, which is usually a flight number, but may be an aircraft's identity letters and/or numbers. The type of aircraft is given, with the entry time to the sector and the planned height, expressed in FL (Flight Levels). The times at, and height over, three or four important beacons are also printed. At first strips were hand-written, later they were typed by an assistant. They are currently printed by computer-based systems deriving the necessary information from computer-stored flight plans (1980-1990). In some countries, controllers still use strips, but 'advanced' systems employ System Data Displays (1990-2000). ODID III, (1991) (a Real-Time Simulation at EUROCONTROL Experimental Centre presented a windowing system for data handling, although conventional R/T was used (Prosser et al.1991). Versions of this display system have been introduced into various contemporary systems.
This brief, partial, history shows how the Air Traffic system has developed over a century, incorporating technical advances in an essentially unplanned manner.

3. Methods

The conventional approach to the design of a large HCI system is well known. Table 1 lists the main steps.

Table 1 – Conventional System Design

1	Task Definition
2	Task Description
3	Task Analysis
4	Operator-System Task Allocation
5	Inter-Operator Task Allocation
6	Interface Design
7	Evaluation
8	Implementation
9	Monitoring

Space does not permit detailed description of this approach (David, 2007a). Some specific points must, however, be emphasized. Task description can be misleading, since it may import unspoken assumptions and obsolete traditions. However, it can be supplemented by detailed studies of specific aspects of the existing system. Task analysis is treated in Kirwan et al (1992), which describes a variety of approaches. When re-designing a system or designing a system from scratch, it may be advisable to consider a variety of levels of involvement of the human operator, and degrees of centralization. Human-system Task Allocation must take account of the need to provide the human operator with a workload that is enjoyable, satisfying and makes good use of his/her human capacity. Where operators work as teams, Inter-operator Task Allocation need not - and probably should not – be formally defined. The definition of the interface(s) is subject to unchanging strategic considerations (simplicity, relevance, closure, etc.) as well as tactical considerations of the equipment currently available (touch screens, auditory warnings, point-and-click controls, speech recognition, haptic devices, etc.) Evaluation may involve real-time or fast-time simulation of the whole or

part system. In some systems implementation is dependent on the agreement of the operators – in others they are not consulted. Monitoring of the revised system is good practice, but may not be acceptable to management.

4. Results

An initial skeleton analysis, concentrating on 'en-route' Air Traffic Control (David, 2015) is available. Space does not permit detailed discussion, but the following points must be made.

4.1 Task Definition
The aim of air traffic services should be to allow aircraft to fly with the minimum of interference necessary to preserve safety.

4.2 Task Description
Table 2 lists the primary tasks of en-route air traffic control for this exercise. (This is based on the existing system, as an example. An ab-initio analysis would be preferable.)

Table 2 – En-Route ATC Task Description (simplified)

No.	Task
1	'Learn' sectors
2	Manipulate and mark strips
3	Plan future streams of aircraft entering their sectors.
4	Check that they will not conflict with each other within the sector
5	**Determine how to resolve conflicts**
6	Match radar images to strips
7	Acknowledge aircraft coming on to the frequency when they enter
8	**Intervene to resolve conflicts**
9	Coordinate their actions with the next sector
10	Monitor aircraft behaviour for deviations from track
11	**Rectify deviations or amend planned flight path**
12	Hand aircraft over to the next sector
13	**Attempt to comply with any special requests (for example for direct routings or changed routings)**
14	**Handle emergencies**

Before leaving the conventional system, it is instructive to review some relevant studies. Mell (1991), a linguist, studied a corpus of Air Traffic communications in France, establishing that it had little correspondence to the ICAO standard. Cushing (1994) came to similar conclusions, based on communications recorded in FAA accident reports. He proposed a visual data link to supplement the air-ground voice link. Loukopoulos et al (2009), in 'The Multitasking Myth', drew attention to the real risks of presenting aircrew with interruptions to tasks, many of these interruptions coming through R/T from the ground. Barshi et al (2013) investigated the problems of communication, using experimental psychology methods, showing by experiment that no more than three or four instructions could be reliably transferred in one message, and even fewer where the aircrew were not native English speakers. Apart from Cushing (1994) none of these investigators suggested remedies for the problems they identified.

4.3 Task Analysis
The current 'en-route' ATC system relies on a structure of routes, defined by beacons, and subdivided into sectors in centres, derived mostly from traditional national boundaries. Procedural controllers, in theory, rely on planned positions over beacons to plan separation, so that aircraft are constrained to fly indirect routes. The necessary changes in flight path are given to the aircraft by the Executive controller, who is also required to check that they are carried out. Each aircraft is required to change frequency manually at sector boundaries, and communications must be heard, responded to, and acted on as they are received. Much time and effort is wasted on routine communications. The 'picture' that controllers maintain they hold was long ago shown to be incomplete (Bisseret, 1995). Aircraft having no problems are quickly forgotten.

4.4 Operator-System Task Allocation
Given modern Flight Management systems, aircraft are better aware of their positions than ground-based radar systems can be. Aircraft can fly direct routes defined in space and time, without the constraints of a beacon and route based system. Conflict detection can be better performed by the system than by human operators, although conflict resolution is an enjoyable human task, given the lead time now available. Routine monitoring can be delegated to the system, including checking that conflict resolution manoeuvres have been performed.
The tasks shown in bold type in Figure 2 form a suitable human task load. Because Air traffic is inherently 'tidal' with strong peaks at some times of the day and night, the workload of the controller should be adjusted to maintain his involvement with the situation. Tasks 5 and 8 (determining how to resolve conflicts and intervening to resolve them) can be combined into a single task carried out well in advance. Tasks 13 (special requests) is relatively rare and not urgent. Task 14 (emergencies) is very rare, but has top priority when it occurs. The extent of Task 11 (rectifying deviations from flight paths) may be adjusted to provide a satisfying level of occupation by varying tolerances as required.

4.5 Inter-operator Task Allocation
Although the traditional Planner/Executive distinction is no longer necessary, there are good reasons to suggest that controllers should work in pairs. Alertness, mutual checking and social needs are improved. In particular, when emergencies occur, it may be vital for one controller to concentrate on the aircraft in distress, while the other adjusts the traffic around the emergency.

4.6 Interface Design
Displays can be provided that give the necessary information for intervention in a relevant form. Contemporary 'windowing' systems should be replaced by a single data display, in a purely graphic format, without using alphanumeric symbols. David (2007b) describes the design of a suitable aircraft symbol; David (2007c) describes the development and design of a conflict resolution display; and David (2008) describes a position monitoring and emergency response display. A subsidiary display may be provided for trajectory displays in conflict resolution, and another for communications. The present 'Ground-system – Controller – Aircrew – Flight Management System' linkage requires both controller and aircrew to transcribe information to and from speech and computer readable forms, with the possibilities of errors and omissions implied thereby. A 'Controller- ground system – Flight Management system – Aircrew' linkage would allow the controller to derive solutions to problems, check them and transmit them to the aircrew in one operation without dangerous delays and transformations. Equally, the aircrew could choose to receive transmissions in a

language of their choice, in verbal or text form, and to recall transmissions without occupying the frequency. Using modern technology, information can flow via encrypted digital channels, for auditory and visual display at each end of the link, allowing communication without requiring the immediate attention of either human operator, so that tasks need not be interrupted, and the capacity of the aircrew is not strained as Barshi et al (2009) describe. The 'social' element in ATC communication, described by Mell (1991) can be maintained without the risk of 'blocking the frequency'. The current incomplete and potentially dangerous 'party line' effect – where aircrews derive partial information from listening to other flights' communications, can be replaced by an explicit copy to other relevant aircraft.

4.7 Evaluation

Most elements of this system can be evaluated by small-scale modelling. For example, the display and conflict resolution system has been evaluated using an 'ad-hoc' real-time Simulator (TROTSKY) as described in David et al (2001, 2003). Full-scale real-time simulation would be required before acceptance.

4.8 Implementation and monitoring

The change from routine operations to event-driven intervention requires specific training to maintain the necessary skills. This implies that controllers should spend a significant part of their normal life in simulations, practicing potential emergency drills, reviewing recent actions and preparing for the unexpected.

5. Discussion

The current Air traffic system has developed by adopting devices and systems to provide the Air Traffic controller (and the Aircrew) with assistance with his task. This is the "Horseless Carriage" approach, where the superficial features of the system are copied in hope that this will ease the acceptance of innovation. This approach imposes much unnecessary work on the operator and neglects many of the benefits that modern computer-based methods can provide. Currently, considerable effort is being devoted to specific developments (SESAR, NextGen and others). Although these address real problems, they do not form part of a strategic reform. In the air, the 'glass cockpit' was the outward sign of a thorough revision of the control of aircraft. A similar process is needed on the ground. Almost all the technology required for the revised system is available now – very little actual additional hardware is required.

6. Conclusions

The current air traffic system is an undesigned collection of expedients (a Kludge). No systematic overall assessments of risk or capacity are available. Some elements, such as the Air-Ground link are clearly overloaded, subject to errors and have inherent dangers. The solution, however, must be to re-design the system as a whole, not to adapt digital technology to mimic traditional methods. This will not require a significant quantity of new equipment, but will produce a faster, simpler, safer and more humane system.

References

Barshi, I. & Farris, C. (2013). Misunderstandings in ATC Communications. Farnham, U.K.: Ashgate

Bisseret, A. (1995). Représentation et Décision Experte – Psychologie Cognitive de la Décision chez les Aiguilleurs du Ciel. Toulouse, France: Octares Editions

Cushing, S. (1994). Fatal Words: Communication Clashes and Aircraft Crashes. Chicago, U.S.A.: University of Chicago Press

David, H. & Bastien J-C (2001). Initial Evaluation of a Radically Revised En-Route Air Traffic Control System. In M.A. Hanson (Ed.) Contemporary Ergonomics 2001 (pp 453-458). London, U.K.: Taylor and Francis

David, H. & Bastien J-C (2003) Second Evaluation of a Radically Revised En-Route Air Traffic Control System. In P.T. McCabe (Ed.) Contemporary Ergonomics 2003 (pp 305-310). London, U.K.: Taylor and Francis

David, H. (2007a). Strategy of Design. In D. Golightly, T. Rose, B.L.W. Wong and A. Light (Eds.). CREATE 2007 Proceedings of the conference on Creative Inventions, Innovations and Everyday Designs in HCI (pp97-102). Loughborough, U.K.: The Ergonomics Society

David, H. (2007b). Redesign of the Aircraft Symbol in Air Traffic Control. In D. Golightly, T. Rose, B.L.W. Wong and A. Light (Eds.). CREATE 2007 Proceedings of the conference on Creative Inventions, Innovations and Everyday Designs in HCI (pp 69-74). Loughborough, U.K.: The Ergonomics Society

David, H. (2007c). Evolution and Design of Air Traffic Conflict Displays. In D. Golightly, T. Rose, B.L.W. Wong and A. Light (Eds.). CREATE 2007 Proceedings of the conference on Creative Inventions, Innovations and Everyday Designs in HCI (pp55-60). Loughborough, U.K.: The Ergonomics Society

David, H. (2015). The Air Traffic Kludge. (In Press)

Grahame-White, C. & Harper, H. (1914). The Aeroplane. London, U.K.: T.C. and E.C. Jack

Granholm, J.W. (1962). How to Design a Kludge. Datamation, February 1962, 30-32.

Kirwan, B., & Ainsworth, L.K. (1992). A Guide to Task Analysis. London, U.K.: Taylor & Francis

Loukopoulos, L. D., Dismukes, R.K. & Barshi, I. (2013). The Multitasking Myth. Farnham, U.K.: Ashgate

Mell, J. (1991). Etude des Communications Verbales entre Pilote et Contrôleur en Situation Standard et Non-Standard (Thèse Doctoral), Toulouse, France : Université de Toulouse

Prosser, M., David H. & Clarke L. (1991). ODID III Real-Time Simulation (EEC Report No. 242). Bretigny-sur-Orge, France: Eurocontrol Experimental Centre.