EUROPEAN ORGANISATION
FOR THE SAFETY OF AIR NAVIGATION

EUROCONTROL

EUROCONTROL EXPERIMENTAL CENTRE

TASK LOAD GENERATED BY FREQUENT SECTOR CHANGES FOR AIRCEWS AND CONTROLLERS

STATE-OF-THE-ART LITERATURE STUDY

EEC Note No. 07/08

LTI-4-20-FREQ Project

REPORT DOCUMENTATION PAGE

Reference: EEC Note No. 07/08	Security Classification: Unclassified
Originator: **EEC - LTI** (**Long-Term Investigation**)	**Originator (Corporate Author) Name/Location:** EUROCONTROL Experimental Centre Centre de Bois des Bordes B.P.15 F - 91222 Brétigny-sur-Orge CEDEX FRANCE Telephone: +33 (0)1 69 88 75 00
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TITLE:

TASK LOAD GENERATED BY FREQUENT SECTOR CHANGES FOR AIRCREWS AND CONTROLLERS – STATE-OF-THE-ART LITERATURE STUDY

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	Project LTI-4-20-FREQ		**Task No. Sponsor**		**Period** 2008	

Distribution Statement:

(a) Controlled by: Marc Brochard Head of LTI
(b) Special Limitations: None

Descriptors (keywords):

ATC, air-ground communication, communication support, broadcast communication, end-to-end communication, routine communications, sector changes, workload, working memory, party line, interruptions, teamwork, human error, human performance, safety, capacity, frequency congestion.

Abstract:

The capacity of the current air traffic control (ATC) system is primarily limited by the maximum number of aircraft that a controller can handle safely in a sector. This has led to small sectors, requiring a large number of radio channels, and generates multiple voice radio calls between aircrew and controllers during sector handover procedures. Analysis of voice communication studies has confirmed that a significant part of current voice communication has no operational content, and is related to radio channel management itself. The current system of voice communication by analogue broadcast radio is one of the obstacles to further increases in ATC capacity.

Recent research at the EUROCONTROL Experimental Centre has suggested the use of end-to-end communication, similar to public mobile telephony (GSM), for air-ground communication. The end-to-end voice communication concept addresses several shortcomings of current ATC air-ground communication. A state-of-the-art literature study has been conducted, from a human factors perspective, in order to gain a better understanding of how the efficiency of ATC communications might be improved. In the literature little is known about the workload generated by voice communication or human errors caused by frequency congestion. No previous study focuses on ways of reducing communication between pilots and controllers in order to reduce workload and errors.

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1. SCOPE OF THE DOCUMENT

The capacity of the current ATC system is primarily limited by the maximum number of aircraft that a controller can handle in a sector. This led in the past to a decrease in sector sizes in order to increase capacity. Small sectors have a strong impact on air-ground radio communication and require a large number of radio channels. The frequent sector handovers in particular generate multiple radio calls, which increase the workload for both controllers and pilots. In this context research at the EUROCONTROL Experimental Centre resulted in an initial idea of how to make the control sectors transparent for the aircrew.

From the aircrew's perspective, a permanent air-ground radio link with the responsible sector controller is required. Let us suppose that an "end-to-end radio communication system" (similar to public mobile telephony – GSM) is able to guarantee this automatically. The operational ATC sector structure is thereby hidden for the aircrew, and the sectors become transparent. As the control sectors are transparent for the user, air-ground communication (voice or data link) related to sector changes is no longer required.

The scope of this document is not to discuss technical benefits or end-to-end communication issues. End-to-end communication will come at the latest with digital links, and will have an impact on the users of air-ground communications.

This document studies the influence of current air-ground radio communications for the human user (aircrew and controller). The literature review presents the state of the art with specific reference to frequent sector changes.

The document:

- Reports on the state-of-the-art process.

- Gives a synthesis of the relevant topics in order to provide an in-depth understanding of communications between the aircrew and controller.

- Identifies the advantages and disadvantages of future mobile ATC communication based on end-to-end communication principles.

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2. CONTROLLER – PILOT COMMUNICATIONS

2.1. INTRODUCTION

The two main objectives of air traffic control (ATC) for the future are to:

- Ensure the safety and efficiency of traffic,

- Cope with the traffic growth forecast for the coming decades.

Communication between pilots and controllers is the ATC basis for meeting these objectives in the current air traffic management model (ATM) (Hopkin, 1995).

"Communication" is considered to be an attempt by a person to distribute and/or acquire information. This involves both the production and reception of messages. Where communication is defined as an exchange taking place between people, most cooperative acts (talking to someone, pointing at a device) can be considered to be communication.

Communication supports the sharing of experience, the creation and updating of knowledge, the establishment and circulation of standards and the negotiation of working domains.

In air navigation, communication consists of verbal messages (spoken communication), written messages (paper documents, information on screen, strips), or "gesture-based" messages (the other person's position or actions within the working space and/or on the environment).

Physical behaviour (movements, deictic) and para-verbal signs (pitch, tone, rhythm of verbal messages) are used to give information or to acquire attention.

Today, communication between controllers and aircrews is supported in two ways. The first and older way is the voice channel supported by radiotelephony. The second, which is becoming more widespread, is alphanumerical and supported by data link.

With radiotelephony, each control centre is assigned a different radio frequency. This creates a communicative network called 'party-line', where all aircraft can listen to all verbal exchanges with the control centre while only one pilot can speak with the controller at any given moment. This allows the pilots to monitor all the messages exchanged and so to collect more information about the traffic situation and to update their mental representation.

The language used is a highly formalised code defined by ICAO norms; an operative standard phraseology based on the English language (a technical jargon) and defined by specific messages, sequences, formats, terminology and pronunciation rules (Federal Aviation Administration [FAA], 2000). The phraseology has been elaborated in order to possibly reduce ambiguities and misunderstandings, to allow strict control over message length and structure in order to shorten the length of communications and to reduce frequency occupancy.

In reality, such measures unfortunately, result in a cumbersome system with substantial channel occupancy times associated with even the simplest messages. As a result, frequency congestion has become a factor that severely constrains the capacity of the airspace. In fact, radiotelephony communication between pilots and controllers, and thus frequency congestion, is one of the major problems in ATC (NASA-ASRS 1994), also because of the ever-increasing amount of air traffic.

In particular, pilots may encounter difficulties interacting with ATC during approach. The traffic around airports and the limited range of available frequencies leads to a shortage of frequencies. For these reasons, time pressure does not help the pilot not flying (PNF) to correctly initiate communication. The message must be as short as possible to avoid masking other messages or being masked by other messages.

Air-ground communication is in many respects the weak link of the system, with many accidents attributed to improper or misunderstood communications (Morrow and al., 1993; Nolan, 1999; Prinzo, 1996; Prinzo and Britton, 1993).

Furthermore, voice communication between pilots and controllers is susceptible to factors such as noise and language problems, which degrade the system's reliability, and to the influence of controllers' and pilots' expectations, bias, and other cognitive factors.

Indeed, according to the phraseology, the controller's message:

- Begins with a call-sign (an alphanumerical string used to identify specific aircraft) of the aircraft contacted (1) followed by the name of the control centre (2).

- A set of instructions follows, needed by pilots to organise the flight and to effect specific manoeuvres (clearances (3) and information (4)).

- The pilot acknowledges the reception of the message (acknowledgement (5)) and repeats it (read-back (6)).

- The controller then verifies the correctness of the read-back (called hear-back), corrects any errors and finally gives an acknowledgement.

So we can see that the number of speech acts, that is to say individual voice messages, initiated by controllers or pilots is already high (VOCALISE's study, Graglia and al., 2005).

Many studies describe the link between the number of exchanges and pilots' and controllers' workload, the communication acts being used as an indicator of the controller's workload.

The workload of ATC has become heavier due to the increase in air traffic demands. Communication problems in ATC have been observed or tackled from various aspects. But most studies have thus far dealt with the communication errors that lead to both major and minor incidents.

Other previous studies identified communication problems in order to reduce the frequency of the problems and improve communication efficiency and accuracy. Little attention has been paid to the workload induced by the amount of communication, and frequency congestion leading to human errors in the current ATC systems. And no study has focused on ways of reducing communication between pilots and controllers in order to reduce workload and errors.

2.2. THE CHALLENGES FOR CONTROLLER-PILOT COMMUNICATIONS IN THE FUTURE

Voice communications between controllers and pilots remain a vital part of air traffic control operations. However, communication problems are involved in 70% of aviation accidents and incidents (Corradini and Cacciari, 2002).

It is therefore important to have an understanding of the nature, type and characteristics of communication between pilots and controllers, and to understand factors associated with voice communication problems.

That is why the present study begins with a state-of-the-art look at how and why controllers on the one hand, and pilots and controllers on the other hand, communicate. The first step of this review of literature will therefore be a classification of communications between these protagonists, the types of communication they use (voice communication, alphanumerical communication), and the associated context of these communications (urgency, routine communication, etc.).

Today, air-ground communication is performed using high frequency (HF) or very high frequency (VHF) radio equipment. This medium enables air traffic controllers (ATCOs) to provide clearances to the aircrew or to request useful information on current aircrew activity. The pilot may request a new route from ATC (for a synthesis on ATC-pilot voice communications, see Prinzo and Button, 1993). However, control and navigation requirements are changing. First, air traffic keeps increasing. Each controller is responsible for a large number of aircraft. Various studies have shown how air-ground communications evolve according to workload increase (e.g. Sperandio, 1978). Second, the introduction of more electronic displays and automation in the cockpit is changing pilots' activities, making aircrews' work easier (Hutchins, 1990).

The two main media used in pilot – controller communication (radiotelephony (R/T) and data link communication) will be investigated and will result in a comparison of each medium, and their advantages and drawbacks.

The issue of pilot – controller communications will also be addressed through the mental aspects associated with communication: mental process, working memory, workload, teamwork and the development of situational awareness leading to the creation of the "party-line".

The analysis of these parameters will result in the addressing of the issue of communication errors and misunderstandings. Moreover, communications may result in task interruptions or be interrupted by other pilot or control tasks. This is the origin of errors, in particular for pilots.

The analysis of ATC communication features from the human factors perspective, is intended to provide a better understanding of how improvements may be possible in order to increase the efficiency of ATC communications. The improvements are discussed in relation to the concept of sectorless radio communication, also called future mobile ATC communication, which meets the objective of making the frequency / sector changes between aircrews and controllers transparent.

Federal Aviation Administration (FAA) forecasts indicate that the number of passengers carried on commercial aircraft will double, reaching one billion by 2015 (FAA Plan to Modernize, 1998). To handle the projected increase in air traffic, the FAA is introducing new technology to aid air traffic control specialists (ATCSs) in their tactical and strategic decision-making.

The National Civil Aviation Review Commission states that the expected growth in aviation cannot be safely accommodated without significant breakthroughs in air traffic modernisation. The Commission also cites air traffic communications as critical components requiring modernisation in the aviation system (Aviation Financing, Air Traffic Control, 1999). Several emerging air traffic control systems will be developed. These examples have been chosen because they implicitly or explicitly address the reduction in controller-pilot communications.

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3. THE "STATE-OF-THE-ART" PROCESS

3.1. FIELD OF INVESTIGATIONS

To perform the state-of-the-art investigation of all the topics mentioned above, the research of the relevant documents began with visits to the websites carrying major human factor reviews, such as:

- Applied Ergonomics,

- International Journal of Aviation Psychology,

- Ergonomics,

- Human Factors and Aerospace Safety,

- Digital Avionics System Conference.

- Etc …

Proceedings from human factors symposiums and meetings were also analysed:

- International Ergonomics Association,

- Annual Meeting of the Human Factors and Ergonomics Society

- International Symposium on Aviation Psychology.

- Annual Meeting of the Aerospace Medical Association.

In addition, websites from the ATC "world", encompassing national and international organisations, research centres, and working group results, were explored to find study reports or synthesis on the topics addressed in future ATC communication projects.

3.2. INVESTIGATED TOPICS

The issues of the study revealed a number of relevant topics for study, including:

- Aircrew and ATCO communications at the time of sector changes.

- Communication media and modality in ATC (voice, data link, verbal, direct voice input, direct voice output, single frequency technology, etc.)

- Communication factors (verbal and non-verbal communications, one-way and two-way communications, implicit versus explicit communications, culture, professional language, etc.)

- Collective work between aircrews and ATCOs.

- Communication impact on the aircrew and ATCO cognitive activities: interruptions, disruptions, etc.

- ATC communication and situation awareness of the aircrews and ATCOs.

- Communication task load and workload in the cockpit and at the control working position.

- Communication errors and their management in ATC.

- Aircrew activity focused on communications, and in particular on the "process of identification and responsibility" communications.

- Collective work between aircrews and ATCOs focused on communications.

- Impact of data link on collective work between aircrews and ATCOs.

3.3. PROCESS DESCRIPTION

3.3.1. Keywords

The following keywords are used:

- Communication and situation awareness.

- Communication and task load.

- Communication and workload.

- Communication and fatigue.

- Communication and safety.

- Communication and human error

- Communication and air traffic performance

- Communication and data link

- Controller – pilot communication during routine operations

- ATC – pilot communication

- Routine "controller – pilot" communication

3.3.2. Database questioning

Source: Website of Ergonomics Abstracts

- "COMMUNICATION" + "SITUATION AWARENESS": 86 references

- "TASK LOAD" + "COMMUNICATION": 2 references

- "WORKLOAD" + "COMMUNICATION": 191 references

- "FATIGUE" + "COMMUNICATION": 42 references

- "AIR TRAFFIC PERFORMANCE": 1 references

- "AIR TRAFFIC CONTROL" + "COMMUNICATION": 528 references

  - o + "WORKLOAD": 3 references.

  - o + "FATIGUE": 0 reference.

  - o + "HUMAN ERROR": 1 reference.

  - o + "SITUATION AWARENESS": 0 references.

Of the references found during the article research phase, 44 relevant references made it possible to construct the literature review. For each of these articles, a synthesis was produced. This is made up of:

- Abstract of the article,

- Introduction setting out the objective of the research,

- Methods used during the study,

- Results,

- Discussion / conclusion, with the study's perspectives,

- References which helped support the research.

4. HUMAN FACTORS APPROACHES TO CONTROLLER – PILOT COMMUNICATIONS

4.1. ROUTINE TASKS OF PILOTS AND AIR TRAFFIC CONTROLLERS

4.1.1. Pilots' routine tasks

Today, modern commercial aircraft are piloted by a two-pilot crew. The captain commands the aircraft and supervises the other crew members. The first officer assists the captain and shares flying duties.

During a flight, aircrews perform systematic tasks:

- File instrument flight plans with air traffic control to ensure that flights are coordinated with other air traffic.

- Check aircraft prior to flights to ensure that the engines, controls, instruments, and other systems are functioning properly.

- Check passenger and cargo distributions and fuel amounts, to ensure that weight and balance specifications are met.

- Consider airport altitudes, outside temperatures, plane weights, and wind speeds and directions in order to calculate the speed needed to become airborne.

- Choose routes, altitudes, and speeds that will provide the fastest, safest, and smoothest flights.

- Brief crews about flight details such as destinations, duties, and responsibilities.

- Contact control towers for take-off clearances, arrival instructions, and other information, using radio equipment.

- Coordinate flight activities with ground crews and air traffic control, and inform crew members of flight and test procedures.

- Monitor engine operation, fuel consumption, and functioning of aircraft systems during flights.

- Plan and manage the crew task load during flights.

Some of these tasks are frequently performed during the flight and become routine tasks. The change of control airspace sector is a routine task, whose frequency of occurrence depends on the sector size. In the core area, the sector sizes are too small to cope with the heavy traffic loads. Consequently, the achievement of tasks associated with sector changes may impact on the aircrew's ongoing activity.

4.1.2. Air traffic controllers' routine tasks

Air traffic controllers manage traffic flows according to established procedures that ensure flight safety. They authorise, regulate and control aircraft in accordance with international and national regulations.

ATC is split into various activities, which may be broken down into three categories:

- Airport tower or terminal controllers,

- En route controllers, and

- Flight service specialists.

Airport tower or terminal controllers use radar and visual observation to regulate a single airport's traffic. During arrival and departure, several controllers direct each aircraft. They communicate with pilots by radio as they give permission to take off and land. They also direct ground traffic, which includes taxiing aircraft, vehicles, and airport workers. Once aircraft leave their assigned airspace, they transfer control of the aircraft to an en route controller.

En route controllers regulate flights between airports. They contact pilots by radio and control their position in the airways between tower jurisdictions. Using radar and computer equipment, they maintain a progressive

check on aircraft and issue instructions, clearance, and advice. When an aircraft leaves the airspace assigned to an en route centre, responsibility of the traffic control passes on to the next centre or to a tower controller. In each en route control centre, the airspace is split into control sectors. In each sector, a team of controllers is responsible for managing traffic safely and efficiently. The process of handing over an aircraft from one sector to another is clearly defined to avoid confusion or loss of responsibility between the teams of controllers of each sector. Today, the process of handing over between two sectors or two en route centres involves communications between aircrews and controllers. When pilots are lost or experiencing difficulties, the centre provides orientation instructions and directions to the nearest emergency landing field. En route controllers work in teams of two or three.

Flight service specialists are experts on the terrain, airports and navigational facilities in their areas. Pilots file their flight plans with flight service specialists who conduct pre-flight briefings on weather conditions, suggested routes, altitudes, indications of turbulence, and other flight safety information. They often use direction-finding equipment to provide special assistance to search and rescue operations.

ATCO tasks, which are systematically performed, are:

- Compile information about flights from flight plans, pilot reports, radar and observations.

- Organise flight plans and traffic management plans to prepare for aircraft about to enter assigned airspace.

- Relay air traffic information such as courses, altitudes, and expected arrival times to control centres.

- Provide flight path changes or directions to emergency landing fields for pilots travelling in bad weather or in emergency situations.

- Transfer control of departing flights to traffic control centres and accept control of arriving flights.

- Inspect, adjust, and control radio equipment and airport lights.

- Complete daily activity reports and keep records of messages from aircraft.

- Initiate and coordinate searches for missing aircraft.

A more exhaustive list of controller tasks is given in an EEC study (Dittmann and al., 2000). The tasks are termed task units and are split into six categories. Of the proposed categories, four relate to communications and two to communications with pilots. Table 4-1 sets out the task categories and underlying task units. The authors distinguish between routine and non-routine communications; non-routine communications are called special communications.

The analysis of routine communications shows that some are clearly related to sector change communications between pilots and controllers. However, the study does not show the results of the quantification of the unit's routine communications tasks in relation to sector changes. Nevertheless, the framework proposed by this study is relevant for a further description of sector change routine communications.

Table 4-1: ATCO task categories and underlying task units

Task Category	Task Units
Routine communication with pilots	− accept a/c − dismiss a/c − climb a/c − descend a/c − turn/direct a/c − speed instructions − instruct pilot (with something else) − give clearance
Special communication with pilots	− accept pilot's request − request information − give special information to pilot
Technical activities	− input radar data (light pen/label) − zoom radar − use planning tools (if available) − other radar/tool activities − check other information
Work related communication, other than to pilots	− communication with planner − coordination with adjacent sectors − communication with flight data assistant
Work-unrelated communication	− private communication − communication with observer
FPS activities	− receive FPSs − include FPSs in active board − change arrangement of FPSs − highlight (flag) FPSs − mark (write on) FPSs − dismiss FPSs − other FPS activities

In a different way, the categorisation of communication tasks is a concern of Action Plan 17 of the EUROCONTROL – FAA Memorandum of Cooperation that discusses recommendations for an adequate future aeronautical mobile communication infrastructure (EUROCONTROL / FAA, 2007). The current infrastructure has to evolve in order to accommodate new functions, and to provide the adequate capacity and quality of services required to supporting evolving air traffic management requirements within the framework of the global ATM operational concept. In order to meet such goals, an analysis and categorisation of future communications is required. Action Plan 17 thus proposes a categorisation of air traffic services making it possible to determine communication needs. Table 4-2 shows the various air traffic services. The routine communications related to the sector changes are included in Data Communications Management Services (DCM) and affect ATC Communication Management (ACM).

Table 4-2: Air traffic services groups

Data Communications Management Services (DCM)	Clearance/ Instruction Services (CIS)	Flight Information Services (FIS)	Advisory Services (AVS)	Flight Position/ Intent/ Preferences Services (FPS)	Emergency Information Services (EIS)	Delegated-Separation Services (DSS)	Miscellaneous Services (MIS)
Data Link Logon (DLL)

ATC Communication Management (ACM) | ATC Clearance (ACL)

Departure Clearance (DCL)

Downstream Clearance (DSC)

ATC Microphone Check (AMC)

Data Link Taxi (D-TAXI)

Common Trajectory Coordination (COTRAC) | Data Link Automatic Terminal Information Service (D-ATIS)

Data Link Operational Terminal Information Service (D-OTIS)

Data Link Operational En Route Information Service (D-ORIS)

Data Link Significant Meteorological Information (D-SIGMET)

Data Link Runway Visual Range (D-RVR)

Data Link Surface Information and Guidance (D-SIG) | Arrival Manager Information Delivery (ARMAND)

Dynamic Route Availability (DYNAV)

Data Link Flight Update (D-FLUP) | Surveillance (SURV)

Flight Plan Consistency (FLIPCY)

Flight Path Intent (FLIPINT)

System Access Parameters (SAP)

Wake Broadcast (WAKE)

Pilot Preferences Downlink (PPD)

Traffic Information Service-Broadcast (TIS-B) | Data Link Alert (D-ALERT)

Urgent Contact (URCO) | In-Trail Procedures (ITP)

Merging and Spacing (M&S)

Crossing and Passing (C&P)

Paired Approach (PAIRAPP) | Air-to-Air Self Separation (AIRSEP)

Auto Execute (A-EXEC) |

4.2. PILOT AND CONTROLLER COMMUNICATIONS

Communication is crucial in air navigation, since it is essential for the performance of at least two types of tasks (Kanki and Palmer, 1993; Andriessen, 1995):

- Interpersonal tasks related to a variety of different areas: team formation and resource management, coordination, tasks and workload distribution, decision-making, situation awareness maintenance, development and updating of mental models and of predictable behavioural patterns (Orasanu and Fischer, 1991, 1992; Orasanu and Salas 1993; Kanki and Foushee, 1989).

- Technical/operational tasks related to the execution of procedures and to the interactions with technical tools (Foushee, 1984; Ginnett, 1993).

In accordance with Suchman's descriptions (1993), each working position can be identified as a coordination centre, which continuously coordinates its activity with other people's activity. Each sector appears as a node within a complex network, in charge of coordinating various actions and decisions.

The network is composed of people involved in the control of flights while these are in a specific sector. These people are pilots, controllers from adjacent sectors, coordinators and data assistants.

For example, the various people interacting with en-route controllers may either:

- Be mutually dependent without sharing operative goals (e.g. cooperation between en-route and approach, which are not directly related, but might affect one another) or;

- Cooperate directly in order to achieve shared goals (e.g. cooperation between two adjacent sectors for the same aircraft, still in one sector but soon to enter the next one).

Each aircraft requires coordination between sectors, at least when the aircraft is handed over. This coordination is usually implicit, as controllers use shared resources in order to anticipate the entry of an aircraft in their sector. There is also explicit and indirect coordination, mediated by pilots, who are first told to change their radio frequency (by the sector they leave), and then are responsible for contacting the new sector.

Coordination between sectors is direct, explicit and verbal, in particular when a specific aircraft might cause problems. In this case, the sector anticipating a problem contacts the adjacent sector in order to agree jointly on a decision.

4.2.1. Controller-to-Controller Communication

Two different types of activity are performed during the approach phase by controllers: individual activities and cooperative activities (Bellorini and al., 1995). Individual activities, i.e. activities performed by a single human operator, include:

- Management of separation rules,

- Management of approach procedures, and

- Control of arrival and departure.

- Cooperative activities, performed by a group interacting to accomplish a task, require:

- Coordination of individual activities

- Common representation of the field in which the activity takes place

- Communication between group members to exchange information and to define a common representation and language.

In the approach, cooperative activities include sequence/order of landing and anticipated transfer of aircraft.

On the basis of the geographical working area criterion, two basic types of cooperation have been defined:

- Face-to-face communication.

- Distance communication.

Face-to-face cooperation is achieved by two modes:

- Explicit mode through verbal communications.

- Implicit mode through non-verbal communications supported by the common representation of the task.

The controllers reach common decisions about the landing order of aircraft through distributed decision-making processes. These decisions are the result of negotiations between controllers on the actions to be performed, task synchronisation and the management of each controller's tasks. An important aspect of this type of cooperation is the use of mutual implicit knowledge and of non-verbal behaviour. These elements play an important role in the process of collective regulation.

Distance cooperation takes place mainly between pilots and executive controllers through radiotelephony. Telephones and other new tools, such as data link, allow distance communications between pilots and approach, tower and en-route controllers. The task consists of the anticipated transfer of aircraft and related information. The types of communication between these protagonists are developed into a further section. Table 4-3 describes the two modes of controller communication.

Table 4-3: Face-to-face and distance cooperation at ATC

TYPE	FACE-TO-FACE COOPERATION	DISTANCE COOPERATION
AGENTS	south radar controller - north rc south rc - departure planner	north/south rc - pilot north/south rc - adjacent sector north/south rc - tower cont.
TASK SUPPORT	direct	mediated: radio frequency, phone
TASK ASPECTS	anticipated transfer of aircraft distributed decision making of landing order of aircraft synchronisation mutual knowledge of workload	anticipated transfer of aircraft information transfer of aircraft
MODES	explicit, implicit	explicit
COMMUN. STYLE	mutual and tacit knowledge free flowing	operative language rules temporal constraint
COMMUN. CONTENT	request/confirm anticipation of future state sequence of future actions	instruction/clearence information request/confirm sequence of future actions anticipation of future states

Before looking at pilot-controller communication, the review focuses on controller-controller communication through field and laboratory studies of intra-controller communication based on the FAA's Controller-to-Controller Communication / Coordination Taxonomy (C4T) (Bailey and al., 2001).

In this study, the authors examined the effects of aircraft density and different kinds of automated decision aids (Conflict Avoidance Tool – CAT - and Flight Path Planning Tool – FPPT) on communication exchanges between R-side (also called executive controller – EXE) and D-side (also called planner controller – PLN) air traffic controllers.

During the field study, a total of 24 hours of communication were recorded. Coding occurred in 30-45 minute blocks of time between the hours of 0700 and 1900. Coders chose to observe the most active sectors to ensure a sufficient number of coding events.

The communication taxonomy allows an initial controller communication classification. This is based on 6 items:

- Phraseology
- Transposition
- Misunderstandings
- Read-back
    - o Altitude
    - o Clearance
    - o Identification
- Acknowledgment
- Other

The coordination taxonomy has 2 communication categories:

- Topic of communication,
- Expression of communication.

Table 4-4STYLEREFSEQ provides the complete controller-to-controller coordination taxonomy (C4T) and the various coordination communication topics.

Table 4-4: C4T taxonomy (C4T): Coordination – Communication Topic

ATC Coordination Communication Topic	Definitions
Approval	Communications about intersector control/approval requests ("Get me control for descent on that aircraft". "APREQ N1234 climbing to FL330."
Handoff	Communications relating to the transfer of radar identification of a particular aircraft ("HandoffN1234" Did you handoffN1234?").
Point Out	Communications relating to the transfer of radar identification of a particular aircraft when radio communication .. radio communications will be retained ("Point ou N1234 to 22").
Traffic	Communications about a traffic situation involving a specific aircraft. Includes conflict, spacing, other protected air space or terrain and the resolution of that situation ("Are you watching that aircraft?").
Altitude	Communications about altitude not in relation to traffic ("N1234 is requesting flight level 220").
Route	Communications regarding headings and/or amendments to route, not in relation to traffic situations ("N1234 is on a 330 heading." 'Next sector, 27, wants N1234 over WEVER.").
Speed	Communications about speed not in relation to traffic situations ("These three aircraft are slowed to 250 knots.").
Weather	Communications about weather display or weather updates (Often communicated nonverbally by passing written information: "Sector 22 says continuous moderate turbulence above FL290").
Frequency	Communications about an aircraft's radio communications transfer of frequency assignment ("Have you switched N1234 yet? Tell them to switch to N1234).
Flow Messages	Communications about traffic flow restrictions not referring to a specific aircraft. (The next sector is requesting 25 miles in trail".) (due to radar outage).
Flight Strips	Communications about flight progress strips ("Where is that strip?'). Often communicated nonverbally.
Equipment	Communications about any ATC hardware (The radar is out of service.")
Aricraft ID	Communications involving identifying a specific aircraft (Who was that who called'.) "That was N1234 who called.").

Table 4-5STYLEREFSEQ: presents the various ATC coordination communication expressions.

Table 4-5: C4T taxonomy (C4T): coordination – communication expression and grammatical form

ATC Coordination-Communication Form	Definitions
Verbal	Use of voice only communication.
Nonverbal	Use of only body movement communication.
Mixed	Communication that contains both a verbal and non verbal component.
Electronic	Not used. Communication that is electronically transferred.

ATC Coordination- Communication Grammatical Form	Definitions
Question	A direct inquiry about the state or status of sector events.
Answer	A response to a direct or implied question
Statement	Providing information, without being asked, about the state or status of sector events.
Command	A direct order to perform a specific act

The last communication category is the grammatical form of communication (e.g. question, answer).

The topic of most intra-controller communications was aircraft traffic (40%) and flight route (15%), with the least communications involving inter-sector coordination approvals (1%).

The R-side (executive controller) and D-side (planner controller) controllers demonstrated no statistical differences in their communication topic. Whereas the D-side had a higher percentage of statements and observations (56% vs. 30%), the R-side had a higher percentage of answers (43% vs. 35%). This suggested that, compared with the R-side, the D-side controller was the initiator of more communication. Finally, there was no intra-controller difference in the method of communication.

The most frequent method of intra-controller communication was verbal only (70%). The remaining 30% of communications contained a mixture of verbal and non-verbal expressions. This latter finding suggested that any changes affecting the line of sight between R-side and D-side positions could disrupt the adaptive use of intra-controller non-verbal communication.

Although field studies preserve operational realism, with a complex task such as air traffic control many variables come into play, making it difficult to determine which factors affect performance. For example, one might wish to know the effects of more or less controller-to-controller communication on sector safety and/or efficiency.

However, controller-to-controller communication is the result of the interaction between the two members and the environment (sector complexity and traffic volume) in which they work. Within a laboratory environment, researchers have greater control over the environmental setting (e.g., equipment, sector complexity, traffic volume, work duration) and, thus, can better understand the effects of the experimental manipulation.

For these reasons, a laboratory study was performed. 3194 communication events were coded using a computerised version of the C4T. Table 4 shows the comparisons for the percentage of R-side and D-side communications related to the topic of communication, its grammatical form, and the mode of expression.

Although Table 4-4 shows that field and laboratory settings differed in the percentage of total communications that were attributed to a given topic, both laboratory and field assessments identified the same top three topics. These included communications about "Traffic," "Route," and "Altitude." Compared to the field, the most noticeable difference in the experiment was the lack of communications about "Weather," "Point-Outs," and "Traffic flow." Additionally, there was only a minimal number of communications concerning "Flight Strips."

The grammatical form of communications also differed between the two environments. The field results show a strong tendency for the D-side to make statements (55.9%) and the R-side (42.8%) to provide answers. In contrast, the experiment's results show both R-side and D-side predominantly making statements (58% vs. 77.3%).

Verbal communication is the method of choice for R-side and D-side controllers. However, as Table 4-4 shows, the D-side had a stronger tendency to use a mixture of verbal and non-verbal expressions in the experiment than did the R-side (24.7% vs. 5%). For the field setting, the percentage of mixed messages was similar for both the R-side and D-side (14.6% vs. 16.8%). Another difference between the two settings is the percentage of non-verbal communications that were used. In the field, 13.9% of the communications were solely non-verbal for both the R-side and the D-side. This is in contrast to the lower percentages recorded during the experiment (R-side 0.5%, D-side 2.8%).

Table 4-6: R-side and D-side communications in field and laboratory settings

	En route Center		Laboratory Setting	
	R-side%	D-side%	R-side%	D-side%
Communication Topic				
Traffic	41.0	37.9	53.7	51.2
Route of flight	14.2	15.6	13.1	11.7
Altitude	7.1	8.0	16.0	21.1
Weather	5.5	6.8	0.0	0.0
Point-out	5.0	6.1	0.0	0.0
Traffic flow	5.2	5.6	0.0	0.0
Frequency	5.9	4.7	3.5	2.7
Flight Strips	5.6	4.5	0.7	1.0
Equipment	3.3	4.0	4.5	4.9
Hand-off	3.6	3.1	2.9	1.8
Speed	2.6	2.8	4.4	2.8
Approval	1.0	0.9	1.0	1.8
Communication Format				
Statement	29.7	55.9	58.0	77.3
Answer	42.8	25.1	18.3	10.4
Question	12.2	16.4	22.9	11.3
Command Answer	5.8	0.3	0.0	0.0
Command	0.5	2.4	0.8	1.0
Communication Mode				
Verbal	77.1	69.3	93.9	69.0
Verbal & Nonverbal	14.7	16.8	5.0	24.7
Nonverbal	13.9	13.9	0.5	2.8
Equipment			0.0	0.1
Equipment & Verbal			0.6	3.4
Equipment & Nonverbal			0.0	0.1

Contrary to the hypothesis made, the number of communications under high workload conditions, as compared to low workload conditions, did not increase. No significant results were observed for any of the subcategories within the grammatical form of communication or the mode of communication. However, considerable effects on workload were observed for two communication topics:

- Communications identifying a specific aircraft.
- Communications involving altitude changes.

In both cases, the high aircraft density condition was associated with more communication exchanges between the R-side and D-side positions.

In the next section, we will focus our study on controllers' collective activities, in particular coordination with pilots.

4.2.1.1.   Pilot – controller communication

4.2.1.2.   Structure of pilot – controller communication

Controller-pilot communication is an example of task-oriented dialogue, in which the task organises the communication. Dynamic aviation operations require rapid communication, and increased operational complexity may increase the frequency and complexity of communication.

According to Morrow and Lee (1993), pilots and controllers understand each other by following a general collaborative scheme made up of three components.

- Speakers initiate a transaction by getting their addressee's attention.

- Speakers present new information about some topic to the addressee. In ATC communication, controllers typically initiate and present information that is intended to help pilots update their mental model of the navigation task and to execute the described actions.

- Speakers and addressees accept the presented information as mutually understood, so they agree that they share the same mental model. To accept information, addressees demonstrate their interpretation for speakers to verify (Clark and Schaefer, 1987). Speakers and addressees also accept information as appropriate: the message must be complete, timely, and relevant.

Controllers and pilots collaborate by using particular speech acts (Goguen and al., 1986). They often initiate transactions with call-sign identifications, present information with reports or commands, and accept this information with acknowledgments. Full acknowledgments with call-sign and read-back are crucial for demonstrating that the intended pilot correctly understood the message.

A transaction was defined as a set of turns between the same controller and pilot, with no more than 5 sec of silence between turns. Transaction length was measured as the number of turns and speech acts.

In 1993, Morrow detailed pilot-controller communication in three phases and sub-phases:

- 1) Controller presents message:

    o   Formulating: According to plan-based approaches to language production, formulating a message involves first deciding which information to present in the message content (Levelt, 1989).

    o   Packaging: Next, controllers decide how much information to present in a single message and in what order to present it.

    o   Delivering: Finally, controllers decide how rapidly to present the message, when to pause, etc. Delivery will also depend on time pressures related to controller workload.

- 2) Pilot understands message. Pilots listen to the messages in order to identify the intended addressee and the actions that the controller expects them to perform.

- 3) Pilot and controller accept message. Accepting the message as mutually understood and appropriate often hinges on pilot read-backs. Pilots keep the message in working memory in order to read-back the commands, and controllers keep the message in working memory in order to verify the read-back. After the message is accepted, the controller continues with the next turn or begins a new transaction, and the pilot responds to the message by operating aircraft controls, telling the pilot flying to do so, or loading the information into the Flight Management System (FMS).

4.2.1.3.   Supports of pilot – controller communication

Nowadays, for most of continental airspace, communications between pilots and air traffic controllers are exclusively through radiotelephony (R/T). However, in areas where traffic density is high, making the congested R/T channel a real brake on increases in capacity, the limitations of such a medium are being reached. A number of remedial measures have been taken over the past few years (such as splitting the airspace into smaller sectors and reducing the VHF channel spacing to 8.33 kHz in Europe).

Moreover, new technology for communication between pilots and ATC, such as air-ground data link communication, has been introduced.

Developments and technological improvements will allow data to be sent by another system: the data link. The term data link refers to new air-ground communication technology that provides alphanumeric information. This new technology should replace (partially or totally) current voice radio communication. A first approach consists in transmitting data in a written form (using a specific display). Hence, the crew will be reading the messages instead of listening to them. The use of this system is likely to induce many changes.

The choice between data link and voice will depend on a variety of factors, such as the urgency and length of messages that need to be transmitted, the ease with which messages can be assembled in either medium and the equipment on board those aircraft that are affected by the transition. The features, advantages and drawbacks of this means of communication, which is data link, will be described in Chapter 5.

The main weaknesses of HF or VHF radio communication are that data can only be transmitted in a sequential manner and air-ground communication is subject to interference. Background noise or speech problems (accent, tone) can disrupt the transmitted message and lead to misunderstandings. However, voice inflection may be very useful in helping the controller detect urgent cases, by transmitting non-verbal information.

In a series of laboratory experiments on interactive communication, Chapanis (1981) found that:

- Modes of communication that have a voice channel are wordier than those that do not have a voice channel, and

- Problems are solved significantly faster in communication modes that have a voice channel than in those that do not.

4.2.1.4.   Quantitative approach to pilot – controller R/T communication

Quantitative aspects of pilot – controller communication are addressed in two en-route air traffic control studies: the VOCALISE study in a real operational environment (Graglia and al., 2005), and the EEC study in a simulation environment (Hering, 2001).

The VOCALISE study shows that on average 324 speech acts between controllers and pilots were recorded per hour in an en-route sector, or about 5 per minute.

Communication capacity metrics for the voice channel were considered both in terms of:

- The number of "speech acts" (individual voice messages initiated by controllers or pilots),

- Or the number of "exchanges" (i.e. distinct, complete two-way operational dialogues);

- And medium occupancy through time.

The mean duration of a speech act is about 3.3 seconds, with a significant difference according to the speaker:

- 3.7 seconds for controller speech acts

- And 2.9 seconds for pilot speech acts.

The mean duration of an exchange is about 11 seconds.

About 50% of complete exchanges are made up of just 2 speech acts. Their mean duration is about 8 seconds.

About one out of two speech acts is at least partly related to either transfer or assume. This result is consistent with the results of Hering's analysis of pilot – controller speeches (Hering, 2008)

R/T channel availability may be considered from different standpoints:

- At a basic level, the physical occupancy is represented by the ratio of the cumulated duration of individual speech acts to the total duration of the measured period.

- At a higher level, the "operational" occupancy can be defined as the ratio of the cumulated duration of voice exchanges - including silences between the speech acts they are made up of - to the duration of the sample.

- Lastly, R/T "congestion", which occurs when there is an additional need for air-ground communication,

would mean that certain messages would have to be postponed.

The physical occupancy of the R/T channel amounts to 30% on average over all samples studied by VOCALISE, with significant variations: between 24% and 36% depending on the sector (over 5 hours) and between 20% and 48% depending on the sample (over one hour).

This seemingly low figure does not mean that the R/T medium is always available: at peak times, the R/T physical occupancy may rise in some cases to more than 75% for more than 8 minutes.

Moreover, because of the synchronous nature of R/T and voice acknowledgement mechanisms, silence on the R/T does not always mean that there is room for an operational dialogue to start immediately. Typically, between a controller's instruction and the pilot's read-back, other pilots do not generally place a request. This is why the operational occupancy provides a further refinement in estimating the R/T load.

The operational occupancy of R/T is on average 37% in area control centre (ACC) sectors (between 26% and 32% according to the sector). This rate may rise to 90% during peak periods for up to 5 minutes.

The analysis of the VOCALISE samples confirmed that a significant proportion of current R/T communication does not carry any operational content, and is related to the channel's management itself. This relates in particular to the following aspects:

- Read-back of instructions over the R/T is a cumbersome and particularly inefficient procedure, generating a high level of information redundancy. In the VOCALISE samples, the pilot read-backs represent approximately 20% of the channel occupancy time. Again, when the R/T channel occupancy increases, operational pressure often leads to adaptation and the pilots may simplify their communications: 20% of read-backs do not explicitly repeat all the elements of the instruction; however this introduces a risk for undetected misunderstandings. The need to explicitly address each voice message is also inefficient by nature. Again, adaptation may occur here (authors recorded 15% of voice messages without a call sign, either in read-backs or during complex exchanges).

- Some voice calls only contain the call sign or ATC unit name and mainly have two functions: requesting attention (from the pilot or controller - for the purpose of preventing misunderstandings/repetitions) and at the same time access to the voice channel; or making sure a flight is actually listening to the frequency. Such communications account for about 2% of the voice channel occupancy in the VOCALISE samples (between 1% and 3% depending on the sector); On average, controllers initiated such calls more than 5 times per hour (between 2 and 9 times per hour depending on the sector, with a maximum of 18 occurrences in a single hour), while pilots did so twice per hour (between 0 and 3 times per hour depending on the sector, with a maximum of 6 occurrences in a single hour).

Finally, as a result of the use of these prevention and correction mechanisms, managed by human operators, communication errors may be avoided only at a heavy price in terms of voice channel occupancy.

4.3. COMMUNICATION AND MENTAL PROCESSES

Communication between pilots and controllers is one of the fundamental principles of air traffic control (ATC). Consequently, air-ground communications will both reflect the task load imposed on the controller and drive the workload experienced by the controller.

The task load represents the work constraints imposed on a person as a result of the performance of a task. The workload is the strain generated by his/her achievement of that task. The workload encompasses two components:

- The active workload resulting from the tasks the person is executing at the time.

- And the residual workload representing effects such as stress and fatigue resulting from the effort expended on those tasks.

Therefore, analysis of ATC communications could potentially reveal a very rich and detailed picture of the demands placed on a controller in a given sector and traffic situation.

4.3.1. Working Memory

Communication problems arise in part because complex air traffic control (ATC) messages sometimes overload pilot memory (for example, incorrect read-backs tend to increase with message length) and in part because longer messages increase the chance of confusion or interference among the constituent message elements (e.g. heading and speed instructions) in the working memory (Morrow and Rodvold, 1998; Prinzo and Britton, 1993, for reviews).

Collaboration is shaped by many factors influencing communication demands on controllers' and pilots' working memories. These factors include:

- Features of controller and pilot messages.
- Communication medium: voice or data link for pilot – controller communication.

4.3.1.1. Impact of message format

The Federal Aviation Administration defines group form as "the pronunciation of a series of numbers as the whole number, or pairs of numbers they represent rather than pronouncing each separate digit." And "The number '0' is pronounced as 'zero,' except where it is used in approved 'group form' for authorized aircraft call signs (e.g., EMAIR One Ten), and in stating altitudes (e.g., Ten-thousand-five hundred)."

Serial numbers are to be spoken as separate digits and "Altitudes" may be restated in group form for added clarity if the controller chooses."

Grouping cues (e.g., pauses, grouped pronunciation of numerical information) allows people to recode information into larger chunks in working memory (Crowder, 1976).

Chunking is a strategy by which individual items are combined into fewer, higher order units. For example, the digits 1776149219181941 are virtually impossible to repeat verbatim from memory. However, when grouped into 4-digit chunks, 1776 1492 1918 1941, the ability to remember all the digits improves. Therefore, chunking strategies should help reduce the constraints of limited short-term storage capacity on memory performance.

Grouping cues improves memory for ATC instructions because either they help pilots recode information into larger chunks, thereby reducing demands on working memory capacity, or they facilitate unique encoding of different instructions, thus reducing interference among parts of the message.

Pilot comprehension and memory of ATC messages are improved by presenting instruction speech acts in a grouped format (Prinzo, 2002).

4.3.1.2. Impact of message length

In Prinzo's study, the length of critical ATC messages was also varied. Longer messages should be responded to less accurately because they increase demands on working memory storage capacity or increase the possibility of interference among parts of the message (Morrow and Rodvold, 1998). Benefits of grouping cues may be greater for long messages because the potential benefits of unique encoding are greater for these messages.

Requests for clarification were more likely to occur after longer ATC messages. This finding suggests that longer messages increased demands on pilots' memory. The finding that older pilots, who presumably experienced greater limits on working memory (Morrow and Rodvold, 1998), were especially likely to request clarification of longer messages provides further evidence that the ATC messages in this study imposed demands on limited working memory capacity.

Morrow, in 1993, found similar results. He investigated the influence of ATC message length and timing (that is to say the time between two messages), as well as non-communication workload, on pilot communication during simulated flight. Controllers either presented one long message (with 4 commands) or divided the message into two short messages (with 2 commands each) with a variable inter-message interval.

Communication problems may be more frequent after long ATC messages. Understanding ATC messages appeals to a limited working memory capacity, and more processing and storage resources are required when more information is presented at once (Billings and Cheaney, 1981; Loftus and al., 1979), particularly when communication competes with other flying tasks (Casali and Wierwille, 1983). Controllers and pilots may cope with these demands by developing strategies to minimise individual and/or collaborative effort.

For example, controllers may produce one long message rather than breaking it into several shorter ones in order to reduce transaction and turn-taking time. Pilots, in turn, may streamline acknowledgments. While reducing individual effort, these strategies may increase collaborative effort if long messages and abbreviated acknowledgments force controllers and pilots to take extra time and effort to clarify the communication.

Finally, the effect of message length depended on age. Older participants produced proportionally more requests for clarification than younger participants for longer messages but not for shorter messages.

Controllers may present long messages in order to save time. While they spend more time on formulating longer messages, they save packaging and delivery time because the number of turns is reduced. However, pilots are more likely to misunderstand long messages because of increased working memory load. With 4 commands presented at once, pilots are less likely to hear or interpret all or part of the message, resulting in more incorrect or partial read-backs and requests for clarification (Billings and Cheaney, 1981). Long ATC messages may decrease communication efficiency as well as accuracy. Transactions with long rather than short ATC messages may be longer overall (containing more turns and speech acts) because more talk is needed to indicate and repair problems.

Furthermore, controllers may need more time to package and deliver two short messages, so they may try to save time by presenting the two messages in quick succession. Presenting shorter messages should reduce pilot misunderstanding by reducing working memory load (Morrow and al., 1993). However, presenting the second message too quickly after the first may interfere with remembering and/or responding to the earlier message. Therefore, pilots may indicate a problem with the first message after the second short message has occurred. These delayed problems are more likely for short intervals between the first and second short message.

To sum up, closely spaced messages should produce memory failures while long messages produce understanding failures. Nonetheless, problems should still be less frequent for short than for long ATC messages. Transaction length may increase for short ATC messages because the controller uses more turns. Transactions will only be longer when they contain long ATC messages if the talk required to clarify communication problems (which are more frequent after long messages) outweighs increases in length due to additional turns in the short message condition.

4.3.1.3. Working memory and procedural deviations

4.3.1.3.1. The message length

Partial read-backs were more frequent after longer controller messages. These partial read-backs may reflect forgetting (Loftus and al, 1979) or an attempt to reduce load on pilot working memory by streamlining acknowledgments. Thus, although long messages may reduce controller workload, they appear to increase load on pilot working memory.

4.3.1.3.2. The message composition

The type as well as amount of information in ATC messages is associated with procedural deviations. Messages with speech acts requiring different kinds of pilot responses (e.g. commands and requests) are sometimes followed by missing and partial read-back (10 to 20% of cases). These messages appear to increase demands on working memory. For example, a message with two commands and a question require the pilot to read-back the commands and to answer the question. Producing two kinds of responses in the same acknowledgment may require more effort than producing either response alone. To cope with these messages, pilots may read-back but not answer the question or vice versa.

4.3.1.4. Summary relating to working memory

Message features influence the load on pilot attention and memory, which complicate the process of accepting the message as mutually understood. The majority of partial and incorrect read-backs are preceded either by messages with multiple commands or by messages that combined commands with requests for traffic reports.

Message length and composition, in combination with R/T and task factors, appear to interfere with collaboration between controllers and pilots. Controllers may produce long messages in order to reduce their workload by minimising transaction and turn-taking time, particularly during high traffic periods or complex operations. However, this strategy may ultimately increase the collaborative effort needed for controllers and pilots to understand each other. Faced with complex controller messages, pilots are more likely to misunderstand them (incorrect read-backs) or to decrease their own effort by abbreviating acknowledgments. In turn, these incorrect or reduced acknowledgments increase the frequency of non-routine transactions, with controllers repeating their message to correct the pilot or to prompt them to acknowledge fully. Additionally, non-routine transactions can lead to further problems because participants focus on resolving problems rather than on following standard communication procedures such as using call-signs.

Message length and message timing influence different cognitive processes involved in controller-pilot communication. While long messages reduced comprehension or immediate memory for messages by overloading working memory, short messages presented in quick succession were more likely to cause forgetting, with the later message intruding into memory for the earlier message.

Controllers and pilots may try to reduce their individual effort by producing long messages or abbreviating acknowledgments, but these strategies raise the chances of non-routine transactions that can increase collaborative effort.

4.3.2. Communication workload

4.3.2.1. Workload and performance

ATC workload can be defined as the number of active aircraft on frequency when the controller initiated a transmission. Other indicators of workload include frequency occupancy time, frequency availability time and the number of messages exchanged between a controller and the pilot of an aircraft during each circuit (Prinzo, 2003).

Communication workload can be determined by counting the number of digits, letter groups, or both that indicated a direction or distance, aircraft call sign, aircraft type, etc. (e.g., 12 o'clock, left, right, north, Ownship123, Boeing 727) in a message element. These digits and letter groups are labelled as bits of information.

An air traffic controller at an en-route centre uses communications to deliver control actions to aircraft. Before communicating, the controller evaluates the situation and decides what action is required. After communicating, the controller evaluates the revised situation and writes the control action down. This process repeats itself continually.

With no aircraft, the controller's workload should be zero. With every aircraft, the controller will speak at least twice: once to acknowledge the pilot joining the frequency, and again to transfer the pilot to the next frequency. Given the required specific phraseology, the controller who is communicating more will have a higher level of workload.

The effect of workload on ATCOs, according to incident and accident databases, can be represented by an inverted U relationship (EATCHIP, 1997). In fact, controllers' performance level decreases:

- During periods of high workload.

- In the periods following a high workload phase, because of a decrease in vigilance after a stressful activity, and when a high workload period follows a light workload period because it requires a sudden reconcentration on the task;

- During periods of very low workload, because of a decrease in attention or controllers' overconfidence.

Because of the evidence suggesting the severe impact of shift work and workload on the cognitive performance of individuals, many studies investigated the ways in which these two factors affected one of the most crucial aspects of ATC, namely the communication exchanges between ATCOs and pilots (Corradini and Cacciari 2000, 2001).

A consistent finding in controller-to-pilot voice communications research is that workload affects the quality and quantity of communication exchanges (e.g., Prinzo and Britton, 1993). In this literature, workload is primarily measured by the number of aircraft at a given time (i.e., aircraft density) under the control of an R-side ATCO. As aircraft density increases, there is a corresponding trend toward an increasing number of communication errors (Morrison and Wright, 1989; Morrow and al., 1993). Research suggests that, as ATCOs and pilots become overburdened the clarity of their communications (e.g., incomplete phraseology, mispronunciation, and rapid speech) begins to suffer.

4.3.2.2. Workload assessment

Rantanen (2005) established a connection between workload and communications.

Of 16 workload measurement techniques employed in his study, 8 were sensitive to communication load manipulations. These techniques included both subjective ratings and objective measures. Hence, it is quite clear that communication load is a workload driver.

Rantanen points out that a communication task is very different for a pilot and a controller. A pilot typically needs to respond to only a small fraction of messages transmitted on the frequency (i.e., only to those addressed to him or her), whereas the ratio of messages controllers receive and transmit is close to one (i.e., controllers talk to all aircraft on frequency).

Hurst and Rose (1978) replicated an earlier study that had indicated that peak traffic and the duration of radio communications were good predictors of the behavioural response of air traffic controllers working in air route traffic control centres.

Porterfield, in 1997, had already shown that communication time was a good predictor of workload (subjective ratings).

An analysis of the proportion of controller communication time showed significant differences between low altitude, high altitude, and super high altitude sectors.

The number of instructional clearances has also been associated with controller workload and clear differences were found between the sectors.

Given that communication time has been found to be a good predictor of workload, Porterfield examined correlations between the communication times recorded from the three sectors. The best correlation was found between the sum of 3 controller activity metrics (altitude changes + heading changes + number of handoffs) and controller communication time.

The premise was that as aircraft altitude and heading changes currently necessitate a clearance, as do handoffs, they can be combined into an index that captures most of controller activity (Activity Count). A regression analysis showed a significant relationship between activity count and communication time.

Analysis of ATC voice data from three different sectors revealed substantial differences between the sectors.

Given that communication duration and number of clearances issued have been shown to be workload drivers, authors may conclude that the sample sectors can indeed be ranked in terms of workload imposed on the controller. In this respect, it appears that the high-altitude and low-altitude sectors were much more demanding than the super high-altitude sector.

Furthermore, it also appears that a simple metric of controller task load, that is, aircraft count, correlated nearly as well with communication duration as did the more complex activity count, clearly favouring the use of the former as an indicator of controller workload.

There are, however, several caveats that should be considered when assessing the validity of these conclusions.

First, important factors might affect controller task load: maximum number of aircraft under the controller's responsibility at any one time, proportion of aircraft changing altitude, handoff acceptance latency not reflected in voice data.

Second, the complexity variables that were computed (proportion of climbing and descending aircraft, average vertical distance between aircraft pairs, and aircraft density) did not show particularly strong correlations with communications measures.

4.3.3. Teamwork

The definitions of teamwork encountered in the literature define the team as a group of people who:

- Are interdependent.

- Work consistently together (including training).

- Have a membership role which is clearly defined and stable for designated periods of time

- Produce synergy (e.g. Brannick and Prince, 1997; Baker and Salas, 1992).

The analysis of communications between group members is one of the tools used to identify and describe the functioning of cooperative activities (Falzon, 1991; van Deale and al., 1991; Reinartz & al., 1989). Cooperative activity (Leplat, 1994), as the activity of a group of people interacting to accomplish a task, requires:

- Coordination of individual activities,

- Common representation of the field in which the activity takes place, and

- Communication between group members in order to exchange information and define a common representation and language.

The analysis of the richness and flexibility of communication in the working group contributes to the understanding of cooperative activities and the identification of their weaknesses.

Most of the information supports, even if individual, are accessible to both controllers. The controllers share visual as well as audio resources. Lastly, thanks to their proximal location, they can monitor one another's position and movements.

The co-located operators have the opportunity to observe each other, distributing and acquiring explicitly as well as implicitly information through verbal messages, visual observation of other operators and information supports such as the radar screen, the strip progress board, the radio or the notepad. Thus, the working position provides some cues and information about current and planned actions and usually enables cooperators to infer colleagues' current intentions and strategies.

Despite an explicit description of each function, air traffic control is considered a joint task, in the sense that close cooperation between the two controllers is required.

Working together closely, the controllers have to integrate various sources of information in order to coordinate their actions in the global mission, which is to transport efficiently and safely human beings and goods from one point to another.

4.3.4. Situation awareness and party line

4.3.4.1. Party line

Party line refers to the air-ground information available on the same radio frequency; that is, each aircrew may listen to air-ground communications directed to all aircraft flying in the same geographical sector. Consequently, pilots elaborate their own representation of the airspace around them and thus increase their situational awareness.

This is particularly important for anticipating and determining the route with respect to weather conditions.

The paradox is that, although the party line may disrupt pilots in high workload situations, they need it the most during these periods.

Party line is very important during the approach phases. According to Pritchett and Hansman (1995), 40% of the data transmitted between the ground and various aircraft are judged critical by pilots when they are on approach (i.e., final approach including landing and terminal area). These elements refer essentially to traffic (e.g. missed approach, approach clearances, terminal routing) and weather conditions (e.g., wind shear, visibility and ceiling, surface winds).

The use of radio systems mixes messages to all aircraft on the same frequency. The crews need to isolate their own message from the others. As Corwin and McCauley (1990) wrote, the acquisition of the relevant information that is necessary to construct aircrew situational awareness leads to too much workload resulting from continuous listening (for extracting useful information). Consequently, the introduction of data link seems to be a positive initiative.

However, pilots fear that the introduction of data link onto the flight deck will decrease radio transmissions and hence reduce party line information. Each request will be directly addressed to the crew, and other aircrews will not have access to it. They will thus lose partial or complete information that they used to consider important and necessary. Loss of party line will "eliminate the pilot's ability to anticipate conditions derived from listening to exchanges between other aircraft and ATC" (Corwin and McCauley, 1990). If we want to keep this situation awareness, certain strategies or crew resource management systems should be established to maintain the supervision (and/or compensation) of potential errors and deviations (Riley, 1992).

Due to the importance of indirectly addressed information, the removal of radio transmissions cannot be done without implementing a system that incorporates party line functionality. First, the integration of a system that efficiently and effectively shares information with other aircraft should be taken into account in the development of data link. Second, pilots' situational awareness should be increased, especially during periods that are most essential, when confusion and misunderstanding risks are the highest.

In this context, the two controllers in charge of a given sector need to share an updated representation of the situation.

In order to make decisions, controllers need to be aware of the current situation, in terms of the features of each aircraft (destination, speed, altitude) as well as the features of the traffic in the sector. It is interesting to observe that in this situation, the system is designed to provide information not to one controller only, but to both of them.

4.3.4.2. Mutual awareness

According to Sarter's study (1997), cooperation between controllers requires them, first, to share an understanding of the current situation, and second, to know that they do share this understanding. In other words, they need to be mutually aware of the situation (including both the process and their respective knowledge).

Mutual awareness is a large concept, referring to individual knowledge of a shared situation. Mutual awareness can be defined as when people are not only aware of each other's activities, but also aware of their reciprocal awareness. The supports for awareness in ATC are audio (radio, telephone, para-verbal signs) and visual (observing gestures, actions, as well as data on the radar and strips).

Awareness can be related to the actors, the system, the availability and location of people and resources, the current objectives, actions, tasks, the context (normal vs. incidental), the situation and the current state of the process:

- Awareness about who is talking: supported by watching the communication keyboard (as a specific button lights up according to the caller, and indicates the sector), by listening to a conversation and identifying its topics, by observing what the speaker is watching, or where he/she is oriented to.

- Awareness about the availability of the other party: supported by observing physical posture, by listening if they are engaged in communication, by observing their actions.

- Awareness about current actions: supported by watching which aircraft are acted upon, by listening to comments from actors while they work, by listening to the instructions they give, by observing their physical behaviour.

- Awareness about the current situation: supported by observing the position of strips, the sequences of aircraft on the radar screen, by listening to the pitch and tone of discussions.

4.4. COMMUNICATION FAILURES: ERRORS, MISUNDERSTANDINGS AND INTERRUPTIONS

4.4.1. Miscommunications

Pilot-controller communication is critical to safe and efficient flight. It is often a challenging component of piloting and controlling, which is reflected in the number of incidents and accidents involving miscommunication.

In 1993, Morrow and al. provided a list of possible failures or breakdowns in routine collaboration existing between pilots and controllers. Morrow's study describes the nature of miscommunications and the factors of miscommunication.

4.3.4.1.1. Nature of miscommunications

4.3.4.1.1.1. Incorrect read-backs

Incorrect read-backs represent less than 1% of all transactions. Partial read-backs were more frequent than missing read-backs. Thus, pilots were more likely to partially acknowledge ATC messages than not to acknowledge them at all.

4.3.4.1.1.2. Call-sign confusions

For 0.2% of all transactions, a pilot responds to a message intended for a different pilot.

4.3.4.1.1.2.1. Initiation failure

The wrong pilot can respond to a message because of call-sign confusion, forcing the controller to correct the addressee and repeat the message for the intended pilot. Pilots may also fail to hear the message, forcing the controller to repeat the message.

4.3.4.1.1.2.2. Understanding failure

Pilots may notice that a message is for them, but misunderstand all or part of the message.

4.3.4.1.1.2.3. Memory failure

Pilots may understand a message but forget it before they respond.

4.3.4.1.1.2.4. Information failure

Finally, a message may be understood and remembered, but the pilot disagrees with its accuracy, timing, or completeness.

4.3.4.1.1.2.5. Omissions

The frequency of the omissions was inversely proportional to the relevance of the elements omitted: clearances were never omitted; information and parameters were absent only in 3% of messages and the information omitted was not crucial. The ellipsis of words or numbers was much more common (26% for controllers and 29% for pilots).

The call-sign is omitted, shortened or replaced by a nickname in 43% of controllers' messages (and in 44% of pilots' messages).

4.3.4.1.1.2.6. Redundancies

Redundant messages might have negative consequences since they unnecessarily keep the radio frequency active, representing also a cognitive load for the receiver.

In most cases, these miscommunications usually prompt the speaker to rectify the problem. Speakers may also repeat unacknowledged messages to ensure that they were understood. Thus, although non-routine transactions may be necessary to clarify communication, they also reduce efficiency.

4.4.1.2. *Factors of miscommunications*

Still (1993) provided a list of causes of problems in routine collaboration between pilots and controllers.

4.4.1.2.1. *Controller message length*

Pilots made more read-back errors after one long message than after two short messages. They also asked for clarification more often after the long messages, indicating that they did not understand the message and had to interrupt routine communication in order to clarify communication. They may have read-back fewer commands after the long messages in order to reduce the workload imposed by these messages. To summarise, pilots were more likely to misunderstand the controller when too much information was presented in one message.

Morrow also examined the impact of ATC message length on overall transaction length by comparing the number of turns and speech acts in transactions with long ATC messages with the number of turns and speech acts in both short ATC message transactions combined. Controllers and pilots talked more when ATC messages were divided into two short messages. There were more short message than long message transactions (mean number of short transactions per flight = 13.5, long transactions per flight = 6.7), creating more turns and speech acts. However, problem turns and speech acts were more frequent for long than for short messages and speech acts. In other words, even though pilots and controllers talked more in order to resolve communication problems after long messages, the amount of routine communication increased with shorter messages because the number of turns increased. Therefore, the strategy of breaking long messages into short messages increases communication accuracy, but at the expense of communication length.

To summarise, the length of controller message is a factor associated with incorrect read-backs. Indeed, these incorrect read-backs are more frequent:

- After longer controller messages,

- After messages with two or more speech acts (commands, reports, requests, and other speech acts containing digits)

- When pilots are required to store information in working memory (increase memory load may increase confusion or interference between items in the message).

For 57% of these read-backs, pilots substituted a digit from another command or report in the message for one of the digits in the incorrectly repeated command.

4.4.1.2.2. *Speech rate*

Incorrect read-backs may be associated with speech rate as well as message length. Moreover, message length (number of speech acts) and speech rate (syllables/sec) were not significantly correlated for all transactions. There is no evidence that ATC messages are misunderstood because of rapid presentation, or that controllers presented longer messages more rapidly.

4.4.1.2.3. *Controller message composition*

In 15% of the incorrect read-backs, the preceding message combined speech acts requiring different kinds of pilot responses. Thus, incorrect read-backs as well as partial and missing ones suggest that pilot workload is influenced by the type as well as by the amount of information in controller messages.

4.4.1.2.4. *Controller message quality*

Low message quality may result from:

- Poor formulation: incorrect or outdated information is presented.

- Poor packaging: Controllers may present too much information in one message, or the message may be too complex.

- Poor delivery: Controllers may present the message too rapidly, with poor enunciation or with misleading stress/intonation cues. These practices can also reduce pilot memory for messages (Monan, 1983). They may also present one message too quickly after a previous one, disrupting comprehension, memory, or response to the earlier message.

4.4.1.2.5.   Non-routine transactions

More than half (62%) of the incorrect read-backs occurred in non-routine transactions, primarily because controllers interrupted routine communication in order to correct the read-back. Thus, like missing acknowledgments, incorrect read-backs led to (rather than resulted from) non-routine transactions.

4.4.1.2.6.   Task factors

For approach sectors, errors are most frequent for runway identifications (either the runway number or left/right designation 21%), tower or approach frequencies (13%), and speech commands (13%).

For departure sectors, errors are most frequent for centre frequencies (30%) and departure clearance (9%). Lastly, heading and altitude commands are often incorrectly read-back in both operations.

4.4.1.2.7.   Similarity of call-signs

In 54% of cases, call-signs are similar (they share at least one number or have the same company name, or both; or the confused numbers sounded similar). Call-sign confusion is due to interference (during perception or memory), between the call-sign in the controller's message and the unintended pilot's own call-sign.

4.4.1.2.8.   Medium factors

Message factors can be compounded by noisy or overloaded radio frequencies (Billings & Cheaney, 1981) or directly traced to voice channel characteristics (i.e. its volatile nature, national accents, or poor quality of the audio signal). Such events have a direct impact on the efficiency of R/T use, if not on safety. As an example, one erroneous pilot read-back was recorded per hour (mainly wrong frequency during transfer of communications), and led to an explicit correction. On average, the VOCALISE samples contain almost 6 requests for repetition or confirmation from pilots per hour, and 2 from controllers, approximately accounting for 3% of the total R/T occupancy (up to 14 such pilot requests can even be found in a single one-hour sample).

4.4.1.2.9.   Organisational factors

4.4.1.2.9.1.   Shift work organisation and level of workload

The working memory demands are more likely to lead to pilot communication problems when concurrent flight tasks compete for limited capacity.

In his study in 2002, Corradini considered organisational factors such as shift work organisation and level of workload, which can affect the characteristics of communications: deviations from the prescribed phraseology occurred significantly more frequently during the nightshifts. In particular, these results show a peak in linguistic deviations in the communications produced during the nightshift in the period of minimum workload that occurred between 2 a.m. and 4 a.m. This corresponds to the maximum decrease in controllers' vigilance and to the highest level of mental fatigue. In this condition, messages were more incorrect in that they presented more native language words (in 78% of the speech turns), incorrect call-signs (in 73% of them) and collective and individual non-standard expressions (each of the speech turns presented on average 1.23 non-standard expressions), controllers omitted more elements (in 69% of the turns) than in other periods.

Communications produced in the morning shifts were, in general, the most correct.

Afternoon shifts showed an intermediate level of correctness.

Linguistic deviations were significantly more frequent during the low workload periods than in the high workload ones.

4.4.1.2.9.2.   Working position

The working position also influenced the communicative patterns of the controllers. All kinds of linguistic deviations were produced more frequently by radar controllers than by tower ones, partly from the use of their native language: differences between the communications of the two operator groups were statistically significant for omissions (present in 39% of the speech turns by EXE and in 27% by PLN), and incorrect call-sign (in 67% of the speech turns by EXE and in 38% by PLN). Non-standard expressions and redundancies, although not reaching significance, showed the same trend (non-standard expressions were found in 83% of EXE speech turns and in 72% of PLN; redundancies in 45% and 44% of the speech turns respectively). Native language, on the other hand, was more often employed by PLN (in 51% of the speech turns) than by EXE (in 40% of the speech turns).

A number of factors could account for these results:

- The fact that EXE produced more phraseology deviations than PLN could be due to their higher medium age and longer length of service.

- The age and longer exposure to shift work could produce a slight decrease in performance correctness and in tolerance to shift work (Reinberg and al., 1980) and a risk of burnout, i.e. changes in mood and behaviour which may become safety-relevant (Dell'Erba and al. 1994).

- PLN employed their native language more frequently than EXE (50% vs. 35% of speech turns); this could be due to the kind of traffic they had to manage: in the aerodrome area there is more local and tourist transit traffic than in the approach area, and it is not uncommon for pilots to be personally known by the controllers.

4.4.1.3. Corrections of miscommunications

Procedural deviations may produce non-routine transactions, which require additional collaborative effort in order to indicate and rectify actual or potential misunderstandings. Non-routine transactions may in turn produce other procedural deviations, which may further increase misunderstandings and the collaborative effort needed to clarify problems.

Controllers rectified 49% of the incorrect read-backs.

They also spoke more rapidly when correcting than when presenting the original message.

Controller repeats or clarifications are of shorter duration than the original message (Cardosi and Boole, 1991).

Pilots usually read-back the corrected information (88% of corrections). However, they often drop their call-sign when doing so (50% of cases), providing additional evidence that procedural deviations (missing call-signs) may result from and lead to non-routine transactions.

In the case of call-sign confusions, controllers corrected the unintended pilot in 77% of cases.

4.4.2. Methods of miscommunication assessment

4.4.2.1. Analysis of speech: transcription, annotation, classification

A complete methodology for the study of error communication was developed by Bouraoui and Vigouroux (2005).

Initially, they developed a transcription and annotation methodology based on a classification of the oral corpus at different levels:

- Orthographic: putting what is said in writing, along with, possibly, the environment sounds. This level can also be augmented by labels of prosodic and extra-linguistic phenomena, such as pauses, hesitations, and so on;

- Phonetically: transcribing what has been said in an I.P.A. (International Phonetic Alphabet). This level is useful for learning acoustic models for automatic speech recognition systems and the various pronunciations of a word (mother tongue for instance).

- Grammatical: assigning grammatical categorisation to words in a sentence. Some analysts also lemmatise words, i.e. any inflected word is reduced to a canonical, basic form, called a lemma;

- Semantic: this level can be processed in different ways. For instance, words and/or sentences may be annotated according to their meaning. On the other hand, the annotator may also focus his interest on the language acts expressed in sentences. In the case of a corpus containing dialogues, it may also be the dialogues acts which are of interest.

- Dialogic: this relates to the structuring of the utterances by dialogue participants. The annotation methodologies for this level are generally based on the works for modelling dialogue and the combination of its components. To sum up, dialogue is subdivided into different hierarchical levels. The main levels, from higher to lower, are: language act (the smallest unit), intervention (by a given speaker, may consist of several language acts), and exchange (set of interventions related to a given topic).

Following examination of the corpus, the authors defined the following classes of errors:

- Attribute: alphanumeric data that can be considered as an argument of a command (for example: aircraft call-sign, position, town, etc.).

- Command: a term corresponding to an order, such as "climb" or "request" substituted for another.

- Utterance structure: a word or a group of words is not in its correct position in the utterance.

- Language used: the speaker does not speak in the correct language.

Finally, when an error is noticed, whether it is by the speaker or interlocutor, this gives rise to various correction and self-correction strategies:

- Self-correction: one kind of self-correction is the false start.

- Correction of a previous utterance: a short dialogue between a controller and a pseudo-pilot.

- Correction from the interlocutor: here again, a dialogue between a controller and a pseudo-pilot.

As regards the results, the authors found the following percentage of errors by category:

- Attribute: 51.36%

- Command: 36.19%

- Utterance structure: 4.28%

- Language: 8.17%

In addition, they found that the most frequent kinds of errors concern "attribute errors" such as call-signs. This is not surprising:

- Memorising values demands an important cognitive load, especially for novice controllers.

- Nearly all utterances contain at least one reference to a call sign, speed, etc.

The same reasoning can be applied to "commands". However, there are 1.5 times fewer errors committed on "commands" than on "attributes". This can be explained by the fact that "attributes", especially call signs and positions, are quite complex sequences of numbers and letters. Furthermore, they are only used in the ATC context. Consequently, they necessitate a considerable cognitive load, thus leading to more errors.

The authors then gave the percentage of the various kinds of correction found in the corpus:

- Self-correction 90.27%.

- Correction of a previous utterance: 6.23%.

- Correction by the interlocutor: 3.50%.

It appears that the most frequent kind of correction is the first one: the speaker corrects himself, during his current utterance.

Most authors acknowledge that, at the end of the speech production process, the interlocutor checks what he actually said, as opposed to what he intended to say.

4.4.2.2. Analysis of miscommunication types and associated human factors

Because there are many aviation accidents/incidents in which the main factors were misunderstandings between pilots and controllers, several studies have addressed errors in communication.

The purpose of Chang's research (2007) was to analyse miscommunication types and human factors that caused these misunderstandings from transcripts of controller-pilot incident reports.

The function of ATC phraseology is to achieve the same meaning of cognition for pilots and ATCOs. The ASRS (Aviation Safety Reporting System) indicates that 70% of the reports involved one type of oral communication problem at least. According to these results, it would be interesting to study the effect of oral communication errors on the risk to aviation safety.

Communication errors caused by pilots and controllers are not limited to language or action-related errors. Chang and al. (2007) showed that communication errors were induced by the interaction of major complex factors in the information transmission process. Hence, the communication errors are classified and induced by 3 types which are:

- Clearance content.

- Syntax/linguistic types.

- Hear-back/read-back in advance.

Chang et al. found 17 communication error types classified on the basis of the transcripts of 30 incidents referring to related literature.

- Three error types specific to ATCOs, including:
    - Published clearance forgotten by air traffic controllers.
    - Incomplete clearance/information.
    - Errors in published clearance/instruction.

- For pilots only, there are 2 types:
    - Improper operation by pilots.
    - Pilot violations.

- Twelve error types relate to both pilots and ATCOs:
    - Errors in Syntax Format.
    - Incomplete Call Sign.
    - Incomplete Hear-back/Read-back.
    - Incomplete Clearance/Information.
    - Uncorrected Responders.
    - Uncorrected Receivers.
    - No Response.
    - Phraseology Misused.
    - Errors in Hear-back/Read-back.
    - Errors in Clearance/Instruction Published.
    - Errors in Information.
    - Call Sign Errors.

According to Chang and al., the most frequent type is the incomplete call sign (61.3%).

The second most frequent type is incomplete clearance/information (12.5%).

The third is errors in syntax format (11.4%).

Many communication errors were caused by non-standard phraseology format and syntax. The more complex the dialogue content, the more frequent the communication error types and quantities.

Due to the increasing complexity of aviation operation, controllers always pay more attention to handling extra situations and solving problems. In the case of ATC incidents, the more complex the aviation-controlled situation, the greater the opportunity for air traffic control phraseology errors.

Finally, the main communication error types were call sign errors, errors in syntax format and misused

phraseology caused by these factors.

As regards the human factors which can influence communication efficiency, authors divided them into 3 categories: psychological, physiological and other (seeTable 4-7STYLEREFSEQ).

Table 4-7: Human factors influencing communication efficiency

Human Factors	Contents
• Physiological	Age, Physical, Workload, Fatigue, Attention Resource, Distraction, Expectation, Memory Limitation,
• Psychological	Situation Awareness, CRM, Time Pressure, Cognition, Organization Climate, Teamwork, Position, Nationality Work Experience Professional
• Others	Training, Education, Culture, Race

4.4.2.3. Analysis of incidents involving pilot–controller miscommunications

The study by Van Es (2004) provided an analysis of the 444 incidents related to air-ground communication between controllers and pilots. The identified incidents occurred from August 2002 to July 2003. The analysed incidents are representative of the situation in Europe. The study is limited to commercially operated aircraft with a takeoff mass of 5,700 kg or higher.

The following consequences are defined in the taxonomy:

- Altitude deviation - A departure from, or failure to attain, an altitude assigned by ATC.

- Runway transgression - the erroneous or improper occupation of a runway or its immediate vicinity by an aircraft that poses a potential collision hazard to other aircraft using the runway, even if no other aircraft were actually present (definition taken from ASRS).

- Wrong aircraft accepted clearance – Self-explanatory.

- Prolonged loss of communication - No response from subject aircraft when called by ATC or other aircraft. Typical duration of communication loss in terms of minutes or more.

- Loss of separation - Less than the prescribed separation between aircraft.

- Heading or track deviation - Failure to fly assigned heading/track.

- Instruction issued to wrong aircraft – Self-explanatory.

- Unknown – Self-explanatory.

- None – Self-explanatory.

The following generic communication problems are used in the taxonomy:

- Read-back/Hear-back errors - the pilot reads back the clearance incorrectly and the controller fails to correct the error. Also used when a pilot of the wrong aircraft reads back the instruction.

- No pilot read-back - A lack of a pilot read-back. The pilot does not indicate to the controller that he/she understands the clearance by repeating (reading back) the message.

- Hear-back errors - The controller fails to notice his or her own error in the pilot's correct read-back or fails to correct critical erroneous information in a pilot's statement of intent.

- Communication equipment problem - Problems caused by the improper functioning of communication equipment in the aircraft or on the ground.

- Loss of communication – Self-explanatory.

- Other – Self-explanatory.

Van Es gave a list of various factors involved in the communication incidents (Table 4-8).

Table 4-8: Overview factors

FACTORS	
Ambiguous phraseology	Sleeping VHF receivers*
Blocked transmission	Partial readback
Content of message inaccurate/incomplete	Pilot accent/non-native
Controller accent/non-native	Pilot distraction
Controller distraction	Pilot expectation
Controller fatigue	Pilot fatigue
Controller high speech rate	Pilot high speech rate
Controller non-standard phraseology	Pilot non-standard phraseology
Controller workload	Pilot workload
Frequency change	Radio equipment malfunction - air
Frequency congestion	Radio equipment malfunction - ground
Garbled message	Radio interference
Issue of a string of instructions to different aircraft	Similar call sign
Language problems	Stuck microphone
Long message	Untimely transmission

Sleeping VHF receivers - loss of communication type in which the VHF frequency becomes silent for a period of time.

4.4.2.4. Analysis of ambiguities in pilot–controller communications

In 2002, Corradini was interested by ambiguity because, according to the author, ambiguity is a major cause of miscommunication in ATC. Ambiguities in pilot–controller communications can occur at different levels:

- Phonetic/perceptual ambiguity: words, nouns and number homophones or near-homophones can cause semantic misunderstandings or confusion regarding the identity of the addressee (Grayson and Billings 1981). A similarity between the call-signs of two different aircraft might produce interference between the call-sign actually uttered by the controller and that relating to another aircraft.

- Lexical/semantic ambiguity: this kind of ambiguity is essentially due to the absence of the standard phraseology or to deviations from it.

- Pragmatic ambiguity: qualitative aspects of spoken language, such as the pauses and the intonation, might produce interpretative ambiguities.

In addition, Corradini established taxonomy of ATC miscommunications and ambiguities forming the grid designed to detect the communication phenomena relevant for ATC. A set of basic categories is identified on the basis of the following sources:

Literature on ATC communication (Morrow and al., 1993; Seamster and al., 1992; Cushing, 1994; NASA-ASRS 1994).

Earlier studies, where both controllers and pilots are interviewed (Cacciari and al., 1997; Depolo and al., 1997).

Field observations.

The taxonomy is structured in the following categories:

- 1) Organisation of the transition:
    - o Routine transitions where no misunderstanding or linguistic deviation from ICAO norms occurs.
    - o Non-routine transitions containing some form of misunderstanding.
- 2) Problems with the medium (radio).
- 3) Lack or misuse of the ICAO phraseology. Four subcategories are distinguished:
    - o Cross-linguistic factors:
        - ▪ 3.1.1 The native language.
        - ▪ A mixed language.
    - o Use of non-standard expressions:
        - ▪ 3.2.1 Collective non-standard expressions.
        - ▪ Individual non-standard expressions.
    - o Omissions:
        - ▪ Clearances, information (about meteorological conditions, take-off/landing time, aircraft position), parameters (such as altitude or speed), words or numbers.
        - ▪ Acknowledgements.
        - ▪ Call-signs.
    - o Redundancies:
        - ▪ Repetitions of information or instructions.
        - ▪ Politeness formula (e.g., thanks, greetings).
        - ▪ Negotiations.
- 4) Confusions of homophones/interference:
    - o Confusion of numbers (flight parameters, meteorological information).
    - o Confusion of call-signs or parts thereof.
    - o Confusion of words.

The results suggested that the taxonomy designed was appropriate for capturing a variety of miscommunications and ambiguities in ATCO communications.

Taxonomy of communication errors

In 2001, Bailey and al. provided an easier taxonomy of communication errors based on the following items:

- Phraseology.
- Transposition.
- Misunderstandings.
- Read-back: altitude and clearance.
- Identification.
- Acknowledgment.
- Other.

4.4.2.5.   Synthesis

Morrow's study confirmed that:

- Long ATC messages tend to overload pilot memory and create problems that disrupt routine communication.

- Certain types of problems are more likely after long ATC messages.

- Requests to repeat the ATC message were particularly frequent, showing that pilots did not hear or did not understand all or part of the message.

- While shortening messages improved accuracy, it tended to lengthen communication, because the number of turns required to convey the same amount of information increased. However, most of this additional communication was routine.

- Transactions with long ATC messages had more problem turns and speech acts than transactions with short messages.

- Accuracy improved at the expense of transaction length when controllers divided long messages into shorter ones.

- The timing between messages influenced communication accuracy.

- Long messages overloaded pilot memory so that they were unable to understand all of the message.

- These problems were immediately indicated and quickly rectified.

- Short messages were usually understood since they imposed fewer demands on pilot working memory.

- Delivery of the second ATC message, however, sometimes disrupted the process of remembering and/or carrying out the first message.

- Because of this interference, pilots tended to forget the command and had to request a repeat or confirmation after responding to the second message.

- Rapid initiation of acknowledgement to the first short message may reflect pilot perception of time pressure after the first message.

- Controllers rarely present several messages to the same pilot in quick succession.

The communicative performance of ATCOs was affected by chrono-psychological and organisational factors. In fact, according to Corradini in 2002, an increase in communicative incorrectness was found in the messages produced during nightshifts. Such increase characterised in particular the period of minimum workload, where a decrease in vigilance levels was presumably associated with an increase in mental fatigue. The fact that no other peak of linguistic incorrectness was observed supports the hypothesis that vigilance plays an important role in determining operators' performance efficiency, as also suggested by the fact that the most correct communications occurred during the morning shift. The workload effect was not so clear-cut; nonetheless communication accuracy and correctness decreased when the workload level was low.

Finally, controllers and pilots created an alternative linguistic code instead of using the correct standard phraseology – a code inspired by standard phraseology but also strongly deviating from it, particularly with respect to: the use of native language instead of English; the use of collective and individual non-standard routines; the omission of words and numbers; the omission and incorrect formulation of call-signs; the presence of redundancies as politeness formula, repetitions, negotiations, expressions, and intrusions of natural language. Even if this jargon was generally well understood, it was capable of producing ambiguities and misunderstandings that might be fatal, especially in non-standard or emergency situations where cognitive, intentional and time resources are modified and restricted.

4.4.3. Interruptions

4.4.3.1. Definition

Interruptions are daily occurrences in commercial aviation operations. They occur in all phases of flight and in all types of operations.

An interruption was defined as occurring only when an external event (stimulus) caused at least one pilot to stop performing (interrupt) an ongoing task (Damos, 2001). Furthermore, the event must have had two characteristics:

- It must have been unanticipated. For example, if a pilot contacted air traffic control (ATC) for information and was told to stand by, the subsequent call from ATC was anticipated and was assumed not to interrupt any of that pilot's ongoing activities.

- The event must have had a distinct beginning. This characteristic excluded events, such as turbulence, that may have a gradual onset.

4.4.3.2. Methods of interruption analysis

4.4.3.2.1. Verbal versus visual interruption

4.4.3.2.1.1. Risser's study (2004)

Information between the flight deck and air traffic control (ATC) is typically communicated via voice. While maintaining communications with ATC, pilots must also perform their duties within the cockpit (e.g., scanning outside, monitoring displays, communicating with the aircrew, completing checklists, etc.).

Risser, in 2004, focused on the information processing characteristics of text and speech that differ and may ultimately affect pilot performance. Furthermore, speech and text message formats may also differ in their susceptibility to interruptions from other tasks performed concurrently (Risser and al., 2002; Risser and al., 2003).

Indeed, verbal ATC information can disrupt the conduct of flying tasks.

Specifically, performance of flying tasks was found to be affected when resources used the same processing code. For example, verbal interruptions had a greater negative impact on reading task performance than visual interruptions because both speech and text formats utilise a common underlying verbal code.

Performance will decrease because both the commands and verbal interruption task use the phonological loop.

The authors showed that visual interruption induced poorer performance when commands were presented as text rather than speech. This suggests that when errors are made in the text condition, supposedly during periods of high demand on resources, interruption is more problematic because greater demands are placed on working memory.

4.4.3.2.1.2. Latorella's study (1997)

The role of the pilot as a task manager on the flight deck is increasingly prominent.

One aspect of task management is "interruption management," i.e. attending appropriately to and accommodating new, interrupting stimuli and tasks. Interruptions naturally and frequently occur in the dynamic and multi-tasking context of the commercial flight deck. While pilots usually manage interruptions without consequence, basic research shows that interruptions tax performance and can contribute to aviation incidents and aviation accidents. Therefore, it is important to identify those attributes of interrupting and ongoing tasks characterising pilots' interruption management performance.

This experiment addresses the performance implications of whether the interrupting task is conveyed visually or aurally and whether this interruption intrudes upon a visual or auditory ongoing task.

The author based her study on three hypotheses:

- Interruptions presented aurally should be more quickly attended to than interruptions presented visually: auditory information is more attention-directing than visual information (Stanton, 1992; Posner and al., 1976). Applied data link research found that pilots typically responded more rapidly to data link, or visual, messages than to auditory radio calls (Kerns, 1990).

- Auditory ongoing tasks should be more resistant to interruption than visual ongoing tasks: Interrupted visual procedural tasks provide an externally available reminder to resume the interrupted task and therefore do not require subjects to retain an internal representation of the interruption position. This reduced memory load and external aid should facilitate subjects' performance compared to that with interrupted auditory procedural tasks.

- Same-modality conditions should negatively affect performance more than cross-modality conditions: tasks are more easily performed simultaneously when they require different processing resources. A visual task should be easier to perform in concert with a secondary task requiring auditory processing than with another simultaneous, integrated visual task.

Fourteen current commercial airline pilots performed approach scenarios in a fixed-base flight simulator. Air traffic control instructions, conveyed either aurally or visually (via a data link system) interrupted a visual task (obtaining information from the Flight Management System) and an auditory task (listening to the automated terminal information service recording).

The results show that aurally presented interruptions were, on average, acknowledged more quickly than visually presented interruptions, although this difference was not significant. However, as hypothesised, auditory ongoing tasks were more resistant to interruption than visual tasks as evidenced by much longer acknowledgement times and, when interrupted by a visually conveyed task, much longer interruption initiation times. Results indicated some evidence of the hypothesised advantage of cross-modality conditions; specifically, subjects committed more than three times as many errors in procedure downstream from the interruption in the auditory/auditory case than in any other case. The hypothesised advantage of the cross-modality condition was not exhibited in other measures of interrupted task performance. On the contrary, subjects committed more errors in performing the interrupting task itself in cross-modality conditions. Only two significant main effects appear to be robust in light of interaction effects: 1) Auditory interruptions extend overall performance time more than visual interruptions, perhaps because visual interruptions persist and therefore may be integrated more efficiently; 2) Interruptions to auditory tasks were not acknowledged as quickly as interruptions to visual tasks.

Rather than supporting theoretically derived hypotheses completely, results indicated that interruptions significantly degraded performance in the four experimental conditions in different ways. Performance of visually presented interrupting tasks in auditory ongoing tasks will not be started for, on average, twice as long as for any other condition. Auditory interruptions to auditory tasks produce three times as many procedure performance errors as any other condition. Auditory interruptions to visual tasks appear to produce more interruption performance errors. The visual interruption/visual ongoing task condition was most resistant to performance degradations induced by interruption management. Interestingly, subjects exhibited individual differences in the speed with which they acknowledged interruptions for both the task modality and interruption modality manipulations.

Finally, the study explicitly addresses the effects of ATC interruptions presented via radio and via a visual data link interface on flight deck procedure performance.

Applied research is concerned with the human performance implications of replacing traditional voice communications to the flight deck with newer, visually-presented communications afforded by digital data link technology.

4.4.3.2.2. Interruption and task prioritisation

In Risser's study (2004), all of the inferences drawn concerning interruptions rest on the assumption that an event could interrupt an ongoing activity only if the event had a higher priority than the activity. That is, if an event and an activity had approximately the same priority, the event had about a 50% chance of interrupting the activity. All of the analyses were constructed to determine if the frequency of interruption for a given activity was statistically greater than 50%. Of the four statistical tests, only the one examining ATC communications versus checklists was significant.

Risser's study showed that an ATC communication had a probability of 1.0 of interrupting a checklist. Thus, ATC communications had a higher priority than checklists.

More importantly, perhaps, the tests examining ATC communications versus housekeeping tasks, ATC communications versus cockpit communications, and TCAS/automatic warnings versus housekeeping tasks were all non-significant.

A priori, ATC communications may be assumed to have a high priority and should interrupt ongoing activities: they often contain safety-critical information, are not repeated (unless missed), and are usually time-critical. Why did they fail to interrupt housekeeping tasks and cockpit communications?

The answer to this question may lie in the nature of the ongoing activity:

- Checklists, briefings, personal activities and programming all had high probabilities of being interrupted. These activities were all relatively long and all were composed of easily identified subunits, such as the steps of a checklist.

- In contrast, housekeeping activities, which had low probabilities of interruption, were relatively short. At least some of these activities, such as tuning the radio frequency, could not be broken down easily into smaller units. The fact that housekeeping tasks were short and not easily segmented could explain the counterintuitive (though non-significant) tendency for TCAS/automatic warnings to have a lower priority than housekeeping tasks. Thus, the length and structure of the ongoing activity may affect its likelihood of being interrupted.

The probability that cockpit communication activities will be interrupted may be affected by different factors. Of the 63 communication activities, 57 reflect talking between crew members. Of these, only 33 (57.9%) were interrupted by the onset of the event, a relatively low percentage.

Some pilots talk "through" ATC communications. To date, no explanation for this continued talking has been given. The tendency to continue talking may represent a communication style or the pilots simply may not hear the communication. Latorella (1998) also noted a similar phenomenon. The author found that pilots were much slower to acknowledge an event when the ongoing activity was auditory as compared to visual.

Another point about interruptions needs to be discussed: interruptions had a positive effect on crew performance: No crew errors or FAR violations were observed. Additionally, the observer did not detect any errors of omission or commission.

In summary, this study examined interruptions in order to determine relative task priorities in commercial flying. ATC communications were found to have a probability of 1.0 of interrupting checklists, which indicates that ATC communications had a significantly higher priority than checklists. Each member of two other event/task pairs (ATC communications versus cockpit communications and ATC communications versus housekeeping tasks) had approximately the same priorities. More importantly, however, the results of this study suggest that the length and structure of the ongoing activity may play a decisive role in its likelihood of interruption, with longer activities with natural subunits having a higher likelihood of interruption than shorter activities with no natural breaks.

4.4.3.2.3.   Implications for data link

Some pilots felt that the arrival of the data link message might act as a distraction while they were already responding to the voice transmission.

From the pilot's perspective, it has been recommended that whenever a data link or voice communication requires a response, that response should be given in the same medium. Controllers have also supported this approach. Talotta and al. (1988) consider cross-media protocols to be unnecessarily complex and operationally unacceptable. Their findings conclude that an acknowledgment by the crew is necessary for data-linked instructions. Moreover, in situations where the crew intends to comply with the instruction, the response should be delivered via data link.

In Kerns' study (1991), mean acknowledgment times for the data link conditions are slightly longer than the average 10 seconds found in previous investigations (Kerns, 1990). The trend observed in this experiment is counter to previous results which suggest that pilots interpret and acknowledge data link messages faster than voiced messages (Kerns, 1990). Pilots take longer to resume after a data link interruption than after a radio interruption.

Based on previous literature and the results of this research, several interface features can be proposed for the reduction of the deleterious effects of interruptions. The advantages of referenceable interrupting task information were evident in the modality results. Presenting ATC calls via data link provides one solution to this problem, but creates other concerns. Flight deck performance may improve by providing a referenceable version of aurally-presented interrupting tasks, e.g. a playback feature allowing pilots to confirm their interpretation of interrupting annunciations. If a data link system is aboard, radio communications might, through speech recognition technology, be referenceable as a visual playback feature. Several studies demonstrate the potential benefits of providing an externalised marker or reference indicator for the interrupted task (Field, 1987; Kreifeldt and McCarthey, 1981). Theoretically, interruptions to inflexible task sets should be more destructive than interruptions to procedural task sets (Adams and al., 1995). In this situation, interfaces could provide historical information about tasks performed to improve interruption resiliency.

4.4.3.2.4.   *Summary relating to interruptions*

Longer message sets compromise the ability to recall and execute ATC-like commands in a simulated cockpit. Performance also suffers more under verbal than visual interruption when correctly setting the controls. These findings were obtained in the absence of a presentation format effect suggesting that both speech and text messages utilise an underlying verbal code and are therefore more susceptible to verbal interruption. More errors may occur during the presentation of text information, especially when there is a greater demand on working memory or additional visual scanning requirements.

Where data link is concerned, changing the message format from speech to text should not have a detrimental effect on the ability to recall and correctly execute commands (Risser and al., 2003; Scerbo and al., 2003). Additionally, potential sources of task interruption that involve verbal processing or the control of attention (e.g., task switching, decision-making, etc.) may be a more serious problem.

ATC communications interrupted more than one pilot 55.6% of the time for two-person crews and 80.0% of the time for three-person crews (Risser et al., 2003; Scerbo et al., 2003). The pilot flying (PF) is interrupted surprisingly often. Again, since radio communications are typically assigned to the PNF (pilot non flying), we would anticipate that only the PNF should be interrupted by ATC. However, when only one pilot is interrupted by ATC, 33.3% of the interruptions involve the PF.

The probability that one of the flight crew will detect the effect of an interruption was about 0.54 for two-person crews and 0.61 for three-person crews. The interrupted pilot has a probability of 0.39 of detecting the effect. This result highlights the need for a coordinated crew response to interruptions.

Pilots, operations managers, and safety analysts have recognised the problems associated with interrupted checklists, which confirm the need for well-learned procedures dealing with interrupted checklists:

- 5 of the 21 errors reported involved checklists that were completely omitted.

- 3 involved checklists that were never resumed.

- 12 reported omitted steps.

Interruptions of the After Take-off and Approach/Descent checklists tend to have more serious outcomes from a safety perspective than do interruptions of the Before Start and Before Take-off checklists.

Pilots were rarely interrupted while programming the FMS or manipulating the automation.

4.5. FREQUENCY CONGESTION

4.5.1. Definition of congestion

Radiotelephony (R/T) congestion could be defined, by analogy with the telecommunication networks theory, as periods of time when the demand in voice communications exceeds the channel's availability, leading to excessive queuing, or even loss, of messages.

With R/T voice communications, there is no message queuing or congestion management of any sort by the system itself (it has to be managed directly by the speakers, in an adaptive manner, via the party line).

Authors who focused their analysis on criteria defining cases where the congestion limit was reached considered periods of time where the speech acts were separated by less than 11 seconds (which is the average duration of exchanges for ACC sectors) and thus during which any additional exchange would have had to be delayed - or would have generated waiting time for other speakers.

4.5.2. Quantitative aspects of congestion

The analysis of VOCALISE's ACC traffic samples (Graglia, 2005) revealed:

- An average of 24 minutes (cumulative duration) of such R/T "congestion" time per hour (corresponding to the definition above, on average over the total 60 hours of recordings),

- Between 18 minutes and 29 minutes per hour of congestion depending on the sector (on average over 5 hour-long recordings per sector).

The most heavily loaded sample shows 37 minutes of "congestion" (cumulative duration over 1 hour).

In other words, the frequency is "congested" approximately 40% of the time on average (and up to 60% over a particular one-hour sample).

4.5.3. Consequences of congestion

These "congested" periods could be problematic in terms of workload for the controllers (having to cope with the air-ground communications bottleneck while still managing the traffic flows as efficiently as possible in a safe manner) and mainly in terms of channel availability for the pilots (who may have particular requests, or information to provide to the controllers).

Nevertheless, during these congestion periods, as stated above, speakers adapt their use of the R/T channel to its limited availability (in terms of number, duration and nature of speech acts) so as to avoid the complete saturation of the medium: pilots and controllers cope with higher communication workload imposed by frequency congestion by streamlining acknowledgments.

4.5.4. Factors of congestion

Many studies have reported on some human factors influencing the communication process in the aeronautical framework. When spoken, pilot-controller communications comprise three components: production, perception and understanding, each component with different delays.

The factors correlated to delays are threefold:

- Time delays.

- Occupancy time.

- Step-on.

4.5.4.1.   Time delays

To understand the potential impact of time delays in controller–pilot communication, it is important to consider in detail the complex multiple-dynamic ATC task environment. Rantanen et al. (2004) point out that, to carry out their tasks, controllers rely on a mental picture comprising static information on the airspace layout, the rules and standard procedures regulating the conduct of flights, aircraft flight plan information and performance characteristics, and the dynamic traffic situation changing from moment to moment. Given the dynamic nature of ATC, the temporal aspects of the controllers' mental picture are apparent, as are the temporal demands of their tasks: controllers need to anticipate aircraft trajectories and pilot intentions well into the future, plan their actions, and then execute the planned actions at a proper time and in an appropriate sequence.

Consequently, time lags, which are always detrimental to human performance in control tasks, are particularly undesirable in ATC. Controllers control traffic by issuing specific instructions and commands to pilots who then after an unavoidable delay execute the instructed manoeuvres. If time delays are very long or highly variable, accurate prediction of their consequences becomes very difficult, substantially increasing controllers' mental workload and the probability of errors.

A thorough understanding and mitigation of the effects of time delays on controller performance is therefore very important.

Three specific types of time delays between the controller's instructions and their actual execution in the cockpit can be identified:

The first, termed audio delay (AD), is a product of the technology used in voice transmissions and is defined as the time elapsed from the depression of the controller's microphone's transmit key to the moment the controller's voice is heard in the aircraft cockpit. It should be noted, however, that this definition does not account for the situation where there is an additional delay between the microphone key press and onset of the controller's speech. This definition also includes the converse, i.e. air–ground communication delays. An important characteristic of this type of delay is that it is constant or nearly constant and very short (less than 1 sec).

The second delay type is a result of the delay in human (i.e., pilot) performance in executing an instructed manoeuvre or responding to the controller. This delay, here termed pilot delay (PD), is defined as the amount of time elapsed from the moment the pilot hears the controller's transmission to the moment he or she unkeys the microphone after responding vocally or manipulating aircraft controls in response. This delay depends on the complexity of the requested manoeuvre or information, other concurrent activities in the cockpit, and the pilot's expectancies of the controller's instructions. Delays of this type are highly variable and can be relatively long, up to several seconds.

The third type of delay that can be identified is controller delay (CD), defined here as the time elapsed from the moment the pilot releases his or her microphone key after ending a transmission to the moment the controller keys his or her microphone in response.

Delays in receiving the critical information may thus result in a loss of separation between aircraft. Because the communication is two-way and several (a minimum of two) transmissions are necessary, the delays in information transmission compound. Hence, the total delay before the controller receives the requested piece of information is a multiple of the individual transmission delays.

A number of studies looked at the amount of time or the number of transmissions required to complete a communication when using data link versus voice communication.

In Sarter's study in 1997, it was shown that total transaction time (i.e. the entire time span when a controller would be concerned with a given communication) was twice as long for data link as for voice.

In his study, Kerns (1991) indicated that the average transaction time for data link was about twice as long as the average voice transaction time:

- 21 sec for data link versus 10 sec for voice according to Talotta and al. (1990) and

- 19 sec for data link versus 8 sec for voice according to Waller and Lohr (1989).

Of course, this has implications for controller workload.

This can be explained by various factors such as the possibility of delayed responses to data link messages or by more time being required to assemble data link messages.

Moreover, intra-cockpit communication influences the transaction speed range of the data link system. Navarro explained in 1999 that because only one pilot (the PNF) acknowledges the message, there is a delay before he or she can pass along its content to the PF or discuss actions and their potential consequences. Consequently, the message acknowledgment time is longer than when radio communication is being used. On the positive side, data link technology increases the number of intra-cockpit communications.

Also, the ability to delay attending and responding to an incoming message until competing task demands allow this can create problems with respect to the timeliness and relevance of information. Temporal gaps in the communication between two parties may require that once the conversation is picked up again, it may be necessary to first establish what has been and is now being talked about. During radio transactions, both pilots receive the message simultaneously, and they hypothetically have a similar situational representation. With data link, the PF's representation may be different from the PNF's representation because they may not share the same information. As previously noted, this problem may be a positive factor of interaction because it requires aircrew to communicate with each other (more often than when using voice media).

In practice, pilots execute these tasks sequentially. They perceive written messages as less important than oral messages even when they include the same information (Hinton & Lohr, 1988). They evaluate ATC requests as less critical when they are written.

Moreover, a request via data link does not necessarily imply an immediate response. Pilots do not answer ATC immediately. This delay may cause problems for controllers in congested areas, such as terminal areas, where the traffic control task is intense (Lee, 1989a). Pilots answer with less urgency a written message than an oral message even if they should answer it as quickly (Lee, 1989b).

When time is critical, pilots prefer radio transmissions (Waller and Lohr, 1989).

Furthermore, crew response time has been shown to vary with flight phase. Waller and Lohr (1989) showed significant differences in mean crew response time between the en route, arrival, and departure phases. Overall, response times tended to be shorter and less variable during the arrival phase. Mean response time appeared to decrease with altitude and distance to the runway. The standard deviations of the response times also decreased with altitude and distance to the runway.

4.5.4.2. Occupancy time

As has been seen in the quantitative aspects of pilot-controller communications (VOCALISE's study, Graglia, 2005), out of the incorrect read-backs, 30% are simple "say again" requests, and another 30% requests for repetition or confirmation of route information.

In turn, these requests trigger confirmations - "that's correct" - or message repetitions. Together with spontaneous repetitions they add up to an average 5 controller repetitions per hour (half of them during transfers) and 3 from pilots, and represent 4% of the total R/T occupancy time.

Overall, the management of misunderstandings over R/T accounts for 7% of the total R/T occupancy time (and up to 9% in some sectors), which can contribute to the problem of congestion.

4.5.4.3. *Step-on*

Today's terrestrial communications channels typically include a 225-msec controller delay when a controller calls an aircraft and practically no pilot delay when a pilot calls the controller (Nadler, 1993). The sender must wait until the setup delay has elapsed before speaking. Any portion of the message uttered before the setup delay has elapsed will not be transmitted, resulting in message clipping.

A push-to-talk switch changes the mode from receiver (default) to transmitter. Thus, for example, the controller will not hear pilot messages that arrive while a controller has the push-to-talk switch depressed. Similarly, the pilot will not hear controller messages that arrive while the pilot is transmitting. Setup and propagation delays lengthen both the time interval between the push-to-talk switch action and the time before the intended receiver is aware that a message was sent. They thus increase the probability that the intended receiver will also begin to transmit, blocking reception of the message in transit. Such blocking is known as a step-on. It is important to take this phenomenon into account because:

- Step-on was among the identified causes of the worst aviation disaster in history.

- Step-on has resulted in aircraft call-sign errors reported anonymously to the Aviation Safety Reporting System (ASRS). Simultaneous transmissions obliterated call-signs, induced misperceptions, blocked transmissions and acknowledgements, and contributed to call-sign similarities during all phases of flight operations.

- Blocked frequency events other than frequency congestion per se caused an estimated 15.5% of all aircraft/ATC communication losses reported to the ASRS.

- Simultaneous transmissions caused 22 AFC operational errors and deviations and 17 pilot deviations (events in which the required separation between aircraft was not maintained) during 1988 and 1989 (Graeber, 1990). Although these numbers indicate that step-on caused less than 1% of all operational errors and deviations, step-on may also have contributed to problems in overlapping categories, such as pilot and controller communication technique, similar-sounding alphanumeric, frequency congestion, and discrete information transfer failure.

Moreover, in his study, Nadler showed that, although there was a significant effect on communications workload, no delay effects were expected because calls made by one pilot were heard by others in the same sector with no delay. However, the regression analysis indicated that there was a statistically significant delay effect and a statistically significant delay caused by communications workload interaction. There was significantly more controller-pilot / pilot-controller step-on in either of the very high communications workload satellite-delay conditions than in either of the very high communications workload non-satellite-delay conditions.

At the very high level of communications workload, the addition of the 260-msec satellite delays to the 225/0 baseline delay condition resulted in a 150% increase in controller-pilot step-on, and when added to the 169/70 delay condition, satellite delays resulted in a 176% increase in this type of step-on.

One of the likely impacts of step-on is the need for the sender to retransmit information which might have been lost due to the step-on. At worst, step-on can generate retransmissions that would themselves be blocked by step-on:

- 48.7% required no additional calls.

- 49.6% of the step-on required one additional call.

- Only 1.7% of the step-on required two additional calls.

Based on these results, areas with very high communications workload should continue to rely on ground-based communications.

In addition, the results emphasise the need for programs such as data link and standardised taxiway routing intended to reduce pilot and controller communications. These programs are likely to decrease the incidence

of step-on. The results also suggest the need for improved aircraft call-sign identification uniqueness, which would mitigate step-on-induced addressee problems.

4.5.5. Digital technology as a solution for congestion?

Nowadays, for most of continental airspace, communications between pilots and air traffic controllers are exclusively effected via radiotelephony (R/T). However, in areas where the traffic density is high, making congested R/T channels a real brake on capacity increases, the limitations of such a medium are being reached. A number of corrective measures have been taken over the past few years (such as splitting the airspace into smaller sectors and reducing the spacing of the VHF channel to 8.33 kHz in Europe), but these measures would not seem able to cope with the air traffic growth expected in the short and medium term. In addition, some of R/T 's core limitations, such as poor integrity due to signal quality, also need to be overcome. On the other hand, for many years now, the introduction of air-ground data link communications has been considered at international level as the way of overcoming the shortcomings of R/T, while significantly improving the level of air-ground information sharing. Numerous activities have been carried out, ranging from fast-time and real-time simulations to pre-operational field trials, in order to investigate the feasibility, acceptability, cost benefits and safety aspects of initial data link concepts.

The main advantage of the replacement of VHF communications by data link is the reduction in bandwidth congestion, which is becoming saturated (increase in traffic). Communication problems between aircraft and ATC, especially in terminal areas, will be greatly reduced. Because the crews ask for or receive clearance in writing, it would leave enough time for radio exchanges to enable pilots to communicate verbally with controllers without too many problems. Air-ground dialogue would be easier and messages more accessible, and the crew would have access to many systems, such as meteorological information or the maintenance office.

Nevertheless, data link has some drawbacks, which we have seen in a previous chapter. Implicit information, for example, is not and cannot be communicated by text. Recognition of the level of urgency is not directly accessible with a written message. The issue of "nonverbal" information transmitted in all messages needs to be examined in order to find a different solution.

So, although voice communication will remain an essential component of ATC into the foreseeable future, much effort has been expended on the development of other means of information transfer. Consequently, to alleviate the shortage of available communication channels and to replace the aging analogue radios currently in use, alternative radio systems based on digital technology have been proposed and are developed in the following chapter.

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5.   WAYS OF REDUCING ROUTINE COMMUNICATIONS

Communications, and in particular routine communications between controllers and aircrews, are a major source of controller and aircrew workload and errors. In the future, air navigation will have to cope with traffic growth, and communications will become a limiting factor for capacity, efficiency and safety.

Consideration needs to be given to evolutions in the ways routine communications are performed. Two types of evolution may be considered in the light of the technologies operationally available in the future:

- The first is to use a new medium of communications between controllers and pilots. This medium is the alphanumeric system developed through the data link concept. In this way, communications between controllers and pilots will stay the same as today, but some of them will be partially or fully performed by a medium (the data link) other than the one currently used (the R/T medium). The underlying hypothesis is that human beings can perform more communications by using two communication mediums rather than just one, or are able to perform the same number of communications, but the workload will be lower with two mediums rather than with one. The cognitive resources released by the use of the two mediums can be used to perform other tasks and cope with heavier traffic.

- The second type is different. The goal is to reduce the number of communications between pilots and controllers. Currently, some tasks require communications. The sector change for an aircraft between two control sectors is a source of routine communications between the aircrews and the controllers of each sector to deal with the frequency and responsibility changes. Currently, this process requires the active participation of the aircrews and the controllers of each sector. The technology used today by public mobile telephony (GSM) may offer a new concept for the achievement of certain tasks. Communications between the aircraft and the ground are performed not by the controllers and pilots, but by the onboard and ground systems. A future mobile ATC communication system could make some tasks that currently require communications between pilots and controllers automatic. Sector and frequency changes are a good subject for such a concept. The future mobile ATC communication system will make sectors transparent for pilots and controllers. Some tasks relating to the transfer of aircraft between control sectors will become obsolete. A positive consequence is that these routine communications will not have to be performed by people. Pilots' and controllers' workload induced by routine communications will be reduced. The future mobile ATC communication system may be seen as the foundation of the sectorless radio com concept.

5.1.   CONTROLLER - PILOT DATA LINK COMMUNICATION (CPDLC)

On the basis of the functions of the data link concept, CPDLC is the relevant function for the purpose of the analysis in this literature review. CPDLC has been the subject of various human factors studies since the beginning of the 1990s. Results are now numerous, and there is a consensus about the human factors-related use of CPDLC. These results can be presented through the human factors-related advantages and drawbacks of data link.

5.1.1. Advantages of data link

Data link communication, with aircraft selective addressing and a less noisy channel, can mitigate problems of phonetic similarities and overlapping transmissions, further reducing ambiguity in controller-pilot communications.

Morrow (1993) showed that because data link provides a more permanent visual communication medium, long messages were less likely to overload pilot working memory and create communication problems. Other researchers have proposed that the data link medium is more appropriate than the voice medium for long, complex ATC messages. However, rapidly presented messages could cause problems in both radio and data link media (Kerns, 1990).

Kerns (1991), in his literature review, discussed the results of Talotta results (Talotta and al., 1990) who found that relative to a voice-only baseline, there was a 28% reduction in controller time spent on the voice channel when 20% of the aircraft under control were data link-equipped, and a 45% reduction in controller time spent on the voice channel when 70% of the aircraft were thus equipped. These results are interpreted

in terms of the considerable reduction in voice radio frequency congestion that will be achievable with a limited data link capability. According to the report, the offloading of selected communications to the data link not only creates additional capacity on the voice channel to encourage better procedural discipline (full read-back), but also reduces the possibility of missing or blocked transmissions.

Two studies (Hinton and Lohr, 1988; Talotta and al., 1990) report that communications system capacity may be improved through the use of data link, but the mechanism postulated to explain this improvement is fewer failures in the information transfer process.

Hinton and Lohr (1988) found that with increasing levels of data link capability the number of data link transmissions did not increase as rapidly as the number of voice transmissions decreased for comparable flight scenarios. At the highest level of data link capability tested, they reported 26% fewer transmissions to the aircraft when both voice and data link were used than when voice alone was used. In this study, the highest level of data link capability included complete two-way exchange of heading, altitude, speed, and free-text messages.

Talotta and al. (1990) found an overall decrease in total-voice and data link-transmissions with increasing levels of data link-equipped aircraft in the traffic. Again, the drop in voice transmissions that was observed as data link-equipped aircraft increased was not completely offset by a corresponding increase in data link transmissions. Both studies attribute the observed reduction in total communications when both voice and data link are used to fewer missed calls and fewer repetitions of information. Other researchers have asserted that data link may improve communication efficiency by allowing more information to be packaged into a single transmission without overloading the crew's short-term memory (Hinton and Lohr, 1988; Uckerman and Radke, 1983).

Related research on interactive communication is consistent with the preceding results showing that data link improves communication's concision and with results presented in the following section showing that data link communications take longer.

From the controller's perspective, data link transaction time was considered one of the most important determinants of application acceptability and workload. As a general statement for the applications evaluated to date, controller operations do not appear to be overly sensitive to the response times associated with data link. No relationship between controller workload and communication response time has been noted.

Data link improved crew workload during a missed approach by allowing reroute information from the controller to be transferred directly from the data link into the flight management system without re-entry. These results suggest that even during the visually busy arrival phase there are circumstances when data link can reduce crew workload and "head down" time. In the non-control information class, certain weather applications have been judged more appropriate for the voice medium in the interest of providing (party-line) information to all potentially affected traffic (Diehl, 1975; Hinton and Lohr, 1988). However, this argument does not necessarily preclude making the same information available through the data link.

In addition to the obvious gains in terms of management and business information, there are many potential advantages associated with data link, including the potential to resolve misunderstandings arising from R/T failures (e.g. blocking of frequencies by simultaneous transmissions). Air/ground data link not only offers the potential to reduce the communication workload of pilots and air traffic controllers and allow them to concentrate on other essential tasks, but also helps ensure higher safety levels in air transport by potentially reducing the number of communication errors that result from mishearing.

The following list, extracted from Kerns (1994), sums up various significant benefits of data link transmission:

- Higher efficiency and capacity of the communications system.
- Unloaded memory burden from lengthy messages.
- Possibility of effective multitasking due to user-pacing communications tasks.
- Improvement of message delivery time.

- Improved consistency of procedures and message content.
- Improved information processing efficiency and accuracy due to display flexibility.
- Improved information transfer to other ATC and flight deck subsystems.

Another advantage of data link is the reduced probability of errors caused by the misunderstanding of transmitted information or by language problems between the controller and the aircrew (Navarro, 1989).

Data link could reduce:

- Confusion, when information is transmitted but the receiver did not understand a part of the message or forgot it;

- Errors, defined as when an incorrect action or event occurred as the result of the communication; and

- Repetition of all or part of the message. Maintaining the message on the display induces this reduction. For the pilots, a written message displayed on a screen is better because they do not have to memorise it or write it down. Crews can easily access the recorded air-ground transaction at any time. In addition, the following data can be checked: the identity of the sender, the time the transaction was received, and the time and the content of the answer.

With automatic data transfer between the data link interface and the flight management system control display unit (FMS-CDU), PNF workload and errors can be reduced. During acknowledgment, the system automatically executes the transfer to the FMS. The PNF does not have to insert data manually into the FMS. However, this automatic transfer may exclude the crew from the air-ground transaction loop. The crew would have a supervisory role rather than an actor role during communications.

The time saved may be used to check ATC requests and thus detect potential errors.

5.1.2. Drawbacks of data link

From the pilot's perspective, applications related to local and ground control functions have been judged unacceptable for data link communications (Hilborn, 1975; Hinton and Lohr, 1988). These include clearances to taxi and take off. The landing clearance was deemed acceptable as a data link instruction, depending on when it was issued (Hinton and Lohr, 1988). Commentary from one study suggests that pilots have reservations about the use of the data link during the departure phase from take-off to 2,000 ft and during the arrival phase for operations below 10,000 ft due to crew workload (Diehl, 1975). However, exceptions to the above concerns about tactical applications have also been identified. Groce and Boucek (1987) found that during a weather deviation scenario, the use of data link to request a heading from ATC increased pilot workload unacceptably.

Moreover, according to Sharples's study (2007), data link has the possible impact of reducing the amount of information available to flight crews, often relayed via non-verbal cues. The 'party-line' effect would also be lost. In conventional R/T communications, multiple aircraft on the same frequency are able to listen to information from other aircrews - ATC communications about weather conditions and traffic density that would not be available with the data link system (Pritchett and Hansman, 1993).

Furthermore, the absence of verbal interaction between pilots and air traffic controllers may make it difficult to establish an effective team relationship under emergency conditions where the immediacy of speech communication would be lost.

In Sarter's study (1997), many researchers and practitioners agree that even in the current ATC system, data link should not be used to transmit time-critical immediate action messages.

For the controller who is supposed to intervene only when safety requires him/her to do so, it is of the utmost importance to have the highest priority at any time. One way of dealing with this problem would be to tag messages according to their urgency - an option that has been proposed in the context of current data link designs.

It is important to keep in mind that this function involves a number of potential problems. First, it will create a new task for the sender and receiver of a message and create an additional step in the creation and screening of a message while in the current voice communication environment, the urgency of a message is often inferred from implicit voice cues (in addition to explicit cues such as the use of the word "immediately").

Also, as pointed out earlier, urgent messages may represent the majority of transmissions in the future tactical air traffic environment. As a result, their relative frequency may increase dramatically and with that, the informativeness of the label "urgent" can be questioned. Finally, the sender alone cannot determine the urgency of a message in a widely distributed network of decision-makers. It is the result of an interaction between the intentions, actions, and limitations of both sender and receiver. Thus, currently proposed schemes may not be appropriate for future ATM operations as they suggest that pilots and controllers do not have to immediately attend to messages unless they are urgent when, in fact, every message has to be checked by the receiver to determine its urgency based on context.

Another important point during any data link implementation is the "head down time". This refers to the time when the pilot looks at the flight deck instruments, rather than outside the aircraft.

With traditional transmissions, pilots use two sensory channels: the auditory channel for voice communication with ATC and the visual channel for flying. With data link, these two activities use the visual channel. If we want both pilots to have the same situational awareness during transmissions, they have to look around the cockpit to read different messages; thus, they may have some difficulty in maintaining flying activity correctly and safely. This point may not be important for the PNF but is crucial for the PF who has to fly and look outside. The time when the pilot is head down may reduce situational awareness and even endanger flight safety.

Cathode Ray Tube (CRT) displays, on which ATC messages arrive, do have certain drawbacks. CRTs are fixed and may be located out of the primary field of vision for the flying pilot, thereby creating a distraction and a perception of increased workload. To make data link information equally accessible to two-member crews, a dual presentation with CRTs mounted in front of each crew member has been used in some simulations.

Printers offer advantages especially for the presentation of longer messages.

Observational evidence reported in the literature suggests a decrease in crew attentiveness when responding to data link communications.

In 1999, Navarro summarised the advantages and drawbacks of the data link system in aviation. The results are reported in the Table 5-1STYLEREFSEQ.

Table 5-1: Advantages and drawbacks of the data link system in aviation

Authors	Advantages	Drawbacks
Corwin & McCauley (1990)	*Elimination of the continuous listening workload*	*Eliminate pilot's ability to anticipate conditions derived from continuous listening; overloading the visual channel (both communication and action)*
Hahn & Hansman (1992)	*Reduction of workload; automatic transfer of data; better possibilities to check over ATC requests*	
Hinton & Lohr (1988)		*Less importance to written messages*
Infield et al. (1995)		*Reduction, loss of party line*
Kerns (1990)	*Reduction of workload and stress*	
Kerns (1994)	*Increased efficiency and communications system capacity; relief from memory burden of length, involved messages; user-pacing of communication tasks allows for more effective multitasking; increased timeliness of message delivery (e.g., where frequencies are congested); greater consistency in procedures and message content (protocol and application standards); display flexibility allows for more efficient and accurate assimilation of information; snore efficient and accurate information transfer to other ATC and flight deck subsystems*	*Longer transmission delays; utility seen as limited for time-critical instructions; less flexibility to handle unanticipated or rapidly changing conditions; visual format seen as disruptive in visually busy environments*
Lee (1989a)		*Could be problematic in approach phases; increase of the head down time*
Lee (1989b)	*Decrease memory load; increase the intracockpit communications*	*Less urgency in the process of written messages*
Lind, Dershowitz, Chandra, & Bussolari (1995)	*Better representation of meteorological conditions*	
Logsdon et al. (1995)		*Response time too long*
Lozito, McGann, & Corker (1993)		*Response rime too long; difficulty in navigating in the displayed synoptics; a crew member might not know the message content*
Riley (1992)		Loss of implicit information
Scanlon & Knox (1990)	Reduction of workload; reduction of PNFs error risk; response time quicker in some cases	
Streeter (1994)		Increase of head down time
Wanke, Chandra, Hansman, & Bussolari (1990)	Increase of avoidance actions of microbursts or wind shears	

Note. ATC air traffic controller; PNF =pilot not flying.

5.1.3. Transaction time with data link

To quantify data link interface efficiency, a number of variables need to be taken into account:

- Time needed for the controller to write a message;

- Transfer time to the aircraft;

- Time needed for the crew to process the message; and

- Time needed to transfer an acknowledgment.

When the information transfer between the data link interface and the subsystems is automatic, the transaction time is similar to voice communication (Scanlon & Knox, 1990). In this case, when a single information element is transmitted, the difference between data link and voice is minimal (10.2 sec for the data link condition vs. 10.8 sec for the voice). This difference increases if several information elements are transmitted (10.7 sec for data link vs. 15.6 sec for the voice).

These results are valid only when transfer is automatic. When the crew needs to enter data manually, data link is slower than voice. Consequently, crew performance depends on ATC requests, and the data link response time is a good workload indicator (Kerns, 1990).

Although the data link interface may provide greater precision than voice, the transaction speed remains a weak point. In dynamic or rapidly evolving situations, transaction delays limit communication efficiency under time pressure (Kerns, 1994). In these situations, voice is more flexible than data link. The rapidity of voice flow can more effectively respond to critical situations. As Billings (1997) wrote, "Data link may eventually enable nearly all routine communication between ATC and aircraft to be carried out without recourse to voice contact, leaving voice for urgent messages and nonroutine transactions between pilot and controller". Groce and Boucek (1988) also stated that data link seems to be a good communication system during low crew activity periods such as the cruise phase.

Based on the same results, Konicke (1990) defined three priority levels for any message:

- The first level concerns very time-critical messages that require immediate awareness and action (e.g. immediate ATC altitude, route, clearance change). According to Konicke, these urgent levels should be transmitted by voice. According to Scanlon and Knox (1990), these messages can also be transferred via data link if they are simultaneously voice synthesised. Information redundancy and presentation over two different sensory channels should increase the urgency of the clearance.

- The second level is for the clearances that require immediate crew awareness, acknowledgment, or quick action.

- At the third level, awareness is less important, and acknowledgment may take longer.

5.1.3.1.   Impact of data link on aircrew and controller workload

Kerns' literature study (1991) mentions that there is no significant effect on pilot or controller workload as a result of use of the data link. However, the research results do document a redistribution of workload across human information-processing resources: visual and manual workload increase whereas auditory and speech workload decrease (Groce and Boucek, 1987).

Consistent with the workload redistribution findings, pilot-oriented simulations involving two-person flight crews have noted different effects on the PF and PNF (who is in charge of communications with ATC) workload as a result of the use of data link. Groce and Boucek (1987) showed a substantial impact of data link on PNF visual task load and a minimal impact on PF tasking. But for the PNF, this increase was largely offset by a corresponding decrease in auditory task load as a result of not having to listen to ATC voice transmissions. PF task load with a visual display of communications, however, tended to reach overload level for brief periods when monitoring of the data link information overlaid the normal instrument-scanning tasks. Perceived workload data from Waller and Lohr (1989) support the same pattern of effects. When operating in the PNF role and therefore handling ATC communications, crew members reported a reduction in workload. But when operating in the PF role, aircrew reports of workload impact were mixed: some felt that

use of data link increased their workload, whereas others felt that data link reduced their workload.

The data from Talotta and al. (1990) on the reduction in time spent by controllers in voice communication when data link is used provide a second statistical confirmation of this same general redistribution effect. In addition to reduced speech workload, Talotta and al. reported an increase in manual inputs when data link was used as compared to when all communications were conducted by voice. There is also no doubt an increase in controller visual workload and a decrease in auditory workload with data link.

Perceived controller workload was found to increase in the data link-only environment (EUROCONTROL, 1986). In addition, this study showed that, without access to the voice channel as a back-up, controllers significantly altered their approach to aircraft separation, increasing the separation between aircraft to compensate for the delays in communication-system response. When data link was used redundantly to confirm voice transactions, controller workload increased (Talotta et al., 1988). But when data link was used as pre-notification of a voice transaction, no noticeable increase in controller workload was observed (Cox, 1988).

5.1.4. Data link and intra-crew communications

Since the data link system significantly alters ground-to-air voice communications, Hrebec (1995) investigated whether it alters intra-crew communications as well. A qualitative change in intra-crew communication patterns, attributable to data link, was identified in prior research (Fielder and al. 1994).

In the research reported here, a more precise quantitative methodology was employed to determine how, specifically, intra-crew communications were affected by two data link implementations.

Hrebec defined four categories of initiation speech acts:

- Command.
- Question.
- Observation.
- Dysfluency.

Each of the four categories of initiation speech act generates one of the three possible types of response speech acts:

- Reply.
- Acknowledgment.
- Null.

All intra-crew communications during the descent to landing segment of the simulation exercise were categorised using this scheme.

Table 5-2: Categories of initiation and response speech acts

Initiation speech acts		Response speech acts	
Category	Brief description	Category	Brief description
Command(C)	Command	Reply (R)	Agreement
	Suggestion		Disagreement
Question (Q)	Inquiry		Answer supplying information
Observation (0)	Observation		Response uncertainty
	Statement of intent	Acknowledgment (A)	Acknowledgment
	Frustration/anger/derisive/comment	Null (N)	No response
	Embarrassment		
	Non-task related		
	Tension relief		
Dysfluency (D)	Laughter		
	Talking to self		
	Non-codable -		

When the Captain initiates communication, the most common categories of sequence variable are:

- Captain command + First Officer acknowledge,

- Captain question + First Officer reply,

- Captain makes observation + First Officer makes no response.

When the First Officer initiates communication, the most common categories are:

- First Officer question + Captain reply,

- First Officer makes observation + Captain makes no response.

When analysing the effects on intra-crew communication of two data link conditions (fully integrated into the instrument panel or integrated into the existing instrument panel through a retrofit), the most salient differences are the display location and the downloading, or gating, capability: the integrated data link display is more conveniently located in the forward CDUs while the retrofit display is in the centre CDU located between, and slightly behind, both pilots.

In the integrated condition, captains could, and did, lean over and read incoming data link messages from the First Officer's CDU.

In the retrofit condition, they were less likely to turn their head around and look down at the centre CDU messages, perhaps because pilots, historically, are averse to performing multi-planar head movements that may result in disorientation.

Also, in the integrated data link configuration, the same multi-function device served the data link communication and FMS programming function, while in the retrofit data link configuration, separate devices were employed. These differences in conditions resulted in a higher number of observations by the captains in the retrofit condition than in the integrated condition. In response to this increase in captains' observations, first officers tended to give more null responses in the retrofit condition.

When comparing the two data link conditions with the standard voice condition, the integrated data link condition is, in theory, more representative of a workload shedding configuration than is the retrofit condition.

When the integrated data link configuration was compared with the voice condition, the most salient findings were the significant increases in the First Officer questions + Captain acknowledgments and First Officer observations + Captain acknowledgments attributable to the integrated condition. These two categories of intra-crew communications contributed to an overall increase in the number of acknowledgments made by the captains in the integrated data link condition.

In addition, the retrofit data link condition introduces the same disruption of the intra-crew handling of ATC clearances as the integrated condition, but does not provide any of the potential for workload shedding.

Crews reacted to the retrofit condition with a higher number of questions, observations, replies and nulls.

First officers tended to utter more initiation speech acts and captains more response speech acts in the retrofit condition than the voice condition.

First officers asked more questions and made more observations in the retrofit condition than in the voice condition. In response, captains gave more acknowledgments.

This may indicate a shift in information power and control from the Captain to the First Officer as a result of data link. Notably, one category of intra-crew communications went against this trend, and displayed a significant decrease in the retrofit data link condition compared with the voice condition: when captains issued commands, they were more likely to receive an acknowledgment from the First Officer in the voice condition than in the retrofit condition.

In contrast, when captains issued commands, they were more likely to receive a reply from the First Officer in the retrofit condition than in the voice condition.

This indicates a possible breakdown in the Captain command First Officer acknowledge speech act pattern considered optimal by some researchers.

In a study of flight crews in a simulated controller-pilot data link environment, Harvey and al. (2002) claimed that intra-crew communication increased for controller-pilot data link flight crews compared with traditional 'radio crews'.

With the Link 2000+ Programme, Goteman and Decker (2005) used this opportunity to study the actual use of controller-pilot data link in the cockpit with line pilots flying normal line flights in a normal operational environment. To trace changes in cockpit work, the authors decided to rely on cockpit observations using ethno-methodological techniques, which had previously shown their usefulness in laying out cockpit communication patterns and cognitive architectures (Hutchins. 1995).

The authors assumed that the pilots would let the PNF handle controller-pilot data link in line with the formal voice communication procedures. This was also the observation in the majority of the flights studied. However, sometimes conflicting with the PNF-communication rule, the authors observed a tendency for the pilot with the most experience of controller-pilot data link to manage the data link communication regardless of the PF/PNF position. This tendency disappeared with the increasing controller-pilot data link experience of both pilots.

During controller-pilot data link communication the intra-cockpit patterns observed were different than with voice communications. The main difference was that the substance of ATC clearances received via CPDCL was not audible to both PNF and PF simultaneously. While using controller-pilot data link, the PF could not participate in the communication loop unless the message was either verbalised by the PNF or read from the cockpit interface by the PF.

During eight of the ten flights observed, the communicating pilot verbalised the message before replying to it via data link, meaning that the pilots worked actively to re-create the intention loop for both pilots.

This intra-cockpit verbalising of the controller-pilot data link message seemed to be a strategy developed naturally by the pilots to mitigate the risk of the communication loop and the other cockpit loops becoming separated.

The PNF responded quickly with a 'WILCO' without sharing the information with the other pilot. This behaviour was mostly observed during high task load situations.

With controller-pilot data link the pilots may fail to execute a clearance accepted by data link if the PNF-PF communication is disrupted.

For legal reasons, pilots had to verify any controller-pilot data link air traffic control clearances not only by using a controller-pilot data link downlink reply, but also by voice.

The voice communication from pilots was done after the controller-pilot data link downlink reply in the majority of cases. In two cases this redundant voice procedure interfered with the internal cockpit coordination work, leading to uncertainty as to who of the two pilots was doing what. In all cases, the pilots replied without hesitation via controller-pilot data link. The required duplication of reply modality is a typical example of how an intended investment in safety can lead to confusion and a breakdown in coordination, thereby being counterproductive to its intentions.

Controller-pilot data link is associated with the acceptance of a slower response time than voice communication. The authors identified a pattern of informal intra-cockpit prioritising:

- Voice air traffic control communication.

- Controller pilot data link communication.

- Cockpit callouts requiring action from the other pilot.

- Approach or take-off briefing.

- Cockpit callouts not requiring action from the other pilot.

- Routine cockpit-cabin crew communication.

- Data link communication with company (ACARS).

Voice air traffic control communication and controller-pilot data link shared the perceived importance, although voice communication is more salient. Controller-pilot data link received a high priority in relation to other cockpit activities in our study. The authors could not determine whether this was due to the novelty of the controller-pilot data link function or an inherent communication path, independent of technological mode.

Controller-pilot data link therefore transforms, or even interferes with, routine intra-cockpit communication during normal line operations. Pilots themselves took initiatives to verbalise data link messages so as to re-create cues for the flight deck intention and action loops that previously were a natural by-product of voice radio-telephony.

The introduction of controller-pilot data link technology creates qualitative changes to work routines. A positive effect of controller-pilot data link is that the communication loop between the aircraft and the controller is strengthened and secured against misunderstandings, reception problems and language barriers. What is given with one hand, however, is taken away with the other: controller-pilot data link changes intra-cockpit communication loops and disrupts coordination routines and procedures previously followed to verify the correct execution of air traffic controller instructions.

5.1.5. Summary of data link

Data link appears to be a relevant alternative to radio communication systems and is currently designed and developed to respond to problems induced by air traffic developments. Billings (1997) stated, "The routine use of data link for controller-pilot communications will change in fundamental ways the interaction processes between these two groups of human operators".

When talking to subject matter experts with respect to data link, the most common response was that it would be particularly suitable for "routine" communications. Results from the experimental programme indicated that text-based input resulted in a higher workload than speech-based input, which suggests that text is most suitable for situations in which the workload is not already high. The most typical example of this is where routes can be planned well in advance, such as in long-haul transatlantic flights. In these situations, a type of data link is already in use. Other types of routine communications which were felt to be particularly appropriate for the use of data link were radio frequency changes and weather reports. The pilot may well wish to refer back once the communication is complete, and a data link system would automatically store this information for future viewing.

In Sharple's study (2007), all experts agreed that in situations in which fast responses were required for communications, voice communication was preferred to text-based communications. Of course, the difficulty with this is that these situations are likely to be non-standard deviations which by their very nature are impossible to anticipate and difficult to handle. The experimental data was slightly contradictory with respect to this recommendation as text was rated as more urgent than speech, which is a potentially desirable feature in situations where a fast response was required. However, other results implied that the use of a text-based system may cause distraction from the primary task.

The anticipated situations in which it might be most appropriate to implement data link have been identified from a combination of laboratory and field data. When considering the impact of future technology, particularly in a safety-critical environment, it is necessary to consider the entire work system before the new technology is introduced.

When the two media are compared, results generally indicate that voice communication is fast and flexible, and data link communication is precise and concise.

Because of inherent (equipment and human) delays, data link communication appears to affect the synchronisation of controller and pilot operating behaviours and alters the distribution of intent information between communicators during the message transaction. Data link also changes the distribution of workload across human information-processing resources, increasing visual and manual workload and reducing auditory and speech workload as compared with voice communication.

Overall, data link appears to be most effective when used as a complement to voice communication for selected ATC applications. Consistent operational procedures for voice and data link appear to be simplest and therefore least prone to error when operating in a dual media communications environment.

Use of data link for routine ATC messages including tactical messages appears to be acceptable, but procedures need to be developed for the use of data link in terminal airspace, exception handling, and failure recovery.

In Sarter's study (1997), most likely, data link will be the preferred medium in situations where a predefined message can be sent to a number of aircraft or where a new broadcast message can be created very easily using the data link system. In contrast, controllers would prefer to use voice communication for extremely urgent messages or when numerous different messages need to be sent to a large number of aircraft. Still, even these preferences may change depending on the design and functionality of the data link system. Controllers state that voice communication may no longer be their preferred technique if data-blocks are updated automatically for them once a message has been sent and acknowledged.

Both groups - pilots and controllers - agree that the choice of the communication medium should be left to the party initiating the communication.

Standard phraseology is considered particularly important to avoid misunderstandings in situations that require immediate compliance with a clearance and also to allow controllers to create predefined messages for data link communication.

Both controllers and pilots are well trained in the significance and meaning of standardised phrases.

5.1.5.1. Compared features of R/T and data link

Data link communication should minimise radio-based problems such as interrupted transactions or call-sign confusion caused by congested frequencies. In addition, increasing ATC automation may simplify controller tasks, which in turn may reduce the complexity and frequency of controller-pilot communication and thus the opportunity for problems to occur.

Of course, data link does not guarantee error-free communication. For example, delays between data link message transmission and acknowledgment of reception (Kerns, 1990) may interfere with the ability to accept messages explicitly as mutually understood. In addition, long ATC messages may increase pilot workload in a visual data link as well as in a voice-only radio system, because message length and complexity can produce reading errors as well as listening errors (Just and Carpenter, 1980). Thus, effective communication in any medium requires procedures that ensure mutual understanding and that balance individual and collaborative effort.

The long ATC messages delivered by data link did not create more voice communication problems or delay acceptance compared with short messages, suggesting that data link may be better suited than voice/radio for delivering long, complex ATC messages (Kerns, 1990).

Reading errors will increase for longer messages, depending on the type of data link format and interface.

The few voice communication problems that did occur in the data link condition appeared to be more frequent for first short messages, and like radio, these problems were delayed until after the second short message. Similarly, acceptance time was faster for first short messages than for either the long message or second short message - the same pattern as for radio acknowledgement time even though data link accept times are much longer than radio acknowledgment times. These findings suggest that message timing may be an issue for data link as well as for radio communication.

ATC working practices in continental airspace are strongly bound to the core characteristics of R/T, this medium being historically the only way of communication between pilots and controllers. Similarly, due to its specific nature, data link is also expected to impact on pilots' and controllers' working methods. Consequently, any projection or extrapolation concerning the effect of data link on the use of R/T channels requires a clear understanding of the compared characteristics of these two media, as summarised in Table 5-3.

Table 5-3: Compared characteristics of voice and data link

Characteristics	Voice (RIT)	Data Link
Operational content and form/scope of communications	Standard phraseology, but direct access to medium © Some room for flexibility if needed.. ® ..But risk of misunderstandings or errors ® No support of system-to-system communications	Pre-formatted / standardised electronic messages ® No easy-to-use deviation from standard.. © ..But no risk of ambiguity © Support of system-to-system communications
Encoding and Presentation of Information	Acoustical © Voice tone (e.g. urgency, stress,..) ® National accents: risks of misunderstandings ® Highly volatile information ® Low bandwidth efficiency	Textual/Silent ® Limited range of message attributes © No ambiguity in message content © Access to History of communications © Bandwidth use efficiency
Communication Mode	Broadcast, Half Duplex © "Party Line" effect ® Users competing for channel access	**(Mainly) Point to Point, Full Duplex** ® Loss of party line © No concurrent access
Management of protocols and dialogues	**Poor separation from operational content** **® End-to-end communication protocol** aspects are mostly a user's responsibility (addressing errors, stuck microphone,.. etc)	Clear separation from operational content © End-to-end communication protocol aspects are implemented by the system,
Quality of Service Characteristics	Highly reactive, medium integrity' **© Real time transmissions** Synchronous nature, but immediate replies needed to close dialogues © Ability to support time critical communications ® Medium signal quality ® Controller-pilot communications range limited to current sector (or ground relaying required).	Significant reaction time, high integrity ® (typical delays 5 seconds) Non immediate replies, but allows for asynchronous and/or parallel dialogues ® Current Technology not suitable for time-critical messages © High level of integrity, reduced risk of errors © Downstream sectors (e.g. oceanic clearances).

5.1.5.2. *Functionality associated with data link*

In order to facilitate controllers' acceptance of data link in an operational setting, some studies test the benefits of functionality coupled with the classic data link functions. The CASCADE Stream 1 real-time simulation (Trzmiel and Rognin, 2006) was conducted in this perspective to test the acceptance and impact of classic data link services and of an automatic transfer function.

The automatic transfer function, called Auto CPDLC or Auto transfer, was used only for aircraft transfer. Auto transfer automates the sending of CPDLC messages from the controller to a single or multiple aircraft; when the exit conditions are met (here 1 minute before the sector exit), the system proposes, by a trigger, execution of an automatic transfer to the next sector at the sector boundary.

Such an automatic function seeks to decrease controller workload induced by routine communications during the sector change.

The classic data link services tested in the CASCADE simulation were ACM (ATC Communications Management), ACL (ATC Clearances), AMC (ATC Microphone Check), ADD (Aircraft-Derived Data), and PPD (Pilot Preference Downlink). The simulation was conducted in upper sectors of Czech airspace.

The Auto transfer results show that the Auto transfer, in this configuration, was used in only 10% of cases and perceived as not acceptable by the controllers. Controllers require a better underlying algorithm taking into account the specific nature of each situation and adapt the auto-transfer accordingly (e.g. earlier, later, manual transfer). In the configuration used during the CASCADE simulation, the controllers suggested keeping the Auto transfer non-active by default, thus allowing them to select it when and if needed.

The CASCADE simulation results are interesting because they assess the Auto transfer functionality which is an attempt to reduce the communication load between controller and aircrew by reducing the workload induced by the various steps of the communication process, the communication always being under the responsibility of the human operators. The Auto transfer seeks to simplify the controller's routine communication work but does not eliminate it.

5.2. FUTURE MOBILE ATC COMMUNICATION SYSTEM

The elimination of some routine communications between controllers and aircrews is the other way to reduce the controller and aircrew workload induced by communications. The data provided by the VOCALISE (Graglia, 2005) and Hering (2001) studies are promising if a technology is able to eliminate sector change communications between controllers and aircrews. The communications relating to sector change routines represent more than 50% of the speech acts in en route, and 15% of these are not ideally conducted. Consequently, these routine communications are a source of errors for which aircrews and controllers use error prevention and recovery strategies; strategies, which in turn increase the aircrew and controller task load and workload. A significant part of the current R/T communications do not have any operational content, and is related to the channel's management itself.

The impact of these routine communications is dual:

- Workload improvement.
- Error increase.

The sectorless radio communication concept is based on the use of so-called end-to-end communication principles from public mobile telephony (GSM) for ATC. The end-to-end communication concept for ATC usage was proposed by Hering (2007a, 2008). The purpose of this study is not to discuss the technological aspects which may be applied in air navigation in order to design a future mobile ATC communication system, but to evaluate the impact of such an end-to-end communication system on the work of aircrews and controllers.

The purpose of a future mobile ATC communication system should be to avoid the routine communications relating to the sector changes. This system guarantees a permanent voice link between the aircraft and the controllers without any action by the aircrew at any time during its trajectory. The onboard (aircraft) and ground (ATC) systems would exchange data on aircraft identification and aircraft location to ensure that the aircraft is at all times able to contact a controller and that a controller is able to contact the aircraft. The activity whereby the aircraft is permanently in contact with controllers is fully free of action on the part of the aircrew. This makes the ATC organisation of sectors invisible and transparent for the aircrew.

In the meaning of end-to-end communication, each aircrew holds one 'end' of the air-ground communication while a controller holds as many communication 'ends' as aircraft controlled. Consequently the use of the end-to-end communication system will be different for aircrew and controller.

During the flight, the aircrew uses its only 'end' of the end-to-end communication to contact the responsible controller; neither the aircrew nor any onboard system needs to know which controller has the aircraft under control and his/her responsibility. The sectors will have no operational meaning for the aircrew and the airspace may be described as "sector-free" or "transparent" for the aircrew.

A controller holds as many 'ends' of end-to-end communication links as aircraft controlled. To speak to an aircraft, the controller first has to select the "end" that is linked to the addressed aircraft. This procedure differs from the current working procedure with broadcast radio communication (only pressing the PTT-switch). Hering (2007b) evaluated the use of a 'selective PTT-switch' to embed a destination address as a digital watermark in the transmitted controller speech. The subjects in the small usability study stated that the new procedure for working with a 'selective PTT-switch' is an acceptable change for the controllers. A similar 'selection' procedure may be used for end-to-end communication.

The future mobile ATC communication system proposes a new, simplified way of transferring responsibility for aircraft between controllers of different sectors.

For the controllers, the sectors are useful for delineating the boundary where responsibility for the aircraft is transferred from one controller to another between adjacent sectors or control centres. Currently the transfer of responsibility for an aircraft to the adjacent sector is a complex, risky procedure involving aircrew and both controllers. After controller-to-controller coordination (verbally or silent) on the transfer, the controller instructs (by voice or data link) the aircraft leaving the sector to change its communication frequency to that of the adjacent sector. The aircrew changes the frequency and announces its presence (by voice or data link) to the controller of the adjacent sector. The controller takes over responsibility for the aircraft. In this process, the aircrew plays an active role in the responsibility transfer via communication with both controllers. In practice, the two controllers transfer the aircraft by the medium of the aircrew, which is, by this action, aware of the transfer process. This communication loop is efficient, and is the result of the possibilities offered by current R/T technology. The transfer process described includes the risk of losing air-

ground voice communication for both sectors, as the aircrew has to select a different communication frequency. The selected frequency may be false because of bad/noisy communication, misspelling/misunderstanding of the frequency, wrong frequency selection, and so on. An aircraft with lost communication cannot be controlled and represents a major risk to safety. Van Es's EUROCONTROL study (2004) states that the highest contributory factors in 'loss of air ground communication' occurrences were radio interference (29%) and frequency change (25%) (all other reasons <3%).

With end-to-end communication new procedures for the transfer of responsibility have to be defined. A direct controller-to-controller transfer of responsibility eliminates the risk of 'loss of communication' during the current transfer procedure. The controller-to-controller transfer of responsibility is transparent for the aircrews.

With the future mobile ATC communication (end-to-end) system, the transfer of communication loop that encompasses the aircrew is not justified. The loop of communication for sector changes is located on the ground, directly only via the controllers involved. The aircrew's awareness of the transfer of responsibility from one controller to another is not required as the aircrew knows that at all times the controller responsible can be contacted. Knowledge of the sector name and sector frequency and the initial and final contact with the sector controllers are not required.

If the elimination of routine communications has the objective of reducing the communication workload, this may have side effects on the way the controllers and aircrews work, separately and collectively. The sector change routine communications are most of the time coupled with another communication in which the intents of the aircrew or of the controllers are expressed to one another. Therefore, the elimination of routine communications will not eliminate the communication act. In addition, the party-line and mutual awareness may be impaired, and solutions for presenting party-line information need to be defined in order to satisfy the cognitive needs of the controllers and aircrews. All these issues require complementary and specific investigations to evaluate the operational validity of the future mobile ATC communication concept.

The elimination of some sector change routine communications will not affect the medium whereby the controllers and aircrews communicate for the remaining communications. In other words, the implementation of a future mobile ATC communication system is not correlated with a choice of medium for the remaining communications. The R/T or data link medium may be used for the remaining communications depending on their own advantages and drawbacks regarding the type and nature of communications.

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6.   CONCLUSION AND PERSPECTIVES

The review of literature concerning pilot-controller communications shows the importance, features and the role of communications in air traffic control.

Numerous studies have been conducted and the various results provide a better understanding of the place and role of communications in controller – pilot relationships, in the cockpit and at the control working position. Indeed, the review has shown the close relationship between communication errors, workload and frequency congestion, and the role of communication errors between pilots and controllers in a number of incidents or accidents has been widely analysed.

To date, the communication medium in use for ATC has been R/T technology, which supports and favours the voice channel. In an attempt to reduce communication errors, workload or the number of communications between pilots and controllers, a new medium based on new technologies was developed, the data link. This new medium of communication has benefits, but more importantly, still has some drawbacks. Moreover, not all flight phases or situations lend themselves to the use of such a system. That is why voice communication remains a central component of air-ground communication.

Nevertheless, the growth in air traffic in the coming years requires researchers to consider the development of systems to ensure and optimise the necessary exchanges between pilots and controllers.

Data link technology, the digital communication system envisioned for the future, was originally developed to address existing problems with voice communication such as frequency congestion, call sign confusion or poor transmission quality. This technology could provide a number of answers to this problem. For example:

- Possibility of reducing errors by facilitating retention of information (e.g., messages kept on display).

- Possibility of reducing errors by using appropriate presentation modes of messages (graphic, iconic, or textual) and presentation formats of these messages (readability).

- Facilitating reaction time by adequate coding for urgent messages.

- Increasing intra-cockpit communication (to ensure shared representation of flying conditions).

- Favouring the use of standardised messages and "phraseology".

However, it is not clear whether the resulting system design will also be adequate for handling communication and coordination in future ATM operations. This technology includes some drawbacks, for example:

- Risk of crew exclusion from the communication loop between ATC and aircraft.

- Workload modification due to manual and automatic data transfer between the data link interface and FMS.

- Transaction time variation due to manual and automatic data transfer between the data link interface and FMS.

- Risk of interference between simultaneous communications and flying actions.

- Increasing visual tasks and visual channel overload.

- Risk of reducing or removing party line information (situational awareness).

These drawbacks led researchers to design systems which will cope with the growth in traffic, R/T congestion and the need for secure air-ground exchanges.

The VOCALISE and Hering studies showed, in an analysis of R/T communications, that there is a possibility in this direction and a margin of profit for reducing R/T congestion and possibly the number of categories of routine communications.

Hering (2007a) proposes to reduce the number of communications between controllers and pilots by the use in air traffic control of the end-to-end principle developed in public mobile telephony – GSM. The way contact

is established with the ground is fully transparent for the aircrew. At all times during a flight, the future mobile ATC communication system automatically ensures contact with the controller in charge of the aircraft. Thus, no communication is required between the flight and the ground as regards management of responsibility for transfer of the aircraft. Without advancing any hypotheses regarding the technological challenges posed by this concept, the advantages would be to reduce some sector change routine communications by shortening the communication loop between controllers during the transfer of responsibility for the aircraft between two sectors. The aircrew is now excluded from the communication loop. The control sectors are of no use for the aircrews; they are used solely by the controllers for transferring responsibility for the aircraft.

The possible use of a future mobile ATC air-ground communication system would introduce transparent, sectorless radio communication in air navigation.

The expected advantages of the use of the mobile ATC communication system would be to:

- Improve safety by reducing workload and miscommunications for aircrews and ATCOs,

- Increase air traffic capacity and efficiency by allowing ATCOs to save cognitive resources and to focus their attention on traffic understanding and management;

- Relieve aircrews of some routine tasks and actions so that they are focussed and fully aware of the other tasks.

However, while the concept is promising, many issues need to be clarified in order to evaluate its operational acceptance.

The state-of-the-art study shows that to date, the human factors studies on pilot – controller communication have not specifically addressed routine communications concerns. The data available is from studies whose focus has not been exclusively routine communications and their impact on controller and pilot activity. However, such data are plentiful and provide a better understanding of the underlying challenges for routine communications. It is clear that if the development of future mobile ATC communications is envisaged, specific studies on routine communications are needed in order to assess the impact of their elimination on controller and pilot activities. To date, the data on routine communication have been bottom-up data extracted from communication studies. But accurate data are now required to evaluate the scope of the concept and its potential acceptance, and a top-down approach is advocated.

The issues for investigation can be summarised as follows:

- The effects of sector size, airspace organisation, and traffic load on sector change routine communications for controllers and pilots.

- The impacts generated by the number of sector change routine communications on controllers' and pilots' cognitive processes (perception, working memory, attention management, situation awareness, decision-making, actions), workload, collaborative work, interruptions of other ATC and piloting tasks (disruption factor and communication management concurrent with another tasks), and traffic safety and efficiency.

- The consequences of a "free sector change communications" setting for evaluation of the effect on cognitive processes, workload and situation awareness, party-line and mutual awareness, operational needs, and traffic performance and safety.

- Lastly, there are certain issues as regards operational acceptance by controllers and pilots. The operational interest has to be clearly identified and described even if its quantification is not easy at this stage of the project. The scope of the project has to be defined with the delineation of the field of application and the potential limitations. In addition, the future mobile ATC communication system has to be considered in relation to other information systems available in the future. Links with the SESAR Project are required in order to schedule the sectorless radio com concept within the SESAR timeframe. From now onwards, the operational consistency of the concept will need to conform with other SESAR communication and automation concepts.

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