Say Again

Mira Zokić, Damir Boras, Nikolaj Lazić

***Abstract*—**One of the prerequisites of a safe and efficient flight is correct and timely communication. The International Civil Aviation Organization (ICAO) strongly emphases the need for improving communication in Air Traffic control and has introduced, in the Document 9835, a set of prescribed rules governing aeronautical communication. According to a survey carried out by the NASA Aviation Safety Reporting System, incorrect or incomplete pilot/controller communication is a causal or circumstantial factor in 80% of accidents and incidents. This paper gives an outline of a language technology system that should detect deviations from the prescribed usage of radiotelephony phraseology by detecting at least 80% of the types of miscommunication related to language-based problems and problems with numbers, and in that way enable the communication between air traffic controllers and pilots to be more reliable and efficient, and contribute to the improvement of aviation safety.

***Keywords*—**air traffic control communication, automatic speech recognition, error correction, speech to text technology, radiotelephony language corpus.

I. Introduction

DUE to a high demand for safety in aviation, a lot of research has been done to improve air traffic control and pilot operational systems. The only segment that has been neglected is communication between air traffic controller and pilot. For the last fifty years, except for the introduction of data link, nothing has been done to improve communication between air traffic controllers and pilots.

In today's crowded airspace, it is important that communication is performed in a standardised and understandable way to all air traffic participants. Constant insisting on proper usage of radiotelephony phraseology results in an automated usage of communication procedures and therefore contributes to air traffic safety. Any deviation from the standardized phraseologies presents an obstacle to the best possible communication. Incorrect use or insufficient knowledge of the English language and radiotelephony phraseology have caused or contributed to many aviation accidents and incidents.

II. Communication

The role of the Air Traffic Control is to ensure safe, orderly and expeditious flow of traffic. One of the most crucial tasks that air traffic controllers, pilots and anyone who takes part in aviation perform is communication. Communication can be defined as an exchange of information, ideas and knowledge. A traditional model of communication proposed by Shannon and Weaver is shown in Fig. 1. In this framework, an information sender and the receiver are required. Information held by the sender is encoded into codes and transmitted to the receiver. The codes are then decoded and the receiver can understand the information.

Fig.1 illustrates this model emphasizing spoken verbal (oral) communication, which is the form of communication that is addressed by the ICAO language proficiency requirements. The speaker and hearer participate in a given phase of communication. The speaker encodes his or her intended meaning in a spoken utterance. The utterance is conveyed via the appropriate channel in the form of a sound-stream which is perceived and decoded by the hearer. The hearer's representation of the meaning of the utterance will, in the case of successful communication, be a perfect or near-perfect match of the speaker's intended meaning.

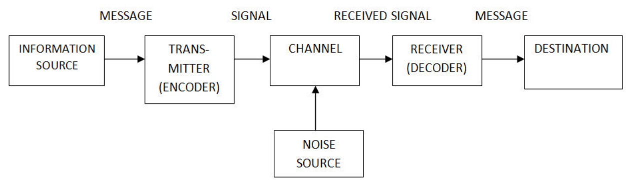

Fig. 1. Traditional model of communication.

When we talk about communication in ATC system, a bit different definition of communication should be taken into account. In Air Traffic Control it is of vital importance that all parties involved in communication understand each other and that the information is delivered and received timely and accurately.

The deadliest accident in aviation history, the Tenerife airport disaster in 1977, was a collision involving two Boeing 747 passenger aircraft with 583 fatalities. When the KLM airplane was in position and holding, the co-pilot asked for a takeoff clearance. Air Traffic Control gave the clearance instructions, but never explicitly said they were cleared for take-off. When the co-pilot read back the clearance, he stated that they were now *Taking off*, but without the explicitly saying *Cleared for takeoff*. When the controller responded back with the words *Oka*' the pilots then regarded this as further clarification that an original clearance had been given. When KLM was on the takeoff roll, the PanAmerican plane and the controllers both radioed at the same time, canceling each other's calls that the KLM should not take off yet. KLM never heard the radio call and continued resulting in a crash that killed hundreds.

It was a defining event in aviation safety and a tragic lesson in communication. This accident demonstrated that information transmitted by radio communication can be understood in a different way to that intended. Ambiguous terminology and/or the obliteration of key words or phrases, and that the oral transmission of essential information, via single and vulnerable radio contacts, carries with it great potential dangers. The major part of communication in Air Traffic Control is voice communication over the radio. Due to many factors such as homonyms, number problems, readback/hearback error, call sign confusion, ambiguity, expectation, noise, open microphones, etc. errors in communication may occur. This paper proposes the idea that language technology can be used to assist in Air Traffic communication and thereby would contribute to the improvement of aviation safety. It also tries to identify opportunities for its improvement and its application within Air Traffic Control Services.

III. Air Traffic Control Structure

According to EUROCONTROL, the European Organisation for the Safety of Air Navigation, air traffic controllers have the responsibility to direct aircraft through their airspace safely and efficiently. The goal of Air Traffic Control is to minimize the risk of aircraft collisions while maximizing the number of aircraft that can fly safely in airspace at the same time. Aircraft pilots and their onboard flight crews work closely with controllers to manage air traffic [2]. The pilots flying the aircraft through the airspace are obliged to follow the instructions of the Air Traffic Controllers precisely since there is no leeway for discrepancy in today's overly crowded airspaces.

Air Traffic Control is a combination of four general elements:

a. The first element is the basic set of flying rules that pilots follow in the air.

b. The second element is the multitude of electronic navigation systems, landing system and instruments that pilots use.

c. The third element is the division of airport surface and air space in different type of control areas. Air traffic controllers operating in each of these areas and the computer systems they use to track aircraft during takeoff, landing and in flight are also part of this element.

d. The fourth element is the communication between pilots-controllers, controllers-controllers and the equipment used for this communication [2].

The purpose of the communication between a pilot and an air traffic controller is to synchronise air traffic controller's decisions through utterances with what pilot does to an airplane. This makes communication a vital part of the air traffic controllers' and pilots' job.

As it can be seen form Fig. 2, every flight is divided into seven different phases: pre-flight, take-off, departure, en-route, descend, approach, and landing. Each phase is defined by what the plane does and is handled by a different controller.

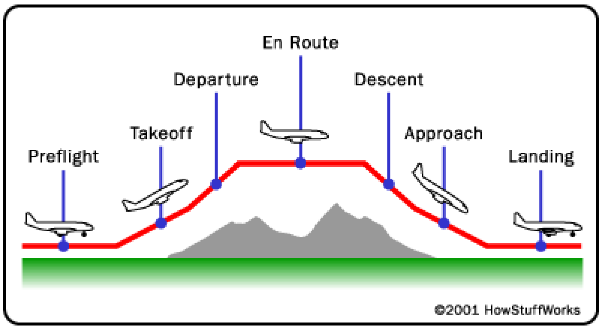

Fig. 2. Phases of flight [10].

As defined in Annex 11 to the Convention on International Civil Aviation, Objectives of Air Traffic Services are:

- to prevent collisions between aircraft in the air and on the manoeuvring areas of aerodromes
- to prevent collisions between aircraft and other vehicles and obstructions on the manoeuvring area of aerodromes
- to maintain a safe, orderly and expeditious flow of air traffic taking into consideration the abatement of avoidable noise
- to provide advice and information useful for the safe, orderly and expeditious conduct of flights
- to notify appropriate organisations regarding aircraft in need of search and rescue and to assist such organisations as required. Division of Air Traffic Services is shown in Fig. 3.

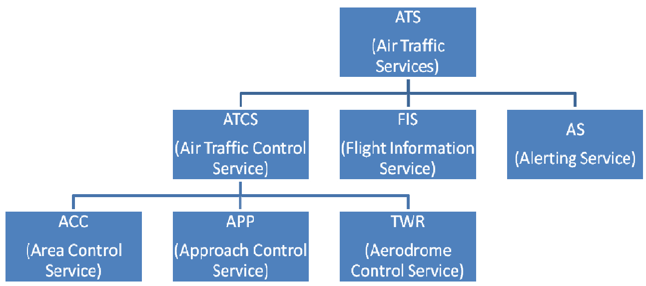

Fig. 3. Division of Air Traffic Services.

As an aircraft travels through a given airspace division, it is monitored by the one or more air traffic controllers responsible for that division. The controller(s) monitor this plane and give instructions to the pilot. As the plane leaves that airspace division and enters another, the air traffic controller passes it off to the controller(s) responsible for the new airspace division.

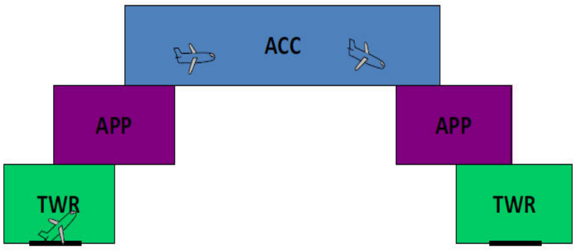

Fig. 4. The profile of a flight.

The proposed language technology system will be done for Approach and Tower control. The Aproach control is a unit established to provide air traffic control service to controlled flights arriving at, or departing from one or more aerodromes.

Approach Control handles:

- departing aircraft;
- arriving aircraft; and
- overflights.

Functions of Approach Control are:

- to provide separation;
- to maintain an expeditious flow of air traffic;
- to assist pilots to avoid areas of adverse weather;
- to assist pilots with navigational problems;
- to issue traffic information;
- to help pilots in special situations (emergencies, search and rescue, flight-tests, calibration flights, etc...).

The primary responsibility of the Tower Control is to ensure that sufficient runway separation exists between aircraft landing and departing.

IV. Air Traffic Control Communication Architecture

A survey by the NASA Aviation Safety Reporting System (ASRS), states that incorrect or incomplete pilot/controller communications is a causal or circumstantial factor in 80 % of incidents or accidents, as illustrated in Table 1. Incorrect communication, absence of communication, and correct but late communication have been identified as factors that have an effect on pilot/controller communication.

Table I. Factors affecting pilot/controller communication [8].

Factor	**Percentage of Reports**
Incorrect Communication	80%
Absence of Communication	33%
Correct but late Communication	12%

The survey also reveals how various modes of communication are affected :

Table II. Affected modes of communication [8].

Factor	**Percentage of Reports**
Listening	45%
Speaking	30%
Reading and Writing	25%

Incorrect or inadequate:

- ATC instructions (e.g., radar vectors, …);
- Weather or traffic information; and/or;
- Advice / service in case of emergency;

are causal factors in more than 30 % of approach-and-landing accidents [8].

Readback / hearback errors may result in one or more of the following types-of-event, ranked by number of events observed over the period 1992-1993:

- Operational deviation (non-adherence to legal requirements);
- Altitude deviation;
- Airborne conflict;
- Less than desired separation;
- Lateral deviation;
- Runway incursion;
- Ground conflict;
- Airspace penetration; and,
- Near midair-collision [8].

Croatia Control Ltd. (CCL) sets the communication system architecture that provides fast, safe and reliable flow of information between aircraft in the controlled airspace and Air Traffic Control (ATC) centres (A/G communications), as well as between Croatian and foreign ATC centres (G/G communications). In the maintenance of these communications it relies on national providers of telecommunication services, as well as on its own systems. CCL manages a wide range of analogue and digital radio and telecommunication systems for transmission of voice and data communications.

The send and receive communication function of ATC Services can be described as follows: the controller utters an instruction through the headset system, the instruction is transmitted via a satellite network to the pilot, the pilot than receives the instruction using his/her headset and replies back.

The responsibility of the pilot and controller overlap in many areas and provide backup. The pilot/controller confirmation/correction process is a “loop” that ensures effective communication and serves as a defence against communication errors.

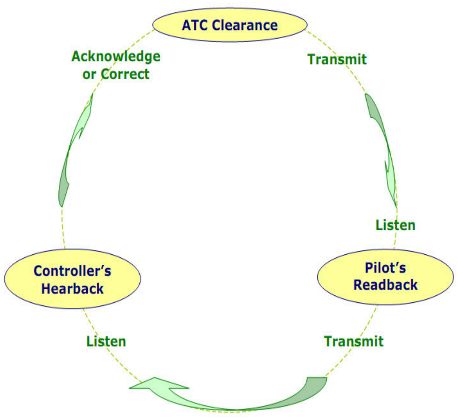

Fig. 5. Pilot/controller communication loop [12].

The environment in which pilot/controller communication takes place is a time-sensitive environment. Pilots and controllers cannot see each other or each other actions, so an important means of error detection is unavailable.

V. Radiotelephony Phraseology

As miscommunication can, and does, occur not only between non-native speakers but also between native speakers of the same language the International Civil Aviation Organisation has introduced a set of prescribed rules governing aeronautical communication. The rules for this language are located in Annex 10, Volume II, and Chapter 12 of Doc 4444. These are the basis of a "restricted" sub-language for routine situations. They contain rules for when to say something, what to say (words and sentence patterns), what to understand and how to pronounce and utter messages/instructions. The use of phraseology is further illustrated in Doc 9432.

Radiotelephony phraseology provides means by which pilots and ground personnel communicate with each other. It is an organised system for transmission of information, advice, instructions, clearances and permissions from the sender to the receiver and vice versa. If it is used properly, it insures safe and expeditions flow of traffic, but if not used properly it can lead to a misunderstanding and even a disaster. At the very beginning of flying, communication was in the language of country over whose territory the flight was performed, so that commercial pilots flying in several neighbouring countries had to be polyglots. In 1927, the introduction of Q codes in aviation was the first attempt to standardize communication in aviation [13].

Usage of different phraseologies in different geographical areas increases chances that communication will be misunderstood.

The standardized Phraseology is intended to be employed by all those involved in aeronautical radiotelephony communications. Phraseology has the specific technical function of ensuring efficient and safe communications. The principal linguistic characteristics of standardized Phraseology (Philps, 1991) are a reduced vocabulary (around 400 words) in which each word has a precise meaning, often exclusive to the aviation domain. Sentences are short resulting from the deletion of "function words" such as determiners (the, your, etc.), auxiliary and link verbs (is/are), subject pronouns (I, you, we) and many prepositions. Sentences also frequently contain nominalizations (verbs transformed into nouns). A high proportion of sentences (around 50 per cent) are imperative or passive.

Examples of such sentences are:

- Cleared to take off.
- Ready for push back.
- Confirm brakes released.
- Requesting low pass.

It is also important to acknowledge that Radiotelephony Phraseology represents a set of operational procedures. However, compliance with ICAO standardized Phraseology is not fully harmonized on a worldwide basis. States publish differences with respect to ICAO Standards. Croatia Control Ltd., Aeronautical Information Service, issues Radio Communication Procedures (Voice Communication in Aeronautical Mobile Service) in a document called AIC. The Croatian RT Phraseology, technique, and procedures are based on ICAO SARPS (Standards and Recommended Practicies). Pilots should always read back the ATS messages/instructions detailed in AIC. Controllers should always ensure that they receive these readbacks. The ATS items listed below are to be read back in full by the pilot.

The mandatory items are:

- Taxi/Towing Instructions
- Level Instructions
- Heading Instructions
- Speed Instructions
- Airways or Route Clearances
- Approach Clearances
- Runway-in-Use
- Clearance to Enter, Land On, Take-Off On, Backtrack, Cross, or Hold Short of any Active Runway
- Secondary Surveillance Radar Operating Instructions
- Altimeter Settings
- VHF Information
- Frequency Changes
- Type of ATS Service
- Transition Levels

If a readback is not received, the pilot will be asked to do so. Similarly, the pilot is expected to request that messages/instructions are repeated or clarified if they are not fully understood.

The language of pilot/controller communication is intended to overcome the basic shortcomings. The first priority of any communication is to establish "an operational context" that defines the following elements:

- Purpose – clearance, instruction, conditional statement or proposal, question or request, confirmation;
- When – immediately, anticipate, expect;
- What and how – altitude (climb, descend, maintain), heading (left, right), airspeed;
- Where – (at [...] waypoint).

The construction of the initial message/instruction and subsequent message(s)/instruction(s) should support this operational context by:

- Following the chronological order of actions;
- Grouping instructions and numbers related to each action;
- Limiting the number of instructions in the transmission.

Standard Phraseology helps lessen the ambiguities of spoken language and facilitates a common understanding among speakers. Nonstandard Phraseology, usage of plain English or the omission of key words may change completely the meaning of the intended message/instruction, resulting in potential traffic conflicts.

The following recommendations to further improve ATC communications and thus the margin of safety in the ground-control environment arise from different investigations:

1. Controllers should keep instructions short. The shorter an instruction, the more likely will it be correctly read back by the pilot.
2. Controllers should listen to what a pilot reads back, especially regarding hold-short and taxi instructions and frequencies. More emphasis should be given to hearback during controller training.
3. Controllers should try to speak slowly especially when they are under pressure and don't have time to repeat information.
4. When talking to foreign pilots, controllers should take into account the potential for phraseology differences and reduced English language proficiency. The Federal Aviation Agency should compile a list phraseology differences to be distributed to controllers and pilots, especially those flying internationally. Controllers also should speak "staccato," that is, to break the instruction up into its component words by inserting short pauses. Recognizing where one word ends and the next begins is notoriously difficult for any inexperienced listener of a foreign language. Repeating numbers in grouped format, i.e., "seven-teen," instead of sequential format, "one seven," as recently authorized for emphasis of altitudes, may backfire with foreign pilots who group numbers differently in their native language.
5. Pilots should ask when they are not sure about a piece of information. But even if pilots are sure that they have heard and remembered correctly, they should at least read back hold-short instructions and frequency changes.
6. Whenever possible, controllers should point out similar callsigns on the same communication frequency. All instructions and readbacks should include the full callsign.
7. Both controllers, when listening to readbacks, and pilots, when taking instructions, should be aware of how their expectations may affect what they hear. Pilots expecting certain instructions must wait for complete aircraft identification before taking action on the instructions.

Non-standard phraseology is a major obstacle to effective communications. Here are several reasons:

1. Standard phraseology in pilot-controller communication is intended to be universally understood.
2. Standard phraseology helps lessen the ambiguities of spoken language and thus facilitates a common understanding among speakers:

(a) Of different native languages; or,

(b) Of the same native language, but who use, pronounce or understand words differently.

3. Non-standard phraseology or the omission of key words may completely change the meaning of the intended message, resulting in potential traffic conflicts.
4. For example, any message containing a number should indicate what the number refers to (e.g. a flight level, a heading or an airspeed). Including key words prevents erroneous interpretation and allows an effective readback/hearback.
5. Particular care is necessary when certain levels are referred to because of the high incidence of confusion between, for example, FL100 and FL110.
6. Non-standard phraseology is sometimes adopted unilaterally by national or local air traffic services, or is used by pilots or controllers in an attempt to alleviate these problems; however, standard phraseology minimises the potential for misunderstanding [12].

Training Program for pilots and air traffic controllers

ATC training simulators provide an efficient supplement to theoretical training and training on the job. By gradually increasing the complexity of the training scenarios, students can be confronted with situations tailored to their growing skills. Emergency scenarios hopefully never encountered in reality may be generated without imposing hazards upon real aircraft. Training simulators are also used to maintain the skills of experienced controllers in critical situations.

A company training program on pilot-controller communications should strive to involve both flight crew and ATC personnel in joint meetings, to discuss operational issues and, in joint flight/ATC simulator sessions, to promote a mutual understanding of each other's working environment, including:

(a) Modern flight decks (e.g. flight management system reprogramming) and ATC equipment;

(b) Operational requirements (e.g. aircraft climb, descent

and deceleration characteristics,
performance, limitations); and,
(c) Procedures for operating and threat and error management (e.g. standard operational
procedures [SOPs]) and instructions (e.g. Crew Resource Management).

Special emphasis should be placed on pilot/controller communications and task management during emergency situations [7].

Air traffic control simulators are also used for research purposes. This helps to test and evaluate new ATC concepts and systems throughout the design phase and before introduction into operational service. The results of the simulations permit the assessment of system performance and usability and the identification of weak points, so that the system can be enhanced accordingly. Also, research simulation facilities are used to scrutinize the mental processes involved in the work of air traffic controllers. Simulations allow for the generation of scenarios according to the specific scope of the investigation and the reproduction of these scenarios if necessary [7].

Most ATC simulation facilities use the pseudo pilot concept to simulate the communication with aircraft pilots. Each controller working position is equipped with a radio communication link to pseudo pilots in an adjacent room. The pseudo pilots listen to the clearances and enter the relevant parameters via a terminal which is connected to the simulation computer. They also read back the clearances, giving the controller the impression he or she had communicated with a real aircraft pilot.

VI. Miscommunication

Miscommunications may broadly be applied to a range of verbal communications problems ranging from misunderstandings, such as those due to ambiguity, cultural differences, language structure, and so on, to more technical problems, such as microphone “clipping” and over-transmitting of another’s radio signal. Studies indicate that miscommunication is a pervasive problem in air traffic control and, has been a causal factor in numerous fatal accidents.
According to the previous researches types of miscommunication can be grouped as follows:

1. Absent-mindedness and Slips
2. Ambiguity
3. Callsign Confusion
4. Code Switching
5. Different Voices
6. Emergencies
7. Enunciation
8. Expectation
9. Headsets
10. Homonyms and Homophony
11. Noise
12. Not Hearing
13. Number Problems
14. Open microphones
15. Readback Error
16. Similarity of SIDs (Standard Instrument Departures), STARs (Standard Recommendations and Practices) and Waypoints
17. Speech Acts
18. Speed of Delivery and Pauses
19. Vigilance.

The following should be emphasised in pilotcontroller communications:
(a) Observe the company SOPs for crosschecking communications;
(b) Recognise and understand respective pilot and controller working environments and constraints;
(c) Use standard phraseology;
(d) Always confirm and read back appropriate messages;
(e) Request clarification or confirmation, when in doubt;
(f) Question an incorrect clearance or inadequate instruction;
(g) Prevent simultaneous transmissions;
(h) Listen to party-line communications as a function of the flight phase;
(i) Use clear and concise communications in an emergency [12].

VII. Language Technology System

The usage of proposed language technology could make communication between air traffic controller and pilot more efficient and reliable and could contribute to the increase in safety of aviation. The system could be used not only to support the pilot/controller communication, but to assist with training.

The system should be used for detecting two groups of problems:

1. language-based communication problems (unfamiliar RT phraseology, incomplete or incorrect readback/hearback utterances); c
2. communication problems with numbers (altitude, heading, etc.).

This proposed system is meant to be tested and applied for the Approach and Tower Control Unit as, according to the interviews with the instructors of RT Communications at the Faculty of Transport and Traffic Sciences in Zagreb and air traffic controllers, the largest portion of communication between a pilot and an air traffic controller takes place during these phases of flight.

The functionality of this language system will be described using scenarios and sequence diagrams to demonstrate communication within the Approach and Tower Control, and will be demonstrated using Wizard of Oz usability test.

Scenarios are a software definition method developed by Carroll and associates. The simplest description is that they are stories that provide a common ground for all stakeholders in a software development team to understand the functionality of the system. The focus is primarily put on the user. They give a context of a plot with actors and the events that lead towards a certain goal or objective. Thinking about the functionality this way compels the designers of the system to look at the rationale for the functionality and to focus on the use of the system. The end result is a fixed interpretation on the functionality that is being designed over the technology being used. The scenarios that describe the situation will be defined and it will be shown what will change if the language technology system is introduced in the system.

For example:
ATC gives the following clearance to the pilot: "*Zagreb Control, CTN 751, with you overhead 60 north 40 west at 0803, flight level 340*."
Pilot replies: "*CTN 751, 60 north 40 west at 0803, flight level 390*."
The language technology system compares the readback with the clearance and discovers the discrepancy between what the pilot said and what the controller cleared. The language technology system warns the controller by sending the following text message to the screen: "*Warning! Flight level incorrect.* "

Sequence diagrams are interaction diagrams that detail how operations are carried out, what messages are sent and when. Sequence diagrams are organized according to time [9].

Sequence diagrams according to the Unified Modelling Language (UML) will be used to more formally depict which parts of the system are interacting to carry out the functionality. UML is a method of making a software system visual to facilitate the design of the system. It is a standard way of describing the system at all levels, from the conceptual stage all the way to interfaces and specific software objects. Sequence diagrams describe the flow of events within a system in the correct time order when a particular functionality is being used in a certain way.

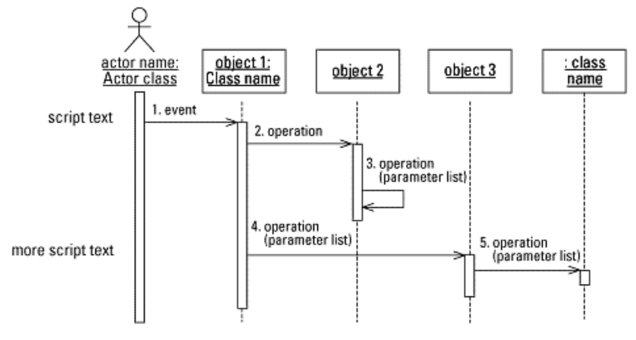

Fig. 6. An example of a sequence diagram.

Additionally, the Wizard of Oz usability test will provide the same scenarios in that the images of the software prototype will be presented to the users by a "wizard" (the experimenter) behind the scenes. The subject acts as a "user" interacting with the system, presumed to be a computer. However, in practice, unknown to the subject, another person takes on the role of the system, producing responses to the user's demands or requesting for clarifications, etc. [2]. The user believes that a fully functional application system is used. The objective of such usability testing is to get information on how the user reacts to the system and how accurately and reliably the system reacts to the user.

The independent variables of the research that will be taken into consideration are:
• nationality, mother tongue, age, years of experience, pilot license (a type rating is required for a specific make and model of aircraft which is dependent on experience, i.e. flight hours), air traffic controller's license (whenever an air traffic controller is posted to a new unit or starts working on a new sector within a particular unit, he/she must undergo a period of training regarding the procedures characteristic to that particular unit and/or sector – the phase of training takes between 6 months and several years).

Two dependent variables of the research that will be taken into consideration are:
•detection of language-based communication problems such as unfamiliar RT terminology, full and partial readback/hearback errors (per flight);
•detection of communication problems not based on language such as problems with numbers, discrepancies between position reports and clearances (altitude, heading, etc.) (per flight).
The data will be collected during a three month period.
Two extraneous variables in the study are:
• pilot's and atc's workload
• congestion at airports (increases pressure).

As it has already been mentioned, this research will be limited to Approach and Tower Control spoken communication.

The results will serve as guidelines for designing a fully functional language technology system. The system will consist of:
1. Radiotelephony corpus;
2. Speech recognition software;
3. Speech-to-text software;
4. Extraction software;
5. Text warning on the screen.

Radiotelephony corpus will be collected from Voice Communication Procedures, National Transportation Safety Board database of accidents and incidents, and recordings from Zagreb Airport. Automatic Speech Recognition tool will be used to identify the words that a pilot or controller utters into a microphone. Speech-to-Text software will convert the utterances into a text. The uttered/written text will be compared with the radiotelephony corpus and related numbers. Finally, in case of any discrepancies or wrong usage of radiotelephony phrases, the system will send a text warning on air traffic controller's screen.
This language technology system will be used as a as a support tool and will not be used to make decisions how the air traffic controllers should control the airspace.

VIII. Conclusion

This research will firstly serve to describe communication processes within air traffic control and to determine the position for the implementation of the language technology system. Then a descriptive model will be developed (an RT corpus will be built, an extraction software will be developed, a speech recognition software will be used) and tested in simulations (using scenarios, sequence diagrams and Wizard of Oz usability test). And finally, the developed and improved language technology system will be applied and data regarding the proper usage of RT phraseology as well as operational data (attitude, heading, frequency data, etc.) will be collected.

The results will be linked to the variables such as age, nationality, mother tongue, years of experience, license to see how the mentioned variables influence proper usage of RT phraseology and operational procedures.

The proposed language technology system should detect deviation at least 80% of errors in pilot/controller communication regarding usage of language and numbers.

Once when the system is tested and approved it might be expanded to be used in other air traffic control units.

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