RELATIONAL MODEL AND DATA LINK FOR AIRCRAFT CONTROL DURING LANDING AND TAKE-OFF

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Abstract

The controller-pilot communicationhas been based on voice radio communication for several decades. It is now facing bandwidth saturation. The communication process can be improved using new existing technologies based on computers. A database modeling of the involved information and asynchronous exchange via database update and querying using data link between controllers and aircraft is proposed. Security improvement aspects are emphasized.

1 Introduction

The ONERA project "Airport of the Futur" has the general objective to propose and validate controller and pilot assistance solutions to improve the safety and efficiency of approach and ground movements in all weather conditions. As a subtopic, the management of the information flows has been studied and new alternatives have been proposed. Considering the communication between controller and pilot an exhaustive set of information has been defined and a new approach using existing technologies has been proposed [5].

This paper presents first, a summary of the existing communication process, the related problems and information in the first section. In the second part it presents the relational model representation [2] of some of the information. In the third part it describes the communication process via Data Link and Database update and special representation needs for security aspect and acknowledgment.

2 Communication Process and Information

Communication process is essential to ask and give information between pilots and controllers. In this section a brief presentation of the departure and arrival processing will emphasize different stage of information communication. The essential problems will then be presented and in a third sub-section a list of involved information that will be used to illustrate our topics is described.

2.1 Departures and Arrival Processing

Before each flight, a Flight Plan should be prepared. Just before starting the first contact of the pilot with the Air Traffic Control (ATC) is with the Start-up Controller to check and validate the Flight Plan. This is done by radio. The pilot contacts then the ground controller (often the same as the start-up) to get the starting clearance. Once the clearance is obtained, the pilot asks for push-back (if needed), completes the check-up and gets instructions by radio to go to the holding point of the assigned runway.

Sometimes during taxiing, the plane has to cross over other runways and must contact the local controller for clearance. At the holding point, the pilot gets the clearance to line up on the runway and control is performed by the local controller. Sometimes when there is no waiting necessity the control is passed from ground to local just before the arriving at the holding point. All these communications and changing are done by radio on the ground frequency and local frequency. Each instruction given to the pilot should be acknowledged by him through a "collation process", i.e. repeating the instruction by radio. At the present time, to save bandwidth, just some starting clearance is given by data link and needs no collation.

Take-off authorization together with other instructions and information (how to reach the planned route, speed, climbing rate, flight levels, wind information, wake vortex presence, etc) are given to the pilot by the local controller. After take-off the pilot contacts (by radio) the approach controller who guide him until the exit of the approach area.

For landing, in the end of the approach phase, the pilot has already the direction and the runway to use, and sometimes the gate to reach for parking. But communication includes meteorogical information for wind burst, visibility, radio frequency for next contact (local control). After landing the pilot informs the controller (local controller), and gives the exit he uses and declares the runway cleared. Then he follows the taxiways to the assigned parking/gate with or without guidance or control from the ground controller. All the communication process is done by radio, usually with only three frequencies: approach, local and ground.

2.2 Related problems

Several incident reports describe misunder-standing [3] [6] between controller and pilot.

Two kinds of problems are related to communication. They can be summarized in two words: quality and quantity.

Quality is related to understanding reliability that could fail either in the communication channel or in the expression or perception stage. Most of the quality problems are related to the pilot's English language proficiency. In some related incidents, call sign confusion is involved [4]. Hopefully such errors are detected and corrected. Low quality communication generates generally incidents but, some accidents may occurr due to misunderstanding.

Quantity is related to the bandwidth of the communication channel. Due to reduced number of radio communication frequencies the bandwidth is shared between several aircraft communication. This is partly useful for the "party line" phenomenon, which is the reception of any aircraft-controller communication by all other pilots in the same area i.e. the same radio frequency. The pilot is thus aware (at least partially) of his "environment". But correspondingly a pilot should wait for a silent period on radio frequency to contact the controller.

2.3 Involved information

The whole set of information needed or exchanged during these processes is too huge to be described in this article. Just a subset of it will be presented in the sequel in order to illustrate the modelization in the relational model and the use of a database instead of radio communication.

Figure 1 gives an overall description of information flow during landing and take-off. The subset of information, which will be considered in this paper, is described below.

At the gate:

- Flight plan (set of information)
- Departure Clearance
- Departure time and time slot
- Radar identity code of the plane (SSR)
- Radio frequency for controllers
- Take-Off runway and Holding Point
- Turning Motors on clearance
- Meteorogical information

During taxiing:

- Beginning of taxiing
- Position and speed
- Destination (Holding Point, Gate)
- Take-Off rank
- Taxi crossing clearance (ground control)
- Runway crossing clearance (local control)
- Line-up ready

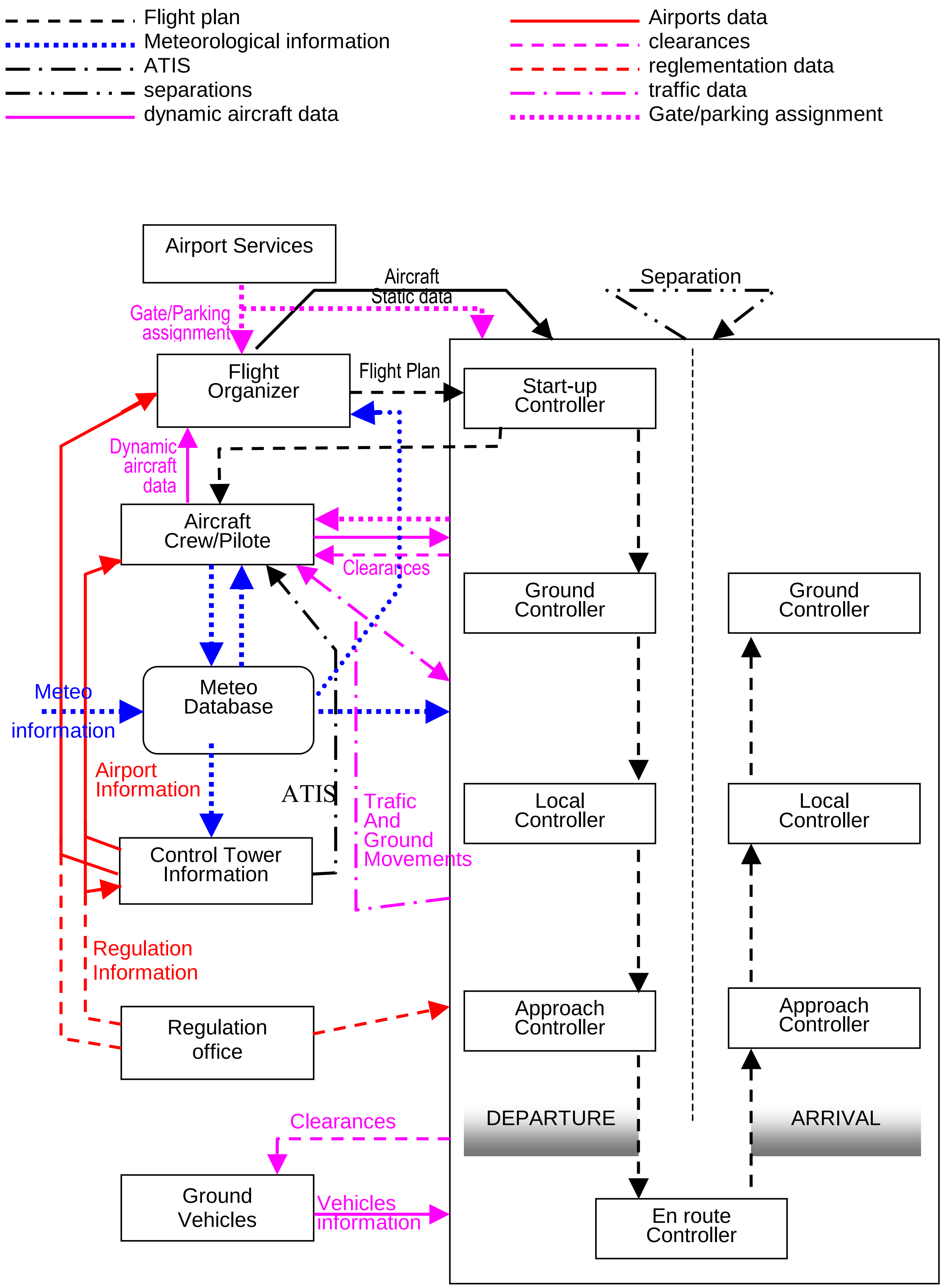

Figure 1: Information flow diagram

- Taxiing instructions (start, speed up, slow down, stop, turn right, turn left)
- Radio frequency for local control

During Take-Off:

- Take-Off clearance
- Departure procedure
- Radio frequency for approach control

After Take-Off:

- Exit point for the approach area
- Radio frequency for en route control

Before landing:

- Approach procedure
- Assigned Runway
- Meteorogical information
- Altitude of the airport
- Elevation of the runway
- Estimated Time of Arrival (ETA)
- Aircraft position, speed, …
- Taxiway information
- Assigned gate or parking (if known)

The Flight Plan includes:

- Departure airport (code, name, position, restrictions, runways
- Waypoints
- Flight levels
- Aircraft company, type, identification, configuration, weights, performances …

3 The Relational Model

The relational database model is well known information representation model for data semantics definition. It is described through a conceptual schema including several *Relations* or *Tables*, which have different *attributes* or *columns* the combination of which gives semantic to the data.

The conceptual schema is built following specific rules in order to have a set of normalized *relations* (*tables*). Over the conceptual schema, different external schemas (also called subschema) can be built to accommodate different corresponding users with adequate and easy to use database interfaces. Data manipulation (information management) is typically done using a Database Manipulation Language (DML), but for a specific application such as aircraft control, DML expressions can be embedded in other interface systems like voice recognition and voice synthesis or click-on querying for predefined queries or automatic update from on-board instrumentation.

Next sections will present some of the relations from the conceptual schema and some from subschema for pilots and controllers.

3.1 Some relations of the conceptual schema

The conceptual schema is composed of 35 relations (tables). We present as examples some of them followed by their attributes (columns) and brief explanation (between parenthesis) of the attributes when needed and not self contained. The key attributes (information identifier) are in bold and prefixed by "$".

The static (i.e. not modified during the flight) aircraft information are stored in the:

Relation: ***Données_statiques_Avion***

$Code_Avion	(Aircraft id-code)
Nom_Avion	(Aircraft name)
Pays_Fabrication	
Catégorie_Avion	
Nombre_Moteurs	(number of motors)
Nombre_portes	(number of doors)
Nombre_issues_secours	(number of emergency exits)
Longueur	(lengh)
Envergure	(width)
Surface_Voilure	
hauteur	
Plafond_théorique	
Altitude_Croisière	
Rayon_Action	
Capacité_Réservoir	(tank content)
Poussée_Maxi_Décollage	(Max take-off thrust)
Max_Zero_Fuel_Weight	
Max_Take_Off_Weight	
Max_Landing_Weight	
Operating_Weight_Empty	
Mach_Maxi	
Mach_Croisière	(Cruise Mach)
Vitesse_Décrochage	(Min speed to flight)
IFR_VFR	(Instrument Flight Ruled/Visual)
Date_Modification	(Last modification date)

Ground movements information of the aircraft are stored in the:

Relation: ***Données_Avion_Au_Sol***

$Numéro_Avion (aircraft id-number)
$Date_Emission (time stamp)
Latitude_Actuelle (latitude at this time)
Longitude_Actuelle (longitude at this time)
Etat_Moteur (Motors on/off)
Cap_Actuel (cap at this time)
Zone_Prochaine_Prévue (next position expected)
Zone_Prochaine_Réelle (effective next position)
Latitude_Destination (dest. latitude)
Longitude_Destination (dest. longitude)
Distance_Restante_Destination (distance to dest.)
ETA_Destination (Estimated Time of Arrival)
Vitesse_Sol (Ground speed)
Type_Ordre (Type of Instruction)
Degré_Ordre (Priority of Instruction)
Masse_Avion (Aircraft mass)
Date_Réception (Instruction recept time)
Date_Criticité (Instruction critical time)
Origine_de_la_requete (Request emitter)

Specific information of a given aircraft are stored in the:

Relation: ***Registre_Avion***

$Numéro_Avion
Code_Avion
Année_Construction (Manufactured year)
Date_Certification (Certification date)
Utilisateur (User / Company)
Type_Moteur (Type of motors)
Mode_Transpondeur (Radar mode)
Temps_Vol_Accumulé (Flight hours)
Date_Modification (last modification time)

Flight numbers define departure and arrival airport thru the:

Relation: ***Vol***

$Numéro_Vol (fliht number)
Code_Aéroport_Départ (departure airport)
Code_Aéroport_Arrivé (arrival airport)

The original flight plan information are stored in several relations for relational normalization reasons. The information are stored in the following relations:

Relation: ***Plan_Vol***

$Numéro_Vol
$Date_Départ
Date_Arrivée (arrival time)
Code_Aéroport_Dégagement
Route_Planifiée (planned route)
Vitesse_croisière_planifiée (planned cruise speed)
Altitude_Croisière_Planifiée (planned cruise altitude)
Distance_A_Parcourir
Nombre_PN (number of crew)
Nombre_Passagers_Prévu (planned pax number)
Nombre_Passagers_Réel (real pax number)
Date_Modification

Relation: ***Vol_Avion***

$Numéro_Avion
$Date_Vol
Numéro_Vol

Relation: ***Plan_Départ***

$Numéro_Vol
$Date_Départ (start time)
ETD (estimated time of departue)
Code_Trajet_sol (on ground way id-code)
Code_Piste (runway id-code)
Ordre_Décollage (take-off rank)
SID (procedur after take-off)
Date_Emission (emission time)

Relation: ***Plan_Arrivée***

$Numéro_Vol
$Date_Arrivée
Code_Piste
Code_Trajet_sol
Zone_Destination
Ordre_Atterrissage (landing rank)
STAR (procedure before landing)
Date_Emission

Relation: ***Route_Planifiée***

$Code_Route
Id_Premier_Waypoint
Id_Deuxième_Waypoint
Distance_Parcours

3.2 Subschemas

The first subschema is for the pilot and the next relation is a full representation of his flight plan. It is built by combination of eight relations of the database schema: Vol, Plan_Vol, Vol_Avion, Plan_Arrivée, Plan_Départ, Route_Planifiée, Données_Statiques_Avion and Registre_Avion.

Accessing information uses the:

Relation: ***Plan_vol_complet_pilote***

$Numéro_vol
$Date_départ
$Date_arrivée
Numéro_avion
Catégorie_avion
IFR_VFR
Code_aéroport_départ
Code_aéroport_arrivée
Code_aéroport_dégagement
Route_planifiée
Vitesse_croisière_planifiée
Altitude_croisiere_planifiée
Distance_à_parcourir
Nombre_PN
Nombre_passager_prévu
Nombre_passager_réel
Date_modification
Id_premier_waypoint
Id_deuxième_waypoint
Distance_parcourue
ETD
Code_taxiway_départ
Code_piste_départ
Ordre_décollage
SID
Date_émission_départ
Code_taxiway_arrivée
Code_piste_arrivée
Zone_destination
Ordre_atterrissage
STAR
Date_émission_arrivée

The pilot subschema includes also the relation Donnees_Avion_Au_Sol defined in the conceptual schema. While taxiing, this relation is used and contains all necessary information for pilot and controllers to manage the aircraft moving from gate to runway or vice-versa.

The second subschema is for controller use. It includes the:

Relation: ***Avion_Sol***

$Numéro_avion
$Date_emission
Code_avion
Utilisateur
Date_modification
Latitude_actuelle
Longitude_actuelle
Etat_moteur
Cap_actuel
Zone_prochaine_prévue
Zone_prochaine_réelle
Latitude_destination
Longitude_destination
Distance_restante_destination
ETA_destination
Vitesse_sol
Type_ordre
Degré_ordre
Masse_avion
Date_criticité
Date_reception
Catégorie_avion
Nombre_portes
Nombres_moteurs
Nombre_issues_secours
Longueur
Envergure
Surface_voilure
Hauteur

This relation gives all needed information to a ground controller about a given aircraft at a given time. It is a combination of three relations of the conceptual schema and is also used to represents instructions to pilots for ground movements.

4 Communication Process and Data Link

The Data Link between ground and aircraft already exists using Arinc Communication And Reporting System (ACARS). Airline companies to communicate with their pilots mainly use this system [1]. The system has been extended under AIRCOM denomination.

It is a real time computerized message sending system already used for maintenance data, meteorological data, operational data (for instance the flight plan or departure clearance), commercial needs and telex.

Radio communication for ACARS uses frequency different from the controller frequencies, connected with a specific ground communication network.

Using ACARS/AIRCOM messaging system or any new data link system under development, database request can be send to or from an aircraft either to query or to update a database.

In the following we will present the proposed communication process and its specific aspects with respect to acknowledgment and security.

4.1 The communication process

As an alternative to voice communication by radio, information as well as instructions and requests can be stored in the previously described database and used from it.

No matter how the database is physically organized, the present techniques allow multiple users to access a shared database through a computer network with good reliability and performance. For sake of commodity, it is proposed to have an on board copy of the database, synchronized with one or more copies on ground computers accessible by controllers.

Instead of radio communication, pilots and controllers will send to the database their requests, or query the database to get information they need.

For instance the pilot (or the on board systems) will regularly update the "Avion_Sol" relation with the actual position and situation of the aircraft, the controller can query the database to get these information and also update this relation with specific instructions about next position to reach or speed variation, and the pilot will also query this relation to get the last instructions he has to follow.

All the communication is performed through the data link and no controller radio frequency bandwidth is used.

Controllers or pilots send all requests and queries when they want, i.e. at moments they have not more important things to do.

Instructions and information are clearly identified, so no call sign confusion could occur.

Pilot and controllers interface can be user specific, and can use voice recognition and voice synthesis systems. Essentially for the pilots, voice interfaces are helpful because of human ability to combine easily hearing with other perception senses (for instance general visual inspection) and speaking with other actions.

4.2 Security aspects

Security is of course the central point of aircraft management.

With the classical communication system, acknowledgment and party line are two aspects to be pointed out.

By using voice radio communication, contact is direct and the rule is to acknowledge any instruction by repeating it back to confirm good reception and understanding even if sometimes this fails.

Communications via database update and data link are asynchronous. As long as computer communication is in concern, acknowledgment and automatic resending techniques can be used to enforce a reliable communication from the sender to the database.

But the human end user (controller or pilot) reception cannot be automatically checked. For this reason the database relation schema includes generally three time stamps needed for the acknowledgment process.

The emitter gives validity or emission time and gives the time information is valid or instruction is to be performed.

Reception time is updated by the receiver through a dedicated man-computer communication interface to sign up that information or instructions have effectively been perceived.

Criticity time is given by the emitter to put an ultimate delay over which the data link communication process is supposed to have failed. By checking the reception time at criticity time, automatically or manually, one can be aware of information or instructions that are not acknowledged through the database/data link communication process within the expected delay.

In this case a voice radio call should be done to enforce security.

Other security aspects improved by the database/data link communication are:

- Adaptative interfaces for each end user: for instance with voice synthesis techniques, information embedded in the database can be expressed in the language chosen by the pilot which can be different from the controller one.
- Multiple providing interfaces: the same information can be displayed in two or more ways, for instance by voice synthesis and also on screen display, or on printed matter.
- Continuous availability of information and instructions: once stored in the database. If needed it can be recalled as many time as wanted without reemission by the emitter.
- Asynchronous communication: each end-user acts at the time he wants, i.e. he is available for the communication task.
- Huge decrease of vocal radio use: voice radio communication can be devoted to critical or emergency situations.

5 Conclusions

The data link communication and database techniques are already existing and available for immediate application.

The proposed communication process, as an alternative to radio voice communication offers more security and comfort aspects compared with the classical communication process in use.

The implementation is essentially based on a computer network using on board computers, ground computers and radio network.

The existing ACARS/AIRCOM system is an already existing framework for data link.

The pilot and controller interfaces have to be designed for an effective implementation of the whole system and for its validation.

Acknowledgments

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