Optimization and Coordination of the Landing, Departure and Surface Management Operations

Jhonny Criollo, Gema Miguel Campos
Kliment Kaloyanov, Jonathan Tefera
Roberto Carlos Villanueva

***Abstract*—Knowing the huge importance that airports have in the future growth of the air navigation industry, in this paper we have focused in the operations that takes part in the landing, departure and ground operations. We have reviewed what have been done in this area and also proposed some ideas based in the modeling of the wind field around an airport, the setting of three different Top of Descent levels depending on the weight of the aircraft and a futuristic technique to help the aircraft in the taking-off phase. The potential benefits of applying these techniques are huge and can lead to fuel saving, less CO_2 emissions, lower times of delays and an increase on safety. Also, these ideas can lead the development in areas like detection and resolution of conflicts, enable Continuous Descent Approaches or creating better routes.**

I. Introduction

The Air Traffic growth of the last decades and the one expected for the next years have created to this industry a very complex and interesting challenge: how to increase the capacity of the system without decreasing the levels of safety.

For this purpose, different programs have been created on both sides of the Atlantic.

a) SESAR(Single European Sky ATM Research): [1] is a project created by the European air transport community with the goal of increasing cooperation and development among them.

b) NextGen: [2] Is a project developed by the USA's National Airspace System in order to transform all the industry, from the ground-based to the satellite-based systems of the air traffic control.

Both of them are working to investigate, develop and apply new technologies and procedures to fulfill the futures demands on capacity. As part of their investigations, they also consider different ways in which other important factors can be improved:

-Reducing the fuel consumption and CO_2 emissions by creating more efficient routes and flights.

-Reducing the impact on the environment by a better noise abatement in the areas close to the airports.

-Improving safety by detecting and avoiding efficiently possible future collisions.

-Decrease the duration of the flight.

-Decrease the cost per operation.

In order to make possible the evolution that it is expected in the ATM network, there must be a huge collaboration between the different projects, with the leading airspace companies and the different governments. It is not an easy task as every phase of the flight must be optimized: from the moment of planning the flight until the moment the aircraft has landed and parked.

In this paper, the focus is going to be on the ways in which the processes that are involved in the landing and the taking off can be optimized. This task is important as airports are one of the highest barriers for the increasing of the air traffic capacity.

Airports are the most congested points in the air navigation network as they are the nodes through which the different aircraft go and come. Airports with high amount of operations per hour suffer a problem known as bottleneck. By this it is meant that due the security restrictions that have to be fulfilled, there are limitations in the number of aircraft that can take off or land in a certain amount of time. If this number is exceeded, the remaining aircraft will have to do additional operations that makes more inefficient the fights.

The results of these inefficiencies is a waste of fuel, an unnecessary emission of CO_2 and noise, an increase of delays and an increase of the costs per operation. As it can be seen, they all are against the objectives that NextGen and SESAR had proposed.

These problems have been studied for a long time now. Many different investigations and implementations have been taken in the last years. The different categories in which this problem can be divided are:

-*Sequencing of arrivals:* A good sequencing will improve the management of resources and operations and will make easier all the others aspects of this problem.

-Ground operations optimization: It includes all the operation that takes place since the aircraft has landed or until it has departed.

-Landing optimization: Actual procedures in the landing have many deficiencies that need to be solved.

-Departure optimization: The need this area is how to implement continuous ascent without creating conflicts or delays with aircraft that wants to land.

-A better detection of conflicts: There is an important need for the optimization of the detection of the real position of the aircraft, the prediction of its future state and the possible conflicts that can appear.

II. Review of the literature (state of the art).

As it has been already said, there are many investigations in this area so the literature is huge. Some of the principal lines of action are:

A. Continuous Descent Approach

This procedure has been studied for long time one due its tremendous advantages with respect a conventional approach. The benefits that it brings are the decrease in fuel consumption(and therefore CO_2 emissions and cost savings), a higher noise abatement and a more efficient and faster process.

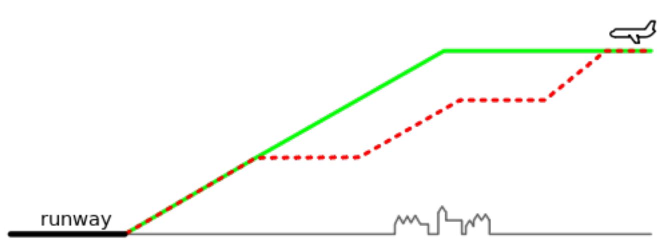

Fig. 1. Conventional Approach (red) vs. Continuous Descent Approach (green).

It has been tested in some airports and through many different simulations and the results show that the savings that can be obtained in fuel consumption and flight time are considerable. In a simulation made in the Louisville International Airport with 697 flights with different types of aircraft has shown that the average flight time saving per aircraft is 2.42 minutes. [3]

[4] suggest the use of a model based on the Total Energy Equation combined with the the state of the aircraft in the moment Top of Descent. In this way, the trajectory along the the continuous descent path can be better predicted making the controller's work easier and fulfilling the minimum distances required between aircraft.

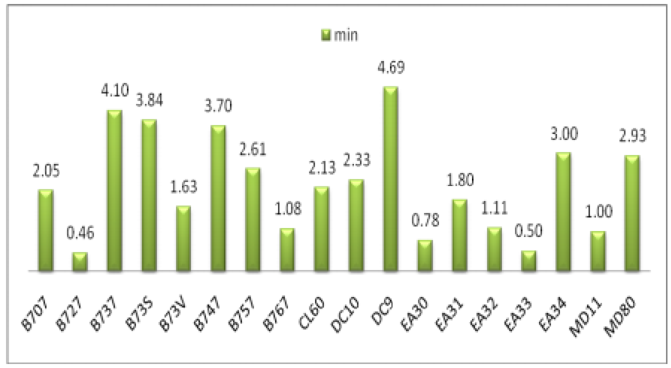

Fig. 2. Average flight time saving for different aircraft using CDA

Even though there have been many investigations done in this area, CDA is not yet completely applied as the workload that it causes to the airport is not yet covered. Once started, the CDA cannot be modified by the controller so these method will require a higher separation between the different aircraft, something that can not be assumed as most of the important airports are congested.

B. i4D + Controlled Time of Arrival

As it has been said, *Continuous Descent Approaches* have a big problem. The workload for the controller that are attached with this procedure is very high and can not be taken by the actual system. Also the distances required between the aircraft are higher than conventional descents. That makes that in a busy airport, it is impossible to apply it. That it is the reason that even though CDA has been studied for more than 30 years, it is very strange that an ATC allows to an aircraft to do it.

As a partial solution to be able to implement *Continuous Descent Approaches* in the future, *Controlled Time of Arrival* systems are being investigated and applied.

Until now, what aircraft usually do is to follow their trajectory until they arrive to the zone close to the airport. If when they reach, there are runways free they landed directly, if not they have to follow flying holding patterns until there is a runway free to land.

What they want to do now is to have a better communication between the tower and the aircraft when this still being in the on-route phase. By this, the air traffic controller can tell to the pilot what is the best time to arrive to the airport in order to do a direct landing without having to wait. Using this information, the pilot can decelerate or accelerate in order to reach at the best moment. This means that time becomes the contrail.

The benefits that CTA can bring are very important: possibilities.

-*Capacity:* By an improvement of efficiency in the use of the available.

-*Delays:* Increase punctuality and flight duration as there won't be need of using flying holding pattern.

-*Organization:* Enables a better sequencing in the landing as aircraft would come in the right moment.

-*CDA:* It helps in the enabling of continuous descent approaches and by this flights becomes cheaper and CO_2 emissions decrease.

-*Cost savings:* Lower costs as delays decrease and potential congestion are avoided.

Cassis*(CTA/ATC SyStem Integration Studies)* is the project launched by Sesar to investigate this area.
More information about this topic it can be found in [5] [6] [7]

C. Optimal sequencing

The Aircraft Scheduling Problem deals with the challenge of how to optimize the sequencing of arrivals and departures and the relation between them to use efficiently critical resources like the runway.

This becomes highly important in busy airports in which many aircraft are involved. The principal objective is therefore on how to decrease the average time of delay of the different aircraft.

The main limitation that this system has to overcome is the minimum distance that has to be between two aircraft at the time of landing and taking off. This distance is required to be fulfilled.

As a way to solve this problem, different mathematical solutions have been investigated. The main focus of all of them is to find an algorithm that takes into account the desired time of arrival, the actual situation of the aircraft and the type and the minimum distance required between two aircraft to be able to rearrange in real time the sequence at which aircraft departs and lands in the airport. [3]

By giving different models, researches will always will have to deal with the ratio between accuracy and computational time of operation. With the developing of more and more powerful machines, more complex and accurate algorithms can be created.

More information can be found in [8][3]

D. Continuous Ascent Departure

Continuos Ascent Departure (CCO)[9] are departure procedures that follow a route based on the pilots needs and characterized by the rare need to use level offs during the climb phase of flight.

In a near by future we plan to implement these procedures due to the benefits that we can achieve from these. All major airlines use aircraft that obtain the best mileage at high altitudes, and thus the sooner we achieve this altitude the more efficient our fuel burn. Studies such as that done by MITRE Corp[10] have estimated potential savings, using data from the 35 most important US airports, to be around 1.67% [11] of the total fuel burn during climb.

But there are many more benifits that have been studied by numerous entities[10][12][13]

- In 2009 many flight trials were conducted to demostrate that aproximately 135,000 tons of CO2 can be saved yearly just on Air France flights Between North america and Europe[13]

- Noise levels are reduced. On multiple test flights noise levels at arrival were reduced by up to 7 dB [13]

- Achieving Cruise altitudes earlier means traveling a farther distance in less time, this can also be cuantified into potential benefits from applying CCO.

- Currently for each step taken during the climb phase ATC must issue a clearence wich takes up valuable time, mean while with the new continuous procedures we will be allowed to issue clearences in a more simple and quick way.

There is also an aspect of CCO that need to be adressed an that is that these operations will increase the spatial complexity of the airspace, and thus increasing the probability of error.
microwave landing system

E. Noise Abatement

During last years NASA has put the objective of reducing about 10 dB of noise in approaching maneuvers, a 10% of actual mean noise.

The idea is proposed as "cleaning" the aircraft. A typical "dirty" aircraft (figure) is the one approaching at high angle of attack and with deployed flaps, slats, and landing gear. The scattering in the trailing edge and the vortex around the lift and control devices produce half of the stridency while descent and brake, caused by high-speed turbulent air flux regimes.

Another aspect which has to be taken into account when talking about non-propulsive noise is that it is a function of the aircraft speed to the power of five($N_{nonpropulsive} \propto V_{\infty}^{5}$)[14] [15]. So it should be mandatory to consider a reduction of minimum velocity for takeoff and touch down

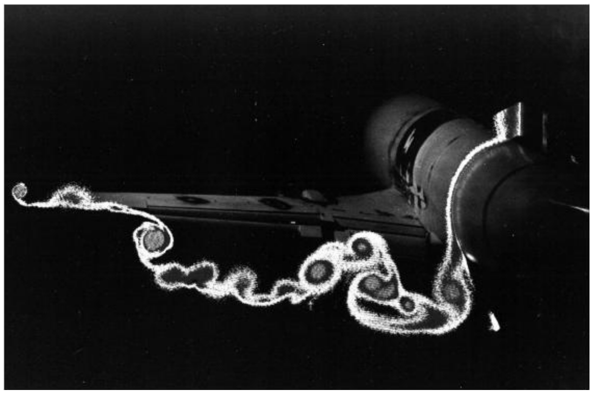

Fig. 3. Turbulent flow trail up to deployed high lift devices.

(optimize V_{stall})

Further developing of glider's noise reductions are taking place, through the studying of how owls fly when hunting. Despite the really high angle of attack of the flight of an owl, it has naturally developed its wings so that its feathers remove the leading edge laminar separation, showing a quasi-turbulent completely attached boundary layer, with the consecutive very low range of frequencies [16].

Another view of the challenge is to reduce engine roar. In the past, the engine was the main source of aircraft noise. Nevertheless, the evolution from the straight-jet engine to the high-bypass ratio engine has greatly reduced its noise emissions.

Nowadays, a better noise reduction would be achieved through idle-trust continuous descent.

F. Surface management and Runway Scheduling optimization

Until now, an optimization in the coordination between departures, arrivals and surface management was not feasible.

Many different projects have been taken to improve the runway scheduling optimization:

-Arrival MANagment(AMAN): It deals systems that helps to the controller to know the arrivals flows and their arrival runway sequencing.

-Departure MANagement(DMAN): It deals with planning tools to optimize the departures flows by a more efficient way of use the runways. This becomes relevant in mixed runways in which both, arrivals and departures are taken.

-Coordination between DMAN and AMAN: Projects like [17] deals with the searching of the best way in which AMAN and DMAN can be coordinated in the use of mixed runways. For that, they use different algorithms and procedures.

-Taxiing optimization: There have been made different studies and simulations[18] in the way in which by a complete description of e airport taxiways, gates, push-backs and runways different set of possible paths for each aircraft are calculated.

Even though many advances have been made in this aspects, the principal challenge nowadays to make a better coordination between them. The bigger difficulties are in the coordination between AMAN/DMAN with the taxiing phase. This is due the different times of anticipations of each, the uncertainties in the position or velocity of the aircraft, the different required separation between the different aircraft.

There have been taken some investigations and simulations in this area [19] that by considering all the difficulties already written try to create better algorithms that will enable a synchronization between the phases decreasing the delays that are produced.

G. Detection and resolution of conflicts

One of the main limitation of all the previous lines of investigations is the big restriction of distance and velocity that aircraft are subjected to due safety requirements.

This distance is one of the main factors in the congestion of busy airports. The repercussions of solving this problem will be an increase in the capacity of the the Terminal Maneuvering Area making possible more operations per hour and less delay time.

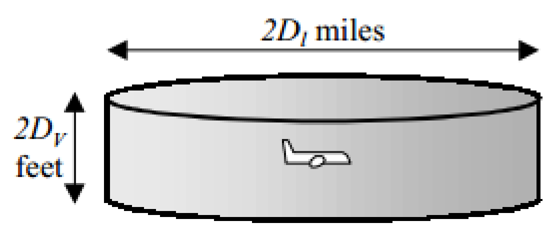

Fig. 4. Separation Distance of an Aircraft

To get systems that are able to detect better future conflicts is the main objective in this area. In order to do that the equipment, the algorithms and the different procedures have to be changed.

Predict the speed and the direction of the wind is something that will solve a lot of problems. Wind is the main factor that gives uncertainty in the prediction of the position of an aircraft. Without wind, the separation distance of an aircraft will decrease highly.

Nowadays, the prediction of the wind is made by complex

numerical calculus and probabilities based in past results. [20] [21] [22] [23]
More information about this can be found in [24] [25]

III. Ideas

After reviewing all the actual problematic and the possible solutions proposed by the different organization, we propose some ideas that can be applied:

A. Ways in which wind modeling can be taken

As it has been said, solving the problem of the unpredictability of the position of an aircraft due the effects of the wind plays a very important role in the overall optimization of the others projects related with the optimization of the ATM services.

What it is needed is a 3d model of the wind field around the airport and in order to do that we propose three different ways:

Deterministic model of the wind: The wind is a fluid and as such it has to fulfill the Navier-Stoke equation. Solving this equation will give a complete description of the wind along time. Now, the solution to this problem does not exist yet and is such the complexity of it that it is included as one of the seven challenges of the Millennium Problems proposed by the Clay Institute of Mathematics[26]. The only thing that can be done for now are simplifications with the acknowledge that there are some errors. We believe that there must be a solution and that soon or later will arrive so with that, we will be able to create a perfect and realistic model that can display in a 4 dimension map the characteristic of the wind.

Stochastic model of the wind: Based on probabilities after comparing past situations in the same airport.

Through different measurements: With this method, we propose the creation of helium balloons able to sustain themselves at high altitudes. They should be equipped with a radio-control system, tools to measure atmospheric conditions like pressure, temperature and vector speed of the wind.

We will release many of this to the air and would organize them in different circles of different radius as the next figure shows.

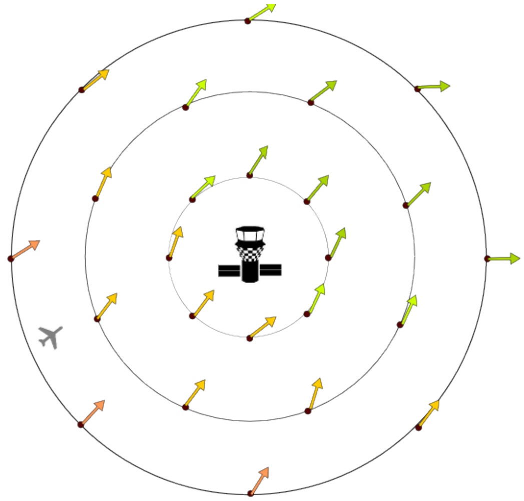

Fig. 5. Organization of the balloons. Top View.

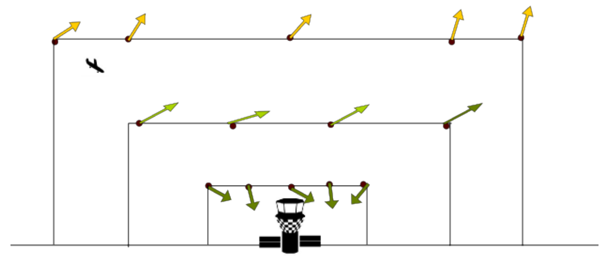

Fig. 6. Organization of the balloons. Lateral view.

In this representation, the vector of the wind is in three dimensions and indicates the direction at each balloon and the intensity of it.

The organization of the balloons in the vertical view corresponds to 3 different levels. The higher one is situated at the point of average Top of Descend. The other two levels cover the space in between. If the we place the balloons at the right strategic positions, it should give us a very realistic information of what is happening around the airport.

The balloons should be able then to send all this information to the the tower where a potent computer should organize the information in order to create the map.

In order to avoid collisions between the different aircraft and the balloons, the central computer should send information to the balloons of when the aircraft is going to pass through that position so they can move to another place.

Each of this methods has it's advantages and disadvantages. The first, even though is the most accurate method, is still far from being accomplished and even when finally it is solved, the calculation of the field will take a very long time. The second one is the one with higher probabilities of error but the fastest. And the third one is in the middle between the other two methods in speed of calculation and accuracy. The biggest problem that it has comparing with the other two is that the information that it gives is in real time. It can't predict future states of the wind.

What we propose after seeing all of this is to use the three methods at the same time. The first one, when it is available, will be used to calculate the wind when the aircraft it is still far. The other two methods will be combined to make a high accuracy system with the possibility of predict future states.

B. Different flight levels depending on the weight of the aircraft

Another idea that we propose is a restructure of the air space close to the airports. We call for a change from the conventional flight levels of Top of Descent to another one that depends on the weight of the aircraft. The division will be made in three different categories, one level for heavy aircraft, another for large and the last one for light aircraft.

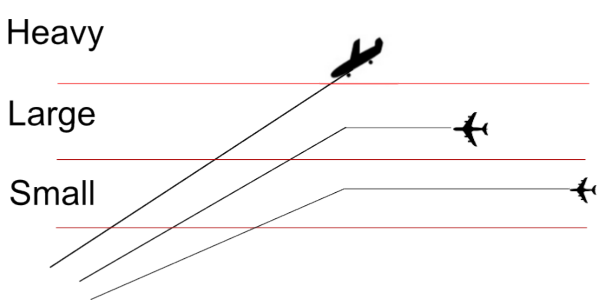

Fig. 7. TOD levels according to the new configuration.

The convectional TOD level that it is being used nowadays will be the one that the heavy aircraft will use with the new configuration. The large and the small aircraft will use levels that are below that one.

The reason we believe on this idea is because we think that this new division of flight levels will make possible a better separation between the aircraft. We think that with this structure of the air space, it will enable a better use of the different speed profiles of the aircraft and their aerodynamic characteristics.

It will be needed the creation of new mathematical models that takes into account the predicted optimal descent path and the position of the aircraft that are in the other levels.

If we combine this idea with the researches made in the Controlled Time of Arrival and Continuous Descent Approach, we will be able to create a framework of investigations in which big savings on fuel consumption can be obtained.

If we add to this idea the possibility of choosing between two(or more) different angle of attack, will enable time saving processes. [9] .

C. Optimizing take off.

Once the plane has received clearance for take off, planes need lots of thrust at takeoff because they have to speed up in a short amount of time. Engines usually run at their maximum takeoff thrust during takeoff and climb. This produces a large stress not only on the engine but on the whole plane and it also implies a high specific thrust.

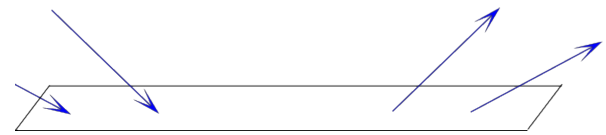

Fig. 8. Two angles of ascent and descent.

Modern day jet engines are designed to be efficient for cruise altitude and speeds, which has nothing to do with the non optimal conditions at takeoff and represents only a very small portion of the total flight time. Based on this, we believe that it is possible to develop a new ground based system that can allow us to reduce takeoff thrust, savings in fuel and reduces stress on the plane during take off.

A possible solution would be to use similar catapult technology as that used on air carriers to partially or fully accelerate the plane to take off speeds.

Another possible solution is a take off platform that attaches to and/or carries the aircraft. In the case of only attaching to the plane, this technology would only reduce the total thrust needed, in other words it would be towing the aircraft to provide additional acceleration.

In the second instance, by giving us the possibility of carrying the aircraft we would be able to not only reduce thrust needed by the plane, but also contemplate the possibility of reducing friction. For example we could design a Maglev[27] [28] platform on which the plane would rest on until take off speed have been achieved.

We must also contemplate the development of a landing counterpart of this system that would reduce landing distances, impact stress and even removing the necessity of having landing gear on board the plane.

Yet we can expect certain problems for this system as increased time in between each take off or landing and the need for this system to be installed in most airports to allow us to achieve its maximum potential.

If we are capable to develop this ground system we can possibly expect valuable savings in fuel, noise reduction, reduction in total stress applied do to max thrust from motors increasing the lifespan of certain parts of the plane, reducing take of distance, aircraft weight and size of runways.

This ground system will most likely use green technologies as a power source, and thus not suffering from problems derived from increasing oil prices and reduce total emissions from the aviation sector.

IV. Conclusions

Future is demanding growth. And growth can not be produced if airports and all the procedures around it are not optimized. The ideas that we have proposed are very different and try to solve different aspects in which the overall problem of optimization of landing and departure processes can be divided.

The most important and useful idea of this paper is the one related with the different ways in which a better modeling of the wind field around an airport can be done. We believe that with the measurements of balloons and the different algorithms we have proposed, in the future a very accurate map of winds can be created. This united with better models will allow the advance of many different ideas:

Distance Separation: The required distance of separation between the different aircraft will be shortened allowing more operations per hour, less congestion and more freedom for the aircraft.

Creation of better routes: Knowing the direction and the speed of the wind, aircraft will be able to take routes that will take advantages of it. This will allow less fuel consumption and as a result less CO_2 emissions.

Increase of safety: With the shortening of the separation distances and a better prediction of future position of the aircraft will open doors to a better safety systems and less false possible conflicts.

These were some of the improvement that this idea could bring. The effects will give a step forward in all the goals established by SESAR and NextGen.

The other two ideas will also be participants of the advantages that the wind modeling would bring. The first one tries to optimize the descent approach. It is the most strategical idea of the three we have proposed and that it is why if in the end it is useful, it will be the easiest one to apply.

On the other hand, the last idea, that tries to create system to help in the take off of the aircraft, is the most futuristic one. It will require changes in all the different stages of this industry. Will require new types of aircraft, new types of runways, procedures, etc. We believe that it is an idea that can't be applied in the short term but only in the long one depending in how the future will evolve.

V. Recommendations

The ideas we have proposed need many more research that go beyond the purpose of this paper. Some of the ways in which a further study have to be taken are:

Configuration of the position of the balloons: In the figures we have proposed, the position of the balloons along the airport are in concentric circumferences along different heights. This configuration is based in intuition and may not be the best way to do it. Another thing to study is the algorithms that are going to be used and how it is going to mix the data provided by the balloons with the one provided by the deterministic or stochastic equations.

Automation: In theory, the ability to know accurately where the aircraft is and where it is going to be, considering the wind, should allow the creation of powerful models of all the ATC processes. We propose further investigation in this area in order to create procedures that can be more and more autonomous.

New materials: As we know, most of the aircraft have similar range of optimal flight level. If in the future, the airspace in the TOD is divided in three different range of flight levels depending on the weight of the aircraft, we propose that future aircraft may be customized in order to be optimal in the flight level that it is going to be applied to them.

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