A theoretical approach to defining the European core area

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Abstract

European studies using air traffic flow are usually restricted to a limited area. This limited area is the area which have the highest volume of traffic in Europe. But limited areas are seldom the same in the different studies. This paper presents three different limited areas validate by a theorical approach. This approach is based on fluid mechanics and in particular Reynolds numbers. This different limited areas correspond to three different types of studies, the core area who is a set of sectors - a sector is a geographical area controlled by an air traffic controller - the country core area who is a set of country and the Air Traffic Control Complexity Area Border who is a set of air traffic control centers.

1 Introduction

European studies using air traffic flow are usually restricted to a limited area. Each study defines its own high traffic density core area [4] [6] [7]. However, the basic concept of the core area of Europe is that it is a large terminal area managed by many different air traffic control (ATC) units which have the highest number of flights in Europe.

This paper presents a new approach aiming to define the core area precisely and definitively. This approach is based on fluid mechanics and in particular Reynolds numbers.

The first part presents different ways of looking at the problem and the corresponding definitions. A short reminder of fluid mechanics is presented in the second part. The third part models all the aspects of the problem. Part four describes our results, and part five presents our conclusions for the construction of the European core area.

2 Problem description

It is recognised that air traffic[1] is higher in the centre of Europe, but to date no studies have been carried out to define precisely where the boundary between low traffic and high traffic areas lies. An initial approach has been made by Eurocontrol, which has defined the ATC Complexity Area Border [3] [2]. This area is composed of a number of European air traffic control centers. However, this set of centers was selected empirically and it could be interesting to validate or change this area. Some studies have used geo-political areas. They cannot therefore use the ATC Complexity Area Border, but have made their own definition of the European core area. The core area is not defined as precisely as the ATC Complexity Area Border. In fact everyone defines the core area differently, some as a set of countries, others as a set of sectors or regions.

In this article we use the following definitions of these different areas.

The ATC Complexity Area Border is a set of air traffic control centers which have the highest volume of traffic in Europe.

The core area is a set of sectors between which the volume of traffic is highest.

The country core area is a set of countries which, both internally and between them, have the highest volume of traffic compared with the rest of Europe.

[1] Air traffic is defined as traffic between sectors, therefore the sector is the unit of measure we have used.

The ATC Complexity Area Border is defined by Eurocontrol as being comprised of the ATC centers of London, Manchester, Maastricht, Amsterdam, Brussels, Dusseldorf, Reins, Paris, Frankfurt, Karlsruhe, Munich, Vienna, Zurich, Geneva, Milan and Aix.

In its different definitions, the core area always comprises at least Belgium, the Netherlands, Luxembourg, western Germany, Switzerland and north-eastern France.

3 Fluid mechanics

Our subject is air traffic flow, and in particular flow. Our problem can therefore be related to fluid mechanics. Fluid flow can be either laminar or turbulent. Turbulence is flow dominated by recirculation, eddies, and apparent randomness. Flow in which turbulence is not exhibited is known as laminar. The factor that determines which type of flow is present is the ratio of inertia forces to viscous forces within the fluid, expressed by the non-dimensional Reynolds Number [5] :

$$R_e = \frac{\rho v D}{\mu}$$

where v mean fluid velocity, D characteristical length, μ dynamic fluid viscosity and ρ fluid density. For example, for fluid flowing in a pipe, v could be the average fluid velocity, and D would be the pipe diameter.

Definition 1 (Density) *Density is a measure of mass per unit of volume. The higher an object's density, the higher its mass per volume.*

Definition 2 (Viscosity) *Viscosity is the "thickness" of a fluid; it is a property of fluids describing their internal resistance to flow.*

Laminar flow within pipes will occur when the Reynolds number is below the critical Reynolds number of $R_{e_{critlow}} = 2300$ and turbulent flow when it is above $R_{e_{critup}} = 3000$. But the critical Reynolds number $R_{e_{crit}}$ depends on the flow type and the definition of the Reynolds number.

4 Modelling

We firstly need to define the core area, because it corresponds better to the concept of flow, due to greater fragmentation and traffic between sectors. We can then construct the other two areas, using this result.

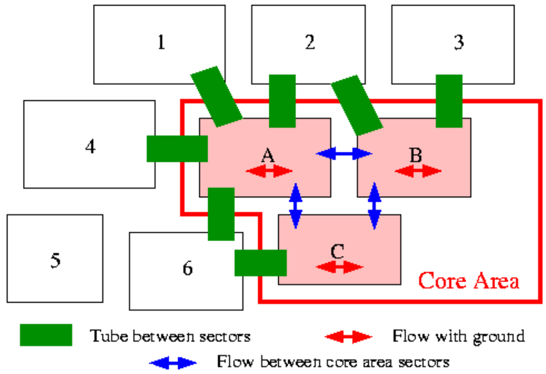

Figure 1: Representation of traffic between sectors

4.1 Core Area

The Reynolds number is used to distinguish two states. In the same way, we define the core area as one set of sectors, which can be distinguished from a second set made up of other sectors by the fact that traffic inside the core area is higher. Flows inside the core area are therefore greater, and we can infer that the state of the core area is turbulent.

A sector is added to the core area after it has been proved that with the addition of that sector the core area is still turbulent according to the Reynolds number. A sector can only be added to the core area if it is related with at least one sector that is already in the core area. Any two sectors are considered as related if there is a flow of traffic between them.

Each sector can be represented as a box. As we have said, related sectors are those with a flow of traffic between them. This flow can be represented as a pipe. Figure 1 shows traffic between sectors.

When a sector is added to the core area, the Reynolds number is calculated again. Total flows inside the core area are considered, as well as flows between the core area and the new sector. As we have seen, the Reynolds number depends on four variables. We shall now look at each of these in more detail.

Density

Air traffic density is simply the air traffic (number of planes) in a given sector, divided by the volume of the sector. In physics, density is defined as mass divided by volume. In our definition, air traffic is comparable to mass. The mass of the core area is the sum of two types of traffic flow: between sectors, and between sectors and the ground. The volume of the sector is its surface multiplied by the number of available fight levels. Finally, fluid density ρ is the mass of the core area divided by the sum of the volume of the sectors in the core area.

Velocity

Velocity is a differential, and the differential in our modelling is between a sector and the core area. In physics, velocity is distance differential divided by time differential. The unit of time we have used to calculate air traffic in a sector is one day (24 hours). Because the unit of time is always the same in our calculation, velocity can be reduced to the distance differential, i.e. traffic. Velocity is therefore the total air traffic between the sectors of the core area and a sector. For example, in Figure 1, velocity between sector 6 and the core area is the sum of traffic between sectors A and 6, plus C and 6.

Viscosity and characteristical length

Viscosity is the resistance of a fluid to change in form. Because the considered flow, i.e. air traffic flow, always has the same characteristics, we can infer that viscosity is constant. Each time we add a new sector to the core area, we perform the same calculation. We also use the same pipe to relate each new sector to the core area. Thus the characteristical length D is constant.

The Reynolds number, in our adaptation, depends on the traffic in and volume of the core area, and the traffic between the new sector and the core area. However it also depends on which sectors were selected at the start in order to define the core area. The model permits a wide selection of initial sectors, either airport sectors, or pairs of sectors, or a combination of the two.

4.2 The Country Core Area and the Complexity Area

Once the core area has been defined, as a result of our calculations, it is easy to define the country core area. In order for a country to be included in the country core area, a minimum percentage of its sectors must be in the core area. If the percentage of the country's sectors in the core area is higher than this minimum, then it is included in the country core area.

The ATC Complexity Area Border is also easy to obtain. To be included in the Complexity Area, an air traffic control center must have a minimum percentage of center's sectors in the core area. If the percentage of a center's sectors in the core area is higher than this minimum, then it is included in the ATC Complexity Area Border.

5 Results

The results presented in this paper were computed using a traffic calculator [1] on 125 days on European traffic between the middle of 2001 and the beginning of 2002. The input parameters were the initial sectors selected, the Reynolds number and of course the air traffic flow for 2001/2002. A graphic interface has been developed to display the resulting core area. The colour coding used is blue (grey) for sectors in the core area and white for sectors not in the core area.

This paper presents the results of three tests using different initial sectors:

- Paris TMA[2].
- The three most important sectors in Europe in term of traffic.
- Maastricht TMA.

5.1 Definition of the core area

In the first test, the initial sector selected was the Paris TMA, which is the most important sector in Europe in terms of traffic for our dates. Table 1 details the number of sectors in the core area obtained for different Reynolds numbers. We can see

[2] Terminal control area, the TMA is controlled by the departure/arrival Air Traffic Control

R_e	1500	2000	2500	2816	2817	3000	3500
Sectors	407	370	318	268	16	14	13

Table 1: Initial sector Paris TMA: the number of sectors in the core area for different Reynolds numbers.

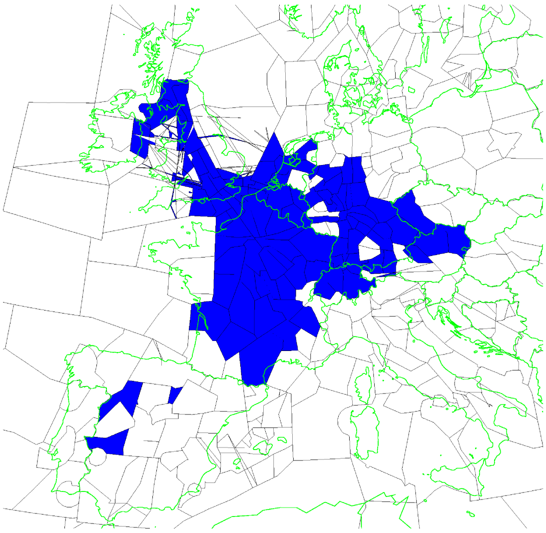

Figure 2: Core area at flight level 220

at once a strikingly significant point between the Reynolds numbers 2816 and 2817. At this point the number of sectors increases dramatically, whereas before and after it, progression is low and roughly linear.

We define the core area just below this significant point. $R_e = 2500$ has been chosen because it is a round number not far from this point. The dramatic increase at this point can be explained by the fact that only one sector was selected as the starting point for this test. Once the Paris approach area is large enough to enter others major European approach area, then the number of sectors increases significantly.

Figures 2 and 3 show the sectors included in the core area at the respective flight levels 220 and 360. As we might expect, the French sectors are well represented, there is too sectors of England, Germany, Belgium, the Netherlands, Switzerland, Austria and some from Spain, Italy, Denmark, Hungary and the Czech Republic.

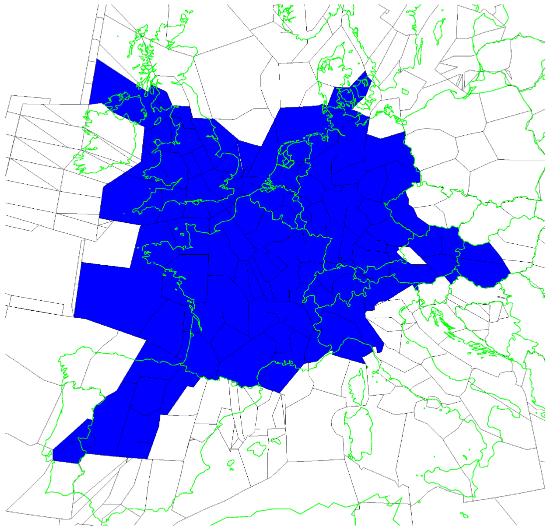

Figure 3: Core area at flight level 360

5.2 Definition of the country core area

In the second test, the initial sectors selected were Paris TMA, Frankfurt TMA and London Heathrow approach, which are the most important sectors in Europe in terms of traffic for our dates. Table 2 details the percentage number of sectors in the core area obtained for different Reynolds numbers.

The three initial sectors are in northern Europe, so northern European countries are understandably better represented than southern European countries. Italy and Spain are thus under-represented. However United Kingdom sectors are not as well represented as we might expect. Only English sectors appear in our test.

In order to separate the countries into two categories, we have fixed the minimum percentage of sectors in the core area at 20%. The Czech Republic is not included in the country core area because it is too near the Frankfurt TMA and has fewer sectors than Switzerland and Austria. Italy is included in the country core area because some sectors are already in the core area and Italy is subject to seasonal traffic.This separation is consolidated by our previous definition of the core area. Twenty of Italy's sectors are included in the core area at all flight levels, whereas only 2 Czech sectors are included. And as we can see in figures 2 and 3, the other countries fall naturally into the country core

R_e	1000	1500	2000	Average
Germany	82%	80%	70%	77%
France	76%	68%	57%	67%
U.K.	52%	47%	47%	49%
Luxembourg	100%	100%	100%	100%
Switzerland	77%	77%	77%	77%
Belgium	72%	72%	72%	72%
Netherlands	50%	45%	45%	47%
Austria	46%	38%	38%	41%
Spain	58%	33%	9%	33%
Denmark	40%	40%	20%	33%
Italy	35%	17%	15%	22%
Czech Rep.	38%	11%	11%	20%
Ireland	28%	19%	9%	19%
Portugal	16%	16%	11%	14%
Hungary	12%	12%	12%	12%
Sweden	12%	0%	0%	4%

Table 2: Three European's initials sectors; percentage numbers of core area's sectors for different Reynolds numbers

area according to this separation.

Thus the set of countries in our country core area includes Germany, France, United Kingdom, Switzerland, Belgium, Netherlands, Austria, Spain, Denmark, Luxembourg and Italy.

5.3 ATC Complexity Area Border

In the third test, the initial sector selected was the Maastricht TMA. This is because the ATC Complexity Area Border has been defined by Eurocontrol and because the Eurocontrol's air traffic control center is in Maastricht. However this test produces almost the same results as the first test, which uses the Paris TMA. This result validates our model.

There are 383 sectors in the ATC Complexity Area Border, distributed across 16 centers. Table 3 presents for each center the percentage of sectors present in the first two tests. The first column lists the country of each sector. The second column lists the centers and their first sector code, if available. The percentages shown in the third column are the percentages of sectors present in the core area. The last column gives this percentage for the second test using the three initial sectors and $R_e = 1500$. The centers highlighted in grey are those included in the ATC Complexity Area Border defined by Eurocontrol.

Country	Center (Code)	Sectors	
		Paris	3 sectors
"Eurocontrol"	Maastricht	83%	93%
Switzerland	Geneva	100%	100%
	Zurich	63%	63%
France	Reins (LFE)	92%	100%
	Paris (LFF)	79%	88%
	Bordeaux (LFB)	53%	53%
	Brest (LFR)	48%	60%
	Aix (LFM)	33%	48%
Germany	Karlsruhe (EDU)	90%	90%
	Frankfurt (EDF)	84%	89%
	Munich (EDM)	76%	76%
	Dusseldorf (EDW)	35%	55%
	Berlin (EDB)	25%	75%
U.K.	Manchester (EGC)	80%	90%
	London	41%	44%
	(EGP)	33%	46%
Belgium	Brussels (EB)	67%	72%
Netherlands	Amsterdam (EH)	45%	40%
Italy	Milan (LIM)	80%	80%
	(LIR)	7%	7%
	(LIP)	3%	8%
Austria	Vienna (LO)	38%	38%
Spain	(LECM)	25%	35%
Denmark	(EK)	12%	20%
Hungary	(LH)	12%	12%
Czech Rep.	(LK)	11%	11%
Ireland	(EI)	9%	16%

Table 3: Percentage numbers of sectors centers present in the two first tests

The lowest percentage in the Complexity Area is Aix, with 33%. Some centers with a percentage higher than 33% are not included the Complexity Area, for instance Bordeaux and Brest, and EGP in the United Kingdom. In order to conserve approximately the same number of centers (16) as the Eurocontrol Complexity Area, a new definition of the Complexity Area could be to include all centers with a percentage higher than 35%. This definition would include all the centers of the Complexity Area except Aix, but including Bordeaux and Brest.

6 Conclusion

We defined three different types of area who concentrate the highest volume of traffic in Europe. The ATC Complexity Area Border is already used by Eurocontrol as we have seen, but can be brought up to date. We hope that the core area, the country core area and the ATC Complexity Area Border can be used in further studies.

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Key Words

Core area, Reynolds number, complexity area border, optimization, traffic flow.

Biography

Jean-Marc Alliot graduated from the Ecole Polytechnique de Paris and from the Ecole Nationale de l'Aviation Civile (ENAC). He also holds a Ph.D. in Computer Science (1992). He is currently in charge of the global optimization laboratory of CENA and ENAC in Toulouse.

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