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To cite this version:

Aleksandra Mozdzanowska, John Hansman, Jonathan Histon, Daniel Delahaye. Emergence of regional jets and the implications on air traffic management. ATM 2003, 5th USA/Europe Air Traffic Management Research and Development Seminar, Jun 2003, Budapest, Hungary. pp xxxx. hal-00938038

HAL Id: hal-00938038

https://enac.hal.science/hal-00938038v1

Submitted on 18 Apr 2014

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EMERGENCE OF REGIONAL JETS AND THE IMPLICATIONS ON AIR TRAFFIC MANAGEMENT

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Abstract

Airlines are increasingly using regional jets to better match aircraft size to high value, but limited demand markets. This has been especially important following increased financial pressure on the industry after September 11th 2001. The increase in regional jets represents a significant change from traditional air traffic patterns. To investigate the possible impacts of this change, this study analyzed the emerging flight patterns and performance of regional jets compared to traditional jets and turboprops. In addition, a comparison between regional jet flight patterns in the United States and Europe was conducted.

Regional jet operations generally cluster in the regions with high traditional jet operation density, implying a high level of interaction between the two aircraft types. The regional jets were observed to fly shorter routes than traditional jets, with few transcontinental flights. However, the gap between regional and narrow body traditional jet stage lengths appears to be closing. In addition, regional jets were observed to exhibit lower climb rates than traditional jets, which may impact air traffic control handling and sector design. It was also observed that regional jets cruise at lower altitudes than traditional jets possibly due to their shorter flight routes. Finally, it was observed that regional jets cruise at a lower Mach number than traditional jets, except on specific high density routes where the regional jets are either slowing down the traditional jet traffic or flying above their optimum cruise speed. Since the composition and utilization of the national fleet is changing, this will pose potential problems for air traffic management. In particular, it may cause serious congestion issues when demand increases during an economic recovery.

Introduction

One of the significant emerging changes to the national air space system is the number of regional jets, which has been increasing at an exponential rate. The rapid emergence of regional jets can be seen in Figure 1, which shows FAA registration data plotted between the third quarter of 1993 and the third quarter of 2002, for some of the regional jets commonly flown in the United States. The figure shows that the growth in regional jets is exponential, with CRJ2 and E145 registration data increasing the fastest.

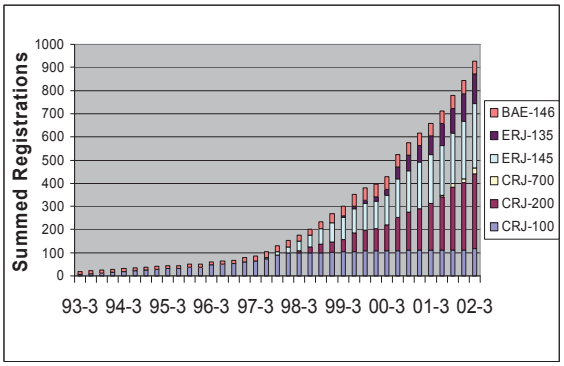

Figure 1: FAA Registration Data for Regional Jets.

Airlines are moving to regional jet operations because the smaller aircraft size allows them to better match the aircraft to high value markets, and the faster turnaround times allow for a higher frequency of service. Regional jets have similar flight profiles, as traditional jets. As a result, the two jet types pose similar demands on airports and airspace. Currently the result of these demands is not fully known, and as a result, the constraints that will emerge are also unknown. This paper analyzes those demands and their possible implications on the air traffic system by studying the national flight patterns as well as the performance

characteristics of regional jets, traditional jets, and turboprops.

Methodology

In order to visualize the emerging trends in the United States, flight data from the Aircraft Situational Display to Industry (ASDI) feed was used. This data is compiled by the Volpe center from the FAA's Enhanced Traffic Management System (ETMS). This study used data for all aircraft that had a take off time between midnight December 19th, 2002 GMT and midnight December 20th, 2002 GMT. While only one day of data is presented here, data starting in April 2002 has been analyzed and has shown similar results. This set of data was broken down into four categories based on aircraft type: the narrow body traditional jets, the wide body traditional jets, the turboprops, and the regional jets. The list of regional jets, regional airlines, and their codes share partners can be seen in Table 1 [2].

In order to conduct a comparison between regional jet operations in the U.S and in Europe simulated track data of European flights was used. The data was created based on filed flight plans for December 19th 2002.

Table 1: Regional Jets and their Corresponding Regional Carriers and Code Share Partners

Aircraft Type	Regional Carrier	Code Share Carrier
E135	American Eagle Continental Express Republic	American Continental America West, Delta, USAirways
E145	American Eagle Continental Express Mesa Republic Trans State	American Continental America West, Frontier, USAirways America West, Delta, USAirways American, US Airways
CRJ1	Comair Sky West	Delta Delta, United
RRJ2	Air Wisconsin Atlantic Southeast Mesa Sky West	Air Tran, United Delta America West, Frontier, USAirways Delta, United
CRJ7	American Eagle Atlantic Southeast Comair Horizon Mesa	American Delta Delta Alaska, Northwest America West, Frontier, USAirways
BA46	Air Wisconsin	Air Tran, United

A technique was developed to generate density maps from the traffic data. An example of a density map is shown in Figure 2. The map shows the number of aircraft which appeared over a specific area during the course of an input time bound. The plot was generated by dividing the map into a grid and counting the number of flights whose paths intersected each grid. The grid was then colored based on the number of flights that flew through it, creating an effective density map. It should be noted that when the size of the grid is changed, the resulting density values may be altered.

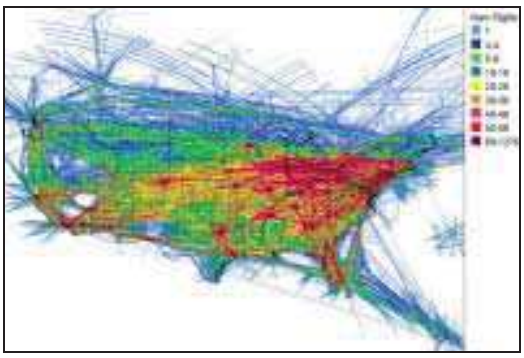

Figure 2: Density Map of all Flights between December 19th and 20th, 2002

Regional Jet Operations

Growth of Regional Jets

The growth of regional jet networks is shown in Figures 3, 4, and 5. These figures show the scheduled regional jet flights in 1998, 2000, and 2002 respectively. The data was obtained from the OAG and a straight line was drawn between the origin and destination creating a network map. It is clear from the figures that the number of regional jets increases with time, and it can also be seen that most of the growth occurs in the north-eastern part of the United States.

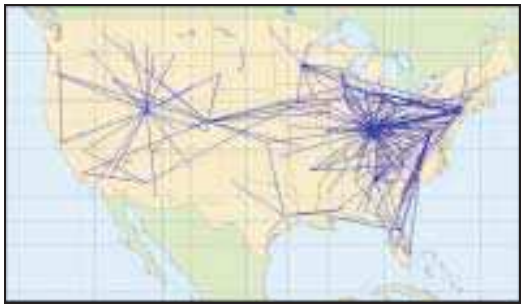

Figure 3: Regional Jet Network Map in 1998 (Courtesy of Ryan Tam)

Figure 4: Regional Jet Network Map in 2000 (Courtesy of Ryan Tam)

Figure 5: Regional Jet Network Map in 2002 (Courtesy of Ryan Tam)

Scope Clause Restrictions

While the number of regional jets has been increasing at a rapid rate for the past five years, a major obstacle to the growth of regional jets has been posed by labor scope clauses. Scope clauses result from labor contracts made with airline pilots and typically limit the number and size of regional jets that an airline can own or operate. Currently it is less expensive for an airline to fly regional jets because the pilots are typically paid much less than the mainline crews. Given that airlines have been facing serious financial problems since 9/11/2001, many are

renegotiating their existing pilot contracts. As a result, the effect of scope clauses is likely to change. At this point it is unclear if changes in scope clauses will result in an increase or decrease in the rate of regional jet operations. Currently only USAirways and United have reached agreements, and both could leverage bankruptcy during the negotiations. However, if the economy does not recover rapidly other carriers may face bankruptcy and force their pilots to agree to more lenient scope clause restrictions.

In addition to limiting growth, scope clauses can help shape the regional jet fleet that an airline owns, since regional jets have to fit within the scope clause limitations. For example, in the fall of 2001, Continental Express had no specific limitation on the number of regional jets. However, the mainline scope clause stated that if the company owned jets with over 59 seats, both the regional and mainline pilots would fly the aircraft. Table 2 shows the number, type, and size of all regional jets owned by Continental Express as of December 2002 [3]. It can be seen that the airline owns only regional jets with less then 50 seats. This is the largest regional jet available with less then 59 seats; the next model has 70 sets. It is possible that Continental Express could not identify a market for larger aircraft, but it is more likely that the increased crew costs made the larger regional jets less attractive.

Table 2: Continental Express RJ Fleet as of December 2002

Aircraft Type	Number of Aircraft	Number of Seats	Restrictions
ERJ 135	30	37	No restrictions on aircraft with under 50 seats
ERJ 145	140	50	
ERJ 145 XR	8	50	

Utilization of Regional Jets

In addition to the rapid growth, the utilization of regional jets is changing. Figure 6 shows the utilization of regional jets introduced into the national air space system between 1992 and 2001 [4]. For that period, it can be seen that a majority of the incoming jets created new routes, and that replacement of turboprops and traditional jets, as well as supplementing traditional jet routes had a smaller impact. This trend seems to have changed after 9/11/2001. It is expected that now most regional jets are replacing and supplementing traditional jet routes, but more data is needed before this can be firmly concluded. However, it is consistent with the similar operation patterns between regional jets and traditional jets, shown throughout this paper

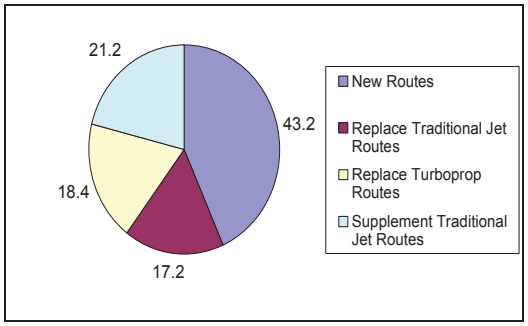

Figure 6: Route Changes between 1992 and 2001 Caused by Emerging Regional Jets [4]

Regional Jet Flight Patterns

In order to study the effects of the dramatic increase of regional jets it is illustrative to look at their flight patterns over the domestic United States compared to the patterns of traditional jets and turboprops. A U.S. density map for each aircraft category is shown in Figures 7, 8, 9, and 10. It can be seen from Figure 7 that the regional jets appear in high numbers in the north-east U.S., and that their operations are focused around the hubs forming networks in much the same way as the narrow body traditional jets. While the flight distances are significant there are very few transcontinental flights.

Figure 8 shows that the narrow body traditional jet flights cover all of the United States and are focused at the hubs. Their largest concentration appears in the north-east, but their presence in the mid-west is also significant. The similarity in operating patterns implies that the interactions between regional and narrow body traditional jets will be the most noticeable at the hubs and in the north-east U.S. Although the narrow body traditional jets are concentrated in the same area of the country as regional jets, it can be seen from the map that they have a significant number of transcontinental flights. Figure 9 show the wide body traditional jet density. The map shows that the wide body traditional jets have a higher density in the mid-

west and a lower density in the south-east. They are not as hub focused as the narrow body traditional jets or the regional jets. The wide body traditional jets have a high number of transcontinental and international flights. Finally, Figure 10 shows that turboprops are also concentrated in the north-east. They are focused around hubs and other larger airports, and have no transcontinental flights and very few flights that connect major airports. These short flight distances are due to the fact that turboprops do not have the capability to fly long routes. As a result, they are mostly used to feed larger airports.

Figure 7: Regional Jet Density

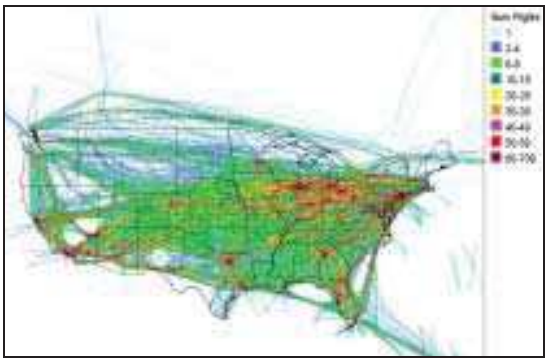

Figure 8: Narrow Body Traditional Jet Density

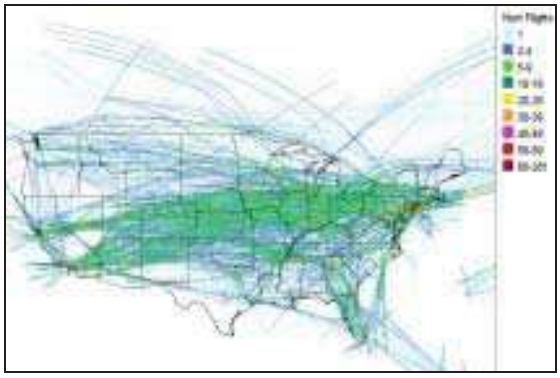

Figure 9: Wide Body Traditional Jet Density

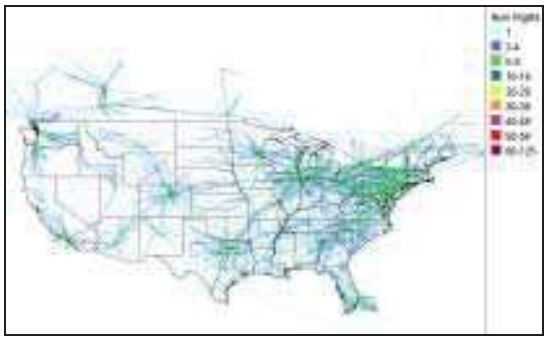

Figure 10: Turboprop Density

Comparison of Regional Jet Flight Patterns in the United States and Europe

In addition to analyzing flight patterns in the United States, a comparison to European aircraft flight patterns was performed. It can be seen from Table 3 that the European airspace handles fewer flights than the U.S airspace. Europe also has a higher percentage of traditional jets flights than the United States, but the United States has more regional jets and significantly more turboprops. This is most likely due to the fact that Europe has an extensive network of trains, which are used for short trips instead of the turboprops.

Table 3: European vs. U.S. Aircraft Category Breakdowns for all Flights during a 24 Hour Period

Aircraft category	Total flights in Europe	Percent of total flights in Europe	Total flights in the USA	Percent of total flights in the USA
Regional jets	2397	13%	6783	19%
Traditional jets (narrow body)	12268	65%	17766	50%
Traditional jets (wide body)	2353	12%	3373	10%
Turboprops	1936	10%	7378	21%

The relative route maps of all the aircraft types in both Europe and the United States can be seen in Figures 11 through 18. The wide body and narrow body jet track patterns look the same between the United States and Europe. In both cases the wide body traditional jets provide international flights, and oceanic flights. The narrow body jets provide transcontinental flights in the United States and international (transcontinental) flights in Europe. The major difference between the United States and Europe can be seen when comparing the regional jets and turboprop operating patterns. In the United States the regional jet flight patterns are very similar to the narrow body jet patterns, and the turboprops can be seen to closely center on the hubs. In Europe the regional jet and turboprop patterns are extremely similar, both aircraft fly short routes, and with less concentration around hubs than is observed in the US operating patterns.

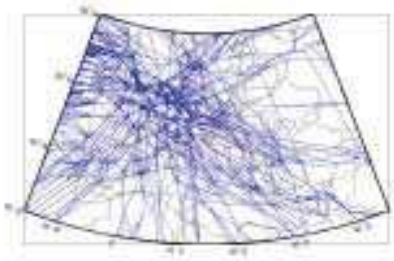

Figure 11: European Wide Body Traditional Jet Flights

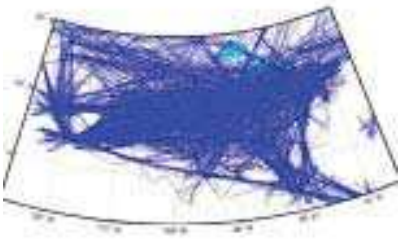

Figure 12: U.S. Wide Body Traditional Jet Flights

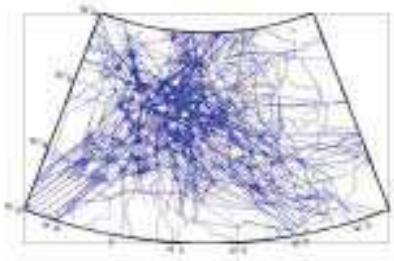

Figure 13: European Narrow Body Traditional Jet Flights

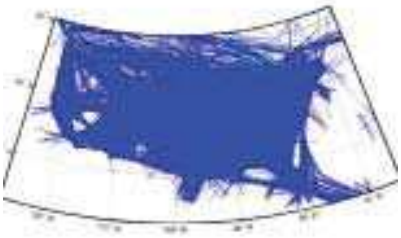

Figure 14: U.S. Narrow Body Traditional jet Flights

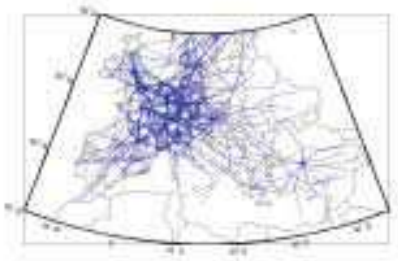

Figure 15: European Regional Jet Flights

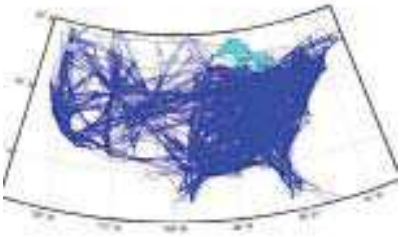

Figure 16: U.S. Regional Jet Flights

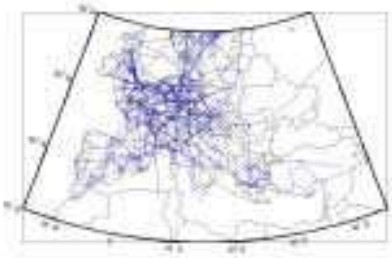

Figure 17: European Turboprop Flights

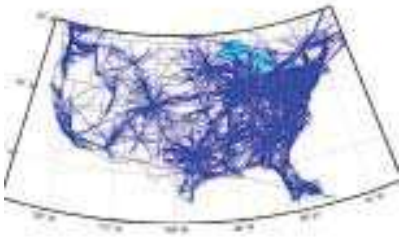

Figure 18: U.S Turboprop Flights

Stage Length Differences

The analysis of the density maps prompted a closer examination of flight distances in the U.S data. Figure 19 shows a distance histogram analyzed by aircraft category. The flight distances were calculated as the great circle distance between the first and last available ETMS record for each flight. The plot shows that turboprops fly short distances, with an average stage length of 187 statute miles, and are not observed to fly routes longer than about 800 statute miles. The regional jet operations outnumber the narrow body traditional jet operations for flights below 650 statute miles. However, for flights above that value the regional jet frequency tapers rapidly, and no regional jets are observed on flights longer then about 1200 statute miles. This results in an average stage length of 394 statute miles for regional jets, and 710 statute miles for narrow body traditional jets. Given that the number of regional jets is increasing, and that some of these jets are replacing traditional jet routes, it is expected that the gap between regional and traditional jets above 650 statute miles will close with time. This prediction is supported by comparing the current average stage length of regional jets to one calculated in 1998, which was 375 statute miles [5]. Finally, the wide body traditional jets have a similar distribution of flight distances as the narrow body traditional jets. However, they have a higher frequency of flights above 1300 statute miles. As a result, the average stage length for wide body traditional jets is 897 statute miles.

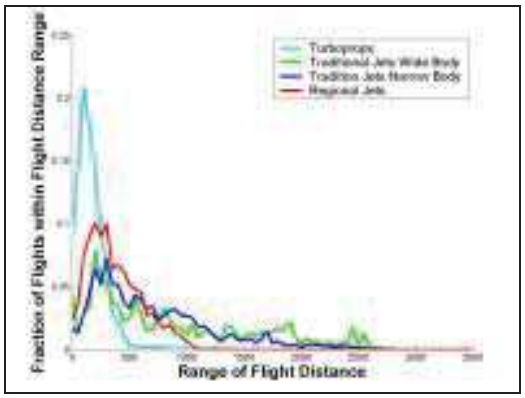

Figure 19: Stage Length Histogram

To examine a specific example of stage length differences, the flight paths of aircraft leaving Dallas Forth Worth were plotted and colored by aircraft category. The results, shown

in Figure 20, demonstrate the increase in stage length from turboprops, to regional jets, to narrow body traditional jets, to wide body traditional jets. In addition it can be seen that most of the regional jets flights are to the east, which is consistent with the results from the density map.

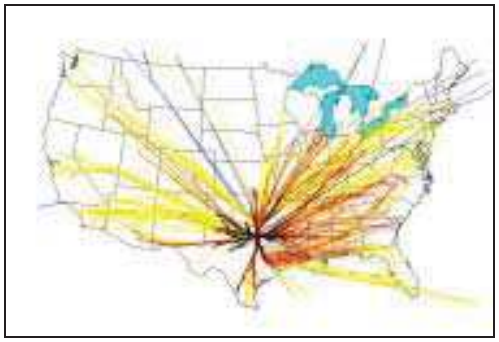

Figure 20: Trajectories for DFW Departing Flights (turboprops in black, regional jets in red, narrow body jets in yellow, wide body jets in blue)

Implications of Regional Jet Performance

Given the rapid growth of regional jets, and their high level of interaction with other aircraft types, it is critical to analyze the implications of these interactions. The observed performance of regional jets in the U.S. data was compared to narrow and wide body traditional jets and turboprops at the airport and terminal areas as well as during cruise.

Implications at the Airport and Terminal Area

In the airport and terminal areas, the main issues resulting from increased regional jet operations will be congestion related. Regional jets typically need to use the same runways as traditional jets, whereas turboprops often use shorter ones. As the number of regional jets increases, they will be competing for runway space, and may exacerbate congestion problems as the number of operations per person will increase.

In addition to runway constrains, local airspace limitations may be exacerbated by regional jet operations. Figure 21 shows the flight tracks for departures from DFW on the 6th of February 2003 between 0000 and 0500 GMT. The black lines indicate turboprop trajectories, and the blue and green lines represent regional and traditional jet trajectories. It can be seen that regional and traditional jets align on the same tracks, while turboprops fly on separate routes. As turboprops are replaced by regional jets, an increase in congestion on the jet arrival and departure routes is expected.

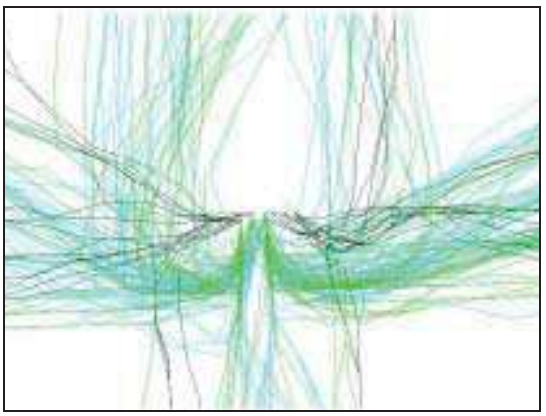

Figure 21: Flight Tracks for Aircraft Leaving DFW

In addition to congestion issues due to an increase in operations, congestion and delay issues may also appear due to climb performance differences between regional and traditional jets. Figure 22, shows the altitude vs. time plot for flights between CLE and ORD. It can be seen from the plot that both the CRJ and ERJ climb slower then the Boeing or Airbus jets. The ERJ in particular stands out as having a slower climb rate. This data represents only one example, and this phenomenon is difficult to study on a system wide basis; however, a number of routes have been studied and have produced similar results.

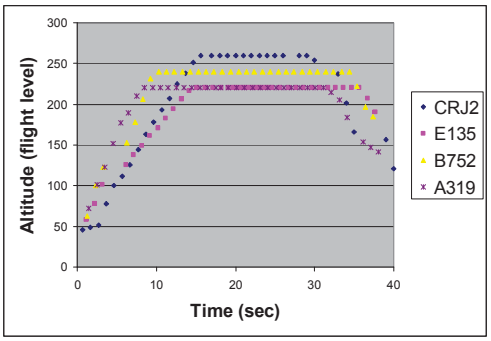

Figure 22: Altitude vs. Time for Flights from CLE to ORD

The slower climb rate of regional jets increases the range of aircraft performance that controllers must manage in order to adhere to proper separation standards. Slower climb rates can change how regional jets interact with the sector structure. Many of the irregular sector shapes found in the current air traffic management system are a direct consequence of modifications targeted at reducing the number of sector boundary crossings. Boundary crossings are avoided due to the increased radio communications and coordination workload associated with each transition. Figure 23 shows a close up of Figure 22 overlaid with a hypothetical sector structure. It can be seen from the figure how the slower climb performance of regional jets could increase the number of sector boundary crossings. This implies that some departure sectors may need to be redesigned in order to accommodate this new range of aircraft performance. The dotted line in the figure shows the proposed new boundary for the lower sector.

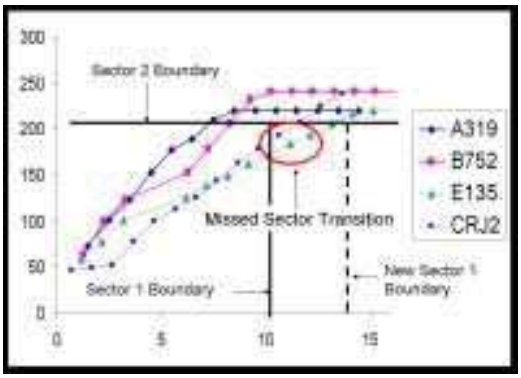

Figure 23: Effect of Climb Rates on Sector Structure

Implications at Cruise

In order to identify potential cruise implications, high altitude cruise performance for all four aircraft types was analyzed. Figure 24 shows a normalized histogram of the primary altitude during cruise for regional jets, narrow body traditional jets, wide body traditional jets, and turboprops. The plot shows that turboprops cruise at the lowest altitude and interact only slightly with regional and traditional jets. The fact that turboprops cruise at a lower altitude is not surprising since this is one of their design characteristics. The wide body traditional jets cruise at the highest altitude, and also have a small level of interaction with the regional jets. The regional jets cruise at a lower altitude then the narrow or wide body traditional jets, but have a high level of interaction with narrow body traditional jets between 25,000 and 32,000 feet. At this time it is not clear from the data why the regional jets cruise at the lower altitude. One possible explanation is the shorter stage lengths of regional jets. The aircraft may be assigned to fly at lower altitudes since they are likely to land before a traditional jet. This connection between stage length and flight altitude is shown in Figure 25.

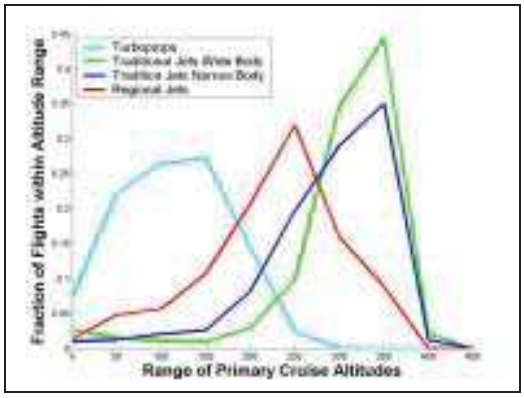

Figure 24: Normalized Histogram of Cruise Altitudes

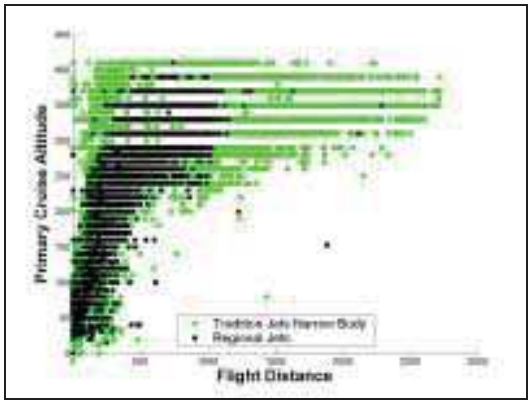

Figure 25: Cruise Altitude vs. Flight Distance

Figure 26 shows the average speeds during cruise for regional jets, narrow body traditional jets, wide body traditional jets, and turboprops. It can be seen that the turboprops fly significantly slower then the other aircraft types and the wide body traditional jets fly slightly faster then the other aircraft types. Once again the regional jets and narrow body traditional jets have a high level of overlap in their performance,

with the regional jets being the slower of the two. The speed difference is another possible explanation for the lower cruise altitudes of regional jets compared to traditional jets. If the regional jets fly too slow they may be relegated to lower altitudes to not slow down the rest of the traffic and cause congestion. However, it is difficult to determine what is cause and effect.

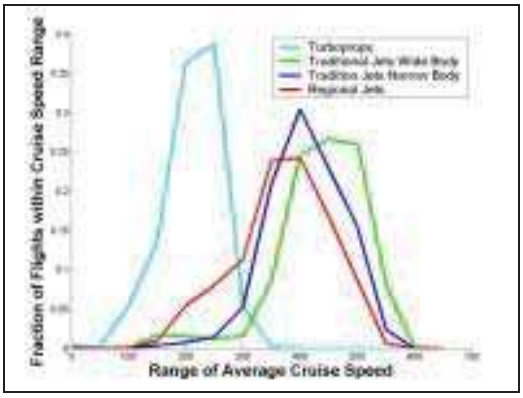

Figure 26: Normalized Histogram of Average Cruise Speeds

Conclusion

Airlines are increasingly using regional jets to better match aircraft size to high value demand markets. This has been especially important due to the increased pressure on the industry following September 11th 2001. The increase in regional jets represents a significant change from traditional air traffic patterns. To investigate the possible impacts of this change, this study analyzed the emerging flight patterns and performance, in the context of air traffic management, of regional jets compared to traditional jets and turboprops. It was found that regional jet operations cluster in the same areas as traditional jets implying a high level of interaction between the two aircraft types. The regional jets were observed to fly shorter routes then traditional jets, with few transcontinental flights. However, it was observed that this gap is closing. An increase in regional jet operations may cause delays at airports, because regional jets compete for the same runway and local airspace resources as traditional jets. Regional jets were observed to exhibit lower climb rates then traditional jets, which may have implications for air traffic control handling and sector design. In addition, it was observed that regional jets cruise at lower altitudes then traditional jets; however, the reasons for this difference are not clear. Finally, it was observed that regional jets cruise at a lower Mach number then traditional jets, except on specific high density routes where flow restrictions reduce the cruise speeds of all aircraft. Since the composition and utilization of the national fleet is changing this implies that the air traffic management system will need to evolve.

Acknowledgements

The authors would like to thank Professor David Gifford at the Laboratory for Computer Science at MIT for archiving the ASDI feed and making it available to the ICAT laboratory, Ryan Tam for providing plots of OAG data, Ian Garrick-Bethell for providing a plot of the regional jet registration data, and Emil Sit for proofreading drafts of the paper.

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